Aquaculture Site Selection: A GIS-based Approach to Marine Spatial Planning in Scotland.

Thesis submitted for the Degree of Doctor of Philosophy – Volume 1

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Abstract

This thesis explores, tests and develops various methods and tools for implementing Marine Spatial Planning and aquaculture site selection within Scottish waters. Utilising geographically referenced data sets from numerous sources, a Geographical Information System (GIS) was used to map the spatial distribution of activities; their associated pressures, locations of marine environments and biological communities within Scotland's sea area. Marine Zoning Schemes such as legislation based Multiple-Use Zoning Scheme and environmentally derived Marine Planning Frameworks have been applied and tested to support and inform the development of a new Prototype Zoning Scheme. The influence of inclusion of different data sets on zone coverage and extent has been explored with specific reference to the amount of protection the resultant zones provide to species and habitats that have significant conservation importance. Building on these zoning schemes, the application of GIS-based Multi-Criteria Analysis models has been appraised and their application investigated for both finfish cage and shellfish long-line aquaculture. This study has explored the suitability of alternative criteria and weighting configurations along with the feasibility of large sea-scale site selection models. In developing and investigating the viability of integrating these models within marine management frameworks such as zoning schemes, this study aims to inform planners, and both aid and inform decision making and management of future aquaculture developments. Together these studies contribute both practical recommendations for sustainable aquaculture development in the future and novel applications within the wider discipline of Marine Spatial Planning. They aim to contribute information to ensure both the sustainability and success of the Scottish aquaculture industry as well as the continued improvement and development of ecosystem-based marine planning and management.

Dedication

Many people have provided me with assistance, guidance and support throughout the time it has taken me to complete my PhD, the complete list would require another volume to be added to this thesis so forgive me if you are not mentioned in person.

Professor Teresa Fernandes I am forever grateful for the encouragement, faith (often when I had none myself) and continuous support that you have provided throughout my studies. Dr Rob Briers, my GIS mentor and constant source of guidance and knowledge in all matters of cartography. My deepest thanks go to both of you without you both this would truly have not been possible.

I am also indebted to Dr. Ian Davies and Dr. Matthew Gubbins whose expert guidance and constructive criticism throughout the course of this study has been invaluable.

This thesis is finally and completely for my mum and dad who have believed in me from such a very young age. Your unconditional support and love have carried me through the hardest days and I cannot put into words how much you both mean to me. I also wish to mention my Gran who should have had this opportunity and never did, you drive me crazy I am truly grateful for all the support you have given. Also special mention to those that I love who are no longer here, I only wish you could have been here to see this day, you are always in my thoughts.

Lastly, but by no means least I would like to say a big thank you to all my other friends and family, you have all been a continuous source of support and inspiration.

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I confirm that although I received much support and guidance from supervisors, sponsors and advisers, the work presented in the thesis is my own work and in no way represents government, agencies or any stakeholders views or policy.

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Declaration

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Acronyms

AHP – Analytical Hierarchy Process

AMAA – Ancient Monuments and Archaeological Areas Act (1979)

AM – Adaptive Management

CAR – Water Environment (Controlled Activities) (Scotland) Regulations

CBD – Convention of Biological Diversity

CEFAS – Centre for Environment Fisheries and Aquaculture Science

CFP – Common Fisheries Policy

CI – Consistency Index

CO_2 – Carbon Dioxide

CPA – Coastal Protection Act

CPZ – Conservation Priority Zone

CR – Consistency Ratio

DECC – Department of Energy and Climate Change

DEFRA – Department for Environment Food and Rural Affairs

DFO – Department of Fisheries and Oceans (Canada)

EBM – Ecosystem-Based Management

EB-MSM – Ecosystem-Based Marine Spatial Management

EC – European Commission

EEC – European Economic Community

EEZ – Exclusive Economic Zone

EIA – Environmental Impact Assessment

ER – Ecologically Rated

ESD – Ecologically Sustainable Development

ESSIM – Eastern Scotian Shelf Integrated Management

EU – European Union

EZ – Exclusive Zone

FEPA – Food and Environment Protection Act (UK)

GBRMP – Great Barrier Reef Marine Park

GIS – Geographical Information System

GW – Giga Watt

HELCOM – Helsinki Commission

ICAM – Integrated Coastal Areas Management

ICES – International Council for the Exploration of the Seas

ICZM – Integrated Coastal Zone Management

ICO – International Oceanographic Commission

IMO – International Maritime Organisation

IMR-Norway – Institute of Marine Research Norway

JNCC – Joint Nature Conservation Committee

LEZ – Limited Exclusion Zone

LWM – Low Water Mark

MARPOL – International Convention for the Prevention of Pollution from Ships

MASPNOSE – Maritime Spatial Planning in the North Sea Project

MBNMS – Monterey Bay National Marine Sanctuary

MCAA – Marine and Coastal Access Act (2009)

MCA – Multi Criteria Analysis

MCE – Multi Criteria Evaluation

MEA – Millennium Ecosystem Assessment

MHWS – Mean High Water Springs

MOD – Military of Defence

MPA – Marine Protected Areas

MPF – Marine Planning Framework

MPP – Marine Planning Partnership

MScA – Marine Scotland Act (2010)

MSA – Merchant Shipping Act (1995)

MSFD – Marine Strategy Framework Directive

MSP – Marine Spatial Planning

MSS – Marine Scotland Science

MW – Mega Watt

NOAA – National Oceanic and Atmospheric Administration

OCMD – Oceans and Coastal Management Division

OS – Ordnance Survey

OSPAR – Oslo Paris Convention for the Protection of the Marine Environment of the North East Atlantic

PAS – Performance Assessment System

PMF – Priority Marine Feature

PMRA – Protection of Military Remains Act

PMZ – Precautionary Management Zone

POM – Particulate Organic Matter

PUs – Planning Units

PWA – Protection of Wrecks Act (1973)

PZ – Protected Zone

RCAHMS – Royal Commission on the Ancient and Historical Monuments of Scotland

RCI – Random Consistency Index

RYA – Royal Yachting Association

SAC – Special Area of Conservation

SAHFOS – Sir Alasdair Hardy Foundation for Ocean Science

SCM – Site Condition Monitoring System

SEA – Strategic Environmental Assessment

SEPA – Scottish Environment Protection Agency

SEZ – Significant Exclusion Zone

SMR – Scottish Marine Region

SNH – Scottish Natural Heritage

SOLAS – Safety of Life at Sea

SPA – Special Protection Area

SSI – Scottish Statutory Instrument

SSSI – Site of Special Scientific Interest

Te – Tonne equivalent

TMZ – Targeted Management Zone

UK – United Kingdom

UKCS – United Kingdom Continental Shelf

UNCLOS - United Nations Convention on the Law of the Sea

UNESCO – United Nations Educational, Scientific and Cultural Organisation

US – United States

USA – United States of America

WCED – World Commission on Environment and Development

WLC – Weighted Linear Combinations

WSSD- World Summit on Sustainable Development

Publications and Presentations

Several relevant scientific conferences and workshops were attended at which work was presented. Two papers were published and a further four papers are also in preparation for publication.

Publications:

Work from Chapter 2 has been accepted and published in the Journal of Ocean and Coastal Management. Title: *The development and testing of a multiple-use zoning scheme for Scottish waters*. A copy of this paper can be found at: http://www.sciencedirect.com/science/article/pii/S0964569114003470

Some of the work from Chapter 2 was included in a paper that has been accepted and published by the Marine Policy Journal. Title: *Can Management Effort be predicted for Marine Protected Areas? New considerations for network design.* A copy of this paper can be found at: http://www.sciencedirect.com/science/article/pii/S0308597X14000372

Work from Chapter 4 has been submitted to the Marine Policy Journal and is currently in revision. Title: *Development of a Prototype Zoning Scheme for Scottish Waters.* A further three papers, see listed below, have been also been prepared and will shortly be submitted to relevant journals for publication.

- *Development of a Marine Planning Framework for Scottish Waters: and Ecosystem-based Zoning Scheme*
- *Marine Spatial Planning in Scotland: can climate change be accommodated?*
- *Incorporation of Climate Change Scenarios into a Marine Spatial Planning Framework for Scotland*

Work from Chapters 6, 7 and 8 will also be prepared for submission to suitable journals in due course.

Presentations:

2011

- World Conference on Marine Biodiversity, 26-30th September 2011, Aberdeen, Scotland, UK. Presenting a Digital Objective.
- MASTS Annual Science Meeting, 22-24th August, Edinburgh Conference Centre, Heriot-Watt University. Presentation of a Scientific Poster.
- Scottish Marine Group Annual Meeting, 20th October 2011, Perth College, University Highlands and Islands. Oral Presentation.

2012

- MASTS Annual Science Meeting, 11-13th September, 2012, Edinburgh Conference Centre, Heriot-Watt University. Presentation of a Digital Poster.
- ECSA Meeting: Scottish Sea Lochs and Adjacent Waters, 16th-18th May, 2013, The Scottish Marine Institute, Oban, Scotland. Poster Presentation.
- Scottish Marine Group Annual Meeting, 28th May 2012, The Scottish Marine Institute, Oban, Scotland. Oral Presentation.

2013

- CoastGIS 18-21st June, 2013. The 11th International Symposium for GIS and Computer Cartography for Coastal Zone Management in Victoria, British Columbia, Canada. Oral Presentation.
- 1st Heriot-Watt University Annual Postgraduate Conference, 12-13th December, 2013, Edinburgh UK. Oral Presentation.
- MASTS Annual Science Meeting, 27-29th August, 2013, Edinburgh Conference Centre, Heriot-Watt University. Oral Presentation.
- ICES Annual Science Conference, 23-27th, September 2013, Reykjavik, Iceland. Oral Presentation.
- MASTS Coastal Zone Workshop, November, 2013, Crieff Hydro, Scotland. Oral Presentation.

2014

- ECSA 54 Coastal Systems under change: tuning and management tools, Sesimbra, Portugal. Workshop Presentation.
- MASTS Coastal Zone Workshop, November, 2014, Crieff Hydro, Scotland. Oral Presentation.

Chapter 1

Setting the Scene

1.1 Background

A significant proportion of the world's seas are under pressure from anthropogenic factors and consequently there is a real need to protect vulnerable species and habitats to ensure that the marine environment can continue to underpin a range of activities and industries. Coastal zones are often a major source of wealth and employment particularly for many rural communities (Rodríguez et al., 2009). For example, in Scottish rural areas over 7,000 jobs are provided by the aquaculture industry alone each year and this is set to increase steadily over the next decade (SNMP, 2011). This growth is already being aided by the backing of local councils, for example in 2009 the Highlands and Islands Council invested £8million into its aquaculture sector (The Highland Council, 2011).

Around the Scottish coast the fish farming industry in particular has developed considerably over the last three decades and farms can now be found along many stretches of coastline and in the majority of sea lochs on the west coast (Gillibrand and Turrell, 1997). The aquaculture industry is currently conducting research into the feasibility of farming other marine species and the techniques which are required for their culture, mainly accommodating their environmental requirements (The Highland Council, 2011). As a result of these endeavours there are increasing levels of Rainbow Trout (*Oncorhynchus mykiss*) production in sea cages, alongside more modest increases in Turbot (*Scophthalmus maximus*), and Haddock (*Melanogrammus aeglefinus*) as well as preliminary production of the mollusc abalone (*Haliotis spp.*) and green sea urchin (*Psammechinus miliaris*), (Henderson and Davies, 2001; The Highland Council, 2011). These latter two species have potential to be cultured in trays or lantern nets suspended on sub-surface longlines and demand for their meats particularly across Europe and Eastern Asia is high (The Highland Council, 2011). Interest in the farming of Halibut (*Hippoglossus hippoglossus*) has been expressed since the early 2000s (Henderson and Davies, 2001). Although it has not been fully realised on a commercial scale yet, Halibut production has increased from 3.6 tonnes in 1999 to 200 tonnes in 2009 (Holmyard, 2009). The problems that have faced Halibut expansion have been that they require reasonably sheltered sites coupled with greater cage surface area compared with a species like Atlantic Salmon (*Salmo salar)*. Other species such as Atlantic Cod (*Gadus morhua*) however may prove to be more feasible to culture in more exposed sites including those currently used for salmon production (The Highland Council, 2011).

One of the many goals of the new Scottish Marine Plan is to not only support the diversification of aquaculture but also the development of Multi-trophic aquaculture (SNMP, 2011), which comprises an approach in which the products of one species are recycled to support the production of another species. Another area set to see significant growth and development in Scotland is the offshore sector (Marine Scotland, 2011). Whilst generating additional wealth, this progression further out into deeper waters has concurrently increased both the volume and variety of pressures being placed on the marine environment (DEFRA, 2007; SNH, 2008; Stelzenmüller et al., 2008). Socio-economic factors coupled with rapid human population growth are resulting in the realisation that prudent management of this expansion is needed to ensure long-term ecological sustainability (Day et al., 2008). The Scottish Sustainable Marine Environment Initiative (SSMEI) was an example of a pilot project dedicated to adopting innovative new approaches towards marine planning in Scotland. Primarily their aim was to establish schemes and test new management initiatives in order to improve our understanding of the needs of Scotland's marine environments. Of the four pilot areas that were involved (The Firth of Clyde, The Shetland Islands, The Sound of Mull and The Berwickshire Coast), nearly all had the focus of their projects centred around the development of a marine spatial plans (Posford Haskoning, 2010).

1.1.1 Study Area

This thesis is focused on Scottish waters (see Figure 1.1), however it should be noted that the research undertaken is applicable to all marine environments from both a marine spatial planning and aquaculture development perspective, albeit with consideration of local or regional variation or priorities.

Being part of an island Scotland is almost completely surrounded by water, with its inshore and offshore waters combining to account for 13% of the European Sea area. Glacial activity during the last ice age forged Scotland's highly indented coastline today along with some 800 islands that surround the mainland. The coastline is around 18,000 km^2 in length and borders a total sea area of some 468,994 km^2. The expansive and complex nature of Scotland's coastline influences life beneath the surface waters and the coastal and marine habitats of Scotland are varied and dynamic in nature. This is reflected by the numerous designations places throughout these waters such as those that are part of the Natura 2000 programme.

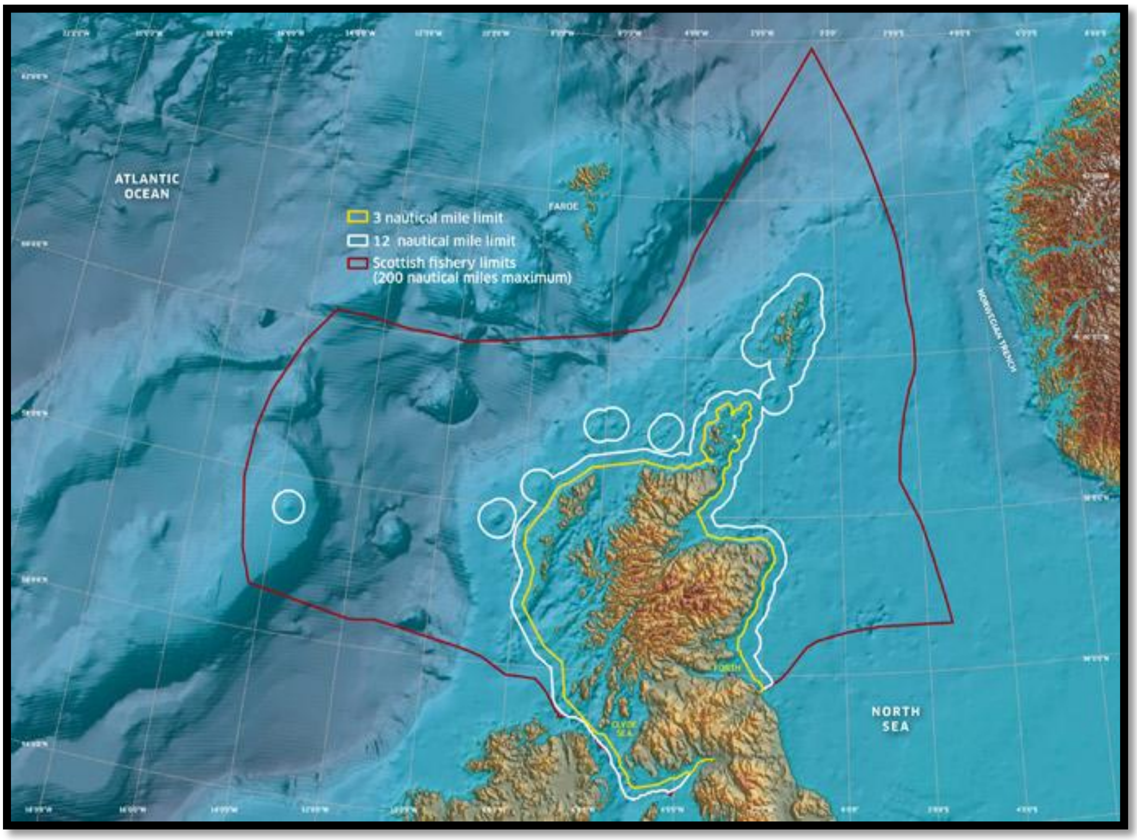

Figure 1.1 - The Study Area: 200nm Limit. The Scottish Government ©

1.1.2 Scottish Marine Policy and Conservation Legislation

In 2008 the Scottish Government agreed with the UK Government through the Joint Ministerial Committee (JMC) that planned Marine Bills from both administrations should be combined. This resulted in the Scottish Government being awarded new devolved executive responsibilities for planning and marine nature conservation out to 200 nm. The agreement included the following points:

- The administrations working together to deliver joined-up marine management
- A UK Marine Policy Statement to be part of an integrated marine management system

- Scotland having the power to designate nature conservation sites out to 200 nM
- The Scottish Government is the leading force for implementing Marine Planning in Scotland; this means integrated planning for wind and wave power, fishing and marine conservation, as well as other relevant activities, out to 200 Nm, with the exception of Oil and Gas.

Scotland has full responsibility for nature conservation out to 12 nm and, within the framework of the Common Fisheries Policy (CFP) for fisheries management out to 200 nm, refer to Fig 1.1. From the 6th April 2011, under the Marine (Scotland) Act 2010 (MScA) the Scottish Government is now also responsible for the new marine licensing system for activities carried out in the inshore region of Scottish waters from 0-12 nm. Additionally under the UK Marine and Coastal Access Act 2009 the Scottish Government is also the licensing and enforcement authority for activities such as renewables in the Scottish offshore region from 12-200nm. With the exception of oil and gas and defence related activities Scotland also has full responsibility for licensing deposits in the sea beyond 12 nm.

Devolved powers for renewable energy consents were also extended out from 12 nm to 200 nm. With the exception of oil and gas related developments, legislative competence for navigational safety under section 34 of the Coast Protection Act 1949 also falls to Scotland.

This new system will allow for consistent decision making on which activities may be allowed to take place at sea and where and under what conditions they may operate. Through the process of marine licensing, and the conditions placed on licenses, both economically and socially beneficial activities will be promoted whilst any adverse effects on the environment, human health and marine users, will be minimised and managed. This is already starting to be realised through the Scottish Governments National Marine Planning Framework (NPF). The NPF is essentially the spatial expression of the Governments Economic Strategy and outlines plans for infrastructure investment.

The Water Framework Directive (2000/60/EC; WFD) is a European piece of legislation that became law in Scotland in 2003 through the implementation of the Water Environment and Water Services (Scotland) Act 2003. The WFD establishes a legal framework for protecting, improving and sustaining the use of surface waters, transitional waters, coastal waters and ground waters across Europe in order to avoid any deterioration, enhance aquatic ecosystems (including ground water) and reduce pollution.

The Water Framework Directive defines coastal waters as:

> *"Surface waters on the landward side of a line, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters.* Article 2(7).

In accordance with the Water Framework Directive (WFD) the ecological status of waters therefore must be classified out to at least to one nautical mile (nm) from the baseline. However the Scottish Government has extended this area out to 3 nm for Scottish Waters. This extension from the baseline out to 3 nm encompasses quite a significant proportion of coastal and marine areas such as the Hebrides, the Minch, the Clyde and the other major Firths which are therefore included within River Basin Management Planning (RBMP).

One of the main functions of the UK Marine Monitoring and Assessment Strategy (UKMMAS) is to prepare periodic reviews of the status of the Marine Environment. Data from various programs, such as WFD and OSPAR monitoring programmes, are summarised by region and then aggregated to form a national picture. Furthermore they can be used to merge information for the two areas of the Marine Strategy Framework Directive's (MSFD) initial assessment, namely; the Greater North Sea (Area II) and the Celtic Seas (Area III). The European MSFD was transposed into Scottish legislation in 2010, through the Marine (Scotland) Act 2010. The MSFD requires all member states to manage their seas so that they maintain or achieve Good Environmental Status (GES) by 2020. Further to this the Marine Strategy Part Two has been published in 2014, that provides a description of the UK's MSFD marine monitoring programme (Defra 2014).

1.2 Discussion and Development of the Research Theme

A fundamental goal of the MScA is to streamline regulation and develop a new framework to coordinate and manage activities around Scotland's coast.

This research project will evaluate and explore the application of different approaches, using Geographical Information Systems (GIS), to the development of a Scottish marine spatial planning framework, with a particular focus on decision-making for future aquaculture sites. Integral to this study will be the accurate assessment of the spatial distribution of human activities and their associated pressures, along with mapping of marine landscapes and determination of the nature of biological communities. Due to the need to integrate and manage all these factors, GIS will be used to capture, organise, analyse and display different types of geographically referenced information. These approaches will be applied and tested using historical data to proposed aquaculture sites, with an overall aim of developing and refining a process for achieving future sustainability for the aquaculture sector.

1.2.1 Relevance and Integration within Planning and Management

The outcomes of these studies will be applied to the planning of future locations and areas for expansion of marine aquaculture where impacts/effects will be manageable and remain within the limits of the ecosystems capacity. Improving the process of site selection in this manner is of particular importance as poor site selection can result in adverse environmental conditions and eventually in the failure of the aquatic enterprises.

In particular the failure rates in the aquatic sector have been strongly linked to the introduction of diseases and viral epidemics such as Infectious Salmon Anaemia (ISA) at many sites. At a small scale (1-2 km) sites are thought to be at an increased risk of infection (Green, 2010), with the spread of disease being attributed to processes such as physical transportation via currents or escaped infected fish moving between farms (Murray et al., 2002; Murray and Peeler, 2005). At larger scales an area subjected to extensive shipping traffic coupled with inadequate regulation is also at an increased risk of spreading infection (Murray et al., 2002). Therefore these aspects will also be taken into account when considering site placement and in particular the concept of placing farms in isolation and avoiding clustering of sites to, in effect, create geographical ‘firewalls’ (Green, 2010) will be explored. It is crucial to consider the role that aquaculture placement can have in the spread of diseases as they can inflict such huge losses across the sector each year. For example, in 1999 the annual cost from ISA alone in Scotland was estimated to be in the region of 21.5 million pounds (Murray et al., 2002).

The value of developing a tool for systematically approaching site selection therefore is potentially considerable when assisting practical decision making regarding future site selection of aquaculture facilities, both in areas with established aquaculture industries and those unexploited or in their infancy (Kapetsky and Aguilar-Manjarrez., 2002).

Intensive farming of fin and shellfish within Scottish waters is continuously under review (Hunter et al., 2006) and the potential for this intensive aquaculture to bring about detrimental effects on the marine environment has lead to their regulation by several governing bodies; the Scottish Environment Protection Agency (SEPA), the Crown Estate Commissioners (CEC) and the Scottish Government. In the past this poor site selection has not only resulted in adverse environmental effects but also in the failure of aquatic developments, such as Static Point fish farm owned by Marine Harvest in Wester-Ross. Therefore there is a clear need for sustainability issues to be considered during preliminary planning stages (Longdill et al., 2008). Further planning and development are therefore foreseen as becoming increasingly important in inner Scottish sea lochs in particular, where there is already a considerable and stable aquaculture presence. The prospects for the expansion of the industry's in loch areas will primarily be limited in the future by the availability of technically viable sites, environmental constraints and other aesthetic interests associated with the landscape (The Highland Council, 2011). However development in less sensitive outer loch regions is considered more feasible and has until recently been reliant on national planning policies such as the National Planning Policy Guideline for Coastal Planning (NPPG13), the Scottish Planning Policy on Planning for Fish Farming (SPP22) to ensure their protection (The Highland Council, 2009). These have since been superseded by the Scottish Planning Policy (2010) as part of the Scottish Government's commitment to rationalising proportionate and practical planning policies (Scottish Government, 2010).

Whilst the localised effects of farms on their immediate surroundings are fairly well known (Fernandes et al., 2001; Sequeira et al., 2008) the consequences they have on a wider scale are less well understood (Tett et al.

2010). To date regulations have been focused specifically on site (local scale) impact of farms and it now has become clear that effects such as disease may be observed within the wider water body and these are of an equal cause for concern (Tett et al., 2010). It is not clear if and how these effects may have implications on other activities taking place in the wider system and as such assessment and, likely management, should be focussed on wider scales.

The Marine (Scotland) Act 2010 and the UKs Marine and Coastal Access Act 2009 provide for implementation of marine spatial planning in Scottish waters out to 200nM. In the Scottish Marine Act (2010) the government recognises the importance of the marine environment and that good management of resources within these waters can help to support local communities and promote economic development. Four key themes run throughout the Marine Act; fisheries, spatial planning, licensing and nature conservation, with all being a direct focus of this research.

This research project is particularly timely given the requisites recently published in the UK Marine Bill and the European Commission's Marine Strategy Framework Directive (MSFD) and its commitment to achieving good environmental status by 2020 (EUROPA 2010). The MSFD aims to protect the resource base upon which marine related economics and social activities depend (SNMP, 2011). One particular aim of the UK Marine Act is; "*to streamline regulation and create a new framework to coordinate activities on and in the marine area around the UK".* Marine plans, like those contributed to with this research for the Scottish coastline will be essential tools for formulating such frameworks. MSP is a tool that is additionally a key instrument for execution of the Integrated EU Maritime Policy (2008) helping public authorities and stakeholders to coordinate their actions and optimise the use of their marine space to benefit the marine environment and the economy. This has since been backed up by the adoption of the EU Marine Spatial Planning Directive (2014). This new piece of planning policy for maritime activities aims to help member states develop and coordinate various activities taking place in European waters.

The Scottish Government, along with local councils, recognise that the aquaculture industry in Scotland supports the local rural economy in areas where there are few job opportunities. In order for the industry to continue to play this vital role in the future, sustainable management of their environmental resources is essential. Application of GIS to provide spatial decision making support in aquaculture would be an advantageous tool in the continuous development of Integrated Coastal Zone Management (ICZM) plans, that are carried out by the Crown Estate and Scottish Natural Heritage (SNH, 2008). This work is important within Scottish Aquaculture as present measures for regulation and site selection by these organisations rely on designated exclusion areas, calculated sensitivities and estimators of environmental impacts (Hunter et al., 2006). These historic approaches at times overlook locally sensitive sites and issues but by employing a GIS based process this would incorporate local factors such as proximity to power lines and nutrient parameters into an overarching site selection tool.

1.2.2 Identified Areas of Further Work and Knowledge Gaps

At present, various policy documents and accompanying reports are at the stage of identifying areas where further work is still required either now or in the future. Featured below Table 1.1 is a summary of the areas identified by some of the key Scottish policy documents that underpin this research.

Table 1.1 - Areas of Further Work and Knowledge Gaps identified in Key Policy Documents and Reports

Policy Document / Report	Area of Knowledge Gap
A Fresh Start - The renewed Strategic Framework for Scottish Aquaculture	**Page 9** – "Scottish aquaculture must ensure that the potential impacts of a changing climate are incorporated into planning and development of the industry" **Page 18** – "A strategic approach to the siting of farms to facilitate sustainable expansion of the aquaculture industry is required. Any new approach will need to sit within the marine planning framework."
Charting Progress 2	**Chapter 5**- Productive Sea (Aquaculture) One of the points highlighted in this report is the fact that the aquaculture licensing system is extremely complex and that it should be streamlined through the Marine and Coastal Access Act 2009 and the Marine (Scotland) Act 2010. **Chapter 5** Productive Seas (Forward Look) - Identifies some key future research areas as follows: • Knowledge and appreciations of spatial and temporal distributions of species, activities and marine features is required to support the assessment of Good Environmental Status for the EU Marine Strategy Framework Directive. • Need a better understanding of pressures related to each activity and cumulative impacts. • Require a better centralisation of collated data on the distribution of activities and pressures.

EU Strategy for the Sustainable Growth of Aquaculture	Overall aim is to encourage growth in the industry while building on the high environmental and quality standards that have been achieved so far.
UK Marine Policy Statement	**Page 12** – "When developing Marine Plans the process will need to be based on an ecosystem approach and be streamlined and efficient. **Page 12** – 'Where evidence is inconclusive, decision makers should make reasonable efforts to fill evidence gaps but will also need to apply precaution within a overall risk based approach" **Page 43** – Aquaculture operation are also viewed as a key focus for the future development of sustainable food sources and as a possible source of employment. Therefore aquaculture needs to be taken into account when developing future marine plans. **Page 44 –** When developing marine plans a means of embracing the significant opportunities for co-existence between aquaculture and other marine activities will need to be ensured.
Scottish Marine Science Strategy	**Page 4** - The strategy identifies sustaining and increasing ecosystem benefits and responding to climate change and its interactions with the environment as two of its three high level science priorities. **Page 5** – It also identifies working across disciplinary boundaries to bridge the gap between natural and social sciences, helping to address the issues of environmental change and being able to tackle identified problems or potential threats to the environment through design as three guiding characteristics to which future science should conform. **Page 8** – Need to identify options for adapting to climate changes in aquatic ecosystems resulting from projected climate change scenarios, social and environmental impacts. **Page 9** – Need to develop decision-making tools to appraise the economic, social and environmental costs and benefits of different uses of resources such as fisheries, aquaculture, recreation, conservation, renewables, carbon capture and storage to inform marine spatial planning. **Page 11** – Need to determine the most sustainable management scenarios for marine aquaculture. **Page 14** – More resources are required for data management and GIS to support spatial analysis and to provide improved data interpretation and accessibility.

1.2.3 Research Theme

In section 1.3 of Scotland's National Marine Plan pre-consultation draft, it outlines the key challenges and objectives for the aquaculture industry in Scotland. It states that: the following are to be achieved by 2020:

- To increase the sustainable production of marine finfish at a rate of 4% per annum to achieve a 50% increase in current production.
- To increase the sustainable production of shellfish, mussels especially by at least 100%.

These clear targets set by the Scottish Government initially provided a basic framework for the development of this research project. This was then further expanded to include the development of a practical planning approach that would aid with future site selection. Coincidently this also proved very timely with the currently ongoing development of the Scottish Marine Plans. Ultimately this resulted in asking the question: ‘How can this work contribute to marine spatial planning currently being implemented in Scotland and, given the need for future expansion, can it be used to help secure the long term success of aquaculture in Scotland?’ The flow chart in Figure 1.2 shows the basic ideas that contribute to this project, the intended goal and potential outcomes and applications from this work. It highlights areas that may be suitable for further investigation, an overview of the literature reviews carried out along with the methodologies utilised and the general conceptual ideas involved when undertaking this work.

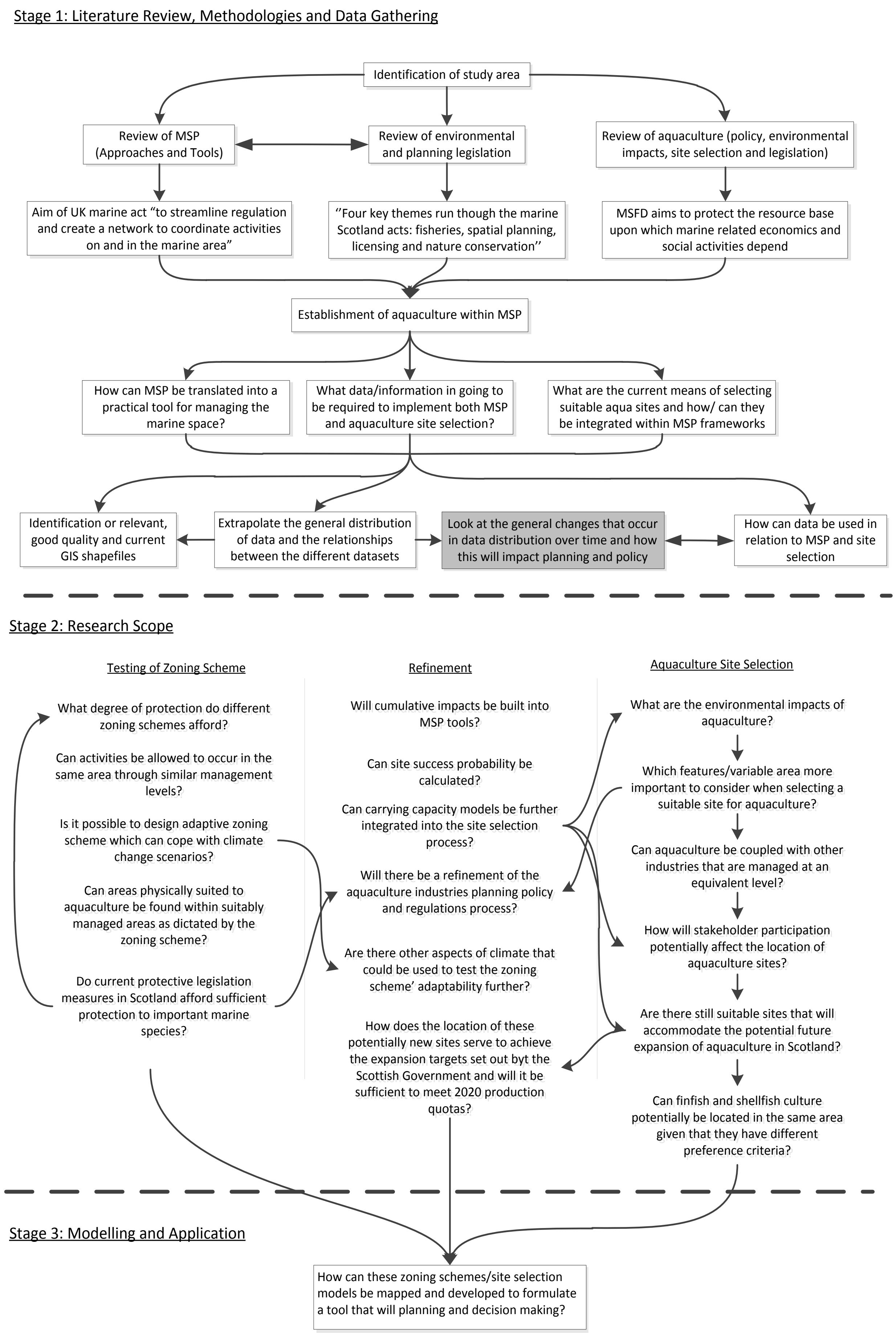

Figure 1.2 - Flow Chart of Research Projects design and study concepts.

1.3 Thesis Aims, Objectives and Deliverables

The aim of this project is to test and develop tools to facilitate the implementation of marine spatial planning in Scotland. The intent is then to focus upon the sustainable development and management of marine aquaculture by giving consideration to future placement of facilities.

Objectives:

- Identify any areas of concentrated user pressure along the Scottish coastline, Western Isles, Orkney and Shetland and construct a series of maps to illustrate where overlapping marine activities occur.
- Assess effectiveness of existing legislation and regulation in providing required/adequate levels of environmental protection and management control across different regional areas through development of a zoning scheme.
- Analyse the strengths and limitations of current legislation and regulations and the highlighting of any areas where regulation is insufficient or absent.
- Construct an integrated framework of environmental and probability models to be used in conjunction with GIS for identifying sustainable aquaculture sites.
- Use existing aquaculture farm data to make comparisons between their historic successes or failures and the likely success of newly identified proposed sites.

Deliverables:

- Establishment of a Scottish Coastal Geodatabase.
- Identification of spatial pressures/areas of conflicting use and the activities involved.
- Production of a series of maps including representations of important biological areas, human activities and areas of increased spatial pressure along with an integrated representation of current management controls (SACs, SSSIs, etc.).
- Development of a zoning scheme that can guide where activities and developments can be permitted to occur and the level of intensity that

can be accommodated in defined areas. The main objective of this scheme will be to show whether or not existing legislation and regulations provides implicitly but not explicitly for increasing levels of environmental protection and management control throughout the zones.

- Implementation of an ecological zoning model that will divide the coastal area based on ecological criteria and identify and define the spatial boundaries of individual zones (potential marine bioregions) and outline objectives derived for sustainable managing for each zone.
- Development of a prototype zoning scheme based on specific ecological criteria, current legislation and relevant policy drivers will be proposed for Scottish coastal waters according to the different management criteria required in order to preserve its functionality.
- Maps will be generated from this prototype zoning scheme that will show the revised proposed management zoning for the Scottish coastline.
- Initial MCE-based model for assessment of aquaculture sites, and application to Scottish coastal waters to give broad-scale scenario of potential for future development.
- Comparison of alternative approaches for aquaculture assessment.
- Development of robust models, validated by stakeholder input, that can be used for allocating sites for various types of aquaculture e.g. finfish/shellfish/algae.
- Proposal of areas with the most suitable conditions for the development of sustainable culture of finfish, shellfish, will be identified, specifically sites suitable for expansion or new locations.
- Development and testing of a probable uncertainty model-GIS framework for the evaluation of proposed sites for further aquaculture development.

A final report outlining the prototype ecological/legislative zoning scheme and approach, as well as maps highlighting proposed sites for finfish, shellfish culture will be produced in the future.

1.3.1 Project Layout and Process

The chapters in this thesis explore the development of “tools to aid the marine planning process and guide sustainable aquaculture development” through assessment and evaluation of established marine zoning schemes and site selection models. They will provide evidence and suggestions to support planning policy alongside tools that could beneficial for aiding the decision making process involved with marine management. Chapter 1, this chapter provides a background to the research undertaken and the study area. Chapters 2-7 are separate studies in their own right but gradually provide more detailed background information about the study area. They all have their own introduction, methodology, results and discussion section and each follows on from, and are linked to, the previous chapters. Chapter 8 provides a discussion of the overall thesis and how each of the exercises and studies undertaken combine and relate to one another; how they can be used inform current management schemes and policy and how ultimately the research can be used to ensure the health of Scotland's marine environment. The chapters aim to address the research questions as described below.

Chapter 1 – A geodatabase was compiled initially in order to identify the location of all the major marine activities that occur within Scotland's water.

Chapter 2 – What is the most practical and proficient method of managing all of these different activities? To start to answer this question different planning tools and approaches were reviewed and analysed. All available data were gathered on biological, oceanographic and socio-economic variables and from this a study method was then selected. This chapter introduces the first of three zoning schemes applied to Scottish waters the Multiple-Use Zoning Scheme that has zones derived purely from legislated activities. To this end it was also the aim of this study to show whether or not existing legislation and regulation provides implicitly but not explicitly for increasing levels of environmental protection and management control.

Chapter 3 – Following on from the study in Chapter 2, another zoning scheme was applied, the Marine Planning Model. Unlike the previous zoning technique this zoning scheme divides marine waters based on specific ecological criteria. This study provides evidence that ecological data, such as important or sensitive environmental features, can also be used to derive a means of spatial planning. The results were analysed to determine whether or not using this of data was any more effective at providing environmental protection and management control than the activities data utilised in the Multiple-use Scheme.

Chapter 4 – Building still further on the studies of Chapters 2 and 3, this study provided evidence that both types of data 'socio-economic' and 'ecological' should be fully utilised when developing a tool for translating the concepts of MSP. In this study we developed our own Prototype zoning scheme that incorporated both current legislation and ecological features as used by the previous two schemes independently and combined and refined them in relation to Scottish policy drivers to provide a single robust zoning scheme.

Chapter 5 – While considering Marine Spatial Planning and policy in the previous chapters it became evident that in the future any management mechanisms put in place now will likely have to deal with the effectives of climate change. Government ministers and policy makers all highlighted that climate change would need to be taken into account and accommodated in the future, but there appeared to be little practical inclusion of these sentiments within the planning frameworks being proposed. To the author's knowledge there were no tools being developed that were either tested or designed to accommodate climate change scenarios. This study tests both the multiple-use zoning scheme and the newly developed Prototype scheme to identify which, if any, of the schemes are able to adapt to potential shifts in ecological features due to increased oceanic temperature scenarios.

Chapter 6 – Having now identified areas suitable for certain activities in Chapters 2-5, this chapter now aims to identify where suitable sites for aquaculture may be located. What criteria/ features were deemed most important for a successful site? And what method would be the most suitable to use given the data available? The study in this chapter focuses on developing a site selection model for salmon aquaculture in Scotland. Multi-Criteria Evaluation (MCE) was used to combine information regarding different classes of criteria through a weighting procedure to derive an overall assessment of suitability. The output from this work will show where potentially the most suitable sites for salmon aquaculture are located around Scotland.

Chapter 7 – Leading directly on from chapter 6, this study again uses the MCE modelling technique but this time the criteria were adapted so that the mussel *Mytilus edulis* would be the target culture species for site selection. This species were chosen for the preliminary development of this model as they have been identified by the Scottish Government as the key species for increasing production yields by 2020 (SNMP, 2011).

Chapter 8 – Incorporation of stakeholder participation in the weighting of criteria within the MCE analysis; does it alter the output sites and if so by how much?

Chapter 9 – Where are potentially the most suitable sites for aquaculture located within the Prototype Zoning Scheme, developed in Chapter 4. A summary of results, general discussion and overall conclusions of this work are presented.

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Chapter 2
Multiple-Use Zoning Scheme

2.1 Scottish Waters

The seas around Scotland support a diverse array of flora and fauna mainly due to the many and varied physical characteristics of the coastline and its waters. Within the coastal zone there are sheltered bays, long straight stretches of exposed coastline and deep and narrow sea lochs all of which host different ecological communities. Offshore Scottish waters vary from sea shelf areas that tend to be shallower than 250 m, to deep oceanic troughs that can descend more than 2,000 m. The European continental shelf includes Hebridean and Malin shelf seas, Orkney and Shetland shelf seas and the North Sea. Waters within these shelf seas are marked by oceanic features such as Stanton Bank (banks) and Beaufort Dyke (deep channels) (Baxter et al., 2008).The diversity of Scottish waters has also given rise to a variety of different users and activities occurring within them. This is true, not just in Scotland but also globally, with marine ecosystems coming under increasing pressure from various stressors such as overfishing, pollutants, invasive species, climate change, coastal developments and other activities. Both individually and combined these stressors act to compromise the stability of coastal and oceanic ecosystems and jeopardise their ability to sustain the production of the goods and services that they provide (Foley et al., 2010). Extraction of ecosystem resources is also progressively moving outwards from coastal waters into deeper, offshore waters, activities such as aquaculture and renewable energy developments, in particular, are moving further offshore for their future developments (Douvere, 2008). The increase of these stresses/pressures being placed on ecosystems predominantly originate from an increase in human activities and also results in the proportional increase in complexity of spatial use (Stelzenmüller et al., 2008) .Therefore maintaining the health of these marine ecosystems, along with the services they provide to the human population, will require the adoption of a new coordinated approach to governing coastal and oceanic activities(Foley et al., 2010).

2.2 Introduction to Marine Spatial Planning

Marine space has historically been regulated and allocated in a number of different ways, but there has been a commonality in that this has largely been approached from a strongly sectoral point of view, with little priority given to integrating or managing multiple uses between economic sectors (Douvere, 2008). This approach does not adequately address the conflicts between alternative uses that have arisen and more recently an emphasis has been placed on broader scale, ecosystem approaches to manage the marine environment and its resources (Stelzenmüller et al., 2008). Marine Spatial Planning (MSP) is an example of a management framework that would allow for the integration, consistency and progression in decision making between sea uses and furthermore can also aid conflict resolution in areas where there is a real demand on space and resources (Boyes et al., 2007). MSP is now widely accepted as an established tool which can support the implementation of an ecosystem-based approach to management (Crowder and Norse, 2008; Douvere, 2008). Through the management of current and future sea uses, marine planning can assist in avoiding or solving conflicts between multiple marine users (Stelzenmüller et al., 2008). Although there are no specific definitions of MSP available, it has previously been summarised as '*a strategic plan (including forward looking and proactive) for regulating, managing and protecting the marine environment, through allocation of space, that addresses the multiple, cumulative, and potentially conflicting uses of the sea and thereby facilitates sustainable development'* (Boyes et al., 2007). However, it should also be acknowledged that the process involved is equally both part of the plan itself and the final outcome of implementing that plan.

The Marine (Scotland) Act 2010 (MScA) contains legislation that underpins and allows for a management framework which aims to oversee the competing demands for space and resources in Scotland's marine waters. The MScA is ultimately the key policy document that provides for MSP, streamlined licensing and marine nature conservation in Scotland. The MScA, along with the MCAA and the CFP covered in the previous chapter combined layout the responsibilities of the Scottish Government in terms of licensing activies out to 200 nM. This study therefore considered the entire Scottish sea area extending out to 200 nM to reflect these responsibilities.

Part 3 of the MScA also delegates Scottish ministers with the task of preparing and implementing a National Marine Plan and following on from this, the option of Regional Marine Plans (The Scottish Government, 2011b). Furthermore the National Marine Plan has also been designed to deliver Scotland's international obligations such as meeting the standards laid out by the Marine Strategy Framework Directive (MSFD). Scottish marine space until very recently has been allocated without a comprehensive spatial planning strategy that determines priority uses in different sea areas.

2.3 A Brief Overview of Zoning Schemes

The management of marine resources is still predominantly characterised by a sector-by-sector approach, with each human activity being managed separately. The anthropogenic threats that can occur from these activities taking place, such as eutrophication or biodiversity loss are numerous and often extremely damaging to marine ecosystems (Halpern et al., 2008). However, current sectoral and ad hoc processes that are used for designating activities by independent organisations such as aquaculture licenses, oil lease sites and conservation areas often overlook the cumulative effects across sectors (Edwards, 2008). Even established land based planning has struggled to develop models that deal with cumulative effects and have often lacked deeper issues such as community and regional well being (Mitchell and Parkins, (2011). More specifically, this conventional sector-by-sector management is not capable of dealing with the full range of activities that now take place within seas and oceans because this method does not account sufficiently for interactions between activities, cumulative impacts (over space and time), the processes by which activities affect the delivery of ecosystem services and trade-offs between activities (Halpern et al., 2008). As a result of these short falls many governments are now being encouraged to develop and implement an approach to manage uses of ocean resources and space by integrating comprehensive zoning schemes into their management plans (Edwards, 2008). Ecosystem-based management that incorporates MSP and specifically comprehensive zoning schemes, could deal with all of these issues through provision of zoning maps or regulations (Halpern et al., 2008; Ehler and Douvere 2009). This said for zoning to function effectively it would need to integrate all activities and users, if each activity were to be liable for their own zoning this would almost certainly lead to spatial conflict. For example, if the fishing industry were to place exclusion zones around critical fisheries this could prohibit other developments such as renewables. Zoning schemes can help to harmonise conservation mechanisms for protecting habitats and species and also when implementing scenarios for sustainable use. They can do this by identifying areas of importance and sensitivity for natural or cultural heritage and areas that are of interest to particular sectors in order to minimise conflict between them (Boyes et al. 2007).

Marine zoning is a cross-sectoral allocation system which incorporates a body which oversees decision making, establishment of regulations and environmental management mechanisms along with separating any incompatible uses/activities into different zones (Edwards, 2008; Halpern et al., 2008). Zoning can be defined as " *the authoritative regulation and allocation of access and use of specific marine geographic areas*" and "*a place-based framework for ecosystem-based management that reduces conflict, uncertainty, and costs by separating incompatible uses and specifying how particular areas may be used*" (Edwards, 2008).

Zoning partitions a region into areas that are designed to permit or prohibit certain activities with the goals such as preserving an overall set of ecosystem services provided by the whole of the zoned area. Deciding which ecosystem services to preserve is itself a difficult decision to make, however, Governments would likely make this selection based on their economic value. Zoning processes need to pay attention to the consequences of allowing multiple activities that conflict with one another to occur within the same area (Halpern et al., 2008). Exclusive use zones, as opposed to single use zones, may include more than one use providing that the other use/uses do not negatively impact upon the sanctioned activity i.e. boating and diving may both be permitted within a marine reserve if it is considered that they would not damaged the features for which the marine reserve was designated (Edwards, 2008). Effective application of zoning schemes can have several benefits. It can allow activities that interact and lead to additive consequences to be separated into different zones, whilst awareness of cumulative impacts allows definition of acceptable levels within zones. Furthermore, if 'dominant' activities are identified that exert disproportionate levels of stress on a habitat or service, they can be prohibited to occur within the zoned areas or only be allowed to occur in zones where no other major activities take place (Halpern et al., 2008), for example oil and gas exploration.

Zoning has in the past been successfully used as a tool to address safety or amenity issues thus proving to be a useful tool for minimising conflict in areas where competition for space on a spatial or temporal basis is high (Boyes et al., 2007). However spatial management by means of zoning cannot control where ecosystem services are produced, therefore the zoning coverage should always be dictated by the spatial scale of the marine habitat and resources rather than by where it is convenient to locate them (Halpern et al., 2008). There are several other issues associated with zoning schemes that can be problematic and ultimately have negative consequences for the area being managed. These include but are not limited to; the names of zones and therefore what they represent, the zone boundaries (often natural features are difficult to define), public understanding, placing physical boundary markers and enforcing/policing zones (Day, 2002)

In the 1970s, 80s and 90s the majority of marine zoning was confined to and promoted within Marine Protected Areas (MPA) zoning schemes to identify areas where the management objectives of MPAs could be realised (Boyes et al., 2005; Gubbay, 2005). However the uses of zoning schemes are not limited to achieving biodiversity conservation goals, they can also be used as a management tool to aid marine spatial planning, as mention previously. Most modern texts on managing marine environments refer to zoning and its use in separating conflicting uses or for keeping sensitive, ecologically vulnerable or valuable sites free from potentially damaging uses.

Currently there are several zoning schemes being implemented in various countries such as USAs and Australia, each with the aim of prioritising or protecting their environmental assets and manage the activities that occur within their waters. Zoning as a management tool has been used to try to regiment and direct current marine decision making. The schemes aim to unite the different mechanisms in place for conserving threatened species and habitats by identifying areas that may be environmentally sensitive or important for cultural heritage (Boyes et al., 2007). Zoning schemes also aim to identify areas that may be favourable for particular industries and activities and this can serve to minimise spatial completion across different sectors. More established zoning schemes, such as that used in the Great Barrier Reef Marine Park (GBRMP), can be used to guide where activities should be allowed to occur, along with the level of the activity that would be deemed permissible in designated areas (Day, 2002; Boyes et al., 2007). The zoning scheme used at the GBRMP in Australia is one of the longest running zoning initiatives in the world; it divides the reef area into 4 ecologically rated zones all with varying degrees of protection assigned to them (Day, 2002; Day et al., 2008). It does this by combining layers of data on habitats and species uniqueness, and by using the natural breaks method (Jenks, 1977; ESRI, 1996), grouping areas into these four zones according to the number of ecological factors (habitats and uniqueness) they have. Other zoning schemes developed have been even more complex than that of the GBRMP, such as the zoning scheme utilised in the Monterey Bay National Marine Sanctuary (MBNMS) off the coast of California in the United States (US Department of Commerce, 2011). The area covered by this zoning scheme contains 72 sites in which specific human activities (commercial and recreational) are permitted to occur. These sites can all be grouped into 13 categories or marine zones each with their own agenda, allowing certain activities to occur and having their own set of regulations attached to them (Brown, 2001). The zones themselves are very varied in their function and this is reflective of the numerous activities that occur within the MBNMS. For example, there are Jade Collection Zones that allow small-scale jade collection sufficient to support the local artisan communities while still protecting the MBNMSs mineral resources. In conjunction with the Jade Zones that are concerned with protecting the sanctuaries natural resources, there are also other zones such as the Recreational Zones that are specifically designated for recreational uses, but also regulated to limit the degradation of natural resources. There are also Shark Attraction Prohibited Zones, in which the attraction of white sharks is prohibited with the intention of preventing the negative impacts that attracting sharks to the area may have on other users and the species themselves (Brown, 2001; US Department of Commerce, 2011).

Most zoning schemes are devised to cover certain areas, however there are a few infrequent examples of zoning schemes, such as that employed at the Tasmanian Seamounts Reserve, that zone activities (primarily fishing) by depth.

This is because at this reserve activities taking place in shallow waters are not thought to have any major impact on the seamounts flora and fauna (Gubbay, 2005).

Zoning is gaining support as a solution to competition for limited space and other inherently spatial problems (Edwards, 2008), however, zoning alone cannot manage all activities, other spatial management tools such as permits and management plans should be used in conjunction with zoning strategies in order to implement an effective framework for marine spatial planning (Halpern et al., 2008).

2.4 The Multiple-Use Zoning Scheme

The multiple-use zoning scheme applied in this study was based on a *posteriori* zoning scheme, which summarised and classified existing zones and regulations, developed by Boyes et al. (2007) for the Irish sea. It was based on existing legislation in order to provide a tool that would aid Marine Spatial Planning at a national scale. It is not an objective-based comprehensive zoning scheme for Scottish waters; this would require a policy-led approach whereby zones are created specifically to protect features requiring conservation or other objectives e.g. promoting productive seas whilst maintaining diversity. It is not the intention of the current zoning scheme to propose policies for application to each of the zones but only to identify areas where different levels of restriction apply to existing activities and where future developments may be, or not, advised.

Scottish seas support a variety of users and activities that all compete for space. These include: aquaculture, archaeology, fisheries, dredging, conservation, military activities, oil and gas, shipping and transportation, submarine pipelines and cables and potential CO_2 storage. Scottish and European legislation and regulations related to marine activities and designated conservation sites presently in force within Scottish waters were identified and summarised.Various non-statutory management measures are in place within Scottish waters, including recommendations and codes of practice. The analysis undertaken in this study however, only considered statutory measures and jurisdictions. It excluded local authority bylaws and therefore did not take into account activities that occur below the high water mark i.e. within intertidal areas.

The current study extends the approach of Boyes et al. (2007) in two key ways. Firstly it determines whether it is possible to adapt the existing scheme to a larger spatial scale, and incorporate a wider range of legislative measures within the categories defined. Secondly, it also determines how well existing legislative and regulatory provisions provide protection for marine features of conservation interest; specifically here rare marine landscapes classified by the UKSeaMap scheme (Connor et al., 2006; McBreen et al., 2011) and a selection of taxa defined as Priority Marine Features within Europe by OSPAR (2008).

2.5 Methods

2.5.1 Implementation of the Zoning Scheme

The main Scottish legislation and regulations relevant to marine nature conservation and activities currently in place within Scottish waters were identified and summarised, see Table 2.1. In Appendix 1, Table A1.0 additionally covers the national legislation which regulates activities within Scottish waters out to 200nm. Much of the information and data used were sourced from local authorities, ports and harbour authorities, the Scottish Environment Protection Agency (SEPA), sea fisheries committees and the Scottish Government. For most licensed activities their locations were obtained from the licensing/regulatory authorities (e.g. the Crown Estate) or the operators of the activities themselves (i.e. fallowing blocks from DECC).

The first stage in developing this zoning scheme was to map these existing activities and areas identified in the initial review using a geographical information system (GIS) (see Figure 2.1.) for full page colour map of Figure 2.1 and individual maps of each groups of activities see Appendix 1 Figures A1.0-A1.11.

Table 2.1 - Data utilized for Legally Permitted Activities within Scottish Waters

Layer	Title	Source	Data Included & Comments
Archaeology	Wrecks	RCAHMS, Historic Scotland	Designated Shipwrecks and Marine Archaeological Sites
Aquaculture	Lease Sites	The Crown Estate	Finfish and Shellfish (Active) Sites
Carbon Dioxide Storage	Storage Sites	DECC	Hydrocarbon Fields and Saline Aquifers
Dredging and Disposal	Regulated Areas	Marine Scotland Science, EDINA	Dredged areas under license and Dumping grounds
Military Activities	Restricted Areas	EDINA	Firing Danger Areas, Submarine Areas and Practice Areas
Nature Conservation	Protected Areas	Scottish Natural Heritage	SPAs, SACs, SSSIs, World Heritage Sites, National Nature Reserves, Ramsar Sites with a Marine Component
Oil and Gas	Regulated Areas	DECC, EDINA	Significant Discoveries and Oil and Gas Seabed Wells information was buffered at 0.005 decimal degrees. Fallowing Blocks, Hydrocarbon Fields and Oil and Gas areas under license.
Ports, Harbours and Shipping	Transportation Areas	Maritime and Coastguard Agency, Department of Transport, RYA, via EDINA and Marine Scotland Science	Harbour Jurisdictions, Shipping and Ferry Routes, Small Craft Facilities, IMO Traffic Scheme, Deep Water Route and Caution Areas
Renewables	Lease Sites	The Crown Estate	Wind Farm Lease Sites, Tidal Lease Sites, Wave Lease Sites and Scottish Energy Awards
Sea Fisheries	Regulated Areas	CEFAS, Marine Scotland Science	Lamlash No Take Zone, Inshore Fisheries Group, Mackerel and Cod Nursery Grounds
Submarine Pipelines and Cables	Spatial Extent	UK Deal via EDINA	Cables (Coaxial, Fibre optic and telegraph) and Pipelines

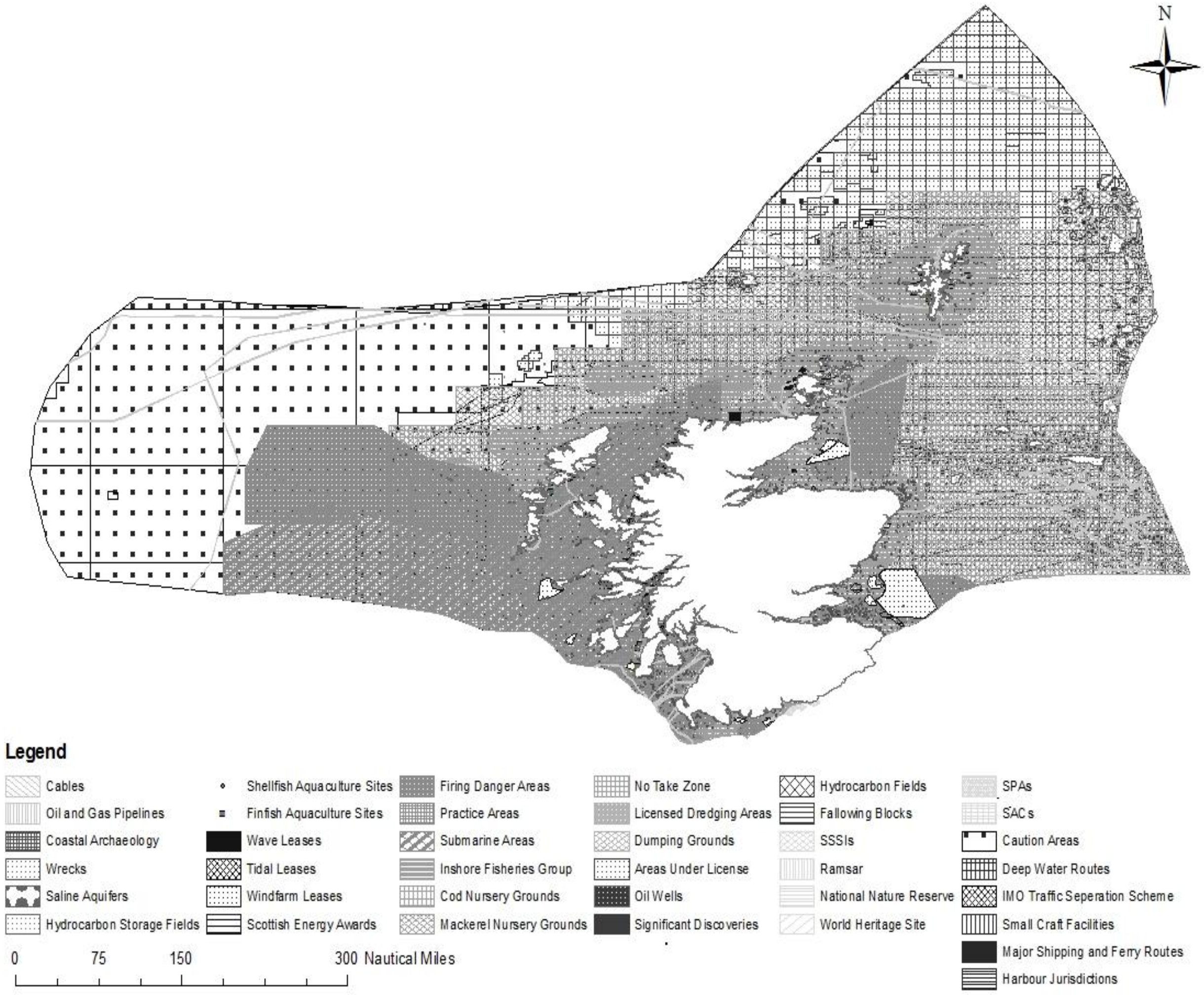

Figure 2.1 - A representation of some of the main activities and important environmental designations within Scottish Waters (McWhinnie et al., 2014).

Current legislation and regulations and any spatial constraints that may also exist for certain activities were combined to produce a four zone scheme (Boyes et al., 2007). Each of the four zones proposed afford an increasing level of protection and level of active management. The four proposed zones are:

1. General Use Zone (containing two sub-zones; Minimal Management Zone and Targeted Management Zone): in principle defines the activities currently permitted by international legislation or those that can occur subject to legally permitted consents and license being issued.

2. Conservation Priority Zone: incorporates all areas designated for their conservation importance, this zone is superimposed on the GUZ because activities are not automatically restricted but often subject to greater control, assessment or monitoring.

3. Exclusion Zone (containing two sub-zones: Limited Exclusion Zone and Significant Exclusion Zone): can incorporate activities which place a temporal or permanent exclusion zone around them on health and safety grounds or to infer exclusion rights on itself.

4. Protected Area Zone: to encompass protected historical areas where irreparable damage can occur if activities are permitted.

The zoning Table in Appendix 1, Table A1.1, identifies the various zones in which the different activities can take place. It should be noted that many of the activities are only permitted to occur when consent has been granted, or within consented areas, i.e. within a licensed block or with the allocation of a permit or license for the activity taking place. The activities considered in this zoning scheme were assessed for the restrictions and level of protection they place on their environment. This then dictated which of the different zones they were allocated to.

A description of the methodology and details of each of the zones and the activities permitted within them is presented by Boyes et al. (2005 and 2007). Activities were mapped within GIS based on the zone where legal restrictions apply. Table 2.2 shows the placement of each of the activities and the justification for their allocation into the different zones. Their placement is for the purposes of research only and is not an indication of which activities would be allowed when implementing an actual MSP scheme. Colour coding has been used to illustrate the different management and protection levels in each zone, as following:

- Blue – Zones where any activity can potentially occur subject to appropriate legislation
- Green → Orange – Increasing restrictions being applied to activities
- Red – All activities are prohibited

The results of applying the scheme described above are shown in map form in Figure 2.2, again colour coding has been used to illustrate the different management and protection levels in each zone.

Table 2.2 - Activity allocation to Multiple-Use Zones and their Justification (Adapted from McWhinnie et al., 2014).

Zone		Justification	Types of Area
4. Protected Area Zone (PZ)		Restricted access, all other activities prohibited	Historical Wrecks
3B. Significant Exclusion Zone (SEZ)	3. Exclusion Zone (EZ)	Restricted access (exclusion) zone established for safety reasons, full exclusion to all activities within 500m (3B) Excludes dredging activities within 250m (3B)	Significant Oil/Gas Discoveries Oil Wells Wind Farm Lease Sites Tidal Farm Lease Sites Wave Farm Lease Sites
3A. Limited Exclusion Zone (LEZ)		Restricted access when MOD activity is occurring and other activities only permitted out with these times (3A) Restricted access to shipping for safety and conservation reasons (3A) Seasonal/annual restrictions on gear/quota/target species, doesn't prevent other activities occurring (3A)	MOD Firing Danger Areas MOD Submarine Areas MOD Practice Areas No Take Zones Cod Nursery Grounds Fishery Closures Marine Finfish Aquaculture Marine Shellfish Aquaculture Submarine Cables Submarine Pipelines Shipping and Ferry Routes Small Craft Facilities Deep Water Routes Caution Areas
2. Conservation Priority Zones (CPZ)		These areas form a suite of marine protected areas between 0-200nm from the coast. Licensed areas for this activity Designated areas for shipping movements Defined areas with associated byelaws and other legislation Licensed Activities in defined areas	Archaeological Sites SSSIs Marine Ramsar Sites National Nature Reserves World Heritage Sites SPAs SACs
1B. Targeted Management Zones (TMZ)	1. General Use Zones (GUZ)	Licensed areas for this activity Designated areas for shipping movements Defined areas with associated byelaws and other legislation Licensed Activities in defined areas	CO_2 Storage Saline Aquifers CO_2 Storage Hydrocarbon Fields Dredging Areas Dumping Grounds Inshore Fisheries Groups Scottish Energy Awards
1A.Minimal Management		All other activities can occur in this zone if legally permitted	Fallowing Blocks Hydrocarbon Fields Oil & Gas Areas Under License Harbour Jurisdictions Traffic Separation Scheme Remainder of the Scottish Sea Areas

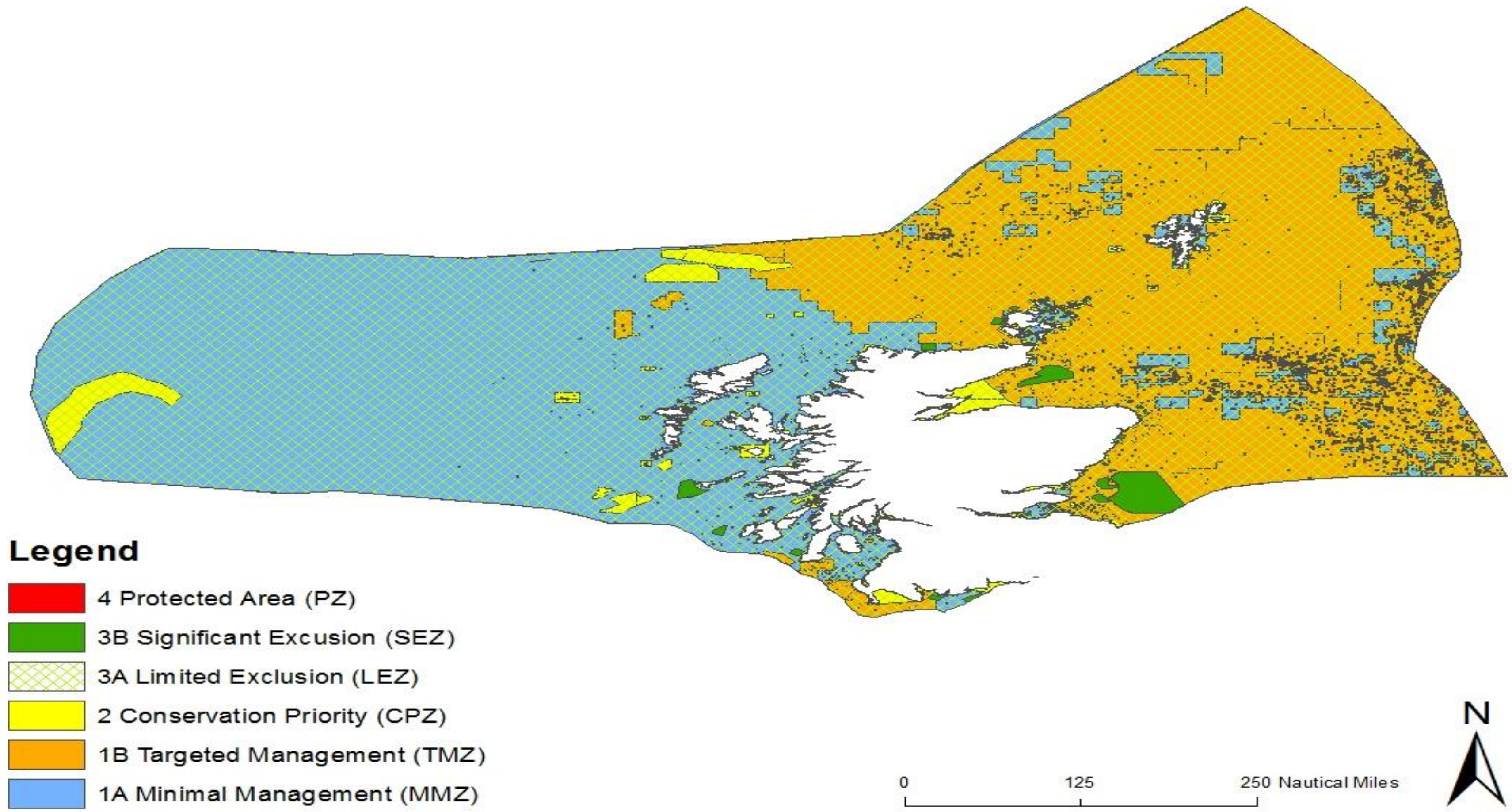

Figure 2.2 - Proposed Multiple-Use Zoning Scheme applied to Scottish Waters © 2014.

Table 2.3 shows the relative proportions of each zone as applied to Scottish waters. It can be seen that the protected area zone (4) has the smallest area coverage of all the zones with only 0.0002%. This is owing to the fact that according to the zoning rules only designated wrecks are permitted within this zone. In direct contrast the Limited Exclusion Zone (3) covers 99.8% of the total sea area involved. It is perhaps interesting to note, because it is an atypical way of constructing a zoning scheme, that both the Limited Exclusion and the Conservation Priority Zone have been designed to overlap with the other zones. As stated previously, in the case of the Conservation Priority Zone, this was established due to activities not necessarily automatically restricted just because they fall within this zone. Instead they may be simply subject to greater levels of assessment, regulation and monitoring. The Limited Exclusion Zone similarly, may exert additional controls and exclude certain activities but importantly this will only happen during allotted periods of time and will not be a permanent restriction. This perhaps goes someway to explain why almost 99.8% of the sea area was covered by this zone as not all the activities in this zone will be occurring at the same time and therefore not applying the level of restriction that would initially appear from identifying this extent of coverage.

Table 2.3 - Relative proportion of each of the Zones within the Multiple-Use Zoning Scheme. It should be noted that the Limited Exclusion Zone (LEZ) was calculated separately as this zone overlies all other zones.

Zone	Subzone	Area (km^2)	Percentage Cover of each Zone (%)
GUZ (1)	MMZ (1A)	244,389	52
	TMZ (1B)	219,667	47
CPZ (2)	n/a	7,432	1.6
EZ (3)	LEZ (3A)	469,228	99.8
	SEZ (3B)	9,843	2.1
PZ (4)	n/a	0.729	0.0002

2.5.2 Testing the Zoning Scheme

Once the different zones had been derived, the scheme was then tested by calculating the proportion of a series of features of conservation interest that were contained in each of the different zones.

2.5.3 Analysis using UKSeaMap 2010

The aim of the UKSeaMap project was to use the best available geological, physical and hydrographical data, combined with ecological information, in order to produce simple broadscale habitat landscape maps (Gaston, 1994). These maps were intended to represent dominant seabed and water column features for the whole sea area under UK jurisdiction.

When determining which landscape types to test the scheme against, there are different definitions of rarity that could be applied (Gaston, 1994). In this case, the decision was taken to analyse the five rarest landscapes (by area) against the multiple-use zoning scheme. The specific landscapes that were analysed were: lagoons, deep sea mounds, shallow mixed sediment plains under moderate tide stress, shelf mixed sediment plains under moderate tide stress and shelf mixed sediment plains under strong tide stress. The locations of these rare landscapes are shown in Figure 2.3. These areas were combined with the multiple-use zones in GIS and the areas that fell within each zone were calculated for each type of landscape.

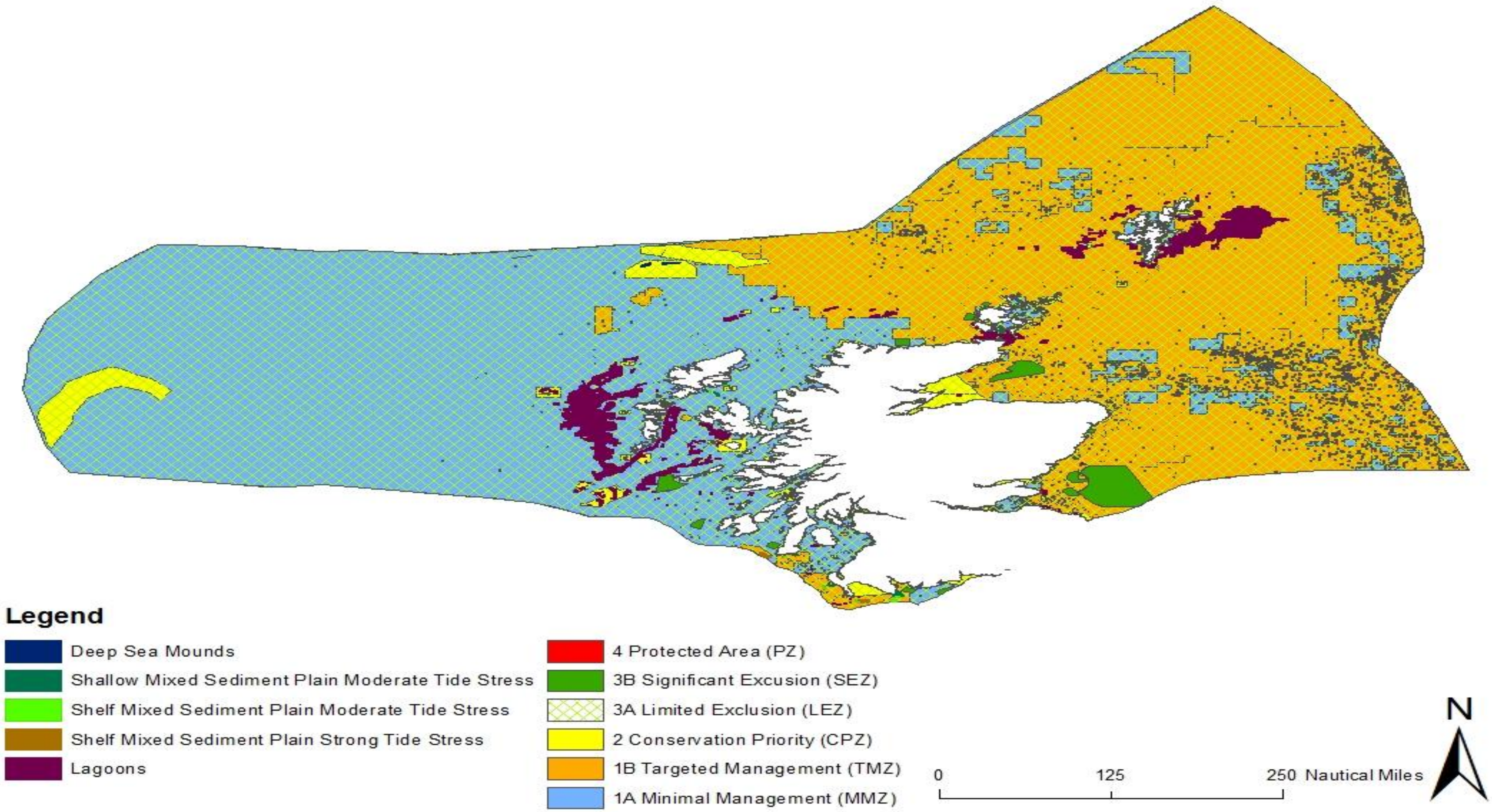

Figure 2.3 - Rare Marine Landscapes from UKSeaMap 2010 within the Multiple-Use Zoning Scheme proposed for Scottish Waters.

2.5.4 Analysis using OSPAR Priority Marine Features

In 2003 the Scottish Government committed to establish an ecologically-coherent network of Marine Protected Areas (MPAs), known as the OSPAR MPA commitment (OSPAR, 2003). The habitats and species listed by OSPAR have since been considered through Scottish Natural Heritage's Priority Marine Features (PMFs) work in order to assess which features are priorities for conservation within Scottish waters (Moore et al., 2011). A subset of PMFs; MPA search features, has been used to help identify MPA locations and develop the protected area network Scotland has committed to implementing within its waters.

PMF species and habitats that were present within Scottish waters were mapped using data from OSPAR and JNCC records (Figure. 2.4). To determine which of the multiple use zones these important marine features fall into they were mapped in GIS with the multiple-use zoning scheme and percentage cover calculated. The results reported represent the percentage of the total number of records of each PMF present in the different zones, rather than areas as features were recorded as point occurrences.

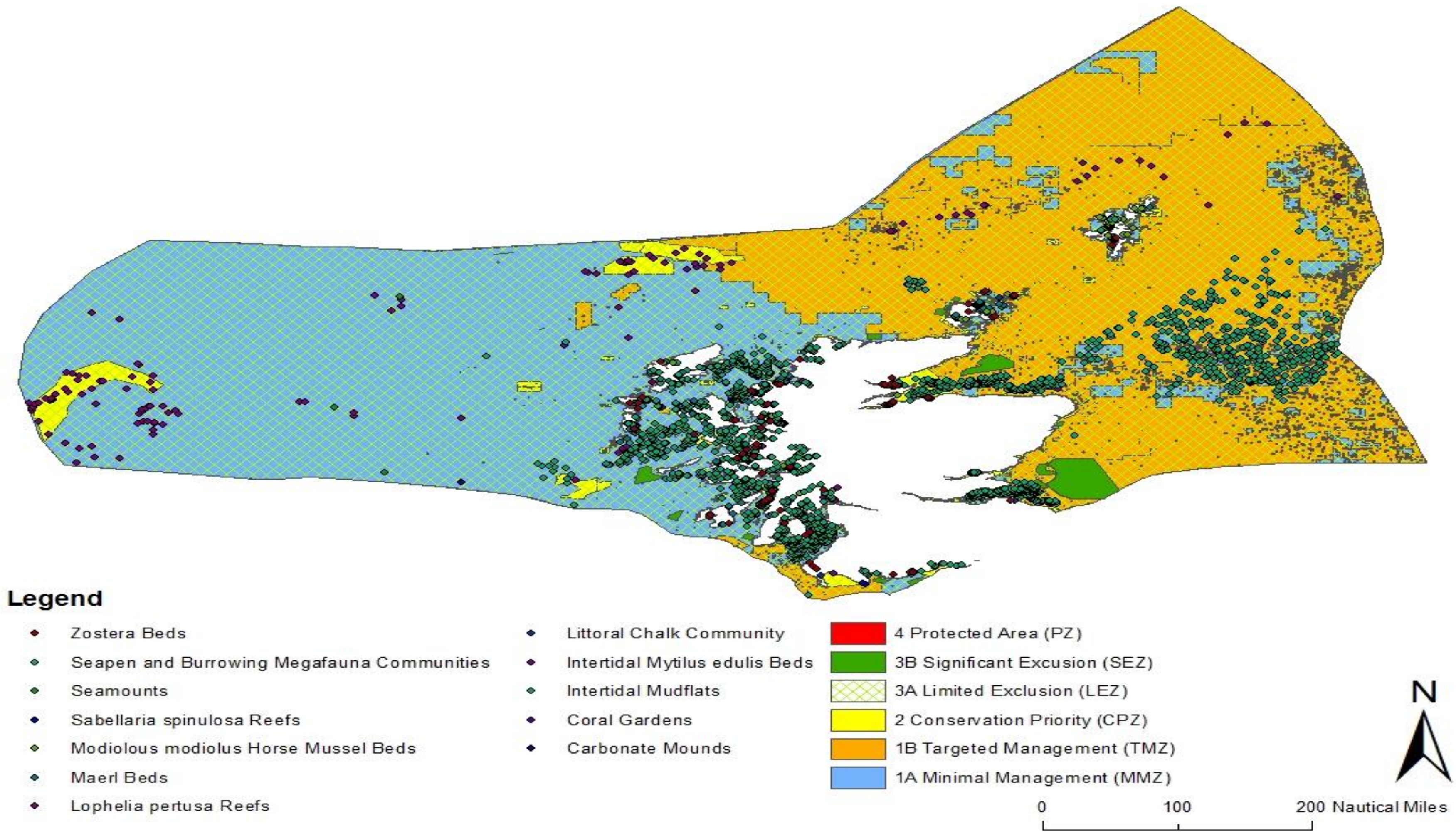

Figure 2.4 - Priority Marine Features within the Multiple-Use Zoning Scheme proposed for Scottish Waters

2.6 Results

2.6.1 Testing with UKSeaMap 2010

Of the five rare landscapes tested (see Table. 2.4) only one small area (0.1km^2) of lagoon falls within zone 4, which affords the highest level of protection against further developments. Furthermore within 3B (significant exclusion) there are only two small areas of lagoon (26.84km^2) and shelf mixed sediment plains with moderate tide stress (0.38km^2). Deep sea mounds are offered no additional protection from developments by the conservation priority zone. However, as previously mentioned, whilst conservation priority zones require greater levels of assessment and monitoring to take place, they do not necessarily restrict developments from occurring. Zone 1B, where legally permitted activities can take place, has all except one of the rare landscapes occurring within it. Activities such as shipping and dredging can both be licensed over these landscape features. All five rare landscapes occur within zone 1A and, based on the data available, all of Scottish deep sea mounds are located within this general use zone.

Zone 3A (limited exclusion) has been calculated separately as this zone overlies all other zones, affording some degree of both temporal and spatial restrictions on activities. Fishery closure areas are an example which provides some restriction on activities that will overlie some of these landscapes. However these are only temporary closures and therefore do not provide constant protection. They also only restrict certain activities (in this case fishing) and do not prevent other licensed activities from occurring in this area.

Table 2.4 - Areas (km^2) of Rare Marine Landscapes within the Multiple-Use Zoning Scheme proposed for Scottish Waters. The percentage of the total area of each landscape is given in parentheses

Landscape and Total Area (km^2)	Minimal Management Zone 1A	Targeted Management Zone 1B	Conservation Priority Zone 2	Significant Exclusion Zone 3B	Protected Areas Zone 4	Limited Exclusion Zone 3A
Lagoons (9679 km^2)	5943.96 (61%)	3620.52 (37%)	256.05 (3%)	26.84 (<1.0%)	0.10 (<1.0%)	9679 (100%)
Deep Sea Mounds (53.08 km^2)	53.08 (100%)	No Overlap	No Overlap	No Overlap	No Overlap	53.08 (100%)
Shallow Mixed Sediment Plain Moderate Tide Stress(74.22 km^2)	27.35 (37%)	45.71 (62%)	3.02 (5%)	No Overlap	No Overlap	74.22 (100%)
Shelf Mixed Sediment Plain Moderate Tide Stress (81.63 km^2)	15.98 (20%)	65.15 (80%)	0.12 (<1.0%)	0.38 (<1.0%)	No Overlap	81.63 (100%)
Shelf Mixed Sediment Plain Strong Tide Stress (96.98 km^2)	10.30 (11%)	86.68 (89%)	0.83 (<1.0%)	No Overlap	No Overlap	96.98 (100%)

2.6.2 Testing with OSPAR Priority Marine Features

None of the twelve PMFs tested fall within Zone 4, where they would be fully protected (see Table. 2.5). Furthermore only two of the features fall within Zone 3B which affords the second highest level of protection, and both of these; *Lophelia* reefs and Sea Pen communities, only have a small fraction of their total area lying within this zone (2.2 and 1.5%, respectively). The inshore species and habitats all have some percentage of their total area falling within Zone 2, the conservation priority zone, affording them greater protection. *Sabellaria* reefs notably have over 61% of their habitat recorded within Zone 2, and a further 90% of their total area also falls within the targeted management zone, although there will be some areas of overlap and certain areas of the reef will be covered by both Zone 2 and 1B. Nevertheless *Sabellaria* reefs appear to be the exception, with the majority of the area or records of the habitats and species considered found within the least protected Zone 1A (general use). As carried out previously with the UKSeaMap landscapes, Zone 3A was calculated separately as it overlaps the other zones, placing temporal and spatial restrictions to the other activities taking place therein. All the species and habitats had a large proportion of their habitat fall within Zone 3A and therefore may be provided some protection by fisheries protected areas (closure areas), but these will only be temporary, spatially variable over time and do not restrict other activities occurring within these areas.

Table 2.5 - Percentage of OSPAR Priority Marine Features within the proposed Multiple-Use Zones for Scottish Waters (km^2)

OSPAR PMFs	Minimal Management Zone 1A (%)	Targeted Management Zone 1B (%)	Conservation Priority Zone 2 (%)	Significant Exclusion Zone 3B (%)	Protected Areas Zone 4(%)	Limited Exclusion Zone 3A (%)
Carbonate Mounds	100					100
Intertidal Mudflats	15.69	10.7	24.8			69.5
Littoral Chalk Community	29.1	2.05	36.4			70.6
Seamounts	100					100
Coral Gardens	100					100
***Modiolus* Beds**	39.8	4.8	30.5			73.1
Intertidal *Mytilus*	37.7		27.8			65.5
***Lophelia* Reefs**	71.5	25	3.6	2.2		100
Maerl Beds	57.8	3.2	24.5			83.5
***Sabellaria* Reefs**		90.7	61.5			90.7
Sea pen Community	50	39.9	9.4	1.5		95.9
***Zostera* Beds**	28.8	8.5	34.8			66

2.7 Discussion

2.7.1 Application of the Multiple-Use Zoning Scheme

The application of this zoning scheme has demonstrated that it is possible to modify and adapt an existing multiple-use zoning scheme to fit Scottish marine waters. This was accomplished by condensing and mapping current spatially derived legislation and regulations and giving consideration to the level of environmental protection that they afford. In particular, the application of the method developed by Boyes et al. (2007) for the smaller Irish Sea area, has shown that the presently defined regulatory and sectoral measures in Scottish waters can be combined within a zoning scheme. It has also highlighted that designated conservation sites can be seen to constitute their own type of multiple use zone and the only areas that show exclusive use by a particular activity are those with sectoral activities that are accompanied by strict regulatory measures.

The zoning scheme applied here was derived from current legislation and regulations alone, with non-statutory policy measures, voluntary agreements and other initiatives not included. In the future, however, it would be pertinent to include these other management mechanisms should their spatial data be available when undertaking a zoning task. Although this scheme identifies four proposed Zones (See Figure 2.3), they are fundamentally only a description of what occurs in each area. Therefore it could be argued that it is not in fact a true zoning scheme as the zones relate largely to the differing levels of restriction on use resulting from existing management controls, rather than having been derived with specific objectives and the purpose in mind. It could perhaps be made even more effective if the criteria were organised into explicit data sets and then linked them to specific objectives.

Zoning, in a marine context, can be viewed as a cross-sector allocation system that has the ability to inform decision making (in this case by the government), establish regulations and integrate environmental management mechanisms and objectives, whilst separating those ‘incompatible’ activities/users into different zones (Edwards, 2008; Halpern et al., 2008). Currently there are several zoning schemes being implemented in various countries such as USA and Australia, each with the aim of prioritising their environmental assets and manage the activities that occur within their waters

(Ruckelshaus et al., 2008). Well established schemes, such as that used in the Great Barrier Reef Marine Park (GBRMP), are used to guide where activities can be allowed to occur, along with the level of activity that is deemed permissible (Boyes et al., 2005; Day et al., 2008). It does this by combining layers of data on habitats and species uniqueness and grouping areas into four zones based on the number of ecological factors (habitats and uniqueness) they have. Other zoning schemes developed have been even more complex than that of the GBRMP, such as the one utilised in Monterey Bay National Marine Sanctuary (MBNMS) off the coast of California in the United States (Brown, 2001; Ruckelshaus et al., 2008). The spatial boundary of this scheme encompasses 72 sites in which specific human activities (commercial and recreational) can occur. Altogether, these sites can be grouped into categories or marine zones each with their own agenda, allowing certain activities to occur and have their own set of regulations attached to them (Brown, 2001; Day et al., 2001; Ruckelshaus et al., 2008). The zones themselves are varied in their function and this is reflective of the numerous activities that occur within the MBNMS. For example, there are zones protecting natural resources, prioritising recreational uses and those designated with prohibiting shark attraction (Brown, 2001; US Department of Commerce, 2011).

For this specific zoning scheme to be developed into an influential tool to guide MSP in Scotland, economic, environmental and social objectives would need to be incorporated. It would then need to be further underpinned by an overall goal of minimising or avoiding spatial conflicts between users and between activities and the environment. Additionally, existing legal controls would also benefit from being aligned to these same economic, environmental and social objectives. Doing so could potentially highlight where incompatibilities lie and where existing controls would have to be modified. At present, such an approach may be more difficult to achieve with sectoral management given that this has often failed to integrate goals across different sectors in a balanced fashion. A good example of failed governance strategies can be seen in northern Alaska where there is long running conflicts between oil and gas developers and has led to loss of biodiversity, pollution and ill-planned coastal developments (Crowder et al., 2006). Nevertheless, the development of zoning schemes such as this one do provide a benchmark against which social and environmental objectives can be assessed.

2.7.2 Limitations of the Zoning Scheme

There were several activities such as recreational sailing and fishing that, due to lack of data, had to be omitted from both the exclusion and the protected zones, however, even if activities do occur within these zones, the level of protection afforded by these zones and in turn the conservational benefits they are able to deliver may be limited. This is primarily due to site size; they are considered to be too small to confer on them the ability to limit harmful development significantly. For example, the Significant Exclusion Zone and the Protected Zone cover an area of 9,843km^2 and 0.729km^2 (see Table 2) respectively which, together, is less than 3% of the total sea area zoned. Conversely, some developments may indirectly improve an area's conservation status e.g. by affording some species and habitats protection through placing controls on certain types of damaging activities within their exclusion areas (such as pipelines and dredging).

However, even within the Significant Exclusion Zone (SEZ), where other activities are predominantly excluded and therefore protection may be inadvertently provided to some species/habitats, the actual licensed development (e.g. oil and gas, renewable energy development etc.) could be having a disproportionately negative effect on the areas conservation status. From a conservation stance, the only zone that will afford a site complete protection will be Zone 4, the smallest of all the zones (see Table 2). This includes an extremely small area, is distributed in pockets surrounding wrecks and military remains, and as a result they have little influence on the protection of features of conservation interest. In practice, in order to achieve sustainable use whilst protecting key features, a balance has to be struck in terms of how and where activities are restricted, which does not appear to be well-achieved using existing legislative controls in Scottish waters.

2.7.3 Marine Landscapes: UKSeaMAP 2010

This current application of the multiple-use zoning scheme highlighted that there is currently very minimal protection afforded to rare marine landscapes. Most designations of protected areas for conservation purposes within the marine environment in the UK have previously focused on species or habitats that are considered in need of protection at an international (mainly EU) level, rather than national level assessments of rarity, such as that used in the

UKSeaMAP analysis, hence this is not entirely surprising. It can be concluded that further measures would be advisable in order to protect these features in the future. These measures could possibly include introducing additional specific protected areas or the further extension of zones that can provide appropriate levels of protection. One desirable objective of this work would perhaps be to identify a network of areas that includes a representative of all the marine landscape types that could be designated to provide them protection from damaging activities using the conservation requirements of important features to inform the decision making process. If for instance a network of areas was to be established that represented all marine landscapes, whereby the conservation legislation alone and not conservation requirements of the feature informed the decision making process, then only a small area of 1 out of the 5 landscapes, see Table 3, are currently represented in Zone 4. Alternatively if the objective was for a certain percentage, for example 10%, of each landscape to be included in such a zone then this objective would also not be met. If instead the objective was to include a proportion of a feature within the protected Zone 4, where activities that may cause it physical damage are prohibited, then only 0.001% of lagoons are currently protected.

2.7.4 OSPAR Priority Marine Features

Testing the scheme on the basis of the PMF data demonstrated that a variable proportion of the priority marine features within Scottish waters fall within zones where there is a degree of restriction placed on activities that are allowed to occur. Currently there are no priority marine features, species or habitats in Scottish waters that are located within Zone 4. If the objective was to include 10% of each features records within areas where conservation is a priority and managed accordingly (Zone 2), then this is not currently being met for all the features with carbonate mounds, seamounts and coral gardens currently lacking any features within these zones. However again it should be noted that while this zone does provide some added protection it does not negate development and can only serve to limit potentially damaging activities. Also, notably, only 36% of *Lophelia* reef features fall within Zone 2 whilst 71.5% falls within 1A the minimal management zone.

2.8 Conclusion

This chapter describes work carried out on the development and testing of a multiple-use zoning scheme for Scottish waters based on the approach set out by Boyes et al. (2007). Given that the scheme applied was based on existing legislative controls implemented for a wide variety of reasons, it is not entirely surprising that the level of protection for Priority Marine Features or landscapes is relatively weak. What this work has highlighted however is that features of National and European importance are located within what are currently in effect multiple-use areas. It is entirely possible that a balance of well-managed activities can take place within such areas, but existing controls may be insufficient to ensure that environmental objectives are achieved within them. Zoning schemes as part of any marine spatial planning framework will be required to acknowledge and encompass any existing designated protected areas such as the Natura 2000 network and more recently designated Marine Protected Areas (MPAs). The ultimate aim is the achievement of environmental sustainability goals in the future, through the application of a broad-scale management approach that incorporates prevailing activities, taking into consideration key environmental aspects. This study has also demonstrated that in order to make more comprehensive progress pertaining to conservation measures, clear objectives will need to be developed. Any objectives should apply to both the wider environment and specific zones. Regarding MPAs, upon definition of any conservation objectives, zoning that takes account of both economic, social and environmental objectives should enable the implementation of a network to be planned and integrated with other conservation measures and activity sectors. In doing this, a future multiple-use zoning scheme, should have the potential to achieve both better integration between conservation and other activities/users, regulation and planning of activities across all sectors.

Finally this study has emphasised that further development of administrative and legislative management mechanisms is required in order to allow the implementation of a zoning scheme such as the one applied here within a marine planning system. On an additional note, a comprehensive system of MSP which includes an effective and enforceable zoning scheme, such as this one, would be unlikely to achieve its objectives purely on a voluntary basis.

Therefore a statutory mechanism with the duties and resources to implement and enforce any scheme would be required. It is likely that this would need to be placed within an agency or appropriate department in order to ensure that the system implemented is workable.

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Chapter 3
A Marine Planning Framework

3.1 Managing Increasing Pressures

Globally, coastal areas, due to their abundant natural resources, attract economic development and residential use, (Worm et al., 2006). People can access employment, leisure and recreation from the oceans' many resources (Shi et al., 2001). The rapid increase in human population, coupled with technological advances and growing consumer demands, has resulted in a considerable increase in the need for more food, energy and trade (Arkema et al., 2006; Douvere, 2008). This situation is not helped by the fact that land resources are greatly diminished and therefore more pressure is being placed on goods and services from coastal and marine areas to meet these emerging requirements and demands (Douvere, 2008).

Anthropogenic activities are also having a multitude of secondary effects on marine resources. For example increased sedimentation of coastal areas also leads to habitat degradation that can specifically affect spawning grounds. Developments along the coastline can also impact upon fragile habitats, whilst irrigation and damming can change habitats and interrupt migration patterns (Curtin and Prellezo, 2010).

3. 2 Ecosystem-based and Integrated Coastal Zone Management

During the last decade many evolving trends and disciplines aimed at protecting marine environments from the accumulating pressure have adopted an ecosystem-based approach to sea use management, recognising that '*the nature of nature itself is connected*' (Douvere, 2008).However, and as mentioned previously, marine areas have traditionally been managed on a case-by-case and sector-by-sector basis, overlooking, the interdependent nature of many ecosystem components (Katsanevakis et al., 2011). To this end, the application of ecosystem approaches in the marine environment builds on the concept of integrated management that is already used to manage some marine areas where activities are more concentrated (Douvere, 2008).

Ecosystem-based management (EBM) is a more holistic approach to managing the marine space; it aims to ensure the sustainability of marine ecosystems and deals with conflicts between various marine users (Katsanevakis et al., 2011) but it requires a greater understanding of how ecosystems work (Curtin and Prellezo, 2010). EBM is an environmental, social and ecological approach to management that recognises all of the various interactions that occur within a marine system, as opposed to considering single issues or species or ecosystem services in isolation (Curtin and Prellezo, 2010; Katsanevakis et al., 2011). It is a broad approach that involves the management of humans, species and other natural commodities that are components of the larger ecosystem (Arkema et al., 2006; Crowder and Norse, 2008). OSPAR and HELCOM have jointly defined an ecosystem approach to sea use management as:

"the comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of goods and services and maintenance of ecosystem integrity".

The ecosystem approach also provides a framework for assessing biodiversity and ecosystem services. The Convention on Biological Diversity (CBD) referred to the ecosystem approach as 'a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way' (Douvere, 2008; Katsanevakis et al., 2011). In 1998 the CBD organised a workshop during which they identified twelve characteristics of the ecosystem approach to biodiversity management, these are now referred to as the Malawi principles. The principles aim to be both complimentary and interlinked and cover both environmental and societal components of management (Jaren et al., 2003).

One proposed way to achieve a better and more effective implementation of EBM in the marine environment is to use MSP (Douvere, 2008), because it is a means of resolving inter-sectoral conflicts over maritime space and is an acknowledged way of improving decision making. In this way ecosystem-based MSP can further aim to bridge the gap between science and practice and try to fill the current needs of both non-government and governmental organisations that require practical tools for implementing EBM in marine areas (Katsanevakis et al., 2011).

One of the primary goals for EBM is to coordinate all the different activities within the sea as a whole. A similar principle is already in place for some coastal areas in the form of Integrated Coastal Zone Management (ICZM). ICZM acknowledges the interrelationships that exist amongst sea uses and the environments that they potentially affect. It is designed to unite the fragmented management methods that are inherent in sectoral management approaches (David Tyldesley Associates 2004). However, the primary aim of ICZM is to promote the sustainable use of the coastal zone by balancing demands for natural resources with the economic, cultural and social needs of the area and by seeking to resolve conflicts of use, by considering the needs of present and future generation (Shi et al., 2001). Furthermore, this process is recognised by the United Nations which consider ICZM to be a:

"*Continuous and dynamic processes by which decisions are taken for sustainable use, development and protection of the coastal and marine areas and resources*"

(David Tyldesley Associates, 2004).

The successful implementation of EBM will require the use of the best available data and science. Emerging tools are being developed that implement: geospatial analysis, remote sensing, molecular techniques, telemetry, modelling and quantitative analysis, that will all help identify the spatial and temporal dynamics of marine ecosystems in relation to environmental variation (Katsanevakis et al., 2011). Additionally because social, cultural, economic and political dynamics overlay ecosystems (biophysically defined areas), approaches that integrate natural and social scientific perspectives on defining and managing places at sea area will also be necessary to implementing EBM (Crowder and Norse, 2008). A study recently released by Gavin et al., (2015) outlines many of the newly developed bio-cultural approaches to conservation management and governance. Many of these emerging techniques draw upon lessons from previous work on heritage and social-ecological systems, and these are all aspects that marine managers will also have to utilise. Ultimately, all of these tools and techniques will need to be combined in order to successfully accomplish the overall aim of EBM, which is for all marine uses and activities to be coordinated. In this context, zoning is seen as an essential tool (Curtin and Prellezo, 2010).

3.3 Ocean Zoning – A Review

The need for management of marine ecosystems at a larger seascape scale is becoming increasingly recognised (Paxinos et al., 2008). The management of marine areas can happen over a range of spatial scales, ranging from meso to micro scale, i.e. from regional seas to habitats and species. Different scales can be relevant to different aspects of an ecosystem functioning (Verfaille et al., 2009) as can social/economic drives such as DPSIR (Gregory et al., 2013).

To date most MSP initiatives are confined within national boundaries considering only local habitats and ecosystems, however, many sea uses, such as shipping and fisheries, may have impacts that span across these boundaries, therefore management should be implemented on both regional and international scales (Katsanevakis et al., 2011). Planning at a larger seascape scale is at various stages throughout the world's oceans with all of these different planning strategies encompassing a variety of different objectives for different regions, all having an economic focus with emphasis being placed on sustainable development, minimising conflict between users and providing protection to the marine environment (Paxinos et al., 2008).

The Eastern Scotian Shelf Integrated Management (ESSIM) Initiative was a collaborative management and planning process led by the Oceans and Coastal Management Division (OCMD), Fisheries and Oceans Canada (DFO), Maritimes Region. The ESSIM Initiative was designed as an intergovernmental and multi-stakeholder management and planning process in order to develop and implement an integrated ocean management plan for the large bio-geographic area involved (Rutherford et al., 2005). The goals and objectives laid out within this plan are now used to advise other process, however it has been recognised that further additions are required in order for this scheme to have a stronger influence on policy. China has also established legislation and management schemes to manage its large marine area. These have been established according to three principles: (1) the right to the sea-use authorisation scheme (according to the law the seas around China are the property of the state), (2) a marine functional zoning scheme and (3) a user-fee system (Douvere 2008). Unlike the Chinese scheme the Canadian ESSIM initiative has four overarching objectives instead of under-lying principles. These are: (1) integration of management of all measures and activities, (2) manage for conservation, sustainability and responsible use of the ocean, (3) restoration and maintenance of biological diversity and productivity and (4) provision of opportunities for economic diversification and sustainable wealth generation (Rutherford et al., 2005). In essence both of these different approaches deal with the multiple use of the sea area, the Chinese scheme through the adoption of a zoning plan and the Canadian scheme by integrating their various management measures. It could be argued that the Canadian scheme is a more ecosystem-based holistic approach than that of the Chinese system, with greater emphasis being placed on maintaining the integrity of the ecosystem. The Chinese scheme appears to perhaps place a greater emphasis on the management of its resources and improving coordination of it activities.

Ocean zoning can be seen as a set of regulatory measures that could be used to implement MSP and address issues such as those raised by both the ESSIM and the Chinese management scheme. Zoning is also considered to be a possible tool for EBM and MSP. Ocean zoning functions by partitioning a region into zones that are designed to permit or prohibit certain activities within them. The aim of this is to maintain the provision of an overall set of ecosystem services provided by the zoned area. Such zoning processes also need to consider the consequences of allowing multiple conflicting activities to occur within the same location (Katsanevakis et al., 2011). This is a key function of a zoning scheme; allowing activities to occur within each zone as long as they are compatible with one another so far as they do not lead to multiplicative consequences. Activities deemed ‘incompatible’, or that may lead to unacceptable ‘cumulative’ impacts can be assigned to separate zones so that overall impacts are reduced and managed (Curtin and Prellezo, 2010). ‘Dominant-use zones’ as opposed to ‘exclusive-use zones’ have also been proposed; these would give priority to one particular activity over all others within that zone.

Currently there are several tools being developed to help implement zoning schemes. One of the most widely trialled is the ‘Marxan with Zones’. This is a software program that uses simulated annealing approaches to create alternative zoning configurations that maximise the goals of social, economic and ecological objectives while minimising the overall social, economic and ecological costs (Katsanevakis et al., 2011). However, many are also wary of such approaches as techno-centric approaches are perceived to lack an understanding of underlying social issues. Other tools for developing zoning schemes such as GIS use analytical methods that focus on mapping the cumulative impacts of different sectors of human activities. The total impact of all human activities on the oceans can be assessed and specific activities can be included or excluded from consideration in order to determine which 'suite' of activities can best meet objectives for a given zone (Douvere 2008; Katsanevakis et al., 2011). For example, in the Great Barrier Reef Marine Park (GBRMP), one of the best known examples of marine spatial planning and zoning, various human activities (e.g. fishing and tourism) are permitted within certain zones while simultaneously providing a high level of protection for certain areas (Douvere 2008). Evidence from this, the largest zoned area of the world, has also shown that a simple zoning classification has been crucial for public acceptance (Katsanevakis et al., 2011), another factor that must also be considered when looking at the design and implementation of zoning and management schemes. Whilst they are well established in Australia, MSP initiatives like the GBRMP are also being implemented in various forms across Europe, America and Canada. For example, The Coastal Zone Management Program in Massachusetts, the Eastern Scotian Shelf Integrated Management (ESSIM) Initiative previously mentioned, in Canada and The Florida Keys Marine Sanctuary Management Plan (Douvere 2008).

Zoning, in addition to being a conservation and management tool, can also be used as a method for resolving user conflicts and determining trade-offs in the provision of ecosystem services and goods (Curtin and Prellezo, 2010). Some experts have argued for ocean zoning that would clearly split the seas into different areas. For example: commercial fishing zones, recreational zones and oil and gas zones. Those in favour of such a scheme argue that by separating 'incompatible uses' this would reduce the costly conflicts that can arise between users and that therefore zoning is the basis for implementation of an ecosystem-based approach to management (Sanchirico et al., 2010). This would be particularly true for sea areas that are shared between different countries and this has already been demonstrated in European waters where MSP and zoning are important management tools of the Trilateral Wadden Sea Cooperation Area. This plan was developed for the Wadden Sea as a trans-boundary initiative between the Netherlands, Germany and Denmark in order to protect and manage a shared coastal wetland system (Douvere 2008).

Other arguments in favour of zoning include indications that it could coordinate single-sector approaches to regulating marine activities which has been proven to lead to conflicting management goals, and government and non-governmental organisations working with little coordination. Additionally, advocates think that oceans would benefit from zoning as they would provide a greater level of protection for biodiversity (Sanchirico et al., 2010). Furthermore it has been proposed that comprehensive ocean zoning could potentially not only reduce conflicts through the creation of permitted activity areas but also encourage users within the zones to coordinate their activities (Katsanevakis et al., 2011). Sanchirico and colleagues (2010) consolidated the evidence derived from attempts at zoning to date and made three key arguments in favour of implementing a comprehensive ocean-zoning scheme:

1. Planning and use-priority management will increase prospects for conservation and efficient resource use
2. Use-priority management along with allocation of user rights creates the potential for ancillary benefits because of the way it changes users' incentives
3. The process of integrating comprehensive zoning into ocean management could be the means for a needed change in scope and scale of ocean governance.

This said it is also important to recognise that zoning is not without its faults and indeed it is not the answer to all aspects of marine conservation. For example issues such as decreasing water quality, unsustainable fisheries and uncontrolled coastal development can collectively cause negative impacts that zoning alone will not prevent or mitigate (Day, 2008).

Therefore to conclude, given the knowledge gained to date, it would seem that a zoning scheme that harmonises the environmental protection of the sea with its uses and users would be the most effective means of mitigating and may even reverse increasingly extensive human impacts on marine ecosystems (Katsanevakis et al., 2011).

3.4 Marine Planning Framework

Presently there are few frameworks that can facilitate integrated strategic and comprehensive planning in relation to all the activities taking place in marine areas. This lack of a structural framework often leads to: the spatial and temporal overlap of activities, a lack of connection between the various responsible authorities, a lack of connection between offshore activities and inshore communities, a lack of conservation of marine areas and a lack of investment certainty for marine developers (Douvere, 2008). This chapter proposes a GIS based zoning methodology for implementing a marine planning frameworks in Scottish waters. This zoning approach was initially selected for project as it was deemed robust, objective and repeatable compared to some other extremely complex applications of zoning schemes. The aim of incorporating an ecosystem-based approach is to allow for the creation of a zoning system that is based on the amount of habitats and species that occur within the marine environment the scheme is being applied to. It also allows for the identification and definition of the spatial boundaries of each of the zones. The application of a Marine Planning Framework (MPF) for Scottish waters was underpinned by three primary principles:

1. **Ecologically Sustainable Development (ESD) –** A report by the World Commission on Environment and Development (WCED, 1987) has also defined this concept as "development (which) meets the needs of the present without compromising the ability of future generations, to meet their own needs". In this Marine Plan proposed here, the ESD principle also incorporates the precautionary principle, in which, if there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation (Day et al., 2008).
2. **Ecosystem-Based Management (EBM) –** As explained earlier, the principles of ecosystem-based management are based on the importance of recognising ecosystem structure and function and then responding to signals from the ecosystem in order to manage anthropogenic activities and uses (Day et al., 2008).

3. **Adaptive Management (AM) –** Adaptive management should involve the acknowledgment that scientific knowledge is dynamic and continuously updated and focus on management as a learning process or as a continuous 'experiment'.

The three principles described above interact in different ways through this marine plan; firstly they drive the development of a simple zoning model and secondly they provide the foundation to link a set of goals, objectives and strategies to each of these zones. The resulting marine plans generated aim to establish an overarching strategic guide that could help inform local councils and the Scottish Government's planners with the ultimate goal of ensuring healthy, productive and diverse marine habitats for current and future users.

3.5 The Marine Planning Model

Assumptions were developed based on managing activities within the assimilative capability of the ecosystem and this approach supported the development of the marine planning model. The key assumptions made were that data availability should reasonably reflect the ecological parameters fundamental to the function of the ecosystem and biological diversity and the spatial distribution of the ecological parameters of the ecosystem.

The aim of the marine planning model was to zone the planning area based on ecological criteria and further identify and define the spatial boundaries of zones.

3.5.1 Scottish Marine Regions

In this initial application of the Marine Planning model to Scottish waters, plans were only prepared for the Scottish inshore area out to 12nm. However the pre-consultation draft of the National Marine Plan covers both this inshore area and offshore waters (out to 200nm), therefore in the future, given data availability, it would be advisable and beneficial to extend the planning model out to cover this offshore area also.

The Marine (Scotland) Act 2010 provides the framework for developing a National Marine Plan and for the further delegation of marine planning at a regional level. Marine regions are envisaged as a large scale maritime area that is defined on biogeographical and physiographical criteria (David Tyldesley

Associates 2004). Subsequently, a key preliminary step in adopting this framework has been the identification of appropriate Scottish Marine Regions (SMRs). These SMRs will be designated through secondary legislation with planning powers and functions being delegated to Marine Planning Partnerships (MPPs) that will generate regional marine plans. The MPPs will be made up of a wide range of stakeholder representatives from those with recreational and commercial interest to those with conservation backgrounds. The aim of this approach, which will bring together different groups, is the facilitation of a better and more effective management of Scotland's marine resources which will avoid the sectoral driven management that has occurred in the past.

A consultation was launched by Marine Scotland in early 2011 that aimed to define the boundaries of the Scottish Marine Regions. Following the analysis of responses to this consultation the Marine Planning Models' boundaries were based on the third option of "Marine Scotland's Scottish Marine Regions: Defining their boundaries" consultation (Marine Scotland, 2010). Under this option there will be 11 defined regions (Argyll, Clyde, Moray, North Coast, North East, Orkney, Shetland, South East, South West, West Highlands, and the Western Isles) that are predominantly determined by physical characteristics (see Figure 3.1).

For the purposes of applying the marine planning model in Scottish waters, Mean High Water Spring tide level (MHWS) will mark the landward limit of the plan and then it will extend out to 12 nM rather than 6 nM as a preference for this larger area to be covered was expressed in both the responses to the written consultation and at a stakeholder event during the consultation period (Marine Scotland, 2011).

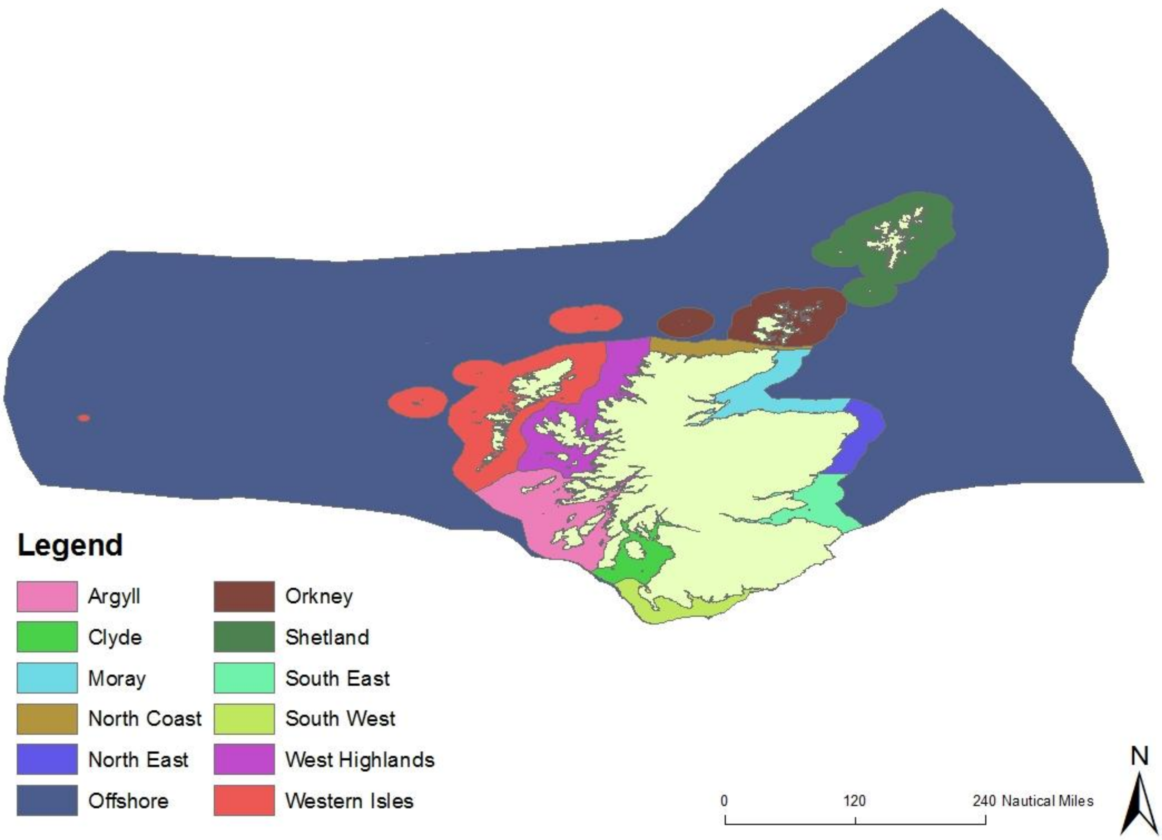

Figure 3.1 - Scotland's Marine Planning Areas showing the 11 Scottish Marine Regions

3.6 Application of the Marine Planning Framework

3.6.1 Data Collection and Processing

The first step in the development of the marine plan involved identifying what data were required, collection and collation of these data and the creation of a series of maps depicting economic, social and cultural factors within the planning area using ArcGIS version 9.3. Data were collected from a variety of different agencies and online resources (refer to Table 3.1) and resulted in up to 21 spatial layers being compiled (the total number of layers depended on data availability for the different regions). Environmental data were used to develop the marine planning model whereas the social, cultural and economic data were used to support it, in the form of the complementary activities maps. Table 3.2 shows the number of environmental and 'socio-economic' layers used in each of the marine plans.

Table 3.1 - Data utilised for the Marine Plans Spatial Layers within Scottish Waters

Layer	Group	Title	Source	Data Included & Comments
Scottish Marine Regions		SMRs	Marine Scotland Science (MSS)	11 Scottish Marine Regions
Priority Marine Features	Habitat	PMFs	JNCC	Carbonate Mounds, Intertidal Mud Flats, Oceanic Ridges and Seamounts, are all PMF habitats however only Intertidal Mudflats fell within the SMRs.
UKSea Map 2010 Seabed Landscapes	Habitat	Seabed Habitats	JNCC	5 rarest (according to area) seabed and coastal marine landscapes were selected however only four of these were used as Deep Sea Mounds were not found within the SMRS.
Beaches with Environmental Awards	Habitat	Beaches	MSS	Beaches include those designated with the following awards: Blue Flag, Clean Safe Seas, Combined Coastal Award and Seaside Awards.
Priority Marine Features	Uniqueness	PMFs	JNCC	Coral Gardens and Deep Sea Sponges were not within the SMRs however, Intertidal *Mytilus*, Littoral Chalk Communities, *Lophelia* Reefs, Maerl Beds, *Modiolus*, *Sabellaria* Reefs, Sea Pen Communities and *Zostera* Beds were all used.
RAMSAR Sites	Uniqueness	RAMSARS	SNH	Identified wetlands of international importance specifically as waterfowl habitats.
Spawning and Nursery Areas of important fisheries	Uniqueness	Spawning and Nursery Areas	CEFAS	High intensity Spawning and Nursery grounds. Nursery grounds are those areas with a high relative abundance of juveniles. More important spawning areas have a higher concentration of eggs and/or larvae.
Seabird Nesting Sites	Uniqueness	Nesting Sites	JNCC	Nesting sites and counts for: Black Guillemot, Fulmar, Gannet, Kittiwake, Little Tern and Puffin
Cetacean Hotspots	Uniqueness	Encounter Rate	MSS/JNCC	Taken from the Atlas of Cetacean Distribution in North West European Waters. Showing areas with a higher than average encounter rate.
Seal haul out sites	Uniqueness	Seal haul out sites	MSS	Common and Grey
No- Take-Zone	Uniqueness	No-take-zone	MSS	Lamlash Bay on the Isle of Aran
Offshore/ SACs, SPA, SSSI, World Heritage Sites	Uniqueness	Offshore/ SACs,SPAs, SSSI, World Heritage Sites	JNCC/SNH	Newly designated offshore SACs and coastal SACs (Special Areas of Conservation), SPAs (Special Areas of Protection), SSSIs (Sites of Special Scientific Interest) and St Kilda World Heritage Site.

Environmental data selected for use in developing the marine zoning model were, as can be seen in Table 3.1, then grouped as being either ‘habitats’ or ‘uniqueness’ layers, as described below. The environmental layers used in the marine plans contained information specifically on habitats and uniqueness on the individual areas covered by each plan. Habitat layers included data on the presence of beaches, intertidal mudflats and lagoons. Uniqueness layers included information on sea bird nesting sites, fish spawning and nursery areas, and endemic, rare and endangered species. Each environmental layer created was then referred to as an ecological variable.

Table 3.2 - Layers utilised for each of the 11 Marine Plans within Scottish waters

Plan Number	Name of Area	Number of Environmental Layers	Environmental Layers Present
1	Shetland	10	Beaches, Lagoons, *Zostera*, Nursery Areas, RAMSAR sites, Sea Pen, Seal Haul-outs, *Modiolus*, Maerl and Littoral Chalk Communities
2	Orkney	10	Lagoons, shelf mixed sediment plain strong tide stress, shelf mixed sediment plain moderate tide stress, shallow mixed sediment plain moderate tide stress, *Zostera* Beds, Nursery Areas, RAMSAR sites, Seal Haul-Outs, *Modiolus* and Maerl
3	Moray	11	Beaches, Lagoons, Mudflats, *Zostera*, Spawning Areas, Nursery Areas, RAMSAR sites, Sea Pens, Seal Haul-outs, *Modiolus* and *Lophelia*
4	North East	8	Beaches, Lagoons, Spawning Areas, Nursery Areas, RAMSAR sites, Sea Pens, High Cetacean Encounters and *Lophelia*
5	South East	9	Beaches, Lagoons, Mudflats, Spawning areas, Nursery areas, RAMSAR sites, Sea Pens, Seal Haul-outs and Littoral Chalk Communities
6	South West	15	Beaches, lagoons, Mudflats, Mixed-Mod, Shelf-Mod, Shelf-Strong, *Zostera*, Spawning areas, Nursery areas, RAMSAR sites, Sea Pen, Seal Haul-outs, *Sabellaria*, *Mytilus* and Littoral Chalk Communities
7	Clyde	16	Beaches, Lagoons, Mudflats, Mixed-Mod, Shelf-Mod, Shelf-Strong, *Zostera*, Nursery Areas, RAMSAR sites, Sea Pens, Seal Haul-outs, No-Take-Zone, *Modiolus*, Maerl, *Mytilus* and Littoral Chalk Communities
8	Argyll	14	Beaches, Lagoons, Mudflats, Mixed-Mod, Shelf-Strong, Zostera, Nursery Areas, RAMSAR sites, Sea pen, Seal Haul-outs, High Cetacean Encounters, *Modiolus*, Maerl and *Mytilus*
9	West Highlands	14	Beaches, Lagoons, Mudflats, Mixed-Mod, *Zostera*, Nursery areas, Sea Pen, Seal Haul-outs, High Cetacean encounters, *Modiolus*, Maerl, *Lophelia*, *Mytilus* and Littoral Chalk Communities
10	Western Isles	14	Lagoons, Mudflats, Mixed-Mod, Shelf-Mod, *Zostera*, Spawning areas, Nursery areas, RAMSAR sites, Sea Pen, Seal Haul-outs, High Cetacean Encounters, *Modiolus*, Maerl and *Lophelia*
11	North Coast	9	Beaches, Lagoons, Mudflats, Nursery Areas, RAMSAR sites, Sea Pens, Seal Haul-outs, *Modiolus* and Maerl

3.6.2 Planning Units

In order to simplify the collation of the extensive amount of data that was amassed for this research, each planning area was divided into grid cells of equal size (0.05 decimal degrees) and was this termed a Planning Unit (PU). Refer to Figure 3.3 for an example of the Argyll Planning Area; this was carried out for each of the SMRs. This size was considered to be practical for natural resource management purposes. Each PU has a known location and a unique numerical identifier. Many of the coastal PUs were not of an equal size as they were clipped to the coastal boundary of the planning area (see Figure 3.2). By using this PU system it simplified the use of the large scale planning areas as well as decreasing the likelihood of spatial errors in terms of the mapping the spatial resolution of different variables as part of the layers. Data utilised in the process were derived at a range of different capture scales and resolution (for example intertidal mud flats were mapped at 1:600,000 and sea bird nesting sites were mapped at 1:60,000). Using the Spatial Join tool in ArcGIS, the Planning Unit layer was then linked with the spatial ecological layers that were compiled for each marine region.

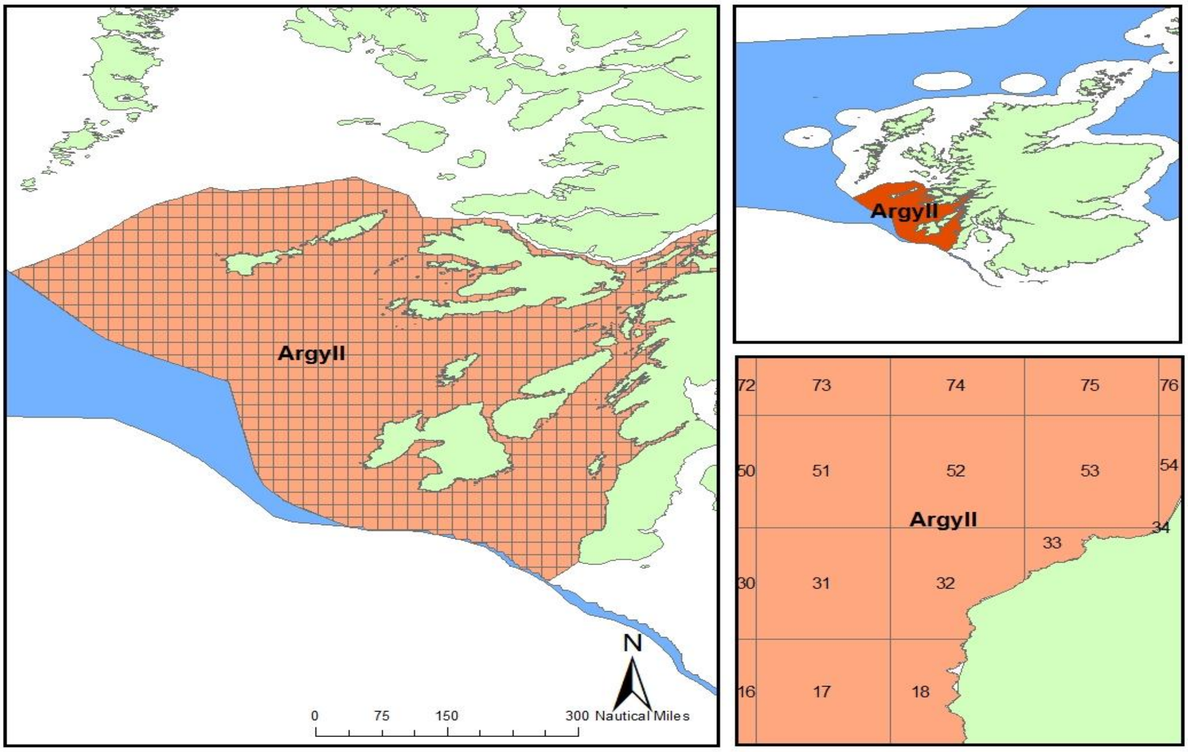

Figure 3.2 - Argyll Marine Planning Area and Planning Units (PUs)

3.6.3 Grouping Data

Several methods of grouping variables are available within ArcGIS, however, because the data were not normally distributed; a non-parametric approach was used in this instance. The default classification method in ArcGIS is the natural breaks method and this was considered to be suitable as it is a robust, non-parametric scheme for grouping variables based on naturally occurring groupings that are inherent within these data. This method uses a statistical formula (Jenks optimisation) that identifies break points within these data by picking the class breaks that best group similar values and maximise the differences between classes (Paxinos et al., 2008).

GIS analysis, using the natural breaks method was used to group PUs over the entire Scottish coastal area, into four zones; see Figure 3.3, (for each of the SMRs and biounits see Appendix 2, Figures A2.0 to A2.10), based on rating areas according to their number or respective ecological factors (habitats and uniqueness) found in each of the PUs . There are three categories of ER zones, each with an increasing level of ecological importance (ER Zones 1-3, with Zone 1 having the highest value) and a fourth zone (ER Zone 4), which has been designated for areas with little or no environmental information assigned to them. Each cell has been categorised in accordance with the information it contains and is distinguished by the relative importance of the contribution made by species, habitats and ecological processes to the functioning of that ecosystem (Paxinos et al., 2008). Each ER zone has specific goals, objectives and strategies associated with it that are aimed at guiding the level of use and development within the area it covers to make sure they fall within the environmental capability of that PU (see Table 3.3). These zones are designed to be continuously reviewed and modified as new additional information and understanding increases or becomes available. This system was originally based on nationally recognised definitions (for habitats and uniqueness) that were used for the National Ecologically Sustainable Development Reporting Framework for Australian Fisheries (Fletcher et al., 2005) and were also used for this study. In the future, however, it may be more appropriate to use recognised definitions devised specifically for Scottish waters.

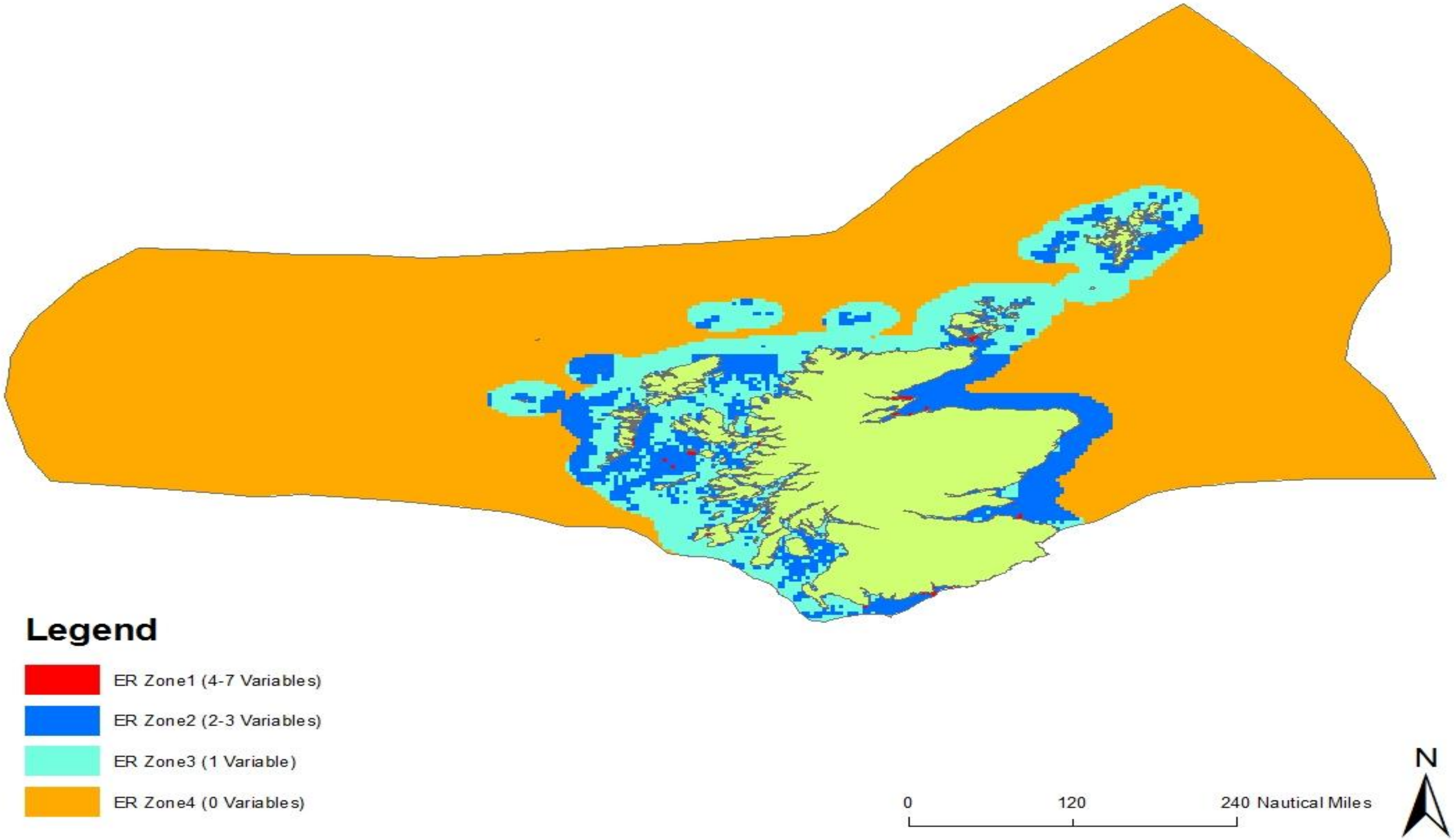

Figure 3.3 - Proposed Ecologically Rated Zones generated by the Marine Planning Model for Scottish waters © Crown Copyright 2015.

3.6.4 Ecologically Rated Zones

Each ER zone has specific goals, objectives and strategies that guide use and development within it which has been designed to ensure the environmental capability of that PU (refer to Appendix 2, Table 2.0). Additionally, further description of the methodology and details of each zone is present by Day et al, (2008).

However to briefly summarise, each zone has an 'impact threshold' for example in ER Zone 1 the impact threshold is negligible and states "not to exceed negligible impacts to habitats or populations and is unlikely to be measurable against background variability e.g. interactions may be occurring but it is unlikely that there would be any change other than natural variation. Recovery is measured in days and will not exceed one month" (Day et al., 2008 and Paxinos et al., 2008). These impact thresholds are based on measures of recovery and guide development and use in particular areas as to the degree of impact they may sustain. At present they are based on definitions used in the National Ecologically Sustainable Development Frameworks for Australian Fisheries (Fletcher et al., 2005). With the development of Scottish Marine Plans these definitions could be replaced with those devised for Scottish systems.

3.6.5 Concentration of Impacts

In order to identify areas that have potentially been impacted, or areas already being impacted upon by marine activities, further analysis was undertaken. Data on the location of activities with known discernible impacts on marine habitats, flora or fauna were collated. For example, aquaculture activities that may affect wild species by spreading disease or have a point source impact on the benthic habitat beneath cage sites. At this stage no account was taken of the varying impacts caused by different activities; each variable was assigned a value of one, thus all activities were assumed to have the same degree of impact. Again GIS classification analysis using the natural breaks method was used to group the activities into four categories of activity concentration. The resultant layer (see Figure 3.4) reflected areas where the highest concentration of use occurred rather than the degree of impact each variable would have, either independently or cumulatively.

ER zone maps for each of the marine regions were also produced as a result of this analysis and were presented by planning unit; see Appendix 2, Figures A2.0 to A2.10. Impact concentration analysis using spatial data provided information on areas where there is a high concentration of use. Because these maps complement the regional ER Zone Maps (See Appendix 2 Fig A2.11 to A2.21 for regional impact concentration maps), regions with very high levels of impact can be aligned with the ER Zones to determine which of the zones high concentrations of activities fall within.

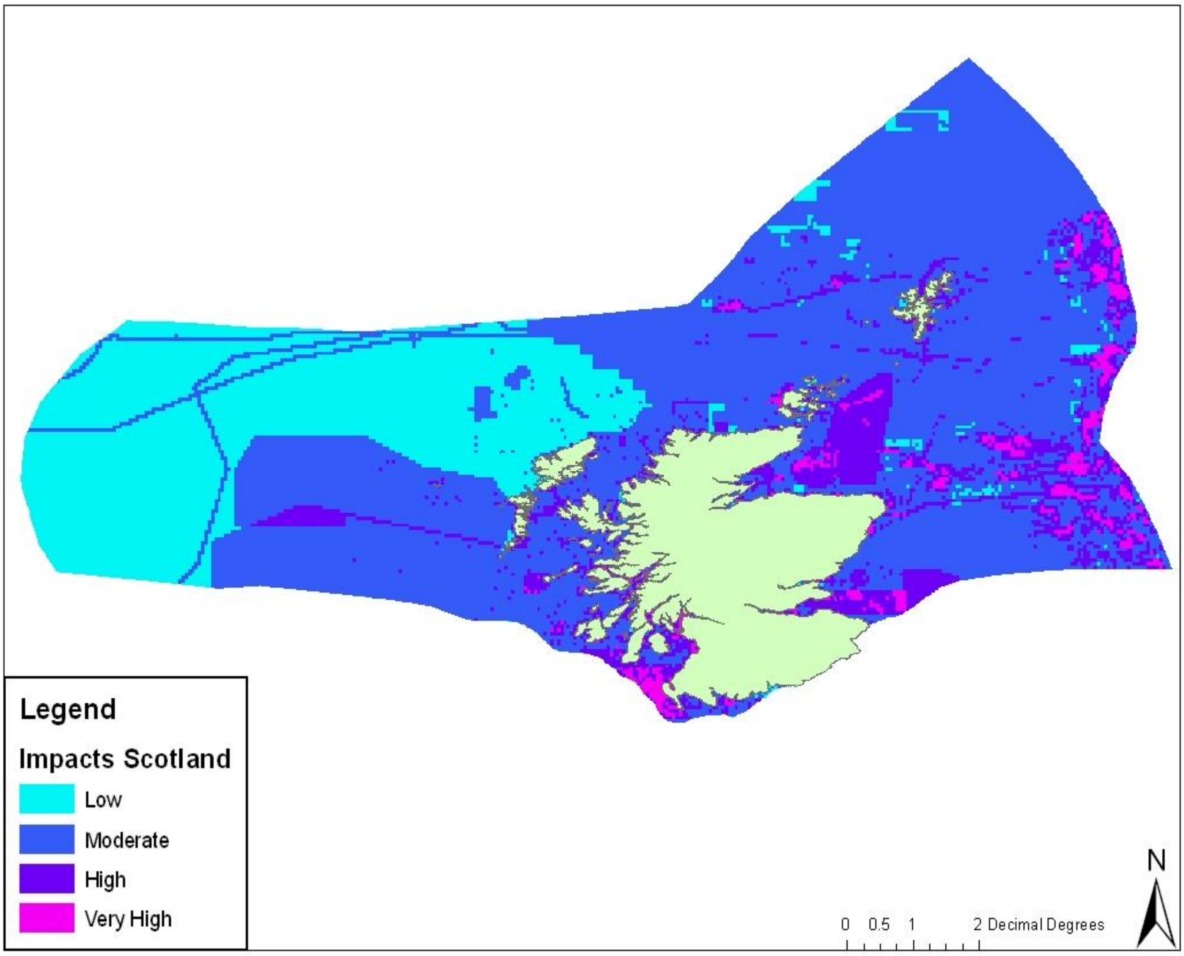

Figure 3 - Scottish waters with potential and present activities mapped.

3.7 Results

ER Zone maps were produced as a result of this analysis and are presented by Planning Unit for each of the eleven Scottish Marine Regions (see Appendix 2 Figures A 2.0- A 2.10). These were also graphically displayed in map format for each of the eleven SMRs; these complementary maps can be seen in Appendix 2 Figures A2.11-A2.21. These were then over lapped in order to analyse the relationship that exists between areas of concentrated activities and areas of differing ecological importance.

The distribution of areas across the SMRs where impact levels are very high can be seen in Table 3.3. It can be seen that in ER Zone 4 (a zone lacking in sufficient environmental data to allow development without further investigation), there is only one marine region, the Clyde, that has a PU within it registered as suffering from a very high concentration of activities. However, all but two of the marine regions (North East and South West) have very high concentrations of activities occurring within ER Zone 1, the zone with highest value for biodiversity. Table 3.4 shows the totals and percentage of PUs overall, and in ER Zone 1, that contains very high concentrations of activities. When the results are extrapolated in this way it can be seen that several of the marine regions have a significantly higher percentage of PUs that fall within ER Zone 1 that also have a very high concentration of activities occurring within them, for example Moray, the North Coast, the South East and the Western Isles are all above 6%.

Table 3.3 - Assessment of Planning Units that contain Very High Concentrations of Activities and the ER Zones they have been allocated to.

Marine Region	No. PUs Very High Conc of Activities (VHCA)	No. of PUs ER Zone 1 with VHCA	No. of PUs ER Zone 2 with VHCA	No. of PUs ER Zone 3 with VHCA	No. of PUs ER Zone 4 with VHCA
Argyll	48	1	23	24	
Clyde	89	2	32	54	1
Moray	23	2	21		
North Coast	16	1	6	9	
North East	13		12	1	
Orkney	78	1	11	66	
Shetland	59	1	18	40	
South East	46	3	37	6	
South West	12		8	4	
West Highland	111	6	61	44	
Western Isles	49	3	25	21	

Table 3.4 - Assessment of Planning Units that contain Very High Concentrations of Activities and the ER Zones they have been allocated to as a precentage.

Marine Region	Total No. Planning Units	No. PUs with VHCA	% of PUs with VHCA	No. of PUs ER Zone 1 with VHCA	% of PUs within ER Zone 1 with VHCA
Argyll	905	48	5.3	1	2.1
Clyde	350	89	25.4	2	2.3
Moray	475	23	4.8	2	8.7
North Coast	234	16	6.8	1	6.3
North East	237	13	5.4		
Orkney	710	78	11	1	1.3
Shetland	976	59	6	1	1.7
South East	360	46	12.8	3	6.5
South West	316	12	3.8		
West Highland	954	111	11.6	6	5.4
Western Isles	1586	49	3.1	3	6.1

3.8 Testing the Marine Plan with Protected Areas

By integrating and expressing different environmental variables within Scottish waters as a zoning scheme, the overall extent of Scotland's ecological diversity can be viewed. Scenarios can then be proposed within the context of this framework. For instance the marine planning model zoning maps allow for the development of further protection measures to be placed within the marine environment. Any areas identified through the application of this planning model, as having a higher than average concentration of important ecological features, that are not currently designated under any protective measures (see figure 3.5) could then be put forward as potentially requiring protection.

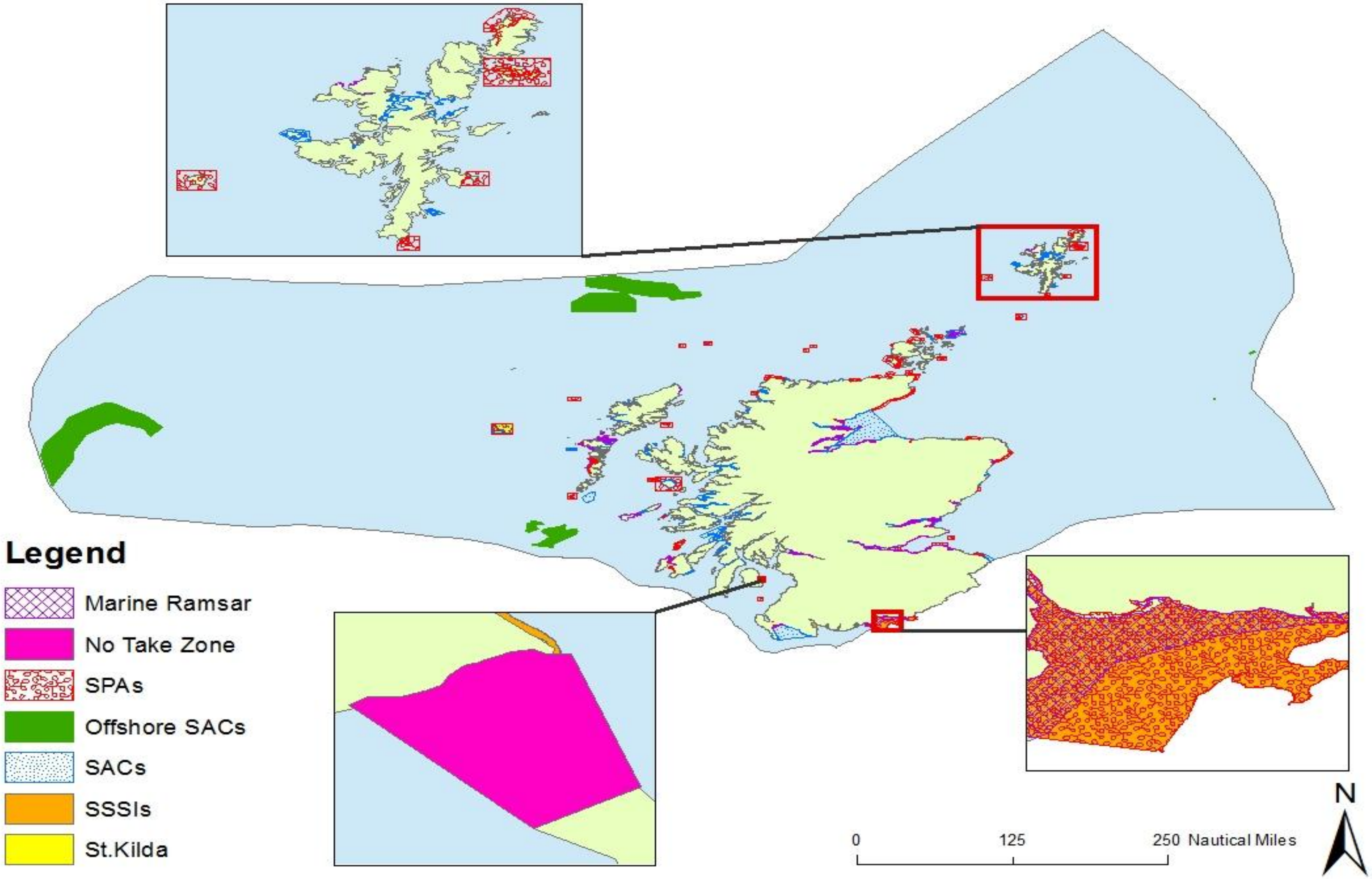

Figure 3.5 – Location of Protected Area Designations around Scotland in 2012. The insert shows the No-Take Zone in Lamlash Bay, Isle of Arran, the overlapping designations in the Solway Firth and the Shetland Isles that are widely protected due primarily to their high level of natural biodiversity. An Ordnance Survey/EDINA supplied service. Data available from Scottish Natural Heritage at *http://www.gateway.snh.gov.uk*

It is possible to take directly from this zoning scheme areas where ecological interactions and 'hotspots' may overlap with areas of concentrated human activities and therefore where conflicts are likely to arise between them. These can then be used to assess what existing measures are in place to help address or negate any spatial conflicts between users and between activities and the natural environment. This zoning scheme could also be viewed as providing a 'benchmark' for other zoning schemes that may be developed in the future. This zoning scheme can also be used to assess the level of nature protection within Scottish waters as highlighted in Tables 3.5 and 3.6.

Table 3 - Designations utilised for assessing the level of nature protection within Scottish waters

Designation	Description/Rational
Special Area of Conservation (SAC)	These are sites that are designated under the European Habitats Directive. Together with SPAs they are termed Natura 2000 sites and they are considered internationally important for the protection of threatened species or habitats. Together Natura 2000 sites form a network of protected areas across Europe. SACs can be designated for a number of species and habitats (both terrestrial and marine) providing they are listed within the Habitats Directive.
Special Protection Area (SPA)	These are designated under the European Birds Directive. SPAs are designated for a variety of rare, threatened or vulnerable bird species that can be found listed in Annex I of the Birds Directive and also for regularly occurring migratory species. In recent years more emphasis has been placed on the marine environment for the seabirds which spend all or a good proportion of their lives at sea or on the coast. The responsibility of identifying sites that lie within inshore (12nm) waters has been placed with SNH and the Joint Nature Conservation Committee (JNCC) and beyond this in offshore waters; the JNCC is leading on the selection of sites.
Site of Special Scientific Interest (SSSI)	In the UK these sites serve to protect species, habitats and geological feature that are of national importance. Some SSSIs have been designated to protect intertidal or sub-tidal habitats or species, however, normally they do not offer protection any further than the low water mark and therefore only afford protection to a limited range of coastal marine life.
World Heritage Site	The non-statutory designation of 'World Heritage Site' is perhaps the highest and most prestigious status that can be given to an area, recognising its globally significant natural and/or cultural heritage. Scotland has one designated World Heritage Site, the islands of St. Kilda, which is both a natural and cultural world heritage site, located around 66 km north west of the North Uist, in the Outer Hebrides. The attainment of this designation requires the statutory protection and management of this area as it is of global interest.
Ramsar	All Scottish Ramsar sites are also either SPAs or SACs and many are additionally also SSSIs, although the boundaries of each individual designation are not always exactly the same. Currently there is no specific legal framework in place that applies to Scottish Ramsar sites since they are managed under specific legislation which applies to sited designated as Natura 2000 (SPAs or SACs) or SSSIs that overlap them and Scottish Natural Heritage (SNH) carry out site condition monitoring.
No-Take Zone	Currently within Scottish waters there is only one designated no-take zone under The Inshore Fishing (Prohibition on Fishing) (Lamlash Bay) (Scotland) Order 2008. The Scottish Government issued this Statutory Instrument (SI) that prohibits all fishing for sea fish within Lamlash Bay on the Isle of Arran, regardless of the methods employed.

These six different types of protected areas (see Table 3.5 and Figure 3.5) were tested against the marine planning model. The protected areas were mapped with the Ecologically Rated Zones and the areas that fell within each of the four zones were calculated for each type of protected area. The results are shown in Appendix 2, Tables A 2.1 to A 2.10. Table 3.6 shows a summary of the number of PU's in each of the marine planning regions and the percentage of these that fall within the protected areas. While Table 3.7 extrapolates this still further and identifies the percentage of the spatial area covered by the conservation designations within each of the SMRs.

Table 3.6 - Percentage of Protected Areas within the proposed Ecologically Higher Rated Zones for Scottish Waters.*

Marine Region	Total. No. of PUs	Total. No. of Protected Area PUs	Protected PUs as a % of the total SMRs PUs
Argyll	905	356	39.3
Clyde	350	102	29.1
Moray	475	465	97.9
North Coast	234	120	51.3
North East	237	68	28.7
Orkney	710	188	26.5
Shetland	976	223	22.9
South East	360	372	103
South West	316	229	72.5
West Highland	954	331	34.7
Western Isles	1586	374	23.6

*There are spatial overlaps with many of the designated protected areas, therefore the percentage cover of Protected PUs currently (shown in this table) should not be considered to be reflective of the spatial coverage of protection within that SMR to date.

Table 3.7 - Percentage of the Spatial Area covered by Conservation Designations within the proposed Marine Regions for Scottish Waters

Marine Region	Area of Marine Region (PUs)	Spatial Coverage of Conservation Designation (PUs)	% of Marine Region Covered by Conservation Designations
Argyll	905	228	25.2
Clyde	350	79	22.6
Moray	475	227	47.8
North Coast	234	73	31.2
North East	237	38	16
Orkney	710	111	15.6
Shetland	976	142	14.5
South East	360	142	39.4
South West	316	144	45.6
West Highland	954	227	23.8
Western Isles	1586	195	12.3

3.9 Discussion

As mentioned above, because of the spatial overlap that occurs between some types of designated protection areas the assessment of these areas within the ER Zones is complicated. However, referring to Table 3.6, it can be calculated that the average percentage cover of 'protected' PUs for each of the zones is around 48%. The actual percentage coverage is, however likely to be a good deal lower than this, given that there is this spatial overlap amongst conservation designations. It should also be noted that some regions, such as the South East and Moray, have almost more than a hundred percent coverage. This is explained by the spatial overlap, for example the Moray Firth has numerous designations in place including SSSIs, SACs and SPAs. However, referring to Table 3.7, it can be seen that when the spatial coverage of all the designated protected areas is calculated (therefore excluding any spatial overlap) that the actual area protected within each SMR is far lower than in Table 6. The average percentage cover from this analysis can be calculated as 26.7%. This is almost 20% less than stated in Table 3.6, indicating the level of overlap that occurs between these conservation designations.

Surprisingly, when looking at Table 2.11, Appendix 2, it can be seen that in the Western Isles marine region, the only region where a World Heritage Site has been designated (St. Kilda), it does not fall within ER Zone 1. In theory it will fall within ER Zones 2 and 3, because there is not a large amount of significant ecological features present to classify the area within ER Zone 1, therefore it would not naturally be afforded the highest level of protection by the zoning scheme. In the future this zoning scheme could be modified and a weighting scheme introduced to ensure that protected areas such as this are allocated within ER Zone 1 and subsequently afforded the greatest level of protection against future developments and activities.

What can also be noticed from looking at Tables 2.1 to 2.11, Appendix 2, is that the vast majority of protected PUs, no matter what protective designation, will fall within ER Zone 2. While this zone will still afford them a certain degree of protection from developments, ideally it would be expected that a greater number of these ‘protected’ PUs would fall within ER Zone 1

3.10 Marine Plans

The methodology can be used to derive marine plans for each of the Marine Regions currently proposed. For the purpose of this thesis, a draft version of the Western Isles Marine Plan has been completed, see document in Appendix 3. As demonstrated in this Draft Western Isles Marine Plan, each of the Plans will contain the following:

- An explanation of the goals, objectives and strategies of the zoning scheme
- A series of maps showing the zoning based on the marine planning model
- A map showing the concentration of present and potential impacts
- Tables explaining the reasons for zoning and current activities or impacts by planning unit.

The marine plans produced are designed to be as simple and easy to use as possible, allowing their use as a guide to allow decision-making authorities to locate the marine areas in which their development and use will occur. Additionally it will allow them to evaluate whether the activity will meet the goals, objectives and strategies laid out by the zoning scheme for that area.

A detailed breakdown of each of the ER Zones can be found in the attached Marine Plan in Appendix 3. In summary, in ER Zone 1, for example, acceptable development or use is only considered to be those activities that will not exceed a negligible level of impact to the biodiversity, habitats and ecological processes of the zone. For some forms of development or activity this can be achieved by simply applying appropriate conditions to their approval. If this is not a viable option then the development may then have to be re-located to ER Zone 2 or ER Zone 3 as the conditions applied within these zones may be more appropriate.

It is recognised that in some areas the impacts from currently existing marine activities may already exceed the benchmarks set to meet the requirements of the ER Zones particular goals and objectives. In these instances, the Marine Plan objectives may be to try to negate current impacts and put plans in place so that future management decisions will be more consistent with objectives of the ER Zone it is located in. Over time it is then hoped that by putting in place these actions they will assist in facilitating the restoration, where possible, of acceptable ecosystem conditions.

3.11 Discussion and Analysis

3.11.1 Argyll

It can be seen in Figure A 2.0 (Appendix 2) that the majority of the Argyll marine region falls within ER Zone 3. Areas of the marine region closer to shore have largely been allocated to ER Zone 2 along with a significant area just North of Coll and Tiree. No area within the Argyll marine region fell within ER Zone 4 and only a few small areas were designated to ER Zone 1. These included a small area North West of Coll, an area of Laggan Bay on the Isle of Islay and several smaller areas within the Sound of Jura.

The concentration of activities and users was found to be predominantly low, see Appendix 2, Figure A 2.11. Perhaps predictably inner areas such as Loch Linnhe, the Firth of Lorn and the Sound of Mull all have higher concentrations of activities. Surprisingly there is a relatively large area to the South West of Tyree that also has a high concentration of activities occurring.

Referring to Tables 3.3 and 3.4 it can be seen that of the 905 PUs that make up the Argyll marine area, 48 of these were found to have a very high concentration of activities occurring within them, 5.3% of the total number of PUs. Of these however, only one PU fell within ER Zone 1, and the rest were split almost evenly between ER Zones 2 and 3 (23 PUs in ER Zone 2 and 24 PUs in ER Zone 3). This can be viewed as a positive finding, as although there is a substantial amount of activity occurring within the Argyll marine area very little has been found to be occurring within ER Zone 1, the most important of the zones ecologically.

3.11.2 Clyde

The majority of the Clyde marine region is designated between ER Zones 2 and 3; see Figure A 2.1, Appendix 2. Two small regions in Loch Fyne and the Kyles of Bute are designated within ER Zone 1 while a very small area in Loch Long has been placed in ER Zone 4.

The Clyde is an area of the Scottish coast that is subjected to many activities and therefore upon analysis for concentration of activities it was not surprising to find that there were relatively few areas where activities concentration was low, see Figure A 2.12, Appendix 2. These areas with lower activity concentrations were found predominantly to the South of the Isle of Arran. Very high concentrations of activities were found in Loch Fyne and the Firth of Clyde and along the coast from Irvine to Ayr and further out to sea in the North Channel. Unexpectedly an area to the South East of Arran, covering both Brodick and Lamlash Bay was found to have very high concentrations of activities occurring. It could therefore, be the case that the no-take zone in operation at Lamlash Bay, while stopping fishing pressure, may not be sufficient to protect this site from the potential effects of other activities.

The Clyde marine region is relatively small with only 350 PUs however, 89 of these have very high levels of impacts occurring within them a total of 25.4% of the whole regions PUs. This meant that the Clyde marine region had the highest percentage of PU’s that had a very high concentration of activities associated with them of all the 11 marine regions that were evaluated. Perhaps an issue that should be of even greater concern is that PU’s with a very high concentration of activities were found within both ER Zone 1 and ER Zone 4.

3.11.3 Moray

Referring to Figure A 2.2, Appendix 2, it can be clearly seen that the majority of the Moray marine region falls within ER Zone 2. An area due West of John O’Groats has been designated in ER Zone 3 alongside another smaller area in just North of Wick. Much of the Dornoch Firth and some of the Moray Firth have been assigned to ER Zone 1.

Despite its remote northerly location the Moray marine region has a considerable number of activities taking place within its waters. This was clearly visible when activity concentration analysis was undertaken; see Figure A 2.13, Appendix 2. There are few substantial areas where activity concentration is low but the largest of these is just South of Brora and to the West of Wick. There are large areas of high activity concentration in the outer Moray Firth north of Lossiemouth and at the mouth of the Dornoch Firth.

The Moray marine region is relatively large with 475 PU's, however, despite its large size only 23 PUs or 4.8% of these have a very high concentration of activities occurring within them. Only two of these PU's are located in ER Zone 2 and none are found within ER Zone 3 or 4; see Tables 3.3 and 3.4.

3.11.4 North Coast

The majority of the North coast marine region falls within ER Zone 2, see Figure A 2.3, Appendix 2. The most extensive of these ER Zone 2 areas is the coastal stretch that runs from Thurso along to John O'Groats. While smaller areas also allocated as ER Zone 2 are to be found around Durness and Whitten head. There are a very few small areas that are designated as belonging to ER Zone 1 or 4 and the largest (areas) of both are found within Loch Eriboll.

Referring to Figure A 2.14, Appendix 2, when the concentration of activities for the North coast marine region was analysed there was found to be a significant amount of the region that had low to moderate concentrations of activities occurring. Five significant 'hotspots' where activity concentrations reached very high levels were observed out to the west of John O'Groats, John O'Groats, Thurso, North of Tongue and around Durness.

Just 16 of the 234 PUs that make up the North Coast marine region have a very high concentration of impacts occurring within them, accounting for just 6.8% of all PUs. Only one of these PUs with a high concentration of activities appears in ER Zone 1, 6 are in ER Zone 2 and the highest number, 9 PUs, are found within ER Zone 3.

3.11.5 North East

The vast majority of the North East marine region falls within ER Zone 2, see Figure 2.4, Appendix 2. Only a small area up beside Ellon and Newburgh falls within ER Zone 1 and two slightly larger areas just north of Aberdeen and Stonehaven were designated within ER Zone 3.

When comparing this map with the complementary activity concentration analysis map, see Figure A 2.15, Appendix 2, it can be seen that the area north of Aberdeen that lies within ER Zone 3 also has a very high level of activities associated with it. Peterhead, and just west of Aberdeen, out into the North Sea, are another two areas that were found to have very high concentrations of activities. While the sea area surrounding Fraserburgh has notably high concentrations of activities occurring within it.

Having identified specific areas where activity concentrations are high, or very high, it was positive to find that only 5.4% of the total PUs in the North East marine region (13 out of 237) had a very high concentration of activities. Therefore, in relative terms, although there are distinct 'hotspots' for activities, there are very few overall. Better still, none of these very high activity PUs occurred within ER Zone 1. However 12 PUs with very high activity concentrations were found within ER Zone 2.

3.11.6 Orkney

In general, Orkney's waters fall within ER Zone 3. The exception to this are the inner waters between Kirkwall, Shapinsay and Wyre and in the more Southerly waters surrounding Hoy, Flotta and South Ronaldsay. There is also a small area at the easterly tip of Hoy that falls within ER Zone 1, see Figure A 2.5, Appendix 2. Referring to Figure 2.16, Appendix 2, the amount of activities that occur within Orkney waters is clearly visible when looking at the concentrations of impacts for the Orkney marine region. There are large areas North West of Stromness and South West of Copinsay that have very high impact concentrations along with several smaller areas such as those around Kirkwall, Eday and Burray.

Although the Orkney marine region is relatively large having 710 PUs, see Table 3.4, 78 of these, or 11% have a very high concentration of activities occurring within them. Fortunately, referring to Table 3.3, the distribution of those high concentration PUs across the ER Zones is favourable. Only one falls within ER Zone 1, 11 are in ER Zone 2 and the remaining 66 are in ER Zone 3.

3.11.7 Shetland

Looking at Figure A 2.6, Appendix 2, it can be seen that the majority of Shetland's marine region falls within ER Zone 3 but a good proportion of the total area is also allocated within ER Zone 2. The predominant area designated in ER Zone 2 runs from Sumburgh on the South mainland up to Lerwick and then west across to Whalsay out in the North Sea. There is also a small area within ER Zone 1 located in the inner waterways just North of Scalloway.

Upon analysis the concentration of impacts from activities and users was found to be really mixed (see Appendix 2, Figure A 2.17). The inner areas around Unst, Yell, Whalsay and Lerwick were found to have very high concentrations of impacts. While waters surrounding Foula in the South West and Sumburgh had only moderate concentrations of impacts.

Referring to Table 3.4, the situation perhaps looks a little better as although Shetland has one of the largest marine regions with 976 PU's, only 59 of these or 6% have a very high concentration of impacts within them. Of the 59 PUs with very high impact concentrations only one falls within ER Zone 1, 18 within ER Zone 2 and 40 within ER Zone 3, see Table 3.3.

3.11.8 South East

The majority of the South East marine region is designated within ER Zone 2, see Figure A 2.7, Appendix 2. Several substantial areas within Zone 3 also exist, most notably those above St. Andrews and off the coast of North Berwick. There are three distinctive areas that have been designated within ER Zone 1. The first and largest is just off the coast around Dunbar, the second is over at Crail, at Fife Ness and the third and smallest is just off the coast of Kirkcaldy.

The Firth of Forth has traditionally been a busy sea area and this can be clearly viewed in Figure A 2.18, Appendix 2. Areas with very high concentrations of activities can be seen not only in the inner waters of the Firth but also in the outer Firth of Forth. The heavy use of this sea area can also be identified in Table 3.4, as it is second only to the Clyde marine region, with one of the highest percentages of PUs with very high concentrations of activities. Unfortunately according to Table 3.3, the majority of these PUs fall within ER Zone 2 (37out of 46), however providing these activities are managed appropriately this should not be too problematic in terms of environmental impact.

3.11.9 South West

Referring to Figure A 2.8, Appendix 2, a good proportion of the Solway Firth is designated as being in ER Zone 2 whilst the waters of Luce Bay and the Mull of Galloway mostly fall within ER Zone 3. There are also several smaller areas designated within ER Zone 1 the most westerly being at Barrow Head with the others being located within the inner Solway Firth as far up as Dalbeattie and Annan.

When looking at the concentration of activities analysis maps for the South West marine region, Figure A 2.19, Appendix 2, surprisingly it is further offshore around Portpatrick and Loch Ryan where the concentrations of activities reach high and very high levels. This is perhaps unexpected as activities are normally thought to be more concentrated further inland and indeed the major town of Carlisle is situated within the inner Solway Firth and yet this does not appear to affect the level of activity occurring.

Overall the South West marine region has one of the best (lowest) percentage covers of PUs with high concentration of activities. Referring to Table 3.4, only 3.8% of the areas total of 316 PU's were found to have a very high concentration activities occurring within them. Additionally, referring to Table 3.3, none of these PUs with high activity concentrations fell within ER Zone 1.

3.11.10 West Highland

There is a large area to the North of the West Highland marine area that falls within ER Zone 3, see Figure A 2.9, Appendix 2. Much of the remaining area falls within either ER Zone 2 or 3 with the exception of small areas allocated within ER Zones 1 and 4. The most northerly of these is an area in ER Zone 1 that is located in Loch Laxford. The largest area located in ER Zone 1 can be found between the Isle of Rum and Canna.

When looking at Figure A 2.20, Appendix 2, it can be clearly seen for the concentration of activity analysis that most of the West Highland marine area suffers from a moderate level of activities. Many of the sea lochs and inner waters around the Isles such as Eigg and Skye are subjected to very high concentrations of activities. The only significant area where the concentration of activities is low is at the most northerly end if the Minches.

The West Highland marine region has a total of 954 PUs, of these 111 or 11.6% have a very high concentration of activities associated with them, see Table 3.4. A point of concern however, is that 6 of these PU units fell within ER Zone 1, the highest number of PU's of all the marine regions to fall within zone 1. A further 61 fall within ER Zone 2 and 44 within ER Zone 3 see Table 3.3.

Incidentally 111 PUs that have a high concentration of activities is the biggest number of PUs for all of the marine regions also.

3.11.11 Western Isles

The Western Isles mostly fall within ER Zones 2 and 3, refer to Figure A 2.10, Appendix 2. Most of the larger ER Zone 2 areas are locate to the west of the Butt of Lewis and out to the west of North and South Uist. There are several smaller areas that have fallen within ER Zone 1 these can be found around South Uist and Lochmaddy on North Uist. Rockall is also considered to be a part of the Western Isles marine region as can be seen on Figure A 2.10 it falls within ER Zone 4, perhaps unsurprisingly given its remote location.

Referring to Figure A 2.21, Appendix 2, upon analysis for concentration of activities the Western Isles were mostly split between low concentrations of impacts in the North and moderate concentrations of activities in the South. There is a scattering of high and very high concentrations of activities especially around Eriskay and Benbecula.

The Western Isles is the largest of all the marine regions with 1586 PUs, see Table 3.4. On a positive note, this region, although the largest, has the smallest relative number of PUs with very high concentration of activities found within it, only 3.1%. The 49 PUs that account for this 3.1%, see Table 3.3, are predominantly spread between ER Zones 2 and 3, having 25 and 21 PUs respectively. The 3 remaining PUs are all located within ER Zone 1.

3.12 Future Additions to the Marine Plans

In the future it would be intended that to accompany the Marine Planning Framework a Performance Assessment System (PAS) would also be developed. This would be designed to evaluate the effectiveness of each of the Marine Plans and this be achieved by assessing and reporting on the maintenance of ecosystem conditions. Any PAS would need to be developed in consultation with both government and non-government agencies that are involved with managing and monitoring of the marine environment. Potentially, this new monitoring scheme could be integrated within the current site condition monitoring system (SCM) operated by Scottish Natural Heritage. Alternatively, the current SCM scheme could be utilised to advise, develop or add to this proposed PAS monitoring scheme. The PAS scheme should establish an agreed approach to monitoring select indicators with the aim of detecting change (both natural and human induced) in the conditions of an areas ecosystems, biodiversity, habitats and species.

When applied to the ER Zone objectives, the results of monitoring using the PAS will reveal whether or not the management measures in place are adequate to conserve and facilitate responsible use of marine, estuarine and coastal resources. The use of a PAS will allow for a coordinate mechanism to be put in place that enables all agencies to contribute to a national collaborative approach to data collection, analysis and reporting on environmental marine conditions. This could be seen as a necessary prerequisite for constructing a best practice, adaptive approach to management and reporting.

A PAS should be developed from the Marine Plan goals and objectives that have been set out for each ER Zone (see Appendix 2, Table 2.0). However these will be expressed as outcomes in the PAS for each ecological variable (for example for *Lophelia* reefs), which are linked to criteria, performance indicators, benchmarks for environmental quality and monitoring protocols, see Figure 3.6. Monitoring of the performance indicators in relation to the benchmarks is desirable as it will allow for differences in natural variability (such as seasonal changes) and changes caused by human activities to be distinguished. Any existing monitoring programs should also be incorporated into and form the basis of the PAS whilst clear guidance should be provided for the development of further comprehensive monitoring as resources become available. Therefore in the future each of the eleven Marine Plans will ideally also have a companion PAS.

Because ER Zones will on the most part allow for a wide-range of activities and the sustainable use of resources, this will generate a set of pressures and potential impacts on marine, estuarine and coastal systems. In order to establish the context and possible causal sources for any such changes that are observed over time, the level of specific pressures (potentially impacting activities or pollution sources) that may be related to changes in environmental conditions will be assessed and reported within the context of the Marine Plan performance. Assessment of the performance indicators in each marine plan will not be intended to replace the role of other agencies in regulating and managing sustainable uses, but will provide a broader perspective for policy decisions and responses.

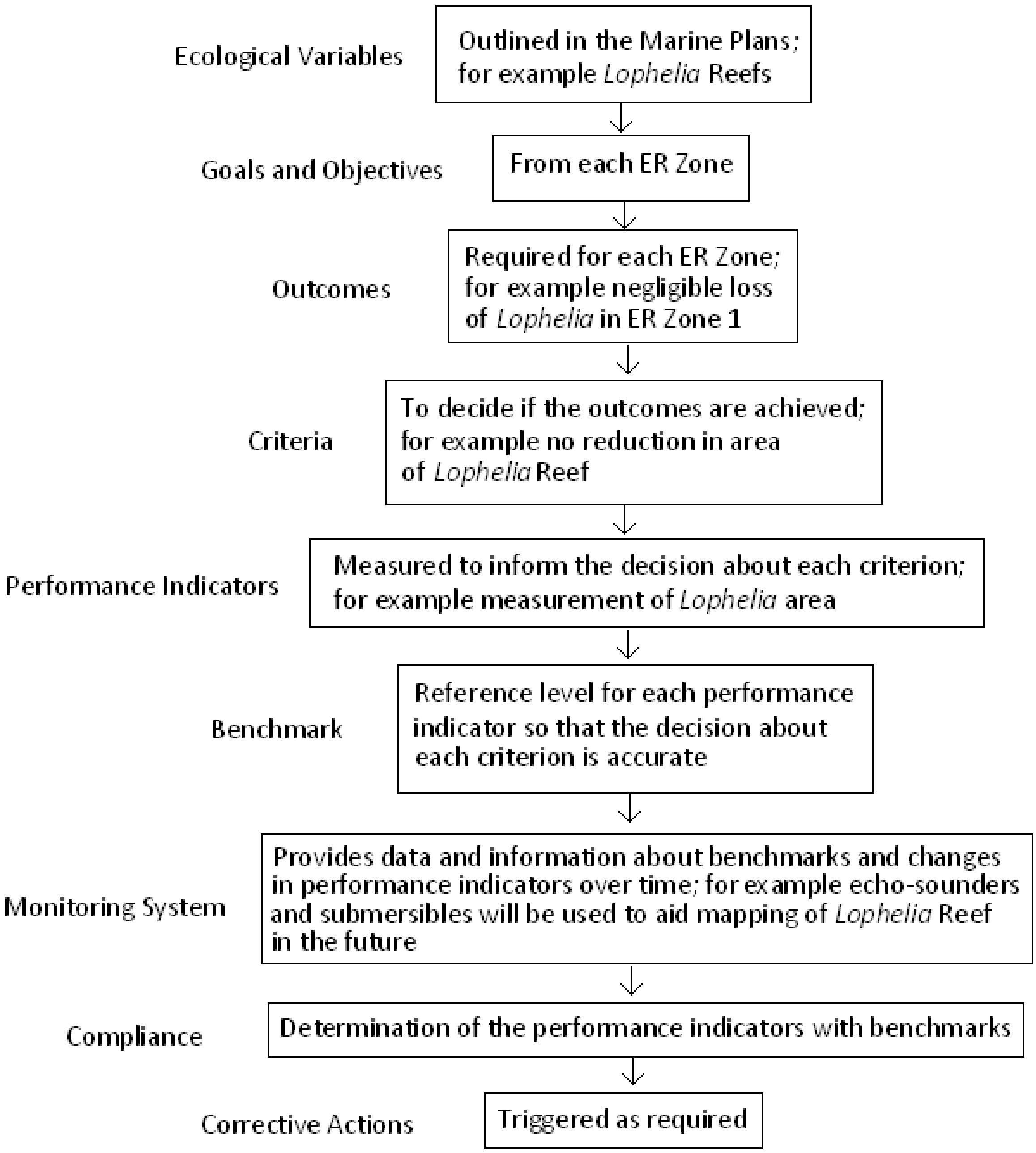

Figure 3.6 - Flow of decision making in the Performance Assessment System (PAS) (Adapted from Day etal., 2008)

3.13 Limitations of the Zoning Scheme

Although the data required a large effort to collate (and is still being actively sourced and expanded) this approach shows that it is possible to create a zoning scheme that is suitable for larger application at a regional sea scale. It was originally presumed that environmental data and the associated geographical limits of ecological features would be relatively easy to obtain, however this proved to not always be the case. The lack of a formal National

Database, out-of-date storage techniques and no standardised data storage system or format, all combined to make this aspect of developing the zoning scheme very complex and time consuming. Utilising GIS to create zoning schemes in the future would greatly benefit from the establishment of a National Database Archive that is made easily accessible to those working in the area.

This zoning scheme is considered to encompass all of the major environmental features and habitats that occur within Scottish waters just as it did encompass all the legislation within Australian waters when it was originally applied and therefore it can be seen as sufficiently robust to transfer into any sea area providing it has a similar level of data availability. This scheme does have its limitations however; although it has been designed as a bottom-up approach to management and it is aimed at mapping existing environmental features as a means of trying to develop a pro-active management scheme for planning it does not account for the degree of vulnerability of some sites. For example a unique marine feature may only be present at on site in the whole of Scotland while another important feature may be present at several sites, this scheme does not allow for any priority to be given to the exclusive site. This is particularly problematic if the unique feature is the only feature present at that site that requires a high level of protection. This could perhaps be overcome if restoration of sites was incorporated as a priority objective within the zoning scheme. The nature of this zoning scheme may also result in unique features being placed in an inappropriate zone. This said, the zoning scheme will evolve through further testing and discussions and by testing this scheme against other datasets the approach can be expanded to other areas. The present scheme for instances only accounts for sea areas out to 12nm and in the future this could be expanded further to encompass the sea area out 200nm.

3.14 Conclusion

Adoption of a ecosystem-based zoning concept for marine spatial planning accompanied with a suitable Performance Assessment System could encourage a new approach to be taken to regulating, managing and monitoring marine activities. Unlike land-based systems where the boundaries of different user groups can be easily distinguished, the many uses of the oceans frequently overlap spatially. This creates conflicts over resource availability and sustainability that is not always very apparent. History has shown that *ad hoc* approaches to resource management will ultimately lead to damaging and unsustainable practices. A united governmental and non-governmental, ecosystem based approach to marine management would seem like the most suitable way to coordinate conflicting uses while still maintaining environmental integrity in the future.

However, despite their many benefits, MPAs in general cover a relatively small geographic area and as such they often leave large areas of habitats and species unprotected. MPAs are also not impervious to diffuse impacts such as decreased water quality and the scale of ecological processes. For example, species dispersal and recruitment into populations are usually much larger than the scale of the MPAs (Allison et al., 1998). As a result, without adequate protection of species and habitats lying outside of protected areas, their effectiveness at protecting marine ecosystems as a whole will be limited. One way of limiting impact inflicted from waters outside of protected areas is to integrate them with broader ocean zoning management plans. The zoning concept applied by this marine planning framework aimed to highlight that some of these areas that are specifically targeted at protecting features that are of national and European importance, and are in effect not always located in areas that bear the most ecological relevance. It has, through testing various scenarios, demonstrated that there may be shortcomings in the spatial measures designated to deliver conservation objectives. Therefore despite the recent progress that has been made in designating various protected sites, these alone will not be enough to deliver a coherent network of protected areas or to provide adequate protection for the various important features that have been identified within Scottish waters.

Furthermore this study also recognises that in order to make greater, comprehensive progress in relation to conservation measures, clear environmental objectives will need to be further developed. Any objectives proposed should apply both to the wider environment and to specific ecologically rated zones.

Currently marine protected areas serve to protect specific habitats and species while fisheries regulations have been put in place to help stabilise specific species stocks. However, both of these types of management need to be coordinated and coupled in order to protect ecosystems that have species with patchy distributions. It would therefore suggest that the implementation of a

Marine Planning Framework such as the one developed here could be key tool for coordinating sea management. Additionally, the Marine Planning Framework could also contribute to the long-term protection of the marine and coastal environment.

Therefore to summarise:

- It is possible to generate a Marine Spatial Planning Framework for Scottish waters by establishing ecologically rated zones that are derived from previously defined ecological criteria
- In the future it would be suggested that an additional criteria weighting scheme be added when developing ecologically rated zones such as those implemented in this planning framework
- In order to establish this type of marine planning framework as a useful tool to guide marine spatial planning, economic, environmental and social objectives will need to be incorporated, alongside an overall aim of protecting ecologically important areas and minimising conflicts between users, and between activities and the environment.

3.15 References

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Chapter 4
The Prototype Zoning Scheme

4.1 Development of Marine Spatial Planning Schemes

Marine spatial planning does not stand alone; it is related to and has emerged from existing management frameworks and tools such as integrated coastal zone management (ICZM) and ecosystem-based management (Agardy et al., 2011). Initially the concept of MSP was conceived through the need to develop and implement Marine Protected Areas (MPAs). During this development, however, it has become apparent that there are even more beneficial aspects in developing MSP than just solely for conservation planning. Most governments that are looking to implement MSP are now focusing more specifically on trying to balance the demands for social and economic development with the commitments they have made to protecting habitats and biodiversity within their waters (Taljaard and Van Niekerk 2012). This incorporation of additional dimensions into MSP has resulted in the development of more modern multiple-use MSP concepts and initiatives such as the multiple-use zoning scheme devised by Boyes et al. (2007) for the Irish Sea (Taljaard and Van Niekerk. 2012). The idea behind the multiple-use MSP concept is that several activities such as aquaculture and renewable energy initiatives could be allowed to occur together at the same location at the same time, and another activity such as a military exercise may also be allowed to occur in the same area, however, it could not occur at the same time (Plasman 2008). A multiple-use planning framework can therefore perhaps be considered as a broader approach to management by allowing a range of uses to be spatially and temporally defined through the use of zoning schemes (Valentine et al., 1997).

MSP ocean zoning is another emerging approach that several countries around the world are considering adopting in an attempt to manage their marine ecosystems more sustainably (Paxinos et al., 2008). Many of the zoning tools that have been developed can be used to specifically separate activities where potential conflicts are more likely to arise; however, this has also shown to result in particular sectors being allocated almost exclusive use of certain sites (Stelzenmüller et al., 2012). Some recent approaches have taken this one step further and have attempted to place the more significant sectors of marine industry such as oil and gas or fisheries into their own zones. These would then be reserved purely for the operational purposes of the industry (Paxinos et al., 2008). This approach would seem impractical in many areas given the amount of competition that already exists between industries for marine space. Other zoning alternatives also exist, some place greater emphasis on an ecosystem approach, locating and designating zones based on features such as the underlying topography and oceanography or distributions of biotic communities, for example the Marine Planning Model developed by Day et al. (2008) for Australian waters. Unlike the exclusive use approaches these zoning schemes allow for multiple activities occurring within zones providing that they do not compromise the aims of the zones they fall within in terms of conservation. These 'ecosystem' zoning schemes have proven to be successful and function by designating a series of user-rules within each zone that are then coupled to monitoring and review processes (Crowder et al., 2006). Although zoning has become one of the mainstays for managing marine spaces and a key tool in developing MSP there are also other important management tools are often coupled with zoning schemes such as impact assessments, best environmental practices and codes of practice and permits (Day 2002).

4. 2 Global Development of Marine Spatial Planning

Government backed, national MSP schemes have already or are currently being developed in a number of different countries including the UK, Belgium, USA, Scotland, Canada, New Zealand, China and South Africa (Calado et al., 2010); see Table 4.1. These different planning strategies are still in varying stages of development and contain a multitude of objectives for individual regions. They do, however, have a common economic focus that places an emphasis on sustainable development and protection of the marine environment. At the same time there is also an emphasis on avoiding conflict between users and the resources (Paxinos et al., 2008). Many European countries have been motivated by both international and European regional legislation, for example Germany, Belgium and the Netherlands, to take multiple-use MSP forward and are now considered to be world leaders in developing and implementing this type of process (Taljaard and Van Niekerk. 2012). It is important as a result, that other countries can and do learn from each other's planning efforts, whether they have developed, or are in the process of developing, their MSP. There are also several international documents that have been produced that give guidance on MSP development including 'A Step-by-Step Approach towards Ecosystem based Management' produced by UNESCO's Intergovernmental Oceanographic Commission (IOC) alongside various MSP plans from regional sea conventions such as OSPAR and HELCOM (OSPAR 2009 and Calado et al., 2010).

Table 4 - Development of MSP Schemes Globally (Adapted from a Table in (Calado et al., 2010))

Country	MSP Initiative	Date Commenced
Australia	Great Barrier Reef Park Zoning Scheme and Marine Bioregional Plans	1978-2005 and 2002-2012
Belgium	Master Plan for the Belgian Part of North Sea	2003-2005
Canada	Large Ocean Management Area Integrated Management Plans and Eastern Scotian Shelf Integrated Management Plans	1998-2007 and 2006-2012
China	Marine Functional Zoning of the Territorial Sea	2002->
Germany	Spatial Plan for the North Sea and Baltic Sea and Spatial Planning for the German State waters of Mecklenburg-Vorpommern.	2004-> and 2005
New Zealand	Marine Protected Areas Policy and Implementation Plan	2006
Norway	Integrated Management Plan for Barents Sea-Lofoten Area and Norwegian Sea Management Plan	2002-2006 and 2009->
Sweden	Marine Environment Enquiry	2006-2008
The Netherlands	Integrated Management Plan for the North Sea 2015	2003->
United Kingdom	Irish Sea Pilot Project	2002-2005
United States	Florida Keys National Marine Sanctuary and Revised Management Plan and Massachusetts Integrated Oceans Management Plan	1990-2007 and 2008-2009

4. 3 Policy Drivers for MSP

There are two international conventions that make up the main international legal framework for MSP; these are the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and the 1992 Convention on Biological Diversity (CBD) although the latter is not strictly marine (Taljaard and Van Niekerk, 2012). Of the two conventions mentioned UNCLOS is responsible for providing the international legal basis upon which the seas are exploited, the rights for allocating activities and any obligations to protect the marine environment. The CBD differs from this in that its primary objectives are to conserve biodiversity and ensure sustainable use of the seas biological resources, it is also significant in that it supports ecosystem-based management (Taljaard and Van Niekerk. 2012), one of the key principles behind MSP.

In complete contrast to land-use planning that is surrounded by a legal framework that unites many different existing rules and has a fixed hierarchy between the different levels of authority that are involved, marine spatial planning is still very much in its infancy. Historically, marine planning involved a multitude of different authorities, regulations and laws and to complicate the situation further still these differ for territorial seas and coastal waters (Plasman 2008). It will therefore be crucial in the future in order to ensure the successful implementation of MSP that all the relevant bodies are fully informed and are all looking at the situation from the same point of view (Plasman, 2008).

4.3.1 Legal Frameworks

Globally there are several different instruments that are all important to MSP development these include the United Nations Convention on the Law of the Sea (UNCLOS), the International Maritime Organisation (IMO), the Convention on Biological Diversity (CBD), Agenda 21 and the World Summit on Sustainable Development Plan of Implementation (Calado et al., 2010). At a smaller scale within Europe there are several other important drivers for example the Maritime Policy or 'Blue Book' (COM Green Paper, 2006) issued by the European Commission in the context of the EU Thematic Strategy, and European legislation on nature conservation such as the Birds Directive (79/409/EEC) and the Habitats Directive (92/43/EEC) (Stelzenmüller et al., 2012). It is then up to individual countries to integrate MSP into their own legal frameworks however they see fit. For example in Portugal they have introduced the National Sea Strategy in order to integrate their existing sectoral policies and define the principles for MSP and Integrated Coastal Zone Management (ICZM). It is hoped that this approach will ensure the sustainable use of their resources and promote the efficient use of the maritime space by integrating and using a cross-sectoral approach (Calado et al., 2010).

It is a difficult process trying to introduce new policies as will be discussed later, however it can often be helpful if governments that are involved all sign up to abide by an international agreement, such is the case in Europe through the new Marine Spatial Planning Directive. This is helpful as sanctions can then be put in place if these agreements are not fulfilled or complied with, furthermore it has been shown to speed up many processes and affect policy making (Plasman 2008). This has been demonstrated in many EU countries such as Britain, Belgium and Spain when legislation such as the Environmental Impact Assessment (EIA) Directives, Strategic Environmental Assessment (SEA) and the European Birds and Habitats Directives were introduced. These along with other legislator instruments have resulted into the designation of protected areas, including the Natura 2000 sites, and implementation of other protective measures (Sheate et al., 2005; Plasman, 2008). Furthermore, overarching directive such as MSP Directive in Europe allow the progression of more regional projects for example ADRIPLAN in the Adriatic Sea (

Within the UK national governments are implementing MSP under the recent UK Marine Acts with the aim of delivering new planning systems that will produce marine plans (Stelzenmüller et al., 2012). Previously they had made several commitments to explore implementation of MSP at both a national and regional scale. These included the Berlin Declaration at the 5th North Sea Conference of Ministers in 2002 and the EU Recommendation on ICZM in May of the same year. As a result, in 2004, a stock-take of current practices of ICZM in the UK was published highlighting the possibilities of linking established ICZM plans with MSP and land-use planning schemes, along with other management mechanisms such as the River Basin Management Plans that were introduced under the EU Water Framework Directive (2000). The Government then mirrored this commitment to adopt an ecosystem-based approach to marine management and better integrate conservation and protection mechanisms with sustainable sea users in both Safeguarding Our Seas (UK Marine Stewardship Report) and Seas of Change (Tyldesley 2004).

Many regulatory controls in the marine area are operated by devolved governments (in Britain this is the job of UK Government departments and the Scottish Government) not at local government level (Tyldesley 2004) there are exceptions however such as aquaculture and harbours. There are arguably several reasons why the UK Government and its devolved administrations have chosen to progress with MSP through implementation of the Marine Acts. Firstly there is presently, and will continue to be, an increasing pressure placed on the marine environment by development activities that are further exacerbated by competing interests and exploitation of finite resources (including space). There is currently not a solid understanding of the cumulative effects that these different activities can have on the marine environment or of the consequences of interactions between various users and developments (Tyldesley 2004). Secondly any development that currently takes place below the low water mark (LWM) is regulated independently of one another, using different licensing schemes. This current approach is complex and fragmented, with no plan-led system that makes provisions for future sustainable development in any one particular area. The complexity of this approach in the past has resulted in confusion between marine developers and consequently significant financial losses have been incurred by industries having to steer their way through expensive consenting regimes. The current sectoral management approach makes it very difficult to assess the cumulative effects of activities and their associated pressures (Stelzenmüller et al., 2012). Crucially the sector by sector approach that is being implemented at present is in direct conflict with the ecosystem-based approach that is now widely recognised as being the future mechanism for marine management.

4.3.2 Science and Policy

In recent years there has been an increase in the number of international conventions and directives relating to marine planning and these are beginning to have an effect on regulatory controls relating for example to water quality or species/habitat protection. They have also encouraged more assessment of environmental effects at sea. The problem is that in many countries regulatory systems are not able to accommodate these changes very easily (Tyldesley, 2004). Often what is needed is a more effective relationship between scientists and policy makers. Scientists will often recognise problems but in truth have very limited power to remedy them unless they are able to be more actively involved in policy making (Plasman, 2008).

This is an issue that will become even more crucial in the future as OSPAR continues to pursue the implementation of MPAs and it is likely that the marine environment will be subjected to even more designations in the future (Tyldesley, 2004). Key to the successful partnership between scientists and policy makers will be the recognition of the different ways of thinking between the two and making better use of scientific information when making policies. This will in turn improve the likelihood of science-based policies being implemented (Plasman, 2008) and this could be imperative for the success of some industries in the future. This could be especially true for aquaculture, the development or growth of which will potentially place further pressures on the environment along with other activities and coastal users. A science-based planning scheme will be essential to resolving any conflicts that may arise from such a development (Tyldesley, 2004).

A good example of a failing between science and policy was in the case of Belgium's North Sea management plans. Although Belgium only claims a small part of the North Sea it is an intensively used area. Between 1999 and 2003 it was considered to be in need of an MSP approach and initial proposals were made. The application lacked a common understanding amongst all the users of the specific North Sea marine area and as a result was not translated into policy. It was only due to several high profile conflicts occurring between marine users (extraction companies and renewable developers) that the issue of MSP was eventually pursued further (Plasman, 2008). Part of the issue in the case of the Belgium North Sea MSP development was that the government lacked sufficient tools for implementing marine use management and the fact that very little legal or institutional arrangements existed at the time. This lack of development is perhaps partly due to the fact that at sea there were no obligations on regulators to prepare marine plans proposals that would serve to coordinate spatial implications, investment programs or any other developments or change (Tyldesley, 2004).

4.3.3 Guidance and Future Development

It was almost a decade ago when the World Summit for Sustainable Development (WSSD) voiced the need for coastal and watershed planning tools to serve as a means of implementing conservation and management in oceanic areas (WSSD, Johannesburg, September 2002). Although none of the early conventions actively endorsed the use of MSP, indirectly they all advocated the development of a practical tool that would advance ecosystem-based management for marine areas (Taljaard and Van Niekerk, 2012). Today, however, several international organisations directly promote the use and development of MSP and provide advice to governments on the subject. For example the United Nations Educational, Scientific and Cultural Organisation (UNESCO) provides practical guidance on the development of spatial plans and an overview of MSP development globally (Stelzenmüller et al., 2012). Other organisations such as OSPAR, the Commission for the Protection for the Marine Environment of the North East Atlantic, has set up working groups with their sole focus on dealing with Marine Spatial Planning (Plasman, 2008). Furthermore in 2008 the European Commission (EC) published their 'Guidelines for an integrated approach to maritime policy: Towards best practice in integrated maritime governance and stakeholder consultation'. Within this they highlighted the fact that there are duplications in regulatory powers, plan coordination of marine uses and discuss the implementation of an ecosystem approach and its use as a main driver for integrated marine management (Calado et al., 2010). The problem is that while these are very relevant and helpful guidelines for MSP they are all conceptual, and the practical tools needed to support MSP implementation are still largely missing. These tools are diverse in nature and can range from planning frameworks to practical solutions. Science will be required to play a significant role in both the initial environmental assessments and the production of spatial management scenario and even after MSP development in the planning and implementation of performance assessments schemes (Stelzenmüller et al., 2012).

4.4 Conception of the Prototype Zoning Scheme

This chapter outlines the development and application of a new prototype zoning scheme that has been designed for Scottish waters but also has the potential to be more widely applicable to other marine areas. The primary aim was to devise a large-scale, ecosystem-based zoning approach for managing existing activities and any new developments within Scotland's marine environment. This new prototype zoning scheme draws upon the approaches taken by two previous studies detailed in Chapters 2 and 3: the multiple-use zoning scheme developed by Boyes et al. (2007) for the UK and Manx waters of the Irish Sea and the Marine Planning Framework for South Australian waters devised by Day et al. (2008).

4.4.1 The Multiple-Use Zoning Scheme

As previously detailed in Chapter 2, the Multiple-Use zoning scheme that was analysed was originally developed by Boyes et al. (2007) and is based on existing legislation and was aimed at providing a tool to aid MSP at a national scale. The scheme applied was *a posteriori* zoning scheme, based on summarising and classifying existing zones and regulations. It is not an objective-based comprehensive zoning scheme; this would require a policy-led approach.

Positive Outcomes and Shortcomings

The application of this zoning scheme demonstrated that it was possible to develop a multiple-use zoning scheme for Scottish waters by condensing and mapping current spatially derived legislation and regulations by considering the level of environmental protection that they afford. In particular it proved that the currently defined regulatory and sectoral measures could be combined within a zoning scheme. It further demonstrated that nature conservation sites could be seen as constituting a type of multiple use zone and in contrast the only areas that are used exclusively are those with sectoral activities that are accompanied by well defined regulatory measures.

There were a number of activities that were omitted from the exclusion and protected zones, however even if activities do occur within them, the protection afforded by these zones and the resultant conservation benefits they can provide would seem to be limited. This is primarily because the sizes of these areas are considered to be too small to provide them with the ability to limit harmful developments significantly. Conversely, some developments may indirectly improve an area's conservation status e.g. by affording some species and habitats protection through placing controls on certain types of damaging activities within their exclusion areas (pipelines and dredging).

However, even within the Significant Exclusion Zone (SEZ), where other activities are predominantly excluded and therefore protection may be inadvertently provided to some species/habitats, the actual licensed development (e.g. oil and gas, renewables etc.) could be having a disproportionately negative effect on the areas conservation status. The only zone that would afford a site complete protection would be Zone 4, the protected areas zone, and when calculated this turned out to be the smallest of all the zones. This situation was made even more worrying as this extremely small area, was also distributed in tiny pockets surrounding wrecks and military remains, and as a result they would likely have little influence in nature conservation.

The progression through the various zones in this scheme correlates with increasing restrictions that each zone places on the type/intensity of legally permitted activities that occur within them. This multiple use zoning scheme depicts the extent to which current regulatory measures provide management and protection throughout a series of defined zones. It can be taken that this zoning scheme was representative of management controls and their various implications for environmental protection. This approach confirmed the sectoral origins of current regulations and consequently the constraints imposed on this basis. Furthermore, the proposed multiple-use zoning scheme demonstrated that there are relatively few mechanisms available via current regulatory schemes that can be used to initiate any type of spatial planning policy. Analysis confirmed that spatial management within Scottish waters was limited and a more comprehensive system would require development from basic principles.

It was not the intention of this study (and the multiple-use zoning scheme) to show where future activities and development should and should not be legally permitted, but by mapping the spatial coverage of statutory controls, it highlighted where future developments may potentially take place, or apply for a license.

The lack of any formal marine spatial planning was clearly seen from the application of the Multiple-Use scheme, the zoning showed that developments could be proposed in most areas within Scottish seas, the exception being where there are existing developments or within Zone 4. The predominant constraints on further developments showed to be current developments with obligatory exclusion zones and restrictions that are attached or already in place rather than any form of planning policy, e.g. activities such as oil and gas installations that occupy the area they have been licensed within and effectively limit any further developments.

Areas for Development

From the application of this zoning scheme it was suggested that further refinement and modifications would be possible that would make the scheme more robust. At the inception of this work it was only possible to include those areas where activities had been licensed but not those where an activity takes place. For the most part the zoning did not necessarily indicate the spatial intensity of an activity or their temporal occurrence, e.g. in theory vessels can move anywhere within the Scottish sea area, and there are other constraints that play a part on this movement other than legislation such as distance between ports and fuel efficiencies.

On a similar note, whilst fishing is permitted in many places the multiple-use zoning scheme did not account for the amount of activity taking place (e.g. days at sea) or the type of fishing taking place (e.g. gear used), when in fact both factors would dictate the level of impact the activity (fishing) may exert on the environment. Integration of these data in the future, would allow this zoning scheme to be further tested against different conservation scenarios.

Although this scheme identified four proposed zones, they were fundamentally only a description of what occurs in each area outlined. Therefore, it is not what can be considered as a true zoning scheme, whereby zones are identified based on clear sets of objectives. For it to be an influential tool to guide MSP, economic, environmental and social objectives would need to be incorporated alongside a goal of minimising or avoiding spatial conflicts between users and between activities and the environment.

The Irish Sea Multiple-Use zoning scheme derived from current legislation and regulations alone, with non-statutory policy measures, voluntary agreement and other initiatives were not included. However, in the future it will be important to include these other important management mechanisms when undertaking a zoning task.

This zoning scheme was considered to encompass all of the major features and activities occurring within Scottish waters just as it did encompass all the legislation within the Irish Sea when it was originally applied and therefore it could be seen as being sufficiently robust to transfer into any sea area providing it has a similar level of data availability. However it should be acknowledged that major gaps still remain and when appropriate data (e.g. fishing) becomes available it would significantly improve the final output integrate these also. This scheme does have its limitations however; as it has been designed as a top-down approach to management and it has been aimed more at mapping existing activities rather than as a means of trying to develop a pro-active management scheme for planning. This said, the zoning scheme could evolve through further testing and discussions and through testing this scheme against other datasets the approach could be expanded to other areas. The present scheme for instance only accounts for sea areas below low water mark and in the future this could be further refined to encompass intertidal areas.

Leading on from this work, the development of a coherent ecosystem-based zoning scheme with linked conservation objectives underpinning each zone may be possible. Following this approach, the derivation of a zoning scheme should incorporate, into additional protection areas, features deemed environmentally important, rare or threatened. As was demonstrated by this study, at present the majority of PMFs would fall within Zone 1A, the Minimal Management Zone, and as such have little protection afforded to them. But the further development of a conservation prioritised zoning scheme would allow for a better level of protection.

4.4.2 The Marine Planning Model

Positive Outcomes and Shortcomings

The work outlined in Chapter 3 demonstrated that it was possible to apply an environmental zoning scheme by considering and mapping important ecological data within Scottish waters and identifying areas where different features co-occur to differing extents. Specifically this demonstrated that the currently defined environmental data that are available could be combined within a zoning scheme. Furthermore, it demonstrates that it is possible to use environmental data, at least partially, as the basis for designating a type of multiple-use zoning scheme. It was not the intention of this zoning scheme to propose policies for each of the zones, only to identify the level of management and types of regulatory measures that would need to accompany each of the proposed zones.

This zoning scheme was considered to encompass all of the major environmental features and habitats that occur within Scottish waters in a similar manner to the original application. It therefore can be seen as being sufficiently robust to transfer into any sea area providing it has a similar level of data availability. This scheme does have its limitations however; although it was designed as a bottom-up approach to management and it was intended for mapping existing environmental features as a means of trying to develop a pro-active management scheme for planning it did not account for the degree of vulnerability of some sites. For example a unique marine feature may only be present at one site in the whole of Scotland while another important feature may be present at several sites, this scheme would not allow for any priority to be given to the exclusive site. This is particularly problematic if the unique feature is the only feature present at that site that requires a high level of protection, the nature of this zoning scheme may result in the unique feature being placed in an inappropriate zone. This is where other approaches such as Marxan may be better. This said, this zoning scheme would evolve through further data availability, results testing and discussions and, furthermore, by testing this scheme against other datasets the approach can be expanded to other areas. The present scheme, for instance, only accounts for sea areas out to 12nm and in the future this could be expanded further to encompass the sea area out 200nm.

This zoning application graphically showed the many important ecological features that are present, and are increasingly being threatened or placed under stress within the Scottish Sea area as well as the real want for some type of spatial planning scheme.

Areas for Development

It was the intention to also develop a Performance Assessment System (PAS) that would accompany the Marine Planning Framework and become an integrated part of the Framework. The intention would be that this PAS would be designed to evaluate the effectiveness of each of the Marine Plans and would achieve this by assessing and reporting on the maintenance of ecosystem conditions. Any PAS developed would need to done in consultation with both government and non-government agencies that are involved with managing and monitoring of the marine environment. Potentially, this new monitoring scheme could be fitted into the current site condition monitoring system (SCM) operated by Scottish Natural Heritage. Alternatively, the current SCM scheme could be utilised to advise, develop or add to this proposed PAS monitoring scheme. The PAS scheme should establish an agreed approach to monitoring select indicators with the aim of detecting change (both natural and human induced) in the conditions of an areas ecosystems, biodiversity, habitats and species.

When applied to the ER Zone objectives, the results of monitoring using the PAS would reveal whether or not the management measures that are in place are adequate to conserve and facilitate responsible use of marine, estuarine and coastal resources. The use of a PAS would also allow for a coordinated mechanism to be put in place that enables all agencies to contribute to a national collaborative approach to data collection, analysis and reporting on environmental marine conditions. This could be seen as a necessary prerequisite for constructing a best practice, adaptive approach to management and reporting.

Because ER Zones would on the most part allow for a wide-range of activities and the sustainable use of resources, this would result in pressures and potential impacts on marine, estuarine and coastal systems to varying degrees. In order to establish the context and possible causal sources for any such changes that are observed over time, the level of specific pressures (potentially impacting activities or pollution sources) that may be related to changes in environmental conditions would be assessed and reported within the context of the Marine Plan performance. Assessment of the performance indicators in each marine plan would not be intended to replace the role of other agencies in regulating and managing sustainable uses, but would serve to provide a broader perspective for policy decisions and responses.

4.5 Development of the Prototype Zoning Scheme

In the development of a new prototype zoning scheme for Scottish waters, plans have been prepared for both Scottish inshore and offshore waters. This is in line with the pre-consultation draft of the National Marine Plan that covers all waters out to 200nm.

This Prototype Zoning Scheme's boundaries are partly based on the third option of Marine Scotland's "Scottish Marine Regions: Defining their boundaries" consultation document as used in the Marine Planning Model. Under this option

there would be 11 defined regions (Argyll, Clyde, Moray, North Coast, North East, Orkney, Shetland, South East, South West, West Highlands, and the Western Isles) that are predominantly determined by physical characteristics. However, because this zoning scheme is intended to fall into line with the Draft Marine Plan and the intended coverage is to extend out to 200nm, a twelfth SMR has been added the Offshore SMR (see Chapter 3.1, Figure 3.1). This extra marine region allows the zoning scheme to produce a prototype zoned region for offshore waters that can in the future be further subdivided as policy makers and planners see fit.
For the purposes of applying this Prototype Zoning Scheme in Scottish waters, Mean High Water Spring tide (MHWS) will once again mark the landward limit of the plan and then it will extend out to 12 and then 200nm.

The initial step in developing this Prototype Zoning Scheme involved identifying the data required within the planning area. Considering the previous two applications of zoning schemes already reviewed dealt with either marine activities or environmental factors in relative isolation, it was deemed important that, in this Prototype Zoning Scheme, the two types of data were in some way integrated. Therefore Activities data used in creating the multiple-use zoning scheme and environmental data used to produce the marine planning framework were both utilised in this scheme. These data were then compiled within a GIS (ArcGIS 9.3) to manipulate and analyse the spatial distribution of data in developing these marine plans.

Data were collated from a variety of different agencies and online resources (refer to Appendix 4, Table A 4.0) and resulted in approximately 71 spatial layers being compiled. The data selected for use in developing this Prototype Zoning Scheme were, as can be seen in Appendix 4, Table A 4.0, grouped as being either ‘Activities’ or ‘Environmental’ layers. The environmental layers used in the zoning scheme contained information specifically on habitats and uniqueness (e.g. seabird nesting sites, seal haul out areas) in the individual areas covered by each plan. Activities layers included data on the presence of licensed or legislated activities within each of the marine planning areas.

In order to simplify the collation of the extensive amount of data that were amassed for this research, each planning area was once again divided into grid cells of equal size (0.05 decimal degrees) and termed a Planning Unit (PU).

This followed the methodology used in the Marine Planning Model detailed previously (refer to Chapter 3, Figure 3.2 for an example of the Argyll Planning Area with numbered PUs).

4.5.1 The Prototype Zones

This Prototype zoning scheme is loosely based on a multiple-use zoning scheme that was originally formulated by Boyes et al. (2005; 2007) that was devised by combining current legislation and regulations and any spatial constraints that may also exist for certain activities to produce a four central zone scheme. The Prototype scheme, also aims to incorporate environmental factors into the production of its management zones and therefore the criteria and zones have been altered appropriately. Each of the five zones proposed afford an increasing level of protection and level of active management. The five proposed zones are:

1. Precautionary Management Zone
2. Targeted Management Zone
3. Exclusion Zone (containing two sub-zones: Limited Exclusion Zone and Significant Exclusion Zone);
4. Conservation Priority Zone

1 Precautionary Management (PMZ)

- Activities that are permitted by international legislation (and can therefore legally occur within these zones), through legally permitted consents or licenses issued by the relevant authorities
- Regulated activities that are unlicensed may also occur within this zone e.g. shipping and fishing activities are not spatially controlled by legislation but can occur within this zone as they are controlled by MARPOL and EU fisheries legislation.
- The granting of future licensing for activities within this zone should firstly be preceded by research to improve knowledge of the area. Currently scientific data may be considered inadequate in order to identify any areas within this zone that are important to the maintenance of biodiversity, ecological health and productivity of ecosystems within it.

2 Targeted Management Zone (TMZ)

- An area has been granted authorisation, license, permit, order or consent for an activity to take place.
- Activities occurring in this zone take place subject to the provisions of regional, national and international legislation and under management by the relevant authorities.

3 Exclusion Zone (EZ)

3A Limited Exclusion Zone (LEZ)

- Incorporates activities which have a temporal exclusion zone attached to them which affect other activities and also activities that place temporal exclusion zones on themselves due to conservation demands
- Examples include MOD areas, no dredge zones around pipelines and cables or fisheries protected areas that may be closed seasonally.
- Although this zone effectively prohibits an activity from occurring within a spatial extent or time frame this does not stop other activities from taking place in that sea area.

3B Significant Exclusion Zone (SEZ)

- This zone contains legally permitted activities that require an exclusion zone due to health and safety reasons.
- Zoning includes both the activity and the 'safety' area.
- This zone includes protected historical sites and areas that have been designated for their conservation attributes e.g. SACs, SPAs, SSSIs etc. where irreparable damage could occur if other activities were to be permitted.

4 Conservation Priority Zone (CPZ)

- Almost all other activities will be prohibited at all times, with a few exceptions such as for research purposes, which would require a permit before being carried out.
- Conservation requirements will dictate decisions about developments and activities that will be permitted within this zone and in turn this zone can only be allocated to sites that have official conservation designations or sites that are designated under the Protection of Wrecks Act 1973 and the Control of Military Remains Act 1986 will be included in this zone.

4.6 Deriving the Zoning Scheme

The Prototype Scheme is derived from the combination of both activities and environmental data. The process of applying this zoning scheme produced three separate schemes; the first allocates zones based on activities data, the second environmental data and the third combines the first two sets of derived zones. Each zoning scheme produced employs the exactly the same zones as outlined in the previous section.

4.6.1 The Activities Layers

Utilising the framework provided by the multiple-use zoning scheme (Boyes et al., 2007) and the regulatory and management measures previously identified for the various marine activities that occur in Scottish waters resulted in general conclusions on where activities would take place and what limitations there may be on development. These conclusions were then used as a basis for formulating the first step of the Prototype Zoning Scheme. Table 4.2 shows the placement of each of the activities and the justification for their allocation into the different zones. Their placement is for the purposes of research only and is not an indication of which activities would be allowed when implementing an actual Marine Spatial Planning scheme. Colour coding has been used to illustrate the different management and protection levels in each zone, as following:

- Blue – Zones where any activity can potentially occur subject to appropriate legislation
- Green → Orange – Increasing restrictions being applied to activities
- Red – All activities are prohibited

This proposed activities zoning scheme for Scottish waters can be seen illustrated as a map in Figure 4.2. This gives an indication of the geographic extent of the zones. Activities were mapped using GIS based on the zone where they were most legally restricted i.e. where the highest level of restrictions applied. This zoning scheme is an indication of where Prototype zones would occur if only marine activities were to be used to derive management areas. To ensure this Prototype scheme acknowledges a wider set of marine factors in its planning, a second group of environmental factors were also zoned.

Table 5 - Activity Allocation to Zones and Justification.

Activity / Use	Zone		Justification
Historical Wrecks	4. Conservation Priority Zone (CPZ)		• Restricted access to select activities such as diving and scientific surveys, all other activities prohibited
Archaeological Sites			
Oil Wells	3B. Significant Exclusion Zone (SEZ)	3. Exclusion Zone (EZ)	• Restricted access (exclusion) zone established for safety reasons, full exclusion to all activities within 500m • Restricted access when MOD activity is occurring and other activities only permitted out with these times • Restricted access to shipping for safety and conservation reasons • Seasonal/annual restrictions on gear/quota/target species, doesn't prevent other activities occurring • Excludes dredging activities within 250m
Scottish Energy Awards			
Wind Farm Lease Sites			
Tidal Farm Lease Sites			
Wave Farm Lease Sites			
MOD Firing Danger Areas	3A. Limited Exclusion Zone (LEZ)		
MOD Practice Areas			
Marine Finfish Aquaculture			
Marine Shellfish Aquaculture			
Submarine Cables			
Submarine Pipelines			
Shipping and Ferry Routes			
Small Craft Facilities			
IMO Scheme	2. Targeted Management Zone (TMZ)		• Activities occurring in this zone take place subject to the provisions of regional, national and international legislation and under management by the relevant
Harbour/ Port Jurisdictions			
Fallowing Blocks			
Hydrocarbon Fields			
Licensed Areas			
MOD Submarine Areas			
Dredging Areas			
Dumping Areas			
Carbon Fields			
Saline Aquifers			
High Intensity			
Remaining Sea Area	1.Precautionary Management Zone (PMZ)		• All other activities can occur in this zone if legally permitted.

4.6.2 The Environmental Layers

Utilising the framework provided by the Multiple-use zoning scheme (Boyes et al., 2007) and the important environmental data recognised by Day et al. (2008) the uniqueness and habitat related environmental data layers that occur in Scottish waters resulted in general conclusions on where they would take place and what limitations there may be on development. These conclusions were then used as a basis for formulating the second step of the Prototype Zoning Scheme.

Table 4.3 shows the placement of each of the environmental factors and the justification for their allocation into the different zones. Their placement is for the purposes of research only and is not an indication of which environmental factors would be considered when implementing an actual Marine Spatial Planning scheme. Colour coding has been used to illustrate the different management and protection levels in each zone, as following:

- Blue – Zones where any activity can potentially occur subject to appropriate legislation
- Green → Orange – Increasing restrictions being applied to activities
- Red – All activities are prohibited

This proposed environmental zoning scheme for Scottish waters can be seen illustrated as a map later in this chapter in Figure 4.3.

Table 4.3 - Environmental Factors allocation to zones and justification.

<table>
<tr><th>Activity / Use</th><th colspan="2">Zone</th><th>Justification</th></tr>
<tr><td>Ramsar</td><td colspan="2" rowspan="5">4. Conservation Priority Zone (CPZ)</td><td rowspan="5">• Restricted access for some activities that are potentially damaging/ degrading to designated features.</td></tr>
<tr><td>SSSI</td></tr>
<tr><td>SAC</td></tr>
<tr><td>SPA</td></tr>
<tr><td>World Heritage Site</td></tr>
<tr><td>Rare Seabed Landscapes</td><td rowspan="5">3B. Significant Exclusion Zone (SEZ)</td><td rowspan="9">3. Exclusion Zone (EZ)</td><td rowspan="9">• Restricted access (exclusion) zone established for safety reasons, full exclusion to all activities within 500m
• Restricted access when MOD activity is occurring and other activities only permitted out with these times
• Restricted access to shipping for safety and conservation reasons
• Seasonal/annual restrictions on gear/quota/target species, doesn’t prevent other activities occurring
• Excludes dredging activities within 250m</td></tr>
<tr><td>Priority Marine Features - Uniqueness</td></tr>
<tr><td>Priority Marine Features - Habitats</td></tr>
<tr><td>Seal Haul Out Areas</td></tr>
<tr><td>No-Take Zones</td></tr>
<tr><td>Beaches with Awards</td><td rowspan="4">3A. Limited Exclusion Zone (LEZ)</td></tr>
<tr><td>Spawning Grounds</td></tr>
<tr><td>Nursery Grounds</td></tr>
<tr><td>Sea Bird Nesting Sites</td></tr>
<tr><td>High Cetacean Encounter Rates</td><td rowspan="2">1.Precautionary Management Zone (PMZ)</td><td rowspan="2"></td><td rowspan="2">• All other activities can occur in this zone if legally permitted.</td></tr>
<tr><td>Remaining Sea Area</td></tr>
</table>

4.6.3 The Prototype Scheme

For the final stage in the Prototype Zoning Scheme the two schemes previously generated derived from both the activities and environmental data layers were combined to form one over-arching zoning scheme. Where there was a spatial overlap and conflict between the two zoning schemes, the planning units where the conflict arose were automatically allocated to the zone with the higher level of protection. For example, when the two zoning schemes were overlaid, if a specific PU was allocated to Zone 2 according to the activities derived zoning scheme and Zone 3A in accordance with the environmental based zoning scheme, then the Prototype scheme would automatically allocate it to Zone 3A.

This proposed Prototype Zoning Scheme for Scottish waters can be seen clearly as a map in Figure 4.3. This visibly shows the geographic extent of the zones and how they differ from the zones derived from solely activities or environmental factors as shown in Figures 4.1 and 4.2.

4.7 The Results

Looking at both Figure 4.1 and Table 4.4 it can be clearly seen that when activities alone were used to derive the zoning scheme the majority of the Scottish sea area fell within the first three zones. Between them, zones 3B and 4, the two zones that afford the highest level of protection, made up less than 15% coverage overall.

Table 4.4 - Table of Percentage Cover of Activities Derived Zones

Zone	No. of Planning Units	% Cover
1	7643	25.08
2	9323	30.6
3A	9190	30.16
3B	2364	7.76
4	1948	6.4

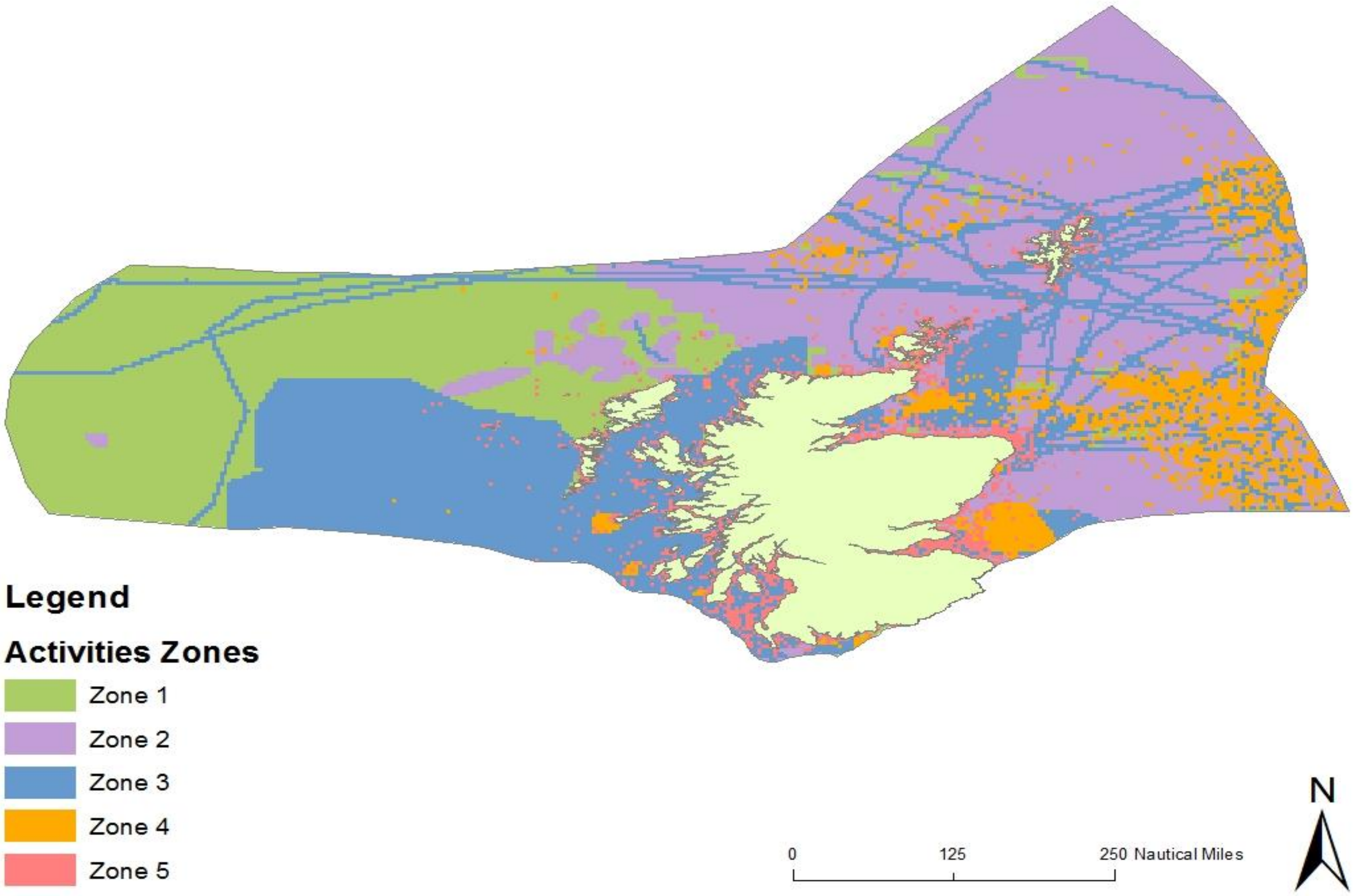

Figure 4.1 - Map of Zones derived from Activities Data Layers

Referring to both Figure 4.2 and Table 4.5 it can be seen that when only environmental criteria were used to derive the zoning scheme the vast majority (>75%) of the Scottish sea area was allocated to Zone 3A. None of the other zones, individually, made up more than 10% of the remaining sea area. No sea space at all was allocated to Zone 2.

Table 4.5 - Table of Percentage Cover of Environmentally Derived Zones.

Zone	No. of Planning Units	% Cover
1	2727	8.95
2		
3A	22921	75.23
3B	2774	9.1
4	2046	6.72

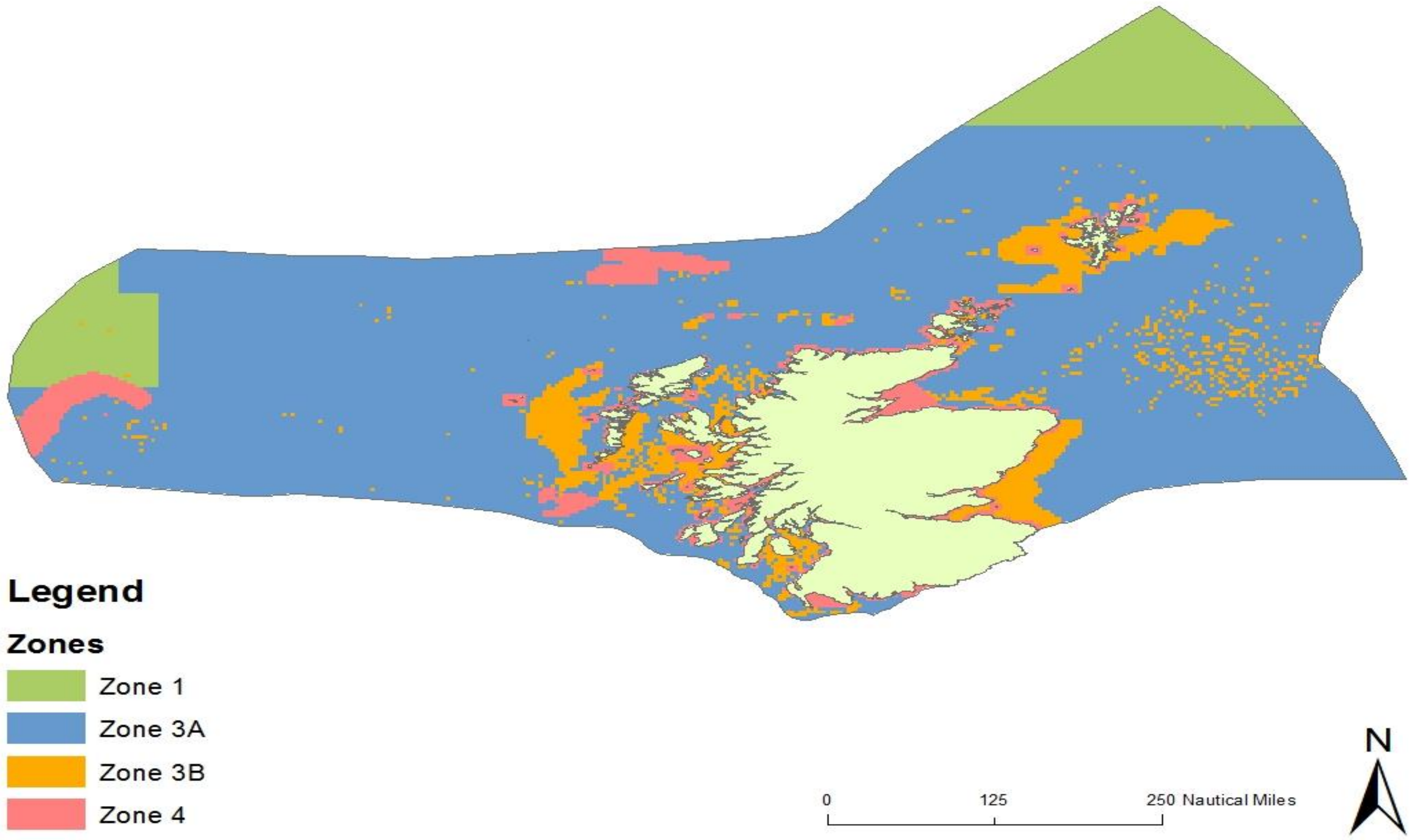

Figure 4.2 - Map of Zones derived from Environmental Data Layers

When the two data sets were combined (activities and environmental factors) the Prototype Zones they produced (see Figure 4.3) showed that the largest amount of sea area fell within zone 3A see Table 4.6). Lesser areas of sea were allocated to Zones 3B and zone 4, the zones that provide a higher amount of protection, 14.4% and 10.27% respectively. Zone 1 had the smallest area coverage at only 3.28%, this being in offshore waters (Figure 4.3).

Table 6 - Table of Percentage Cover of Prototype Zones

Zone	No. of Planning Units	% Cover
1	999	3.28
2	1562	5.13
3A	20391	66.92
3B	4387	14.4
4	3129	10.27

When comparing the percentage coverage of each of the zones across the three applications of the zoning scheme (see Table 4.7) it can be clearly seen that the consideration of the different data sets alters the distribution of the zones within Scottish waters. The result of combining the two data sets has led to an increase in the overall percentage coverage of zone 3B and zone 4 in the Prototype scheme. There was also a significant drop in the coverage of zone two in the final scheme from 30.6% in the activities based zoning to just 5.13% in the Prototype scheme. While the activities derived zones appeared to have no zone that was completely dominant both the environmentally derived zones and the Prototype scheme saw the majority of the Scottish sea area allocated to zone 3A.

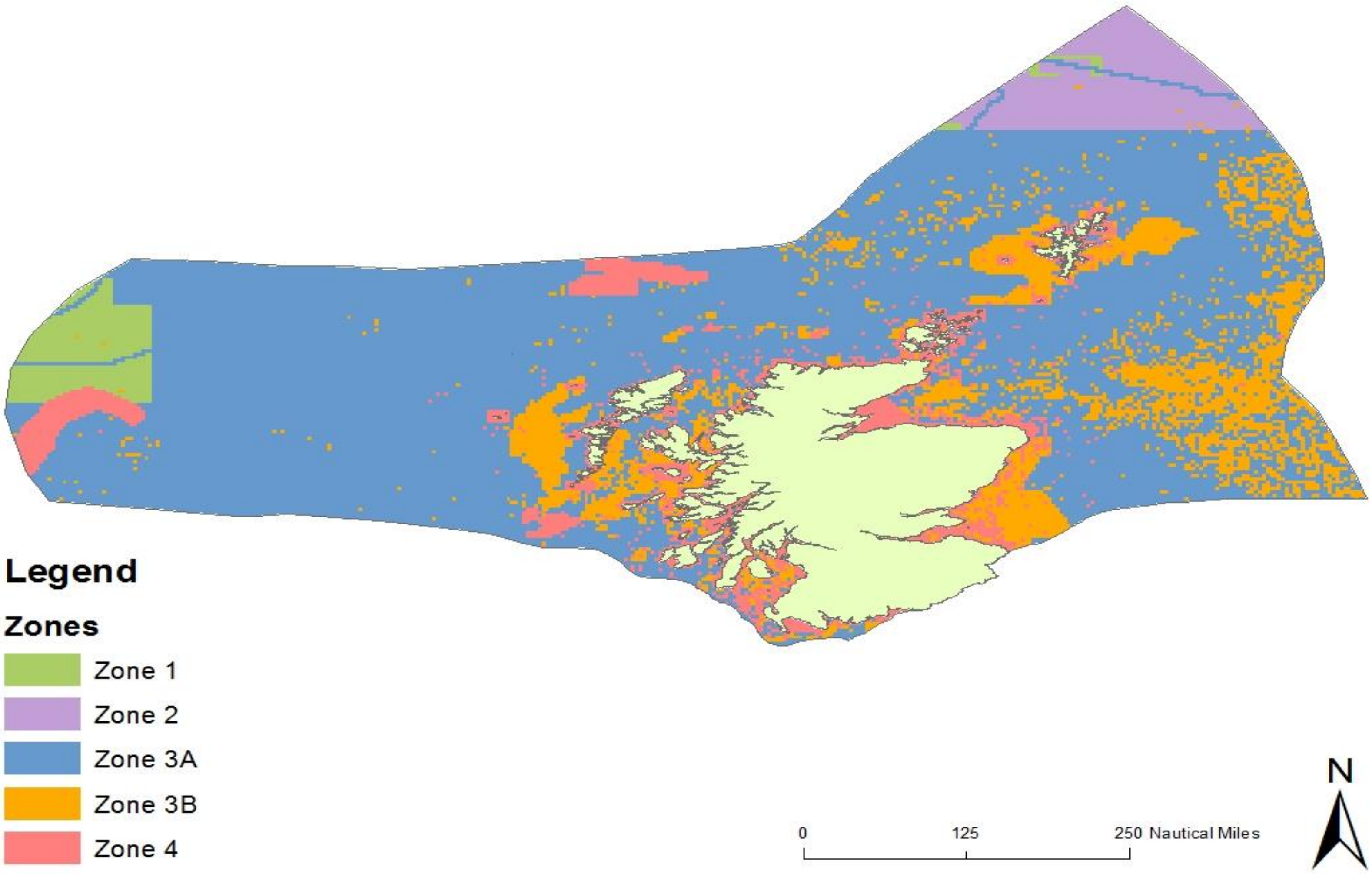

Figure 4.3 - Map of Planning Zones derived from the Prototype Zoning Scheme

Table 4.7 - Table of Changes in Percentage Cover between the different applications of the Zoning Scheme

Zone	Activities Layers	Environmental Layers	Prototype Zoning Scheme
1	25.08	8.95	3.28
2	30.6		5.13
3A	30.16	75.23	66.92
3B	7.76	9.1	14.4
4	6.4	6.72	10.27

When each of the marine regions was separately analysed (See Appendix 4, Figures A 4.0- A4.12 and Tables A 4.1 – A 4.11), to assess the percentage coverage of each of the zones it was found that nearly all of the marine regions were dominated by a particular zone and zoning dominance varied depending on the location of the marine region. For example, referring to Table 4.8, those marine areas located on the East coast (Moray, South East and North East) have a large percentage of their area allocated to zone 4. More remote marine regions such as Orkney, North Coast, Western Isles and Offshore appear to be dominated by zone 3A coverage. However what is particularly notable from looking at Table 4.8, is that Zones 1 and 2 are only found in the most remote and northerly marine regions and even here there coverage is slight, ranging from just 0.43% to 6.3%.

Table 4.8 - Table of Change in Percentage Cover between the SMRs

Zone	Offshore	Shetland	Moray	North East	South East	Clyde	Orkney	North Coast	South West	Argyll	Western Isles	West Highlands
1	4.03							0.43				
2	6.3											
3A	74.47	32.49	21.85	16.89		14.56	59.49	48.92	28.82	41.16	54.43	33.14
3B	11.95	41.93	17.34	38.96	37.13	18.44	9.92	8.66	16.67	23.81	26.63	26.53
4	3.25	25.58	60.81	44.15	62.87	67	30.59	41.99	54.51	35.03	18.94	40.33

4.8 Analysis and Discussion

4.8.1 The Activities Zoning Application

The activities data layers have all been previously utilised in creating a multiple-use zoning scheme for Scottish waters. Based purely on legislated activities the data layers used span a wide range of activities and were selected to represent the activities that currently occur within Scottish waters (see

Appendix 4 Table A 4.0 for full listing of activities and Table A 2 for grouping within the zones).

Zones 3B and 4 have the smallest percentage cover with 7.76% and 6.4%, respectively. Zone 3B is predominantly spread across Eastern waters; this is mostly the result of offshore oil and gas exploitation in the North Sea. Zone 4 (referring to Figure 4.3) is most commonly located close to the shore and around Orkney and Shetland.

Zone 1, unsurprisingly, is mostly found within offshore Western waters. The number of activities occurring in this area is significantly less due to its remoteness. This zone in particular is important to consider in terms of activities in the future as many industries have expressed their intentions of moving further offshore when technology and resources allow. Thus, Zone 1 stipulates that activities proposed for development in this zone should firstly be preceded by research to ensure that there is sufficient scientific data to identify areas that are ecologically important or sensitive. The intention is to ensure that any future developments take place or progress in a sustainable manner and do not have any significant detrimental effect on the environment.

Table 4.4 shows that Zones 2 and 3A are the most abundant zones to be derived in terms of area coverage, from the activities data layers. Looking at Figure 4.1 it can be seen that Zone 2 appears to be dominant in the East and 3A prevails in the West. This division referring to Table 4.1 is most likely attributed due to the large areas used for MOD activities.

4.8.2 The Environmental Zoning Application

The environmental data layers were a mixture of habitat derived data features and uniqueness layers. They were not gathered to represent conditions within Scottish waters but to highlight important or significant marine features including those that were deemed either unique or vulnerable. They were placed in zones (see Table 4.3) according to where they appear to fit most appropriately and primarily because of the management type/level they most required. As can be seen in Table 4.5, no areas fell within Zone 2 and only a small fraction (<10%) of Scottish sea area was allocated to Zone 1. As with the activities zoning scheme, most of the area allocated to Zone 1 was in offshore waters. However, unlike in the activities zoning scheme, where Zone 1 was predominantly found in Western offshore waters, this time the coverage was more evenly split between the north easterly tip of Scottish territorial waters and those same offshore western waters, see Figure 4.2.

The most predominant zone in terms of percentage coverage was zone 3A by far, accounting for around three quarters of the entire sea area analysed. The remaining two zones, 3B and 4, each accounted for less than 10% of the area coverage. For the most part both of these zones are located close to shore, either around the mainland, Orkney or Shetland. Those areas that are attributed with Zone 4 that are further offshore (see Figure 4.2) are most likely the result of the newly designated offshore SACs.

4.8.3 The Prototype Zoning Application

The prototype zoning scheme is the result of combining both the activities and environmental data layers. The zones were designed so that they afford an increasing level of protection and active management as they ascend through them. PUs with conflicting zoning allocations when the two datasets were combined, were automatically allocated to the higher 'ranking' zone in terms of the protection afforded. This was seen as a second means of incorporating the precautionary principle into this zoning scheme alongside the establishment of zone 1. One of the implications, with this 'upgrading shift' in zoned areas, is that some activities that were previously suitable to occur within the lower level management zone are no longer able to continue within the higher management zone. Effectively this could mean that the area where higher impacting activities is reduced considerably. This will have to be carefully investigated and the solution may be to introduce specific zones where those specific high impact activities are allowed to occur.

In the prototype zoning scheme (see Figure 4.3 and Table 4.6) zones 1 and 2 make up just 3.28% and 5.13% respectively, all of this small area being located in offshore waters, either to the far north east or far north west. Again as with the environmental zoning scheme the predominant zone is zone 3A the limited exclusion zone.

In the prototype scheme zone 3B and 4 have the second and third greatest percentage cover, and, given that they are the two zones that offer the highest level of protection this could be viewed as a positive thing. However, in terms of actual area coverage even combined they still only account for a quarter of the whole sea area being analysed. Zone 3B (see Figure 4.3) can be seen to have an overall wider distribution than Zone 4. Zone 4, excluding two sizeable offshore areas in the west, is predominantly found around inshore mainland waters.

4.8.4 Comparison of Zoning Applications

When comparing the percentage overage between the three applications of the zoning scheme (see Table 4.7) it is interesting to note not only the changes in distribution of percentage cover of zones between the different applications, but also the changes in locational distribution between the various schemes of the zones (see Figures 4.1, 4.2 and 4.3).

As in the environmental scheme, the most predominant zone in the final prototype zoning scheme is Zone 3A the limited exclusion zone. This is in part perhaps a reflection on the amount of both activities and environmental features that occur on a spatially temporal basis, for example, mating grounds, nesting sites and MOD firing exercises.

As with the activities application of this zoning approach, the prototype scheme allocates a small area to zone 1 that is located in the far north west. Of all the zoning applications the prototype scheme has the smallest area located to Zone 1. This is most likely the result of PUs from the environmental application being ‘upgraded’ due to a spatial overlap with higher ‘ranking’ PUs from the activities application of the zoning scheme. This has resulted in the prototype zoning scheme having some area allocated to Zone 2 unlike the environmental zoning scheme that had no areas allocated to Zone 2. This said, overall the area allocated to Zone 2 in the prototype scheme is still substantially less than it is in the activities application (see Table 4.7).

Zone 3B and 4 are always distributed in a similar manner across the three zoning applications, however in the prototype scheme they have the greatest percentage cover of all three applications. This could be seen to be expected, giving the rules of the zoning scheme dictated that PUs be ‘upgraded’ when the two datasets were combined.

4.8.5 Prototype Zoning Scheme applied to SMRs

When the individual marine regions were analysed for the distribution of the zones between them (see Table 4.8 and Appendix 4, Figure A 4.0 to A 4.12), some patterns in the zoning distribution became apparent.

Zones 1 and 2 were only found in the North Coast and Offshore marine regions and of these, only the Offshore region, which was also the largest region, had the full complement of zones allocated within it.

The majority of the Zones had a dominant marine region, and, from the output of the prototype scheme this was expected to be Zone 3A. However, the SMRs in the East (Moray, South East and North East marine regions) all had Zone 4 as there most prolific zone. Zone 4 was also the most expansive zone in the Clyde, South West and West Highland marine regions. This is most likely due to two factors. Firstly, these marine regions are the location of a significant number of wreck and archaeological sites and secondly, there is a considerable number of designated conservation sites located within these marine regions.

Only one marine region differed from having its dominant zone as being either 3A or 4 and that was the Shetland SMR. Shetland's dominant zone was 3B the significant exclusion zone, the most likely reason for this is the type of activities and environmental are present combined with its remoteness.

4.8.6 Limitations of the Zoning Scheme

This prototype zoning scheme aimed to bring together data concerning activities and environmental factors in order to inform the development of a multiple-use marine zoning scheme for Scottish waters. It proved to be possible to combine the two different datasets, however the data that were utilised in each could in time be replaced with better data as and when they become available. This would include the use of higher resolution data, larger and more comprehensive datasets and further data from other resources to help broaden the spectrum of data being used both in terms of activities and environmental factors. However the data used in the development of this scheme were the best available as the data being used had to be free and accessible. To avoid any issues that may have arisen due to data from different sources having different resolutions, planning units were incorporated into the methodology; see section 4.4 for further details.

The application of this prototype scheme has produced some encouraging results (with busy inland waters being afforded the greatest area coverage from the ‘higher ranking’ more protective zones). The main issue that has arisen from the results has been the distribution and dominance of certain zones particularly within certain SMRs.

The zones that were generated by implementing the scheme, at all three separate stages (activities, environmental and prototype) showed variations in both size and distribution. When considering the total coverage of the zones across the whole sea area, (see Figure 4.3) the results appeared to show a relatively good division between the different zones. Although there was a dominant zone (3A), the temporal nature of this designation would make this seem both plausible and also perhaps as not as dictatorial as it may seem when initially looking at the percentage cover of the zones, see Table 4.6. However, when the individual SMRs were then analysed for their individual zone coverage, it became apparent that the zone distribution was not as balanced as it initially appeared when looking at the entire sea area.

Only the Offshore SMR has the full complement of zones and this is mostly likely due to the fact that this SMR is substantially bigger than all of the other SMRs involved in the study. The majority of the SMRs (9 out of 12) had only three zone types present within their planning regions and one SMR (the South East) had only two zones dividing its entire area. This was not the intended outcome of developing a zoning scheme, as it was intended to produce a range of zones for each region. The goal of this prototype and any zoning scheme is to ensure that sufficient levels of protection are provided for an area as well as also establishing areas that have the potential to be suitable for further development. This situation could be potentially addressed in one of either two ways. The first being that the zones themselves could be revised and adjustments made to either the guidance rules for the zones in designating activities and environmental factors to them, or the very definitions of the zones themselves and their intended purpose could be changed. The second option would be to revise the zones in the zoning scheme completely by adding either more zones or subzones that would allow for a more detailed breakdown of the marine area being managed.

The main issue with this latter option is that the design of this prototype zoning scheme has been devised to be as simplistic as possible for a reason; it makes it more practical to implement and makes it easier for policy makers, developers and general marine users to understand. It was recognised, during background research that over complexity of zoning schemes in the past has often been one of their major failings. All things considered, however, it would still probably be advisable to add more zones to this prototype scheme to improve its specific applicability further.

One option to try to minimise the effects of increasing the number of zones being used, and therefore the complexity of the zoning scheme, would be to change the area encompassed by the planning units. Potentially by making the PUs bigger there would be more zones present but not over such discreet areas within the SMRs. Of course this could equally prove not to be the case and it may lead to further dominance by different zones. This would be a potential area that could be explored further to see what the optimum size of Planning Units and the number of zones would be so as to allow the largest range of zones to appear within each of the SMRs.

In the future it is suggested that, to accompany this Prototype zoning scheme, a Performance Assessment System (PAS) would also be developed. This would be designed to evaluate the effectiveness of the zoning scheme in each of the SMRs and achieved by assessing and reporting on the maintenance of ecosystem conditions. Potentially, this new monitoring scheme could be fitted into the current site condition monitoring system (SCM) operated by Scottish Natural Heritage. Alternatively, the current SCM scheme could be utilised to advise, develop or add to this proposed PAS monitoring scheme. The PAS scheme should establish an agreed approach to monitoring select indicators with the aim of detecting change (both natural and human induced) in the conditions of an areas ecosystems, biodiversity, habitats and species.

In the future it may also be worth exploring the possibility of adding a further dataset containing additional layers considering ecological parameters such as areas of nutrient upwelling and strong current flow. This could be particularly important in terms of mitigating the effects or impacts of industry as it has been proven that parameters such as water depth, exposure and flushing rates can help negate impacts of some industries such as aquaculture.

4.9 Conclusion

The adoption of a zoning scheme such as the one developed here, that incorporates both activities in the marine environment and important environmental considerations, could spearhead a new approach that can be taken to regulating, managing and monitoring marine activities within Scottish waters. In the past it has been shown that traditional ad hoc approaches to resource management have ultimately failed and allowed damaging and unsustainable practices to occur. A united approach, incorporating both a precautionary and ecosystem-based approach to marine management would seem like the most forward thinking way to coordinate conflicting uses whilst still managing to maintain environmental integrity in the future.

Additionally any zoning scheme, such as the prototype scheme developed here, that is developed as part of marine spatial planning initiatives for the future, will need to recognise and combine existing marine protection designations such as the Natura 2000 network and world heritage sites. This prototype scheme aims to ensure that these areas that are designated specifically to protect habitats and species of national and European importance receive an appropriate level of protection regardless of the ecological relevance of their location.

This study recognises that in order to make greater, more comprehensive progress in relation to conservation measures, clear environmental objectives will need to be devised for each of the zones.

Therefore to summarise:

- It is possible to generate a Zoning Scheme to aid Marine Spatial Planning for Scottish waters by establishing zones that are derived from known ecological criteria and legislated marine activities.
- In the future it would be suggested that additional environmental objectives be derived and added when developing zones such as those implemented in this prototype scheme.
- The addition of a Performance Assessment System that feeds back into the management and revision of the zones would be a necessary development in the future in order to ensure this prototype scheme would be a progressive and practical tool were it to be developed further for implementation.

- In order to establish this type of zoning scheme as a useful tool to guide marine spatial planning, economic, environmental and social objectives will need to be further incorporated, alongside an overall aim of protecting ecologically important areas and minimising conflicts between users, and between activities and the environment.

4.10 References

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Chapter 5
Marine Spatial Planning and Climate Change

5.1 Managing Climate Change in Scotland

5.1.1 Climate Change

Within the last decade, scientific consensus has led to a more general acceptance that climate change is ‘real’ and we are now beginning to experience the early stages of this phenomenon. The Intergovernmental Panel on Climate Change (IPCC) has suggested that the way in which the climate will continue to change during the 21st century will be as a result of both natural changes and the response of climate systems to human activities (IPCC 2007, 2014). Changes in oceanic conditions in addition to having a significant influence on the world’s climate may also have a substantial and often direct, effect on many coastal and marine users in the not too distant future.

Globally there is widespread degradation of marine habitats that has already resulted in a depletion of resources and a loss of biodiversity (Katsanevakis et al., 2011) and this could be further impacted upon by climate change. The effects of climate change are often perceived to be a distant threat, however, in reality the impacts from these changes are now evident (Ruckelshaus et al., 2013) and may have already resulted in several recent species extinctions (Heller and Zavaleta 2009). Other associated impacts include shifts in species distribution, alterations to both the strength and direction of oceanic currents, reduction of population connectivity and the exceeding of maximum survival thresholds for some species (Levy and Ban, 2013).

5.1.2 Planning for Climate Change

While climate change is recognised as a key threat to marine systems, to date MSP and conservation planning and design has rarely addressed climate-related disturbances directly in a spatially explicit manner (Levy and Ban, 2013). An integrated MSP method that balances climate change scenarios in addition to any requirements and conflicting objectives of stakeholders, whilst still reflecting the dynamic changes of coastal marine systems, is needed (Tsung-Ting and Yang-Chi, 2012). Although frequently mentioned, and being a topic interest in marine conservation since the early 1990s climate change is typically ignored in the development of ocean management strategies and seldom incorporated directly into planning (Levy and Ban, 2013; Ruckelshaus et al., 2013). Therefore the aim of this study was to illustrate the development of an approach for incorporating the projected movement of important marine features, due to climate change, directly into marine spatial planning.

5.1.3 Biodiversity and Species Distribution

As discussed previously, maintaining the health of marine ecosystems, along with the services they provide to the human population, requires the adoption of new coordinated approaches to governing coastal and oceanic activities (Foley et al., 2010) a task complicated further by the major new challenges posed by climate change (Heller and Zavaleta 2009). The effectiveness of current management and protective measures can be considered questionable considering current techniques predominantly rely on fixed systems of protected areas to safeguard certain species and habitats (Scott et al., 2002). Given the predicted magnitude of climate change impacts it is more than feasible to expect that many types of habitat and certain species will no longer be represented within these ‘protected areas’ (Araujo et al., 2004).

An important factor that must be recognised with all marine species or habitats, especially in terms of planning, is that their natural distribution will be dictated by their individual environmental requirements (Pearson et al., 2002). So much so that when the International Council for the Exploration of the Seas (ICES) defined the term ‘habitat’ they stated that it is “can be distinguished by its abiotic characteristics and associated biological assemblages, operating at particular, but dynamic spatial and temporal scales in a recognisable geographic area” (Verfaille et al., 2009). Globally there is widespread degradation of marine habitats that has already resulted in a depletion of resources and a loss of biodiversity (Katsanevakis et al., 2011) and this could be further impacted upon by climate change. It is already well recognised that climate change will likely influence the distribution of habitats, potentially altering their range through either expansion, contraction or migration (Thomas et al., 2012; Gormley et al., 2013). Indeed it a report by the IACCF in 2010, it was found that cold water species of plankton, fish and intertidal invertebrates are retreating northwards around the UK and the ranges of southern species are expanding. Therefore the potential effects that climate change could exert on geographical distribution of habitats and species could in turn result in further loses to biodiversity and threaten the conservation status of many species.

5.1.4 Scotland's Priority Marine Features

As mentioned, climate change will likely influence the distribution of species and habitats, potentially altering their range through either expansion, contraction or migration (Thomas et al., 2012; Gormley et al., 2013). Indeed many species ranges have already shown signs of movement, usually upward in elevation or polewards, and this is a trend that seems almost certain to continue (Heller and Zavaleta 2009). Present day patterns of biodiversity are already and will continue to be altered, and could as a direct result impair the ability of established conservation designations such as Marine Protected Areas (MPAs) to protect the features they were intended for (Levy and Ban 2013). Furthermore, given the predicted magnitude of climate change impacts, it is more than feasible to expect that many types of habitat and certain species will no longer be represented within these 'protected areas' (Araujo et al., 2004). Therefore, changes induced by climate raise concerns about the effectiveness of existing biodiversity protection strategies (Halpin 1997; Scott et al., 2002 and Heller and Zavaleta 2009) particularly because current techniques rely predominantly on fixed systems of protected areas to safeguard certain species and habitats (Scott et al., 2002). This has led some to question whether we should be trying to modify our current biodiversity protection strategies to encompass climate change?

Priority Marine Features (PMFs), as an example, have been defined under the OSPAR convention for the protection of the marine environment of the North-East Atlantic (1992) as being 'threatened' and/or declining species and habitats. PMFs are recognised as having significant marine conservational importance within Scottish waters and are being used to support advice on marine biodiversity conservation and help deliver marine planning and licensing systems set out in the Marine (Scotland) Act. They will also, under the European Union, Marine Strategy Framework Directive, contribute to the attainment of 'Good Environmental Status' (GES) by 2020 (MSFD; 2008/56/EC). Maintaining the health of marine ecosystems, along with the services they provide to the human population requires the development of coordinated approaches to governing coastal and oceanic activities (Foley et al., 2010). European regional conservation legislation is also one of the key drivers for implementing Marine Spatial Planning (MSP) (Christie et al., 2005; Wanfei and Jones 2013).

5.1.5 Incorporation of Climate Change into a Zoning Tool

The objective of this study was to firstly investigate the capabilities of a multiple-use zoning scheme (derived from existing legal mechanisms and designed to inform spatial planning and management of activities) outlined in Chapter 2 to accommodate movements in geographic distribution of important marine features due to climate change scenarios. And secondly to test the Prototype zoning scheme developed in Chapter 4 to see whether or not it will provide coverage for PMFs both now and in the future given possible climate change events projected. Both of these objectives will be accomplished by using a previously developed Species Distribution Model (SDM). The SDM model has been applied to determine the extent of habitat suitability for each of the PMFs found within Scottish waters under current baseline conditions and also under increased oceanic temperature scenarios. Oceanic temperature was focused on as it was considered to be a crucial aspect of climate change in this instance.

5.2 Methods

5.2.1The Multiple Use Scheme

Scottish and European legislation and regulations related to marine activities and designated conservation sites presently in force within Scottish waters were previously identified and summarised in Chapter 2. Spatial elements were mapped for each of these management measures and combined using the Multiple-Use Zoning Scheme originally developed by Boyes et al. (2007). A detailed description of the methodology and details of each of the zones and the activities permitted within them has been covered in Chapter 2 and additionally presented in McWhinnie et al. (2014).

To briefly summarise the approach, this zoning scheme was devised by combining current legislation and regulations and any spatial constraints that may also exist for certain activities to produce a primarily four zone scheme. Each of the proposed zones affords an increasing level of protection and active management. Figure 5.1, depicts each of the zones as they appear within the Scottish sea area and are as follows:

1. General Use Zone (containing two sub-zones: Minimal Management Zone and Targeted Management Zone);
2. Conservation Priority Zone;
3. Exclusion Zone (containing two sub-zones: Limited Exclusion Zone and Significant Exclusion Zone);
4. Protected Zone.

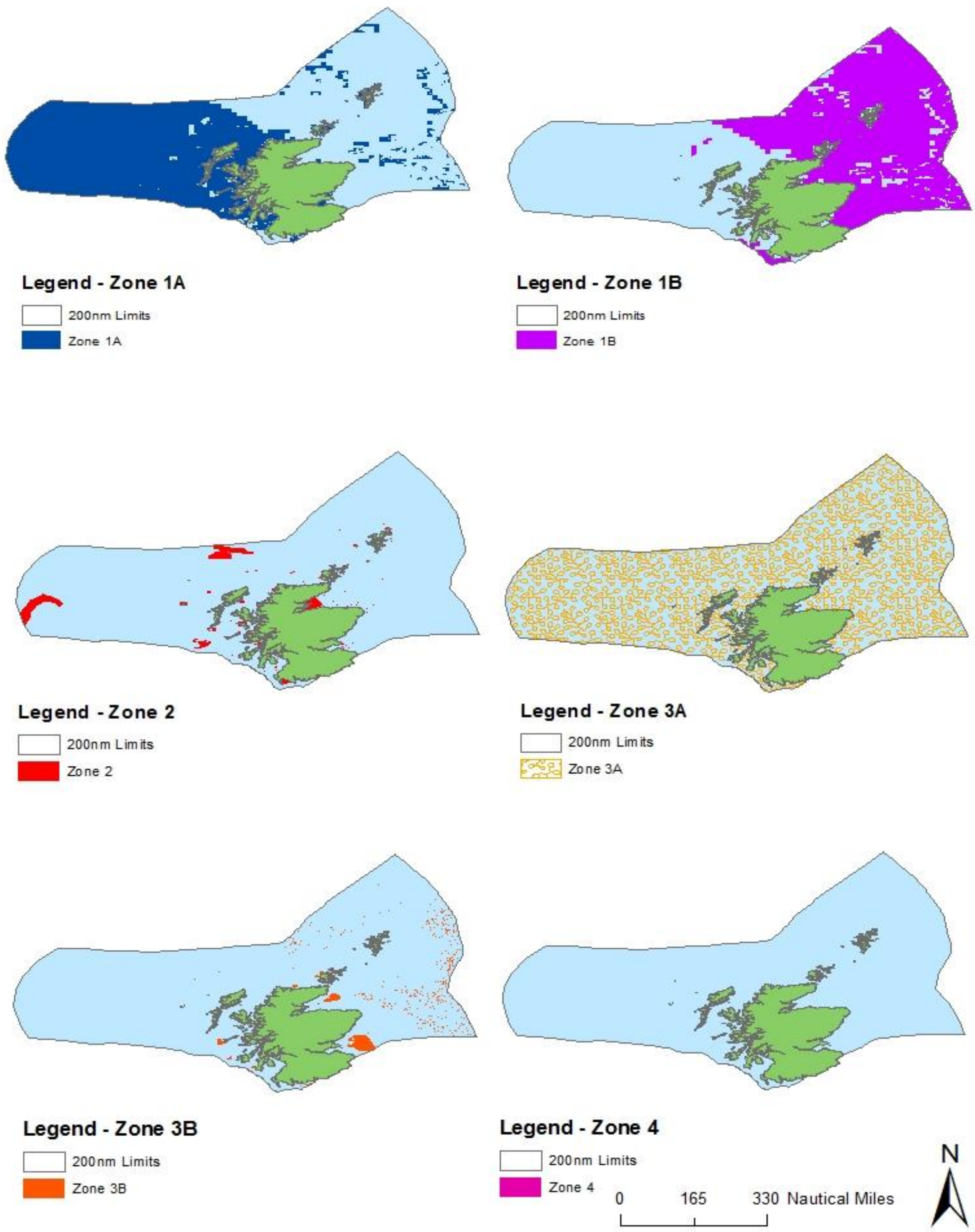

Figure 5.1 - Zones of the proposed Multiple-Use Zoning Scheme as applied to Scottish Waters

5.2.2 The Prototype Scheme

The Prototype scheme described previously in Chapter 4 was also used in this study as it differs from the Multiple-Use Scheme in that it designates areas within different zones according to a combination of both ecological features and existing legally permitted management mechanisms for any activities taking place.

A detailed description of the methodology and details of each of the zones and the features and activities permitted within them has been covered in Chapter 4. To briefly summarise, Figure 5.2 shows each of the zones as they appear within the Scottish sea area, the five proposed zones are:

1. Precautionary Management Zone
2. Targeted Management Zone
3. Exclusion Zone (containing two sub-zones: Limited Exclusion and Significant Exclusion)
4. Conservation Priority Zone

The process of applying the Prototype Scheme produced three separate schemes; the first allocated zones based on activities data, the second environmental data and the third combined the first two sets of derived zones to form one over-arching zoning scheme. Where there was a spatial overlap and conflict between the two zoning schemes, the planning units where the conflict arose were automatically allocated to the zone with the higher level of protection, see Chapter 4. The application of this Prototype zoning scheme can be seen in Figure 5.2 where the geographic extent of the zones can be clearly viewed.

One of the major aims when developing the Prototype scheme was to design a scheme that facilitated the long-term protection of the marine environment. Therefore, one of the goals of this exercise was to test the capabilities of this zoning scheme to accommodate for long term changes in environmental condition through the incorporation of modelled ‘most suitable’ PMF habitats over the next fifty years.

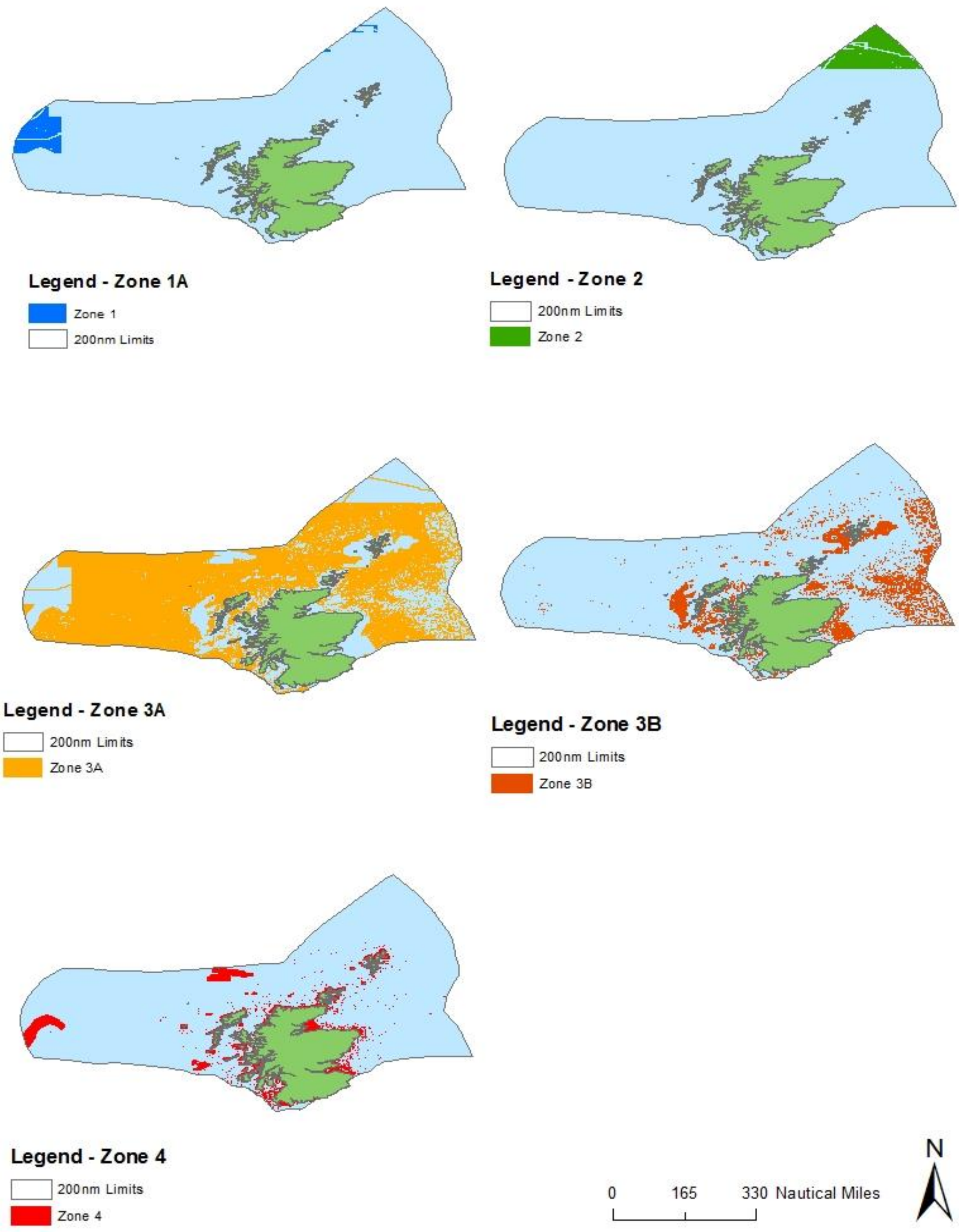

Figure 5.2 - Zones proposed for the Prototype Zoning Scheme as applied to Scottish Waters

5.2.3 Priority Marine Feature Modelling

PMF data was taken from the 2012 OSPAR priority marine habitats and species dataset provided by the Joint Nature Conservation Committee (JNCC). The following eight PMF were found to occur within Scottish waters (the study area):

- Coral gardens
- *Zostera* beds
- Deep sea sponge aggregations
- Intertidal *Mytilus edulis* beds on mixed and sandy sediments
- *Lophelia pertusa* reefs
- *Maerl* beds
- *Modiolus modiolus* beds
- Sea pen and burrowing mega fauna communities.

To predict where these PMF could potentially occur, a species distribution model (SDM) was utilised in order to predict the PMF's potential range. This Maxtent modelling technique is explained in more detail in studies by Gormley et al. (2013) and Ross and Howell. (2012).

In this study, data related to environmental variables that are considered biologically relevant to the PMF such as slope, bathymetry, salinity, landscape, seabed temperature and current velocity, were then obtained, imported, and assigned to a 0.005° grid set to the same extent as the zoning scheme using ArcMap GIS 9.3 software. The SDM was then run for each of the PMF following this technique used by Gormley et al. (2013) and the resultant PMF areas were exported into ArcMap. Occurrence values estimated in the Maxtent model (0-1) were divided into three categories; most suitable (0.5-1), less suitable (0.1-0.49) and least suitable (0-0.09); see Figure 5.3. Model predictions were again tested as per Gormley et al. (2013) using the 'area under the curve' produced by Maxtent. The data were randomly split into 90% training/10% test datasets using the models internal random test setting and cross validated for 10 replicate runs. Following this, 10,000 randomly chosen pseudo-absence/.background points were run for the entire Scottish sea area.

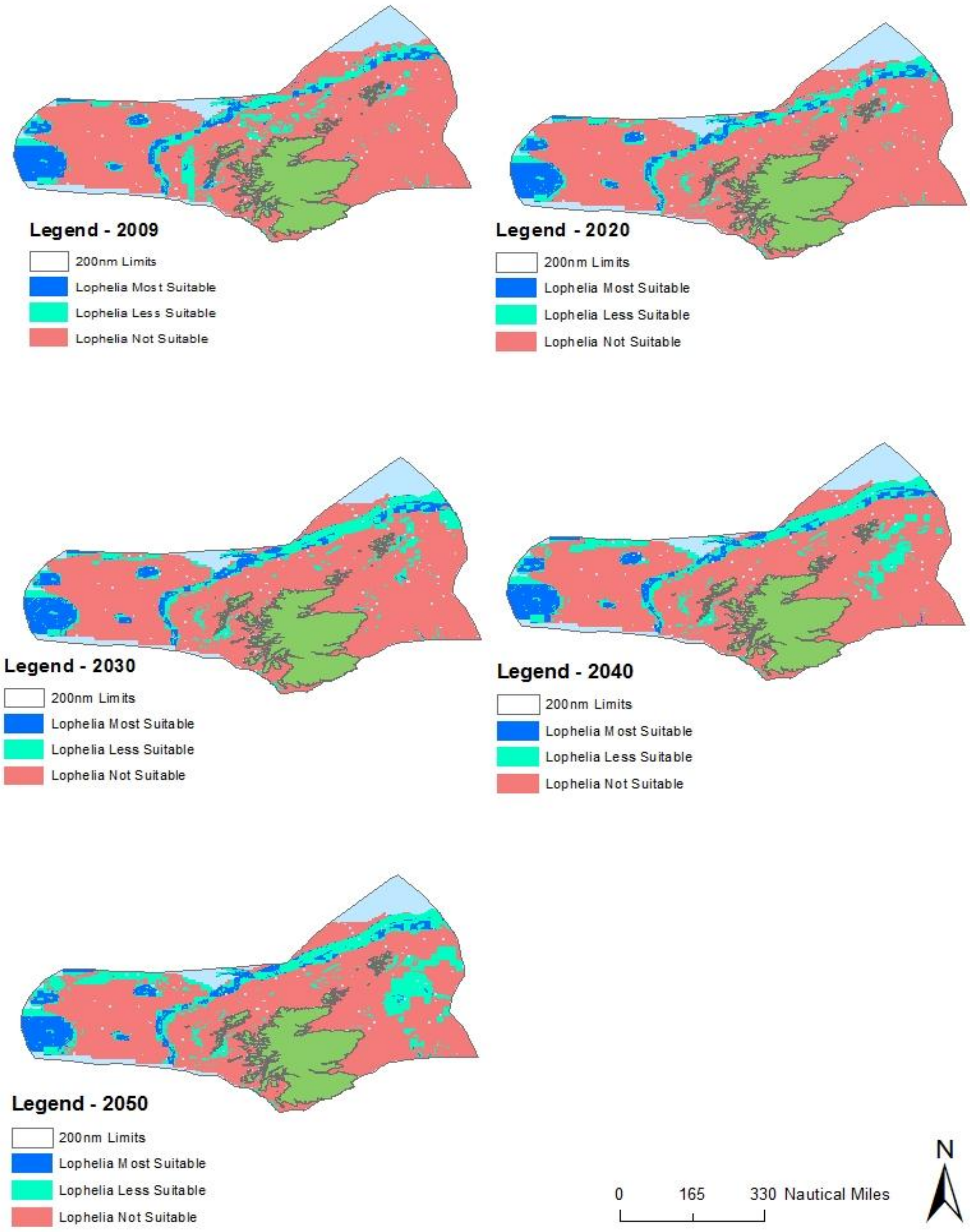

Figure 5.3 - Species Distribution Model prediction maps for *Lophelia pertusa* (Linnaeus,1758) reefs for the five projected climate change scenarios (2009, 2020, 2030, 2040 and 2050).

Increasing ocean temperatures were also established for the following years: 2020, 2030, 2040 and 2050 based on Locamini et al. (2010) and the International Panel on Climate Change (IPCC) scenario planning methodology (IPCC, 2007), see Gormley et al. (2013) for further details. However, it should be noted that the modelled scenarios assumed a uniform increase in temperature over the entire Scottish sea area and throughout the water column. The SDM was then run again for each PMF with the predicted temperature conditions and these were then combined with the baseline (2009) model results to establish the percentage of most suitable areas for each PMF.

5.2.4 Integrating PMFs within the Multiple-Use Zoning Scheme

In order to determine the area of 'most suitable' habitat for each PMF scenario that was afforded protection in each of the zones within the multiple-use scheme the modelled layers were combined with the zoning layers within the GIS, see Figure 5.4. This Figure shows the Shetland Isles in particular but for larger individual maps of the whole sea area refer to Appendix 5, Figures 5.0-5.4. This required each of the zone layers to be unionized individually with each of the eight modelled PMF layers. Those areas that overlapped (i.e. the area within each zone that had the most suitable conditions for that PMF), were extracted and their areas calculated; see Appendix Table 5.0.

It was deemed necessary to accommodate for the changing area coverage of the zones and the difference in MS habitat presence between the PMFs so that relative size of each of the 'most suitable' areas within the zones could be compared with one another. This was carried out using the following using the following methodology:

$$\%\ Cover\ of\ MS\ in\ Zone\ (weighted\ per\ zone\ within\ Scottish\ Sea\ area) = \left(\frac{Area\ of\ MS\ Features\ in\ Zone}{Total\ Area\ of\ MS\ Feature}\right) \times \left(\frac{Total\ Area\ of\ Zone}{Area\ of\ Scottish\ Sea} \times 100\right)$$

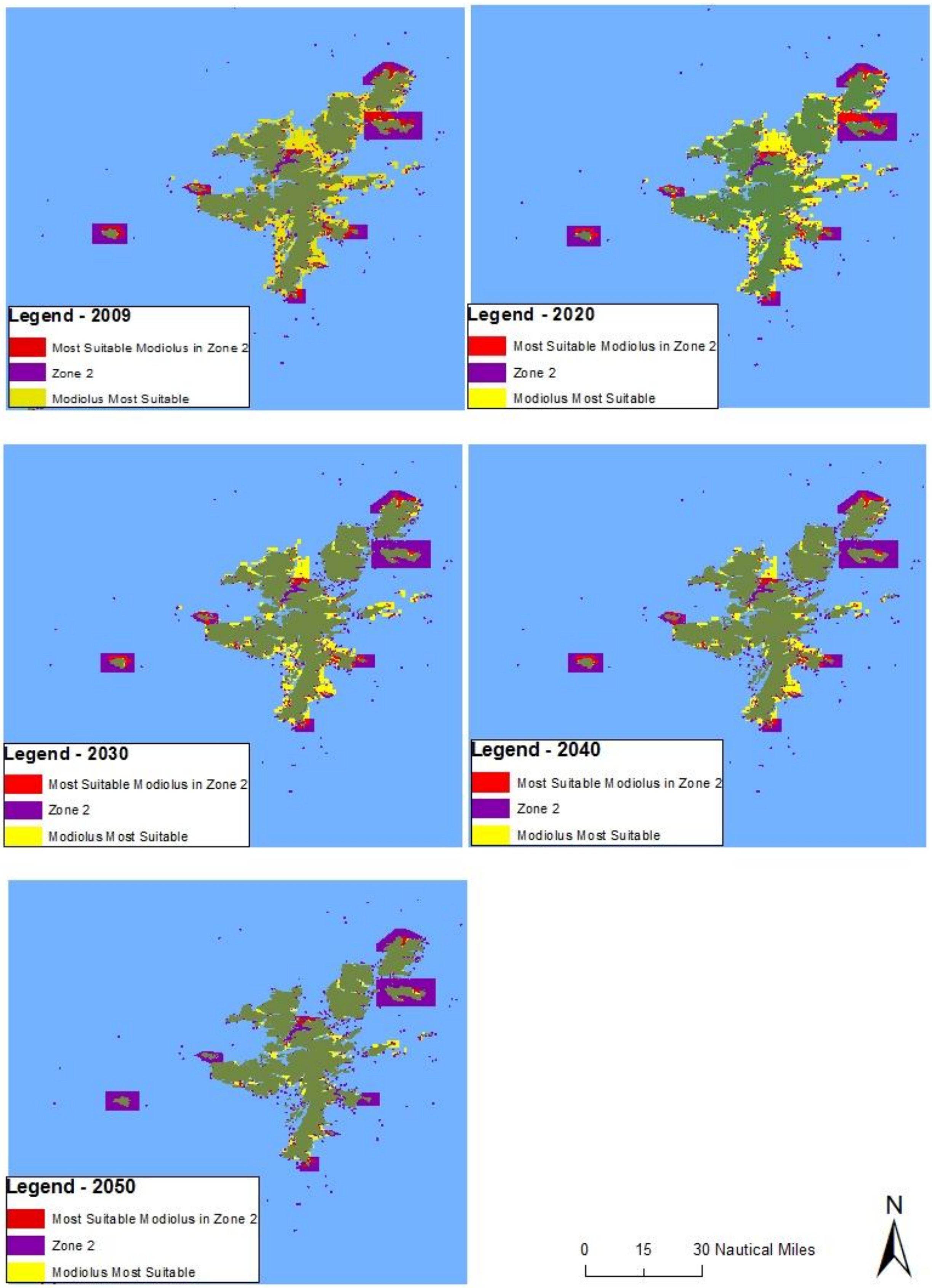

Figure 5.4 - Identification of the 'Most Suitable' habitats for *Modiolus modiolus* within Zone 2 (Conservation Priority Zone) over the different years groups modelled.

The area calculations for each PMF within the various Multiple-use and Prototype Zones were then extracted into Excel where they were extrapolated further to show relative area coverage. Table 5.1 shows an example of this analysis for Coral Gardens in Multiple-Use ones in 2009, it should be noted that the value for the Scottish Sea Area used was calculated from the Shapefile and used throughout this analysis and was considered to be a representative rather the definite value.

Table 5.17 - Extrapolation of Relative % Coverage of Coral Gardens within Multiple Use Zones in 2009.

2009	1a	1b	2	3a	3b	4
Area of zone	242452	207270	15608	471823	9856	0.7
Area of MS Habitat in zone	24485	391	129	25016	10	0
Total area of MS Habitat	25019	25019	25019	25019	25019	25019
%cover of MS in zones	10.09	0.19	0.83	5.30	0	0
Total % MS cover	98	2	1	100	0	0
Area of Scottish Sea	472653	472653	47265 3	472653	472653	47265 3
% cover of Zone in Scottish Sea	51.29	43.85	3.30	99.82	2.08	0.0001
%cover MS in zone (Weighted per zone within Scottish Sea area)	50	0.685	0.0	100	0	0

5.3 Results Analysis

5.3.1 Most Suitable PMF areas within the Multiple-Use Zoning Scheme

The preliminary assessment consisted of combining the MS habitat for each of the PMFs over the different year groups with the six different zones and sub-zones of the multiple-use zoning scheme and calculating the area present within each zone as shown in Appendix 5, Table 5.0. These areas were then used to calculate the percentage cover of MS habitat within each zone. The analysis showed that the majority of MS habitats for PMFs (the only exception being Sea-pen and burying Mega-fauna communities) were found in Zone 1A, the Minimal Management Zone (MMZ) and Zone 3A, the limited exclusion zone (LEZ). Zones 3B, the significant exclusion Zone (SEZ) and Zone 4, the Protected Zone (PZ) are the two zones that afford the highest level of protection to PMF through their higher level of management. However, as seen in Appendix 5, Table A 5.0, only a small area of Maerl (0.07km^2 in 2050) and Horse mussel (0.02km^2 in 2050) beds will fall within the most protected Zone 4 in the future and none fall within this zone at present. The situation is only marginally better within Zone 3B, although six out of the eight PMFs have MS habitat found within this zone, out of these 25 recorded MS habitat presences, the average are coverage is only 0.53%. However it should be noted that each zone varies considerably in size as does the area of MS habitat for each PMF, therefore further extrapolation of the data was required to ascertain the relative coverage of each PMF within the various zones. Zone 2, the conservation priority zone (CPZ), allows activities to be permitted if the users/developers can demonstrate that no significant detrimental effects on the environment will occur as a result of their activity and therefore will not impact on the sites conservational status. Thus the CPZ should be considered to provide adequate protection for PMF's, however, only half of the PMFs (Maerl, *Modiolus modiolus*, *Mytilus edulis* and Zostera beds) had more than 10% of their MS habitat located in this Zone at some stage and in the case of Coral Gardens and Sea-pen and burying Mega-fauna communities, by 2050 they do not have any MS habitat located within this zone at all.

5.3.2 Relative Size Analysis

The relative coverage of each PMF in the various zones over the different year groups was derived (see Table 5.1) for each of the PMF year classes and can be viewed in Appendix 5, Table A 5.1. This secondary analysis is designed to assess the proportional distribution of each of the MS PMF habitats within the zones and there is a notable difference between these results and those shown in Table A 5.3. Most notably, when the relative size of each zone and MS habitat coverage is taken into account there is no notable MS habitat coverage for any of the PMF habitats found within Zones 3B and 4 (those that afford suitable protection). It should also be highlighted, that Zone 3A, the limited exclusion zone (LEZ), places temporal and spatial restrictions to any activities taking place therein and therefore should be considered separately as it overlaps the other zones. As a result although all the PMF's both now and in the future have a large proportion (>92%), of their MS habitats fall within Zone 3A, and they may be provided some protection, for example from fisheries closures, this protection will only be temporary or spatially variable over time and will not necessarily restrict other activities taking place within this area.

Zone 2, the CPZ, was designed to include areas that were designated for their conservation attributes, however, it can be seen in Appendix 5, Table A 5.1 only a minute fraction, less than 2% of the MS habitat of each PMF, is found to lie within this zone. Additionally, in the case of Coral Gardens, there is now no longer any notable MS habitat protected within this zone. With the exception, of Sea-pen and burying mega-fauna communities the majority of the PMF MS habitats are found within Zone 1A followed by Zone 1B. Both of these are classified as general use zones where all regulated activities can occur. The main difference being that those activities occurring within Zone 1A can be unlicensed (spatially), for example, fishing and shipping but are permitted by international controls such as MARPOL, and those within Zone1B have been authorised via a license, permit, order or consent such as aquaculture facilities or renewable developments. As shown in Appendix 5, Table A 5.1, in most cases around half of the MS suitable habitat found for these PMF were located within these two zones and therefore afforded little or no protection from the impacts of marine activities and users within this space.

5.3.3 Most Suitable PMF areas within the Prototype Zoning Scheme

The next assessment consisted of combining the MS habitat for each of the PMFs over the different year groups with the five different zones and sub-zones of the Prototype zoning scheme and calculating the area present within each zone as show in Figure 5.5 and Appendix 5, Table A 5.2. These areas were then used to calculate the percentage cover of MS habitat within each zone. The analysis showed that the for the majority of MS habitats for PMF's were found in Zone 3B, the Significant Exclusion zone (SEZ) and Zone 4, the Conservation Priority zone (CPZ). These also happen to be the two zones that afford the highest level of protection to PMF through their higher level of management. Three of the eight PMFs (Maerl beds, *Modiolus modilous* beds and *Mytilus edulis* beds on mixed and sandy sediments) analysed had also had small areas (<3%) of their most suitable habitats fall within Zone 3A, the Limited Exclusion zone (LEZ). When calculate, the percentage of most suitable areas Zones 1 and 2 did not have any of the PMFs most suitable habitat fall within them.

When we look at the change in percentage coverage over the year groups, again referring to Figure 5.5 and Table A 5.2 in Appendix 5, we can see that most of the fluctuations in area coverage are quite small, only 1 or 2% in the case of *Lophelia pertusa* (b), Coral gardens (a) and Maerl Beds (c) and Intertidal *Mytilus edulis* (e) didn't change in % cover at all between 2009 and 2050. *Modiolus modiolus* (d) had the biggest change in most suitable area covered within the zones with Zone 3B in coverage by 25%, from 316km^2 down to 94km^2, and Zone 4 decreasing by 26% to compensate. However, it should be noted that any of these shifts in coverage do not impact significantly on the protection the most suitable habitats are afforded as they still always shift between the two highest zones.

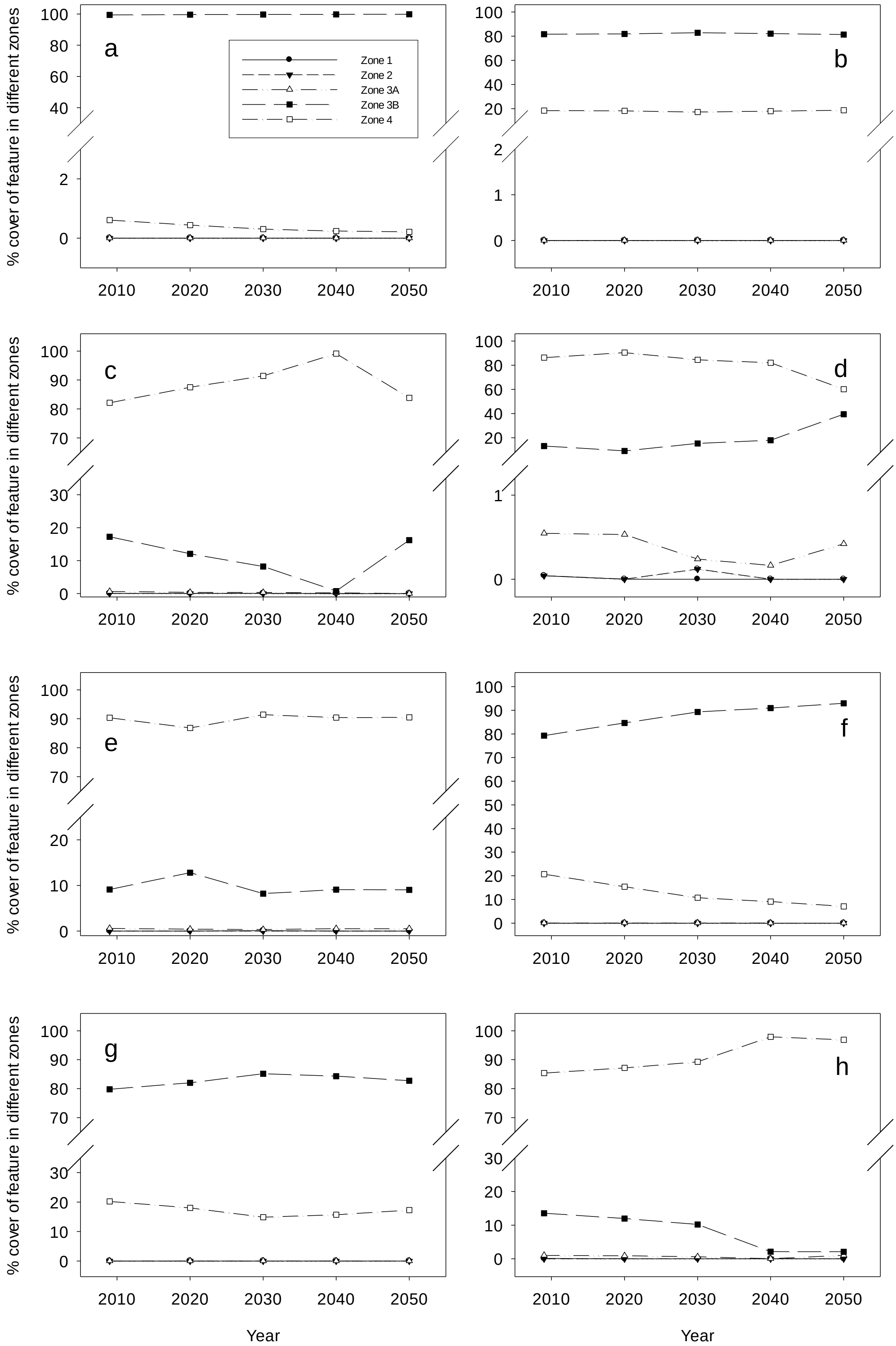

Figure 4 - SIGMA PLOT showing the % Coverage of PMFs (a) Corals, b) Lophelia, c) Maerl, d) Modiolus, e) Mytilus, f) Seapens, g) Sponges and h) Zostera) within the Multiple-Use Zoning Scheme

5.3.4 Relative Size Analysis

The relative coverage of each PMF in the various zones over the different year groups was derived (see Appendix 5, Table A 5.3) for each of the PMF year classes as shown in Table A 5.1. This was again undertaken in order to assess the proportional distribution of each of the MS PMF habitats within the zones and there is a notable difference between these results and those shown in Appendix 5, Table A 5.2. Although the zones that were dominant in their coverage of the PMFs have not changed, i.e. Zone3B is dominant for Coral Gardens for both percentage cover and relative percentage cover, the amount of coverage they provide is always reduced. Again using Coral Gardens as an example, its relative coverage varied between 33-45% while not taking into account relative size had placed the amount of coverage far higher at 81-83%.

When comparing the results of the relative cover analysis it showed that only half of the PMFs have less than 30% coverage of their most suitable areas falling within Zones 3B or 4. The remaining four PMFs have between 30-45% of their most suitable habitats falling within these protected zones.

5.4 Discussion

There are several zoning schemes being implemented (Brown 2001; Day et al., 2008; Paxinos, 2008; the US Department of Commerce 2011) and numerous schemes under development in various countries (Shi et al., 2001; Boyes et al., 2007; Halpern et al., 2008;and Sanchirico et al., 2010), all with the aim of prioritising their environmental assets and managing the activities that occur within their waters. However, this is the first study that the author is aware of which attempts to look at the robustness of a zoning scheme when having to deal with increasing sea temperatures under climate change scenarios.

5.4.1 The Species Distribution Model

In this study the Maxtent model produced an overview of the 'Most Suitable' habitats for each of the PMFs used, it was found that overall the trained model could be assumed to be showing a good predictive range for all the PMFs. This said there are limitations associated with using a SDM method, as identified by Gormley et al. (2013), regarding the quality of the data inputted. However in general the methodology is considered to provide a defensible means of addressing any gaps in data and coverage maps that are deemed robust enough for contributing to management decisions (Ross and Howell, 2012).

5.4.2 Climate Change and the Multiple-Use Zoning Scheme

One of the goals of this study was to model the distribution of priority marine features, of high conservation management interest within Scottish waters and place them within a Multiple-Use Zoning Scheme to demonstrate their importance when considering future marine management and development of MSP tools. The zoning scheme utilised in this study was exclusively derived from current legislation and regulations, and non-statutory policy measures, voluntary agreements and other initiatives were not included. As a result there are limitations associated with this time of zoning scheme which are addressed by McWhinnie et al. (2014). In short, for this specific zoning scheme to be developed into an influential tool to guide MSP in the future, it would also appear to be pertinent to incorporate further, economic, environmental and social objectives. While having the overall goal of minimising or avoiding spatial conflicts between users and between activities and the environment, it would perhaps also need to be additionally underpinned by a ‘coverage target’ for protecting important marine features.

Due to the design of this zoning scheme, it was perhaps not unexpected to find from the results that much of the most suitable areas for PMFs did not fall within the zones that afforded the highest amount of protection (Zones 3B and 4), see Appendix 5, Table A 5.1. This was most probably the result of this zoning scheme not including any environmental parameters in its plan as this was not the original intention for this scheme (McWhinnie et al., 2014). However, what was unexpected was the small coverage of the most suitable areas within Zone 2, the Conservation Priority Zone. By virtue of design it was expected that this zone which evolved from conservation designations that are often attributed due to the presence of PMF would at least provide a considerable amount of coverage for these features. The results; see Appendix 5, Table A 5.2, found that the relative % coverage was always less than 2% for all PMFs and in the case of Coral Gardens, it provided zero coverage. Looking at the coverage over the time increments tested, the results were less defined, in the majority of instances coverage did not change, for two PMFs: Maerl and *Zostera* beds coverage increased and for another two: Sea-pens and *Modiolus*

modiolus, the coverage decreased. However, any change in coverage was always by less than 1% and given the small amount of total coverage provided this change may be considered insignificant.

5.4.3 Climate Change and the Prototype Scheme

Another important goal of this study was to model the distribution of PMFs within the newly developed Prototype Zoning to see whether or not the further inclusion of environmental features within the design of a zoning scheme, will better allow for the consideration of climate scenarios.

As discussed previously, the Prototype zoning scheme, unlike the Multiple-Use Scheme, utilised activities and their associated legislation and regulations as well as important environmental and ecological features. The potential limitations of this type of zoning scheme were discussed extensively previously in Chapter 4.

In summary, for this specific zoning scheme to be developed into an influential tool to guide MSP in the future, it would also require the further incorporation of economic and social objectives. Additionally, there will need to be an overall aim of protecting ecologically important areas and minimising conflicts between users, and between activities and the environment. It would also be beneficial to derive and include additional environmental objectives when developing any future zones.

It was the prediction that due to the design of this zoning scheme, the most suitable PMF habitats would have a higher coverage within the Zones that afforded them the most protection. Looking at the results (see Table A 5.2, Appendix 5) it can be seen that the majority of the most suitable habitats for all of the PMFs fall within Zone 3B and 4, the zones with the highest level of protection. In this scheme Zone 3B is the Significant Exclusion Zone and Zone 4 is the Conservation Priority Zone, so regardless of which zone is dominant in terms of the coverage it provides, both will ensure maximum levels of protection for these features. In terms of being an adaptive tool it was additionally positive to see that the design of this scheme seemed to successfully allow for the movement of the PMFs. Referring to Appendix 5, Table A 5.3, it could be seen by looking at the Relative % coverage that in all but one of the PMFs analysed the total coverage provided by Zones 3B and 4 actually increased as time progressed, some by as much as 12% (Coral Gardens). *Zostera* beds were the only exception to this their coverage fell by 3%, but this can perhaps partly be explained by the fact that their most suitable habitat within the zoning scheme also dramatically declined during this same time frame from 909km^2 to just 96km^2 according to the SDM (see Appendix 5, Table A 5.2).

5.5 Conclusion

Given prioritisation within a zoning scheme it has been shown by this study that it is possible for important features such as the PMFs used, to be given significant and specified levels of protection. A zoning scheme that is adaptable and structured so that given new or improved data can be easily updated, should be seen as the basic starting point to the design of any adaptive management tool. The Prototype scheme has demonstrated that it is possible to design tools that can be considered as ‘adaptive’ and therefore can help in terms of planning and conservation to mitigate against some of the effects of climate change.

Zoning schemes as part of any marine spatial planning framework will be required to acknowledge and encompass any existing designated protected areas such as the Marine Protected Areas (MPAs) currently being designated using PMFs. This study has also demonstrated that in order to make more comprehensive progress pertaining to conservation measures in the future, clear objectives will need to be further developed and should take into consideration climate change scenarios. Regarding future implementation of MPAs, a zoning scheme that takes account of economic, social and environmental objectives should complement the development of a network that will integrate with other management measures and activity sectors. Any future multiple-use zoning schemes, should have the potential to achieve both better integration between conservation and other activities/users and be tolerant and adaptable to predicted changes in environmental conditions. This can be achieved through the inclusion and prioritisation of ecological features when deriving zones and better definition of development locations and where activities are restricted and permitted.

Finally this study has emphasised that further consideration must be given as to how future climactic conditions may alter the distribution of features important to marine conservation and the implications this will have for planning, management and conservation strategies. There is sufficient evidence from this study to suggest that development of management tools that will be able to accommodate and adapt to environmental changes are required.

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Chapter 6
Finfish Aquaculture Site Selection Model

6.1 Aquaculture

According to the Food and Agriculture Organisation of the United Nations (FAO, 2012), over half of the world's capture fisheries have been overexploited, are depleted or are recovering from depletion in recent years (Thomas and Bassett 2010). The aquaculture industry has grown rapidly over the past few decades, as many now believe that aquaculture is the only hope for meeting the world demand for fish and fishery products (Boyd and Schmittou 2008).

Aquaculture, sometimes referred to as mariculture, constitutes a significant and rapidly expanding component of the world's total aquatic production (Burbridge et al., 2001). Specifically, aquaculture is the process of producing both aquatic animals and plants within managed, unnatural aquatic ecosystems for a profit (Boyd and Schmittou 2008). This profit means that in many countries, such as Scotland, the aquaculture industry now plays a major contribution to the economy (Aquaculture Planning Taskforce, 2010). However, while aquaculture has resulted in substantial economic benefits, its rapid expansion and development has also led to increased environmental concerns and questions about possible ecological impacts (Pérez et al., 2002).

Commercial aquaculture arose in the 1970s and by mid 1980-1990s had become a well established sector of industry (Baxter et al., 2008). According to Vincenzi et al. (2006) global commercial aquaculture production has more than doubled in volume during the last two decades, it is also predicted to undergo further growth; largely due to marine aquaculture being one of the only animal proteins not dependant on freshwater consumption (Tsagaraki et al., 2010). This, accompanied with an ever increasing population and level of consumption per head, are continuing to drive total global production figures upwards (Thomas and Bassett, 2010). While presently it is already probably the fastest growing food industry in the world (Ross et al., 1993) with projected population growth, this promises continued growth for aquaculture in the future (Boyd and Schmittou, 2008).

Aquaculture is also proving to be a vitally important industry, in terms of the geographic locations in which it often operates (Baxter et al., 2008). Often aquaculture enterprises are established in areas where there are few alternatives for employment and therefore the industry can play a major role in helping to reverse rural depopulation (Burbridge et al., 2001). For example, aquaculture in Scotland is predominantly situated in the West, North West, Western Isles and Northern Isles where many rural communities are now sustained by the employment provided, particularly by salmon farming (Baxter et al., 2008). Aquaculture growth has therefore now also been proven to both increase and diversify economic opportunities at both national and more local scales (Burbridge et al., 2001).

Most food production systems, including aquaculture, have or can have a negative impact on their surroundings, and it is important that any of these impacts be kept within socially acceptable limits. In the past, aquaculture development and management in some areas was allowed to proceed in an irresponsible manner (Tsagaraki et al., 2010) and now dramatic steps have been taken to resolve this. In many instances where problems have arisen as a result of aquaculture, they have done so due to a lack of understanding of the aquatic environment and the use of unreliable means for resource assessment, rather than production technology problems themselves (Ross et al., 1993). Any negative impacts such as a drop in expected production or increased mortality will counteract any benefits that may be gained from aquaculture (Tsagaraki et al., 2010).

In many ways the environmental impacts from aquaculture are quite different from the impacts associated with other types of marine developments (SEPA 2012) such as the effects they can have on wild fish populations. However some of the other negative effects reported have been more familiar such as the destruction of wetlands and other rare/sensitive habitats, water pollution, reduction of biodiversity, salinisation of freshwaters, displacement of tourism, waste of resources and a loss of access to fishing grounds (Boyd and Schmittou 2008).

Learning from past mistakes and in order to ensure the sustainability and success of future and present aquaculture development it is very important that adaptive management systems and policies are designed and implemented. This will greatly help to avoid these recognised ecological and economic impacts and their consequences (Vincenzi et al., 2006). In terms of development of aquaculture production specifically, care must be taken when new fin and shellfish facilities are developed and in particular they should be kept within a reasonable scale (The Highland Council 2011) that is suitable for the location. Siting criteria for new sites should include physical factors such as bathymetry, topography and climate as well as the capacity of the environment to absorb effluent outputs. The density of facilities not just the scale of the farms should also be considered so that the (waste) absorbing or assimilative capacity of the environment is not exceeded (Primavera 2006). It is imperative that good environmental conditions are maintained and not degraded by an aquaculture establishment not least because good environmental conditions are also necessary for the culture of aquatic animals. It is therefore in the self-interest of aquaculture producers and the industry as a whole to protect the surrounding environment (Boyd and Schmittou 2008). It is the objective of aquaculture, like most farming practices, to make use of a natural resource to generate a viable and sustainable production level (Zeng et al., 2003) if environmental conditions are degraded them the industry will be no longer viable.

6.1.1 Finfish Culture

Finfish aquaculture is the breeding and rearing of finfish species for either the purpose of re-stocking/stock enhancement of natural or manmade fisheries or for the eventual harvest for human consumption. In Scotland this sector of the aquaculture industry is monitored by several agencies, the lead agency that regulates farms under CAR (Controlled Activities Regulations) is SEPA (Scottish Environment Protection Agency). SEPA is particularly focused on the benthic health at farm sites while SNH (Scottish National Heritage) another regulatory body, is responsible for ensuring the biodiversity of the seabed and other habitats is not impacted. This is due to fish production generating considerable amounts of effluent in the form of nutrients, waste feed and faeces along with other associated by-products such as medication and pesticides (Fernandes et al., 2001; McKindsey et al., 2006) that can negatively affect the surrounding seabed. Marine finfish production is almost exclusively carried out in floating cages or netpens that have no means of containing these waste products. It is because of the open nature of these culture systems that regulation measures must be taken (Black et al., 2008). Their ‘leakiness’ allows a considerable proportion of waste materials to participate in external biological, chemical and ecological systems where they may cause unwanted effects (McKindsey et al., 2008; Black et al., 2008).

Marine cage culture, as with the majority of aquaculture ventures need to be located in areas that have good water quality, thus the water properties of an area strongly influence the location of aquaculture facilities. For example cages should be located in areas uncontaminated by industrial, municipal or agricultural pollutants (Pérez et al., 2003). It is also necessary for aquaculture to be considered in the context of other activities once it has been established in a coastal area. For instance, fishing should not be permitted to occur close to fish farms as this might have the effect of increasing catch per unit effort if target species aggregate there (Black et al., 2008). In general, marine farm cage facilities are placed in relatively sheltered coastal waters, however, the problem has now arisen, that there are only a finite number of suitable sites left (Pérez et al., 2005). In many coastal areas that are desirable for aquaculture production often the concentration of other marine activities occurring is also high. Therefore, this makes them less suitable sites and has resulted in salmon farms occupying only a tiny fraction of the coastal waters that could be suitable for them. Designating areas for aquaculture, or giving farmers exclusive access to sites, could potentially also act as refuges for some species targeted by fishing or those sedentary species that are disturbed or harmed by fishing activity (Black et al., 2008). Another aspect which is affecting availability of sites is the social perceptions of aquaculture. Attitudes towards aquaculture are at best considered neutral however there is a considerable body of evidence from around the world that indicated many social perceptions are more hostile (Barrington et al., 2010).

The rising number of aquaculture facilities is now increasingly beginning to instigate competition between farmers and other users of coastal areas. Therefore, to avoid conflict, there is a great need to allocate aquaculture to suitable locations (site selection) to ensure sustainable development of this industry and to avoid undesirable impact on the environment, as well as ensuring the long-term profitability of the operation (Pérez et al., 2005). Presently salmon farming is still considered to have good growth prospects within Scotland and there was capital investment of £8m across the Highland in 2009. The Scottish Government has recently estimated that for each pound paid to employees in the fish farming sector a further £4-5 is generated in the local economy (The Highland Council 2011). To summarise, the correct choice of farm site is vitally important since it influences the economic viability of the facility and this in turn supports the economy. However, the availability of suitable areas for aquaculture is diminishing because of water quality degradation (Pérez et al., 2003).

6.1.2 Salmon Culture

In the mid 1970s, salmon farming trials and breeding programmes began to be established and developed in several countries including Shetland and mainland Scotland (Thomas and Bassett, 2010). The sector was a huge success and by the late 1970s, salmon aquaculture had grown into a global industry in its own right, with over a million tonnes of salmon being produced each year (Ford and Myers 2008).The Atlantic salmon (*Salmo salar*) is the predominant culture species in temperate marine waters (Black et al., 2008) and in Scotland aquaculture production is dominated by this species (Davies and Slaski, 2003). The Marine Scotland Science (formerly known as FRS; Fisheries Research Services), carry out annual production surveys on behalf of the Scottish Government (Marine Scotland) which collates annual production data from registered fish farm sites, the last full year of data available is 2014. The total production of Atlantic salmon during 2013 was 163,234 tonnes, an increase of 1,011 tonnes (0.6%) on 2012 production levels (MSS, 2013). Atlantic salmon has become so established in Scotland that it is now the largest producer in the EU and the third largest producer in the world behind Norway and Chile (Baxter et al., 2008). However these statistics could be set to change as leading EU producer organisations have forecast that the global market for Atlantic salmon will have an undersupply as the output from Chile has declined and further reductions are predicted (Aquaculture Planning Taskforce, 2010). This decline in production in Chile has been largely attributed to the uncontrolled expansion of the aquaculture industry in the country over the last few decades. The effects were really noticed in 2006 when a range of negative environmental impacts were found to have resulted from the aquaculture taking place there. These effects included loss of benthic diversity, changes in sediment chemistry, pharmaceutical contamination, dinoflagellate bloom increase and up to a five-fold increase in abundance of omnivorous diving and carrion-feeding marine birds in salmon farm areas (Silva et al., 2011). Although there are great differences between farms in different parts of the world, marine finfish farms tend to have more problems and attract a greater range of predator species than land-based and freshwater farms (Quick et al., 2004). For example, in Scotland there are a small proportion of seal attacks on finfish farms, while they are not frequent they can do substantial damage to stocks (Thomas and Bassett 2010). Cormorants (*Phalacrocorax carbo*), shags (*Phalacrocorax aristotelis*), herons (*Ardea cinerea*), otters (*Lutra lutra*) and mink (*Mustela vision*) have also been reported to cause problems at farm sites in Scotland but appear to raise less concern than seals (Quick et al., 2004).

Marine finfish aquaculture is not only affected by wild fauna such as these opportunistic predators it can also affect wild populations of animals and in particular wild fish species. With the majority of wild salmon biomass being held in open cages/pens in coastal areas it is almost inevitable that they come into contact with wild salmon that are migrating from the rivers to the ocean (Ford and Myers (2008). A study by Ford and Myers (2008) compared marine plus rod catches of Atlantic salmon from the east coast of Scotland to catches from the west coast of Scotland. Salmon farms were found to be located in the majority of bays along the west coast, in well over 300 sites, so all salmon rivers on this side were considered to be exposed. Salmon from the east coast did not pass by salmon farms in Scotland because of the direction of their migration routes, although they still may come into contact with farms if they approach the Norwegian coast (Ford and Myers 2008). The interactions between wild salmon and farm sites is of great interest due to the negative effects they may have on wild populations such as, genetic disturbances and transfer of diseases and sea lice by escapees, or from ingestion of contaminated wastes and more general effects on the wider environment (Fernandes et al., 2001).

6.1.3 The future of Aquaculture

In the European Union (EU) alone it is estimated that fish consumption will grow by a minimum 0.5% per year for the next thirty years. This has meant that an increase in fish and fish product production has emerged as an EU priority (Aquaculture Planning Taskforce, 2010). The Scottish Government's vision for aquaculture is set out in the 'strategic framework for Scottish aquaculture'. Their vision is that "*Scotland will have a sustainable, diverse, competitive and* *economically viable aquaculture industry, of which it can be justifiably proud. It will deliver high quality, healthy food to consumers at home and abroad, and social and economic benefits to communities, particularly in rural and remote areas. It will operate responsibly, working within the carrying capacity of the environment, both locally and nationally and throughout its supply chain*" (Baxter et al., 2008). Whilst continuing to emphasise quality, health, provenance and environmental sustainability, there is scope for the sustainable growth of Scottish fin fish and shellfish industry to capitalise on the predicted increase in market demand (Aquaculture Planning Taskforce, 2010).

A key commercial constraint on growth is the availability of good sites as in most countries the availability of new sites is strictly limited (Black et al., 2008). The lack of available coastal sites for aquaculture has resulted in the industry's proposals to look at moving into offshore, less spatially competitive waters. The proponents of offshore aquaculture point out that 'mounting spatial pressures make the move offshore inevitable', whereas detractors insist that there is not enough profit to drive the capital investment required for offshore farming (Pérez et al., 2003). Aquaculture development continues to be hindered other constraints such as, concerns regarding negative environmental impacts, and multi-use conflicts (Frankic and Hershner 2003; Radiarta et al., 2008). Selection of a suitable site for an aquaculture venture is perhaps one of the most important and limiting steps affecting both its success and sustainable development (Radiarta et al., 2008). In Europe aquaculture development is now guided by the Strategic Guidelines for the sustainable development of EU aquaculture (COM/2013/229) as well as strategic plans produced by their own respective countries. Site selection can determines investment, running cost and strongly influences the ultimate success in the resulting aquaculture enterprise (Pérez et al., 2003). The expansion of the aquaculture industry is likely to depend on its ability to participate as a trustworthy partner in integrating marine management. An emphasis must be placed on clarifying the industries need for marine resources like such as space and recipient capacity. Equally important is the need to further define sustainable and publically accepted environmental quality standards for aquaculture (Black et al., 2008).

6.2 Aquaculture Policy and Planning in Scotland

As from April 2007, all new aquaculture developments and alterations to existing sites were brought within the scope of the Town and Country Planning system. This means that in many cases sites can now have permanent planning permission once they have been through the planning process (The Highland Council 2011). This was followed in March 2010, by the publication of 'Delivering Marine Planning Reform for Aquaculture' by the Scottish Government. This document lays out what stakeholders will be expected to contribute and how they will be brought together to refine the existing planning system. This document was then followed by 'A Fresh Start: The Renewed Strategic Framework for Scottish Aquaculture' (SFSA, 2009) sets out the Scottish Government's objectives for aquaculture across Scotland, including planning and River Basin Management Planning. The SFSA document and the Scottish Planning Policy (SPP) have both identified sustainability (economic, environmental and social) as the main guiding principle for aquaculture development in Scotland. They also advise local authorities to develop local planning guidance for aquaculture in appropriate areas in consultation with the relevant interests and they also encourage community engagement (The Highland Council 2011).

The Scottish Government introduced planning policy in 1997 to locate farms on only the West coast and Islands (Thomas and Bassett 2010). The presumption against new marine fish farms on the North and East coasts in SPP is designed to safeguard migratory fish species (in particular wild salmon); this is acknowledged in paragraph 109, in that aquaculture development may pose a risk to angling interests. SPP (paragraph 105) states that development plans should identify areas which are potentially suitable for new or modified fish farm developments and those sensitive areas which are unlikely to be appropriate for such development.

Marine Scotland is responsible for the production of *Locational Guidelines* that provide an indication of where the expansion of fin fish farming is likely to be acceptable in terms of water quality and benthic impacts on the whole water body. These guidelines are predominantly based on predicted nutrient enhancement, benthic impact and natural heritage sensitivities direct farm location (Thomas and Bassett 2010). *Locational Guidelines* tie into the

Governments position on no new marine finfish farms being sited on the North and East coasts by default, as they calculate enhancement to the benthic and nutrient load from only proposed and existing farms (SEPA 2012).

The Crown Estate lease areas of the seabed for commercial operations, including finfish and shellfish development, and previously, until 2007, determined applications for marine finfish farms. Since this time SEPA are now the statutory consultee any new fish farms or modifications to existing farms within the 3-mile limit of UK territorial waters adjacent to Scotland (Black et al., 2008), that require consent under the Town & Country Planning (Scotland) Act 1997. At present applications require an EIA where:

a) Any part of the proposed development is to be carried out in a sensitive area e.g. SSSI, SPA or SAC;
b) The proposed development is designed to hold a biomass of 100 tonnes or greater or...
c) The proposed development will extend to 0.1 hectare or more of the surface area of the marine waters, including any proposed structures or excavations.

Shellfish farm applications however, are not currently subject to the EIA regulations so SEPA receive planning application consultations but not screening, scoping or environmental statements for these.

Aquaculture has to be incorporated into the coastal management plans and needs to reduce negative impacts on other resource users in the same location whilst also earning the respect of other users in regard to its own development (Radiarta et al., 2008). The aquaculture industry is frequently subjected to lobbies by other water users, regulatory authorities and environmental agencies and is also facing increasing numbers of objections from those in the tourist industry who regard fish farms as an offensive intrusion upon the best natural vistas (Pérez et al., 2003). The aquaculture industry must minimise these conflict with other users and uses of the marine environment. Though some conflicts may be solved through dialogue, compromise, or compensation, avoidance is often the best solution and this can be achieved during the early planning stages (Longdill et al., 2008).

Environmental managers and regulators have pointed out the necessity of minimising environmental impacts if productivity in the aquaculture industry is to be sustainable (e.g. Scottish Executive, 1999) (Pérez et al., 2002). Therefore there is a clear need for sustainability issues to be considered during the early planning stages for all types of aquaculture (Longdill et al., 2008). Whilst planning is often cited as a priority for aquaculture development (Ross et al., 1993) the identification of sustainable aquaculture sites is a complex spatial problem requiring in depth knowledge of the marine environment as well as an understanding of numerous social and civil factors (Longdill et al., 2008). Therefore good aquaculture planning and management increasingly relies on collation and analysis of spatial environmental and production information (Zeng et al., 2003).

6.2.1 Site Suitability

Optimal sites for aquaculture can be characterised by having conditions that lead to reasonably enhanced growth rates (relatively low species stocking densities (and hence less environmental stress); essentially quick growth and high quality products are the factors the economic sustainability of aquaculture. Where sites are not this ideal however, similar economic returns can still be achieved with higher stocking densities, although the level of environmental impact is likely to be significantly higher (Longdill et al., 2008). To this end it is also important to assess the potential carrying capacity of an area during the planning stages, this is the area which is geographically available and physically adequate for a certain type of aquaculture, and which will not be unduly affected by the operation of the activity (McKindsey et al., 2006).

All aspects of a site’s location need to be considered including all the possible consequences of placing a farm therein. For example, a sheltered site while protecting the integrity of the farm itself may lessen the health of the culture species due to poor dispersal of waste products from cages or from the risk of local pollution. Locating a farm in a more exposed site could result in the opposite occurring (Pérez et al., 2003). Both finfish and shellfish development will also have to take into account the need for reasonable separation to avoid cumulative impacts (The Highland Council 2011).

Interactions between aquaculture and sensitive habitats or species can be minimised by planning and regular monitoring and tight regulations. Sensitive/important/rare habitats, or designations that regulate developments with respect to their interactions with particular features of concern, e.g. in Europe, SACs established under the Habitats Directive (92/43/EEC) for protection of specific habitats (Black et al., 2008) should all be integrated and considered during the planning and application stages. Indeed, where SEPA has identified that a fish farm proposal would have a likely significant effect on any SAC or SPA, then under The Conservation (Natural Habitats, &c) Regulations 1994, as amended (Provision No. 48) SEPA are required to undertake an Appropriate Assessment (AA) before determining the CAR licence. Marine Scotland Science carries out the scientific appraisal of the impacts of the proposals on the qualifying interests, in consultation with SNH (SEPA 2012).

To summarise, selection of the most suitable sites for aquaculture must be based on environmental, economic and social factors, in other words they must include sites which would result in the least environmental stress, maximum potential for species growth, minimum production costs and avoiding, or at least minimising, potential conflicts with other users (Pérez et al., 2005).

6.3 Aquaculture and GIS

GIS was first used in aquaculture in the mid-1980s (Gifford et al., 2011) but has since been taken up rather slowly, but its use has been investigated and actively promoted over the last fifteen years (Simms, 2002). A wide range of studies targeting different species (fish, shrimps, mussels, oysters, clams, scallops and algae) at different scales (local, regional, national and continental) has shown the general usefulness of the methodology (Pérez et al., 2003). The extent of GIS applications in aquaculture includes: site selection for target species, environmental impacts assessments, conflicts and trade-offs between alternate uses of natural resources, and consideration of the potential for aquaculture from the perspectives of technical assistance and alleviation of food security (Nath et al., 2000; Pérez et al., 2005). Some studies have used GIS tools to determine areas with the appropriate environment for farming while also minimising potential conflicts with other users (Black et al., 2008). For example, work by Aguillar-Manjarrez and Ross (1995) for shrimp site selection or the fully integrated information system (British Columbia Aquaculture System BCAS); within which GIS tools play a key role, to provide guidance for assessment of site capability of shellfish and finfish aquaculture (Carswell 1998).

GIS-based models can be used to understand and resolve issues relating to competing demands, minimising undesirable impacts and maximising the profitability and sustainability of aquaculture operations through the rational use of the coastal space (Longdill et al., 2008). GIS not only provides a visual inventory of the physical, biological and economical characteristics of the environment, but its modelling capability also allows generation of suitability map layers for different uses or activities without complex and time consuming manipulations (Aguillar-Manjarrez and Ross 1995 and Pérez et al., 2003).

To use GIS for decision support in aquaculture management, the GIS system design and data collection have to be aligned with management objectives, which needs to be translated into a few key questions, so that GIS analysis can provide the answers or solution options to the managers (Zeng et al., 2003). Environmental decision making is particularly complex and requires exploration of numerous scenarios and options, often under conditions involving considerable risk and uncertainty. GIS technology provides some of the wherewithal required for supporting any decisions (Aguillar-Manjarrez and Ross 1995).

All in all there are many opportunities to use GIS to improve aquaculture sustainability (Kapetsky and Aguilar-Manjarrez 2002). In general, however, increased deployment of GIS for practical decision making in aquaculture is hampered by several constraints including: a lack of appreciation of the benefits of such systems on the part of key decision-makers, limited understanding about GIS principles and associated methodology, inadequate administrative support to ensure GIS continuity among organisations and poor levels of interaction among GIS analysts, subject matter specialists and end users of the technology (Nath et al., 2000).

6.3.1 Multi-Criteria Evaluation (MCE)

Multi-Criteria Evaluation (MCE), or Multi-Criteria Decision Analysis (MCDA) is defined as the evaluation of a set of alternatives based on multiple criteria where the criteria are quantifiable indicators of the extent to which decision objectives are realised (Wood and Dragicevic 2007). In practical terms a MCE is an attempt to combine a set of criteria (using a particular weight for each) to achieve a single amalgamated basis for a decision according to a specific objective (Pérez et al., 2003; Aguilar-Manjarrez et al., 2008).

Although a variety of MCE methods exist, all of them obey the same principle; the pairwise comparison of the scores for all the alternatives and for each criterion (Kitsiou et al., 2002). Over the last decade, many MCE techniques have been implemented in the GIS environment including: the Boolean procedure; weighted linear combinations (WLC); Ideal points methods, concordance analysis, Analytical Hierarchy Process (AHP); Analytical Network Process (ANP); Order Weighted Average (OWA); and recently the Linguistic Quantifier Ordered Weighted Averaging (Aguilar-Manjarrez et al., 2008). Among these procedures, the WLC and Boolean overlay operation are considered the most straightforward and have traditionally dominated the use of GIS as decision support tools.

MCE methods linked with geographic information systems (GIS) can be used to help make decisions that are spatial in nature (Chen et al., 2001) more specifically it is an approach that can be used to define site selection decision problems (Silva et al., 2011). To carryout MCE the most common technique in GIS processing is that of the topological overlaying in which multiple data layers are overlaid in a vertical manner (Nath et al., 2000). Criteria (i.e. production variables that affect location such as proximity to roads), representing suitability may be combined through a MCE, to form suitability maps using the GIS capabilities, from which the final choice will be made (Aguilar-Manjarrez et al., 2008). This allows the outcomes to be easily visualised and is one of the major advantages to GIS-based MCE that has meant it has been used extensively in the resolution of terrestrial resource allocation problems in fields as varied as agriculture development, risk analysis and environmental impact assessments (Wood and Dragicevic 2007).

6.3.2 MCE and Spatial Decision Making

Decision-making is a process, so there are a number of alternative ways to organise the sequence of activities in the decision-making process, however, it has been noted that applications MCE-GIS approach generally has the following steps:

1) Identify the decision-making problem
2) Identify the criteria that are relevant to the decision problem
3) Assign values to the criteria and conduct standardisation
4) Determine weights between criteria

5) Link criteria and weights with MCE-GIS methods

6) Make a provisional decision

7) Perform sensitivity analysis and

8) Interpretation

Decision-making can therefore be seen as a sequential process (Chen et al., 2001). Once the decision problem is defined, along with all criteria that reflect various aspects of the problem, weightings are often then applied to the criteria. The purpose of weights is to express the importance or preference of each criterion relative to other criteria. Alternatives are often determined by constraints, which limit the decision space of feasible alternatives (Aguilar-Manjarrez et al., 2008). When MCE and GIS are combined the criterion map layers and decision-maker preferences are aggregated according to a decision rule this yields an optimal solution. When objectives are in conflict, an ‘optimal compromise’ solution is found (Wood and Dragicevic 2007). Decision rules integrate criteria, weights and preferences to generate an overall assessment of the alternatives. Recommendations are based on a ranking of the alternatives, with reference to possible uncertainties or sensitivities. Sensitivities are changes in the input of the analysis that bias the outcome (Aguilar-Manjarrez et al., 2008). Ultimately the role of a decision support system is to assist the decision maker in selecting the ‘best’ alternative from among the number of feasible alternatives (Mwasi 2001).

This type of analysis can be built according to specific criteria including environment characteristics (physical, biological, and ecological factors), social economics and support facilities (Radiarta et al., 2008). While the specific requirements for many given species and aquaculture systems may be clear, the complexity lies in identifying the places that meet the largest number of positive factors, minimal negative factors and none of the strictly restrictive ones (Buitrago et al., 2005).

6.4 Methods

6.4.1 Study Area

In this initial application of the MCE model for identifying suitable aquaculture sites to Scottish waters, sites were only explored in Northern waters and those to the West of the mainland in line with Planning Policy guidelines about siting farms on the East coast. However because the pre-consultation draft of the

National Marine Plan covers both inshore area and offshore waters (out to 200nm), and the aquaculture industry is looking to expand into offshore waters in the future, given data availability, it is the intention of this study to extend this MCE model out to cover this offshore area also, therefore the whole of the Scottish marine area has been analysed.

6.4.2 Site Selection Criteria

There are a very large number of factors that comprise a good finfish site and in general there is a lack of such sites at least in countries such as Scotland where the industry is already developed. Compromises are therefore sometimes required. Recently some sites have been abandoned as farmers seek to benefit from economies of scale. This can lead to environmental benefits when poor sites are closed but also environmental costs if the assimilative capacity is breached in the process (Black et al., 2008). The general requirements in siting an aquaculture venture are related to the tolerances of the culture species and the engineering of systems. Some of the main factors to be considered in salmonid cage culture for example are: depth, currents, salinity, temperature and dissolved oxygen. These criteria then need to be supplemented by data on local infrastructure, topography and exposure of the site in any assessments (Ross et al., 1993).

In general a good finfish farm site has moderately strong currents (means of 5-10cms^{-1}) (Black et al., 2008) as enhanced current speeds, in addition to affecting the rate of food supply, can act beneficially to improve waste dispersal from cage sites (Longdill et al., 2008). They must also be moderately deep (40+m) and have low exposure to large waves (significant wave heights[8] of 2m or less), (Black et al., 2008). Other water quality parameters, such as temperature, pH, presence of nitrogenous compounds, dissolved oxygen etc. should be within the ranges that provide life support and growth for the cultured species (Pérez et al., 2003). Additionally, sites should not contribute additional nutrients to the water body that would exceed the assimilative capacity taking other sources into account (Black et al., 2008).The natural benthic environment (e.g. high organic content fine sediments, coarse sand, rocky reef) and its assimilative capacity, relating to the specific additional inputs, plays a further role in determining the impact magnitude (Longdill et al., 2008). Finfish production may also be adversely affected by algal blooms. Some species of algae, if present in sufficiently large numbers, can damage the gills of farmed fish. This may result in mortality in the worst cases. Fish are also susceptible to blooms of zooplankton, such as juvenile jellyfish (The Highland Council 2011). Other possible toxins and pollutants such as hydrocarbons, heavy metals and pesticides have a strong potential influence on aquaculture viability (Pérez et al., 2003). Some species, such as corals, are more likely to be damaged by aquaculture than others due to their physiology. In the UK the Marine Life Information Network has set up a database illustrating the species predominantly at risk from aquaculture practices which can be consulted (Hunter et al., 2006).

There are of course additional social and commercial considerations that must also be taken into account. For example there have been issues in the past where feed pipes from farms were blocking the entrance to anchorage points in lochs, upsetting local fishermen and boat users. Therefore it is important that any future developments do not impinge on commercial traffic or present a navigational hazard to smaller coastal vessels (The Highland Council 2011). While sites must be within a convenient distance to human infrastructure such as labour, accommodation, transport facilities, and ideally markets (Black et al., 2008). It is equally important that they are not too close to other factors. For instance its essential that there is sufficient separation distance between adjacent sites and that developments for salmonids especially, are located away from the entrance to important game fishing rivers given the potential for escapes and the subsequent effects on wild fisheries (Black et al., 2008; The Highland Council 2011).

A site with the above characteristics should reduce the risk of significant environmental damage allowing the farmer to operate at a scale that allows economic production in a highly competitive market (Black et al., 2008).

6.4.3 Identification and Collection of Data

The identification of pertinent data sets is integral to the success of the GIS MCE technique (see Figure 6.1). When determining suitable areas for sustainable finfish aquaculture operation, consideration was given to the natural conditions present, the requirements of the aquaculture operation and the particular needs of the species being cultured, in this case Atlantic Salmon. A planning analysis such as this aiming to identify sustainable finfish sites must recognise development in dependent factors which can influence the growth quality of culture species (economic sustainability), the potential level of impacts from cultured species (environmental sustainability) and also the existing users, alongside their societal values relating to the coastal marine region.

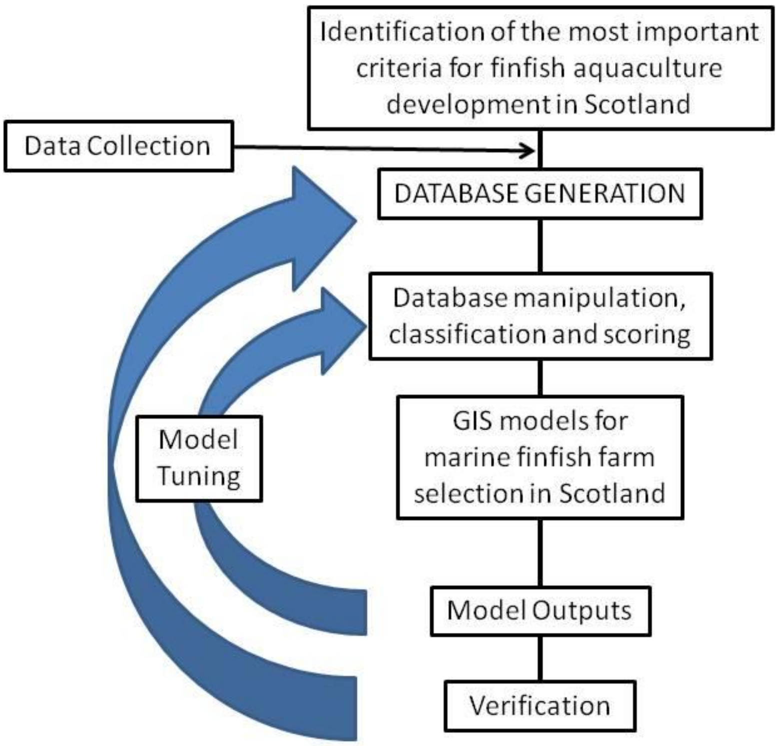

Figure 5 - A schematic diagram outlining the process implemented to identify suitable sites for finfish aquaculture in Scotland.

Although many factors have to be considered for developing sustainable aquaculture, the most important depends on the culture system being utilised by the farmers. The influence of biological factors such as sea temperature, food availability (chlorophyll a), wave heights and bathymetry on the growth of farmed fish are all widely recognised as are the additional effects of social and infrastructure operations. Therefore, these factors were all used for identifying suitable sites for sustainable finfish aquaculture around Scotland (see Table 6.1).

Table 6.1 - Criteria used for Scottish finfish aquaculture site selection

Submodel	Criteria	Interpretation of Criteria	Data Sources
Biophysical	Water Depth	Favourable depth for salmon culture as cage nets can drop between 18 and 20m	JEBCO
	Current Velocity	Current speed fast enough to prevent degradation of the surround in area	IMR-Norway
	Chlorophyll a	Availability of Natural Food (Phytoplankton)	SAHFOS
	Temperature	Favourable Temperature for Finfish Culture	NOAA
	Sediment Type	Least sensitive to benthic impacts from cages	JNCC
	Maximum Wave Height	Wave height that will not increase the chances of damage/escapees	DECC
Social Infrastructure	Distance from Beaches	Pollution threat	MSS
	Distance from Pollution/ Discharge Sites	Pollution threat	SEPA
	Distance from Aquaculture Sites	Pollution, Navigation, Spread of Disease and Potential Accumulative Effects of Competition for Natural Resources	Crown Estate
	Distance to Roads	Support Services and Transport to Markets	OS data
	Distance from Towns and Natural/Social Heritage	Support Services and Viewshed	RCHAMS, Historic Scotland and OS data
	Distance from Conflicting Activities	Hazard	Multiple Data Sources
	Distance from Small Craft Facilities	Pollution and Navigation	Edina
	Distance from Ports and Harbours	Support Service but also Pollution and Navigation	MSS
Constraints	Fish nursery and Spawning Grounds	Ensure no negative impact on wild fisheries	CEFAS
	Designated Protected Areas	Dependant on site designation aquaculture may be permitted within this area	SNH and JNCC
	Predators: Cetaceans/Pinnipeds/Birds	Avoidance of stock loss and damage to cages	MSS and DEFRA
	Species Sensitive to Aquaculture (PMFs)	Safe distance to ensure sensitive species are not put under stress	MSS
	Important Fishing Grounds	Ensure no negative impact on wild fisheries	MSS
	Salmon River Mouths	Safe distance to ensure that wild salmonids will be exposed to farms	MSS

6.4.4 Database generation and the Weighting Procedure

The model structure for identifying suitable sites for sustainable finfish culture around Scotland was built based on hierarchical structures (also sometimes referred to as value structure). Hierarchical structures breakdown all criteria into smaller groups (or sub-models). At the highest levels are the most general of the objectives which can be further defined at still lower levels, while the lowest levels of hierarchy are attributes, see Figure 6.2. This study identified 20 criteria according to the basic requisites for finfish aquaculture in Scotland. These criteria were organised into three sub-models (Biophysical, Social-Infrastructure and Constraint) and represented as either factors or constraints.

A factor can be defined as a criterion, which enhances or detracts from the suitability of a specific alternative for the activity under consideration. Conversely, a constraint is a criterion which serves to limit the alternatives under consideration (Aguillar-Manjarrez and Ross 1995; Mwasi, 2001; Buitrago et al., 2005; Pérez et al., 2005; Radiarta et al., 2008). Criteria are measured on a continuous scale, as they are continuous values, constraints by contrast, serves to limit the region under consideration. A constraint is therefore Boolean, either possible or not (Mwasi, 2001; Buitrago et al., 2005). For example, fishing from beaches and rocky headlands (e.g. by long-lines) is popular in some regions. These long-lines can typically extend out a considerable distance from the coast and other activities may not be able to occur there. A constraint layer, as a coastal buffer zone, can therefore be applied to represent this use within an MCE model (Longdill et al., 2008).

All data integrated into the spatial database required some form of manipulation and reclassification to create a standard scoring method. Scoring of raw data was based on the requirement of the finfish species in culture; in this instance we used salmon cage culture as our benchmark culture system. A suitability score for each criterion was established according to Pérez et al., (2005) using a scoring system from 1 to 8, with 8 being the most suitable and 1 being the least suitable for developing finfish culture, see Appendix 6, Table A 6.0 and A 6.1.

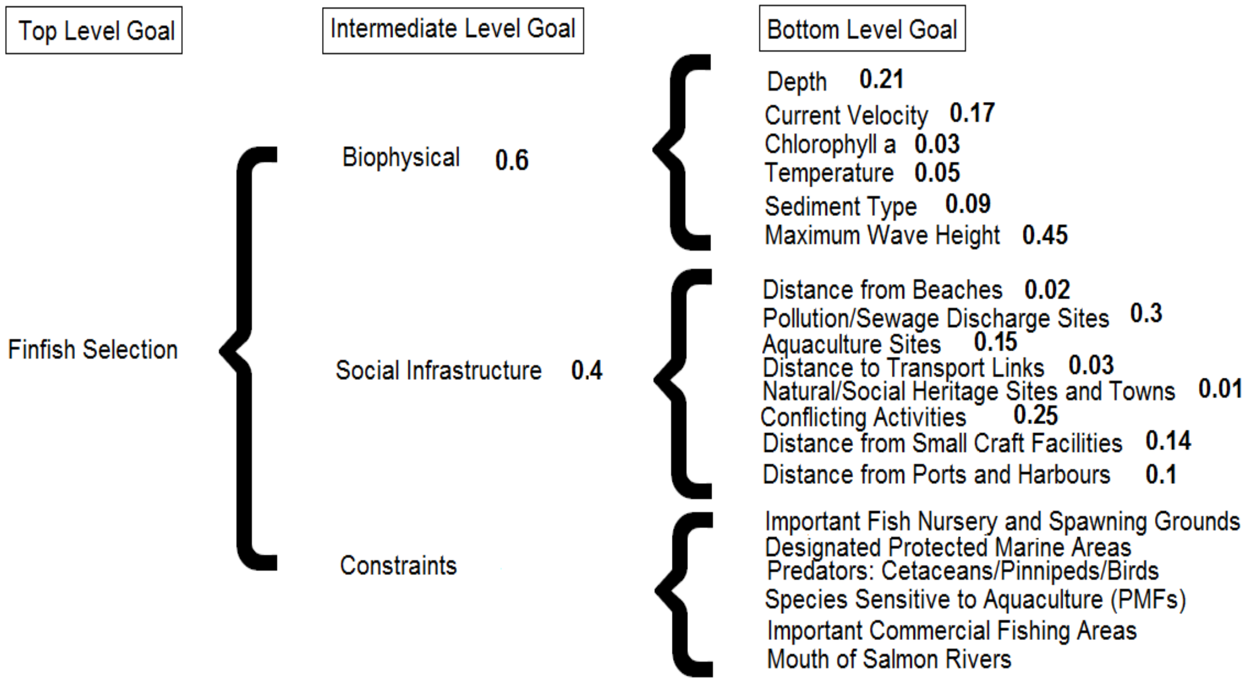

Figure 6 - A hierarchical modelling scheme to identify suitable sites for finfish aquaculture in Scotland.

The next step was to ascertain a weighting for each criterion and factor. A variety of weighting techniques exist, however the pairwise comparison method developed by Saaty (1977) in the context of the Analytical Hierarchy Process (AHP) was used to develop a set of relative weights for each parameter in MCE. Consequently, information regarding the relative importance of each criterion is required. At this point, decision-makers preferences regarding the evaluation criteria were incorporated into the decision model. The preferences were typically defined as a value assigned to an evaluation criterion that indicates its importance in relation to the other criterion under consideration. Criteria were rated according to an extensive literature review and experts opinion based on their relative importance using the pairwise comparison method (See Appendix 6 Tables A 6.2 and A 6.3). By making a pair-wise comparison between each criterion and factor, relative weights were developed in order to account for the changes in the range of variation for each criterion and different degrees of importance that were attributed to these ranges in variation (Radiarta et al., 2008). In using the pairwise comparison technique, the relative importance of the criteria could be evaluated on a 17-point continuous scale from least important (1/9) to most important (9) for each activity being evaluated. After comparisons were made, the principle eigenvector of the pairwise comparison matrix was incorporated (see Equation 1.) to produce the best fit for a total weight of 1. The major advantage of using the AHP is its capability to calculate the consistency ratio of weight distribution and its consequent evaluation of the weighting process; see Appendix 6 Tables 6.2 and 6.3.

$$Consistency\ Ratio(CR) = \frac{Consistency\ Index\ (CI)}{Random\ Consistency\ Index\ (RCI)}$$

$$CI = \frac{(\lambda max - n)}{n - 1}$$

$$\lambda \max = principle\ eigenvector$$

Equation 1 - Normalisation and Weight determination for carrying out the Pair-wise Comparison Matrix

This value indicates the probability that ratings were randomly assigned. A consistency ratio of 0.1 or less was considered acceptable and demonstrated good and consistent judgement (Saaty, 1977).

6.4.5 Constructing the GIS Model

The model of site suitability has been constructed based on the MCE procedure known as weighted linear combination, in which the weight of relative importance assigned to each criterion and a total score, $V(x_i)$, is then obtained for each of the criteria by multiplying the weight assigned by the scale value for that particular criteria, and summing the product over all parameters as follows:

$$V(x_i) = \sum_j w_j r_{ij}$$

where w_j is a normalised weight, such that $\sum w_j = 1$and r_{ij} is the attribute transformed into the comparable scale. The weights represent the relative importance of the attributes. The most preferred alternative is selected by identifying the maximum value of $V(x_i)$ for $i = 1, 2, , . . , m$.

The final suitability map was created by combining the two different sub-models. These models were calculated using the different relative importance weight scenarios for bio-physical and social-infrastructure sub-models, see Appendix 6 Table A 6.4. A more general purpose of this analysis was to find out the influence of different criteria weights on the spatial pattern of the suitable sites. The relative importance weight scenarios were assigned according to the situation not only of the present day but also in the long run. For example, depending on the societal priorities, the requirement and demand for a specific activity may take precedence from considerations on environmental impacts. In such situation social infrastructure features, such as transportation, may have a greater influence in site selection. It was therefore possible to change the weights of different preference criteria. For each scenario, a different decision factor is given the greatest importance. The biophysical>social-infrastructure set were used as model 1 and the social-infrastructure>biophysical set as model 2. This analysis can be particularly useful in situations where uncertainties exist in the definition of the importance of different factors sub-model). In many instances it is also important to know how the result will change as a result of changing the weighting.

6.4.6 Model Verification

Verification is absolutely essential both for quality control of certain data sets and for testing the outcome of the analysis. In this study model verification was carried out by making a comparison between the suitable sites identified by the MCE analysis and existing finfish operations. A shapefile of existing finfish sites was mapped and overlaid with the potentially suitable sites that have been identified to determine how much the existing finfish culture matched with these new modelled sites.

6.5 Results

Suitability maps for each parameter were made for the whole of the Scottish sea area (over 472,000 km^2) and the area distribution of suitability scores for each criterion was also calculated. The results for the 14 criteria (as factors) is presented separately in two sub-models; biophysical and social-infrastructure, enabling comprehensive analysis.

The classification of surface areas for each criterion are summarised in Table 6.2, the corresponding spatial distributions of suitability sites are shown in Appendix 6, Figures A 6.0 and A 6.2. The spatial distribution of suitable sites for the sub-models can be seen in Figures 6.3 and 6.4.

Table 6.2 - Different suitability levels (expressed as a percentage of the total potential areas) for Finfish aquaculture in Scotland.

Factors/Criteria	**Suitability Score**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Biophysical								
Water Depth	82	5	2	2.5	2.5	2	2	2
Current Velocity	81	2	2	3	2	2	2	6
Chlorophyll a	13			3	1	2	16	65
Temperature						1	3	96
Sediment Type	23	9	5		8	12		43
Max Wave Height	83	4	3	2	1	1		6
Sub-Overall	2	34.5	46	9	6	2	0.5	
Social-Infrastructure								
Distance from Beaches	1	2	3	4	4	8	12	66
Distance from Sewage/Pollution Sites	11	6	4	3	4	3	3	66
Distance from Aquaculture	12	6	6	6	6	6	5	53
Distance to Transport Links	57	5	5	6	6	6	8	77
Natural/Social Heritage Sites and Towns	43	1	13	1	6	3		33
Conflicting Activities	2	3	4	4	4	3	3	7
Distance from Small Craft Facilities	1	1	2	2	2	2	2	88
Distance from Ports and Harbours	2	4	4	4	5	1	5	75
Sub-Overall			4	10	7	6	12	61
Overall Model 1			2	10	18	65	4	1
Overall Model 2			3	18	72	6		1
Overall Suitability		0.02	2	14.5	72	5		6.3

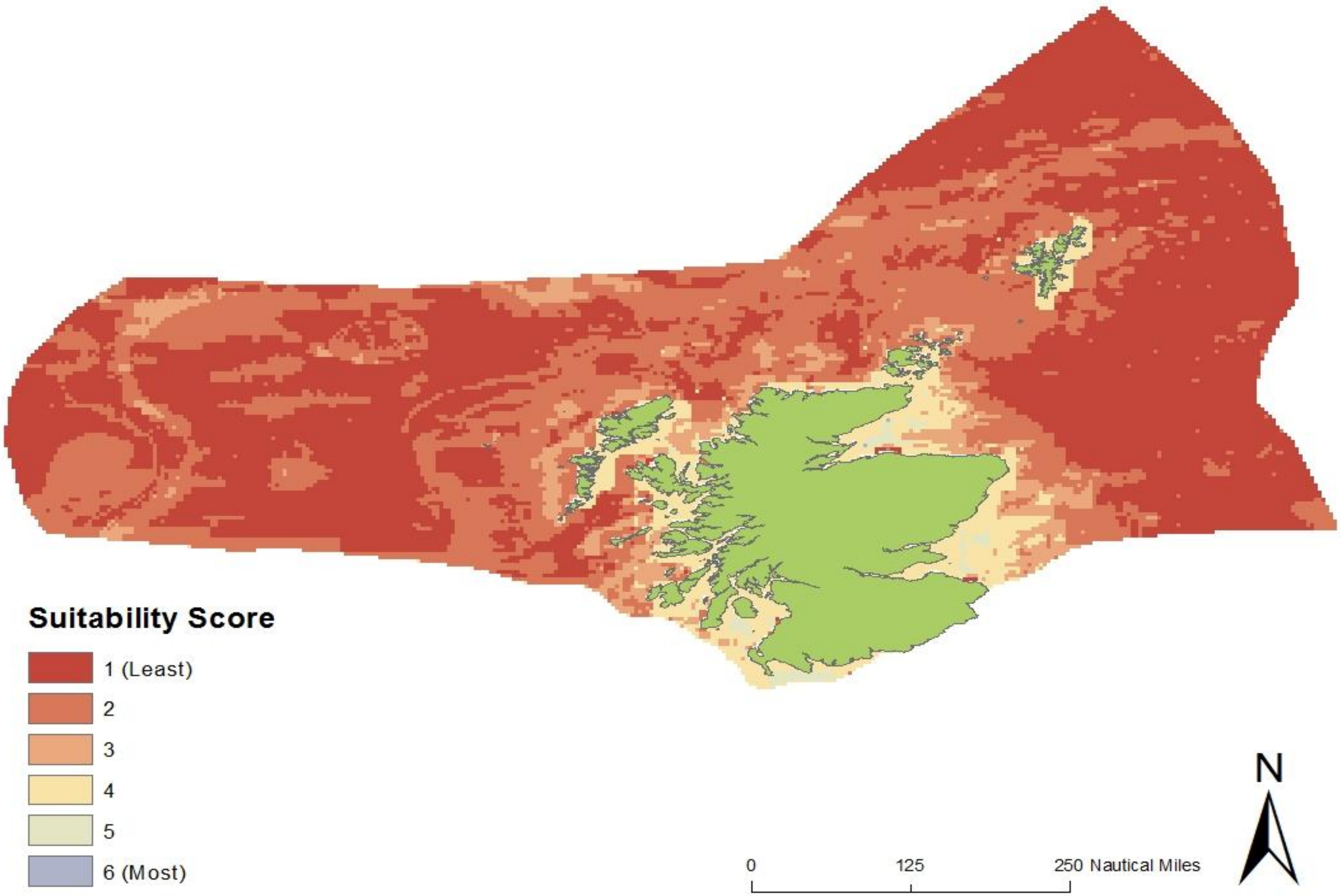

Figure 7 - Suitability map of Biophysical Sub-Model generated for Finfish Aquaculture in Scotland.

The potential sites should have appropriate biophysical variations including both biological habitat and physical environmental parameters in order to provide the optimum conditions for growth and survival of the fish being cultured. In our model, bathymetry, current velocity, chlorophyll, water temperature, sediment type and maximum wave height were the criteria used to examine biophysical characteristics. Approximately 2.5% of the potential area was identified as having a score between 6 and 8 (most suitable), and this area was located close to inner shoreline of the mainland and along the coast of the Western Isles, Hebrides, Orkney and Shetland, see Figure 6.3 above. Approximately 65-96% of the potential area has scores of 8 (most suitable) for finfish aquaculture in terms of sea temperature and chlorophyll a concentration. While sediment type accounted for 43%, current velocity and wave height 6% each and water depth for 2% respectively for the score of 8. See Table 6.2 for further details.

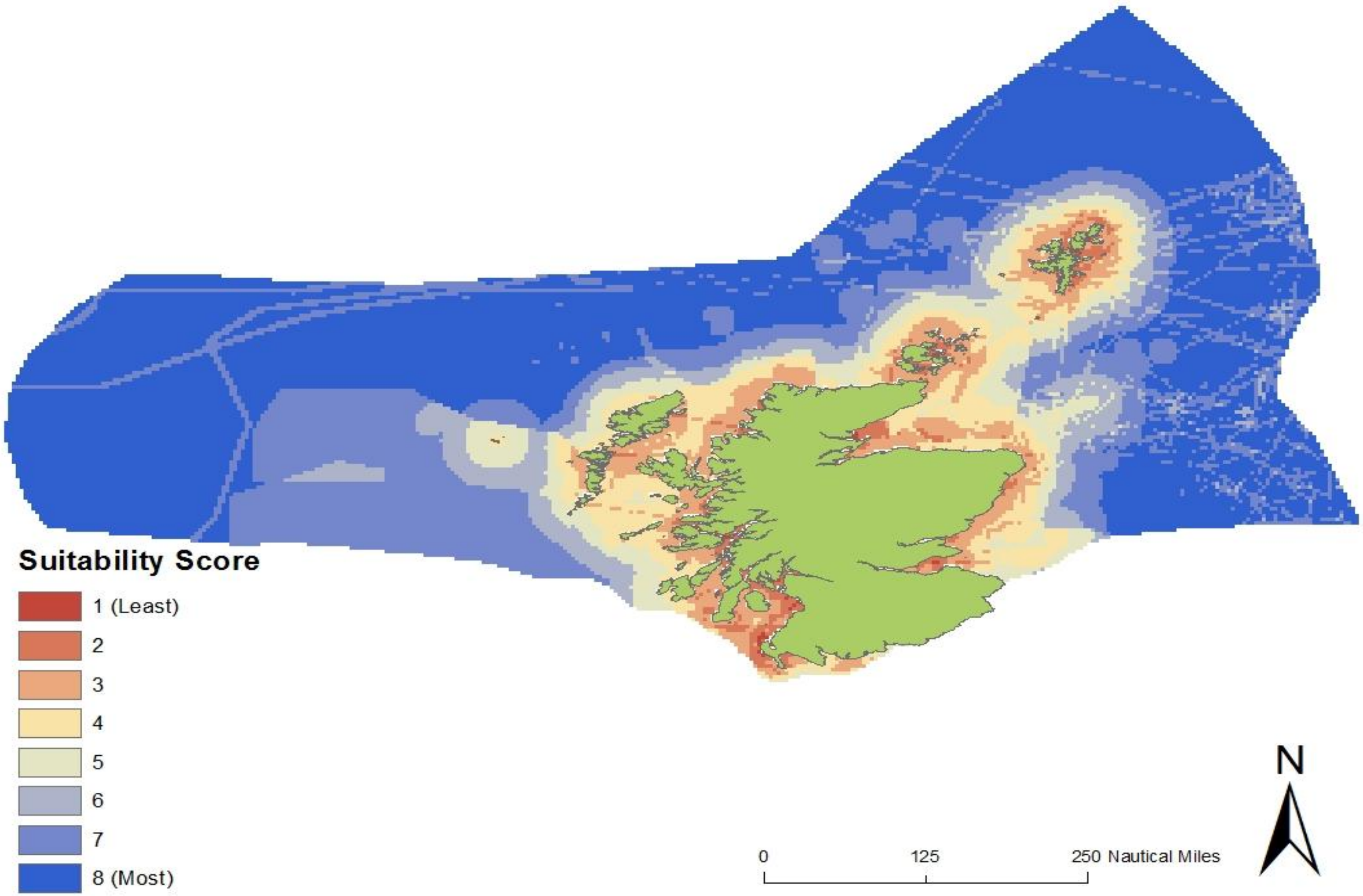

Figure 8 - Suitability map of Socio-Infrastructure Sub-Model generated for Finfish Aquaculture in Scotland

Social-Infrastructure layers, see Figure 6.4, can be used to improve productivity and product quality. Social-Infrastructure layers such as distance to transport links for example, are all relatively well supported for finfish aquaculture development throughout Scotland, see Table 6.2. Approximately 61% of the potential area was classified as score 8 (most suitable) for finfish aquaculture in terms of social infrastructural factor. About 12% had a score of 7 and 6% had a score of 6. This amounts to approximately 24% and then a further 21% of the potential area was classified as middle score (sum of 3, 4, and 5). The lower scores (1 and 2) had less than 1%.

The constraints layer limits the area of suitable sites for finfish aquaculture, see Figure 6.5. Important commercial finfish spawning and nursery grounds, designated marine protected areas, areas with known predator species, species sensitive to aquaculture, high intensity fishing grounds and the mouths of salmon spawning rivers were all considered as constraints (score 0). They covered about 35% of the potential sea area in the current site selection model.

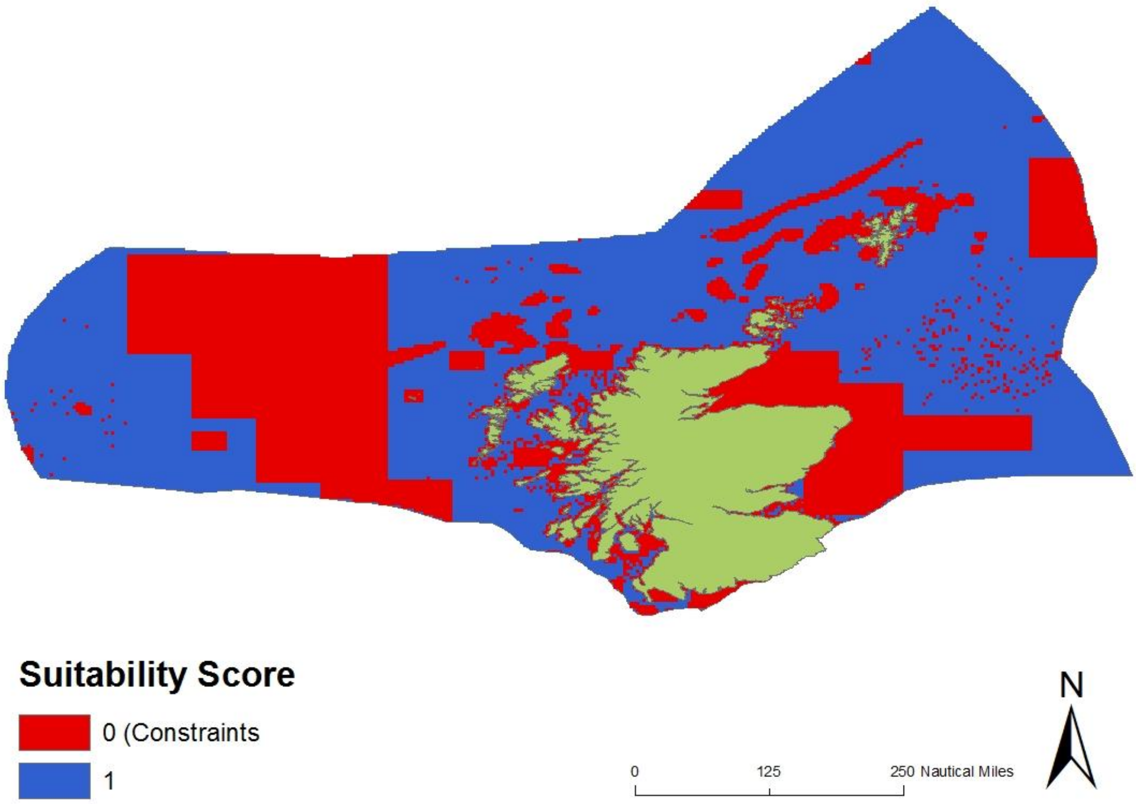

Figure 9 - Constraints map showing areas unsuitable for finfish aquaculture.

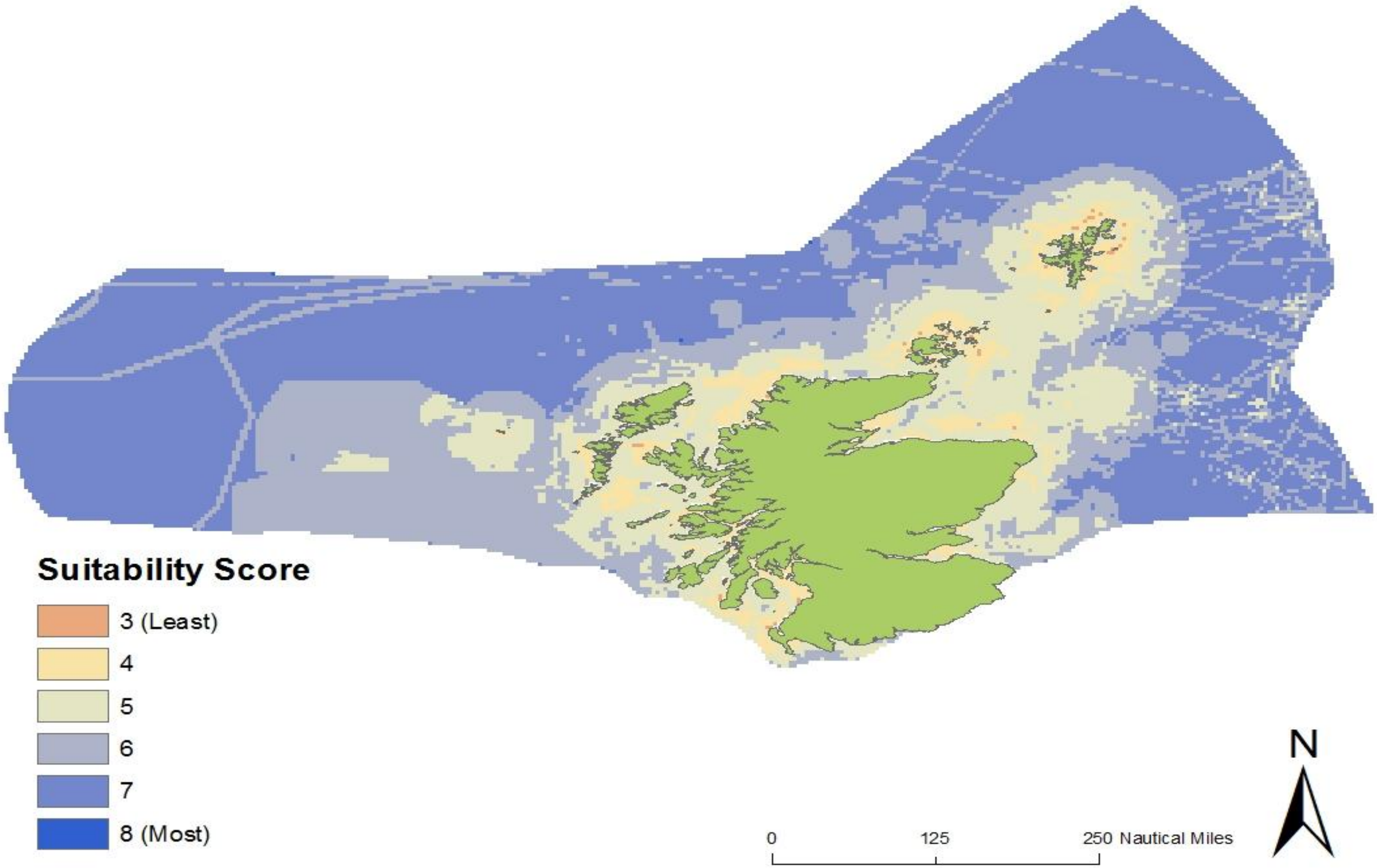

Figure 10 - Suitability map of Model 1 Scenario 1 (Socio-Infrastructure > Biophysical)

Different relative importance weight scenarios were applied for two sub-models (biophysical and Social-Infrastructure), this enabled the sensitivity analysis to be incorporated in the process of producing the suitable area. They were also considered in order to investigate how changing the weight of various factors affected the determination of the preferred area. The different suitability scores for each model can be seen in Table 6.2, and the corresponding distribution of the suitable sites is shown in Figure 6.6, above, and Figure 6.7, below. In Model 1, social-infrastructure is given the greatest relative importance (Figure 6.8). Only 1% of the total sea area was identified as having a score of 8 (most suitable), while 4% had a score of 7. Around 83% of the potential area had scores of 5 and 6, and 12% with scores of 3 and 4. There was no area identified as having lower scores (1 and 2).

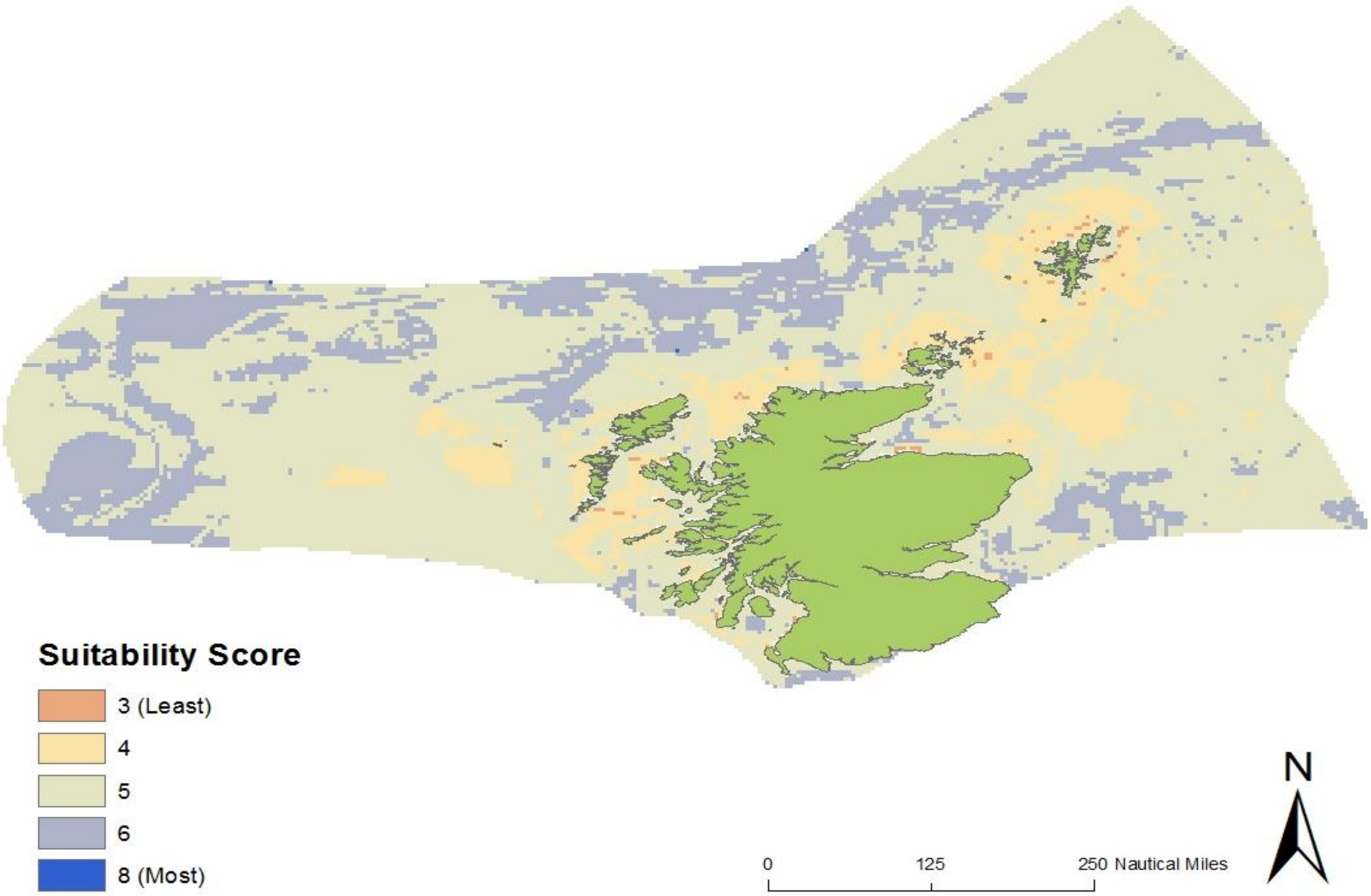

Figure 11 - Suitability map of Model 2 Scenario 2 (Biophysical > Socio-Infrastructure)

When biophysical factors are given the greatest relative importance the results are quite different, see Figure 6.7. Although again 1% of the total area was identified as having a score of 8, there was no area calculated to score 7, and only 6% allocated to score 6. Most suitable areas (scores 6, 7 and 8) have decreased from 70% in Model 1 to only 7% in Model 2. This, perhaps, can be mainly attributed to a high relative importance being placed on other activities that could potentially conflict with aquaculture enterprises. Furthermore, 21% was allocated to scores 3 and 4 in contrast to the 12% that was given to these scores in Model 1. However, once again no area was identified as belonging to scores 1 and 2.

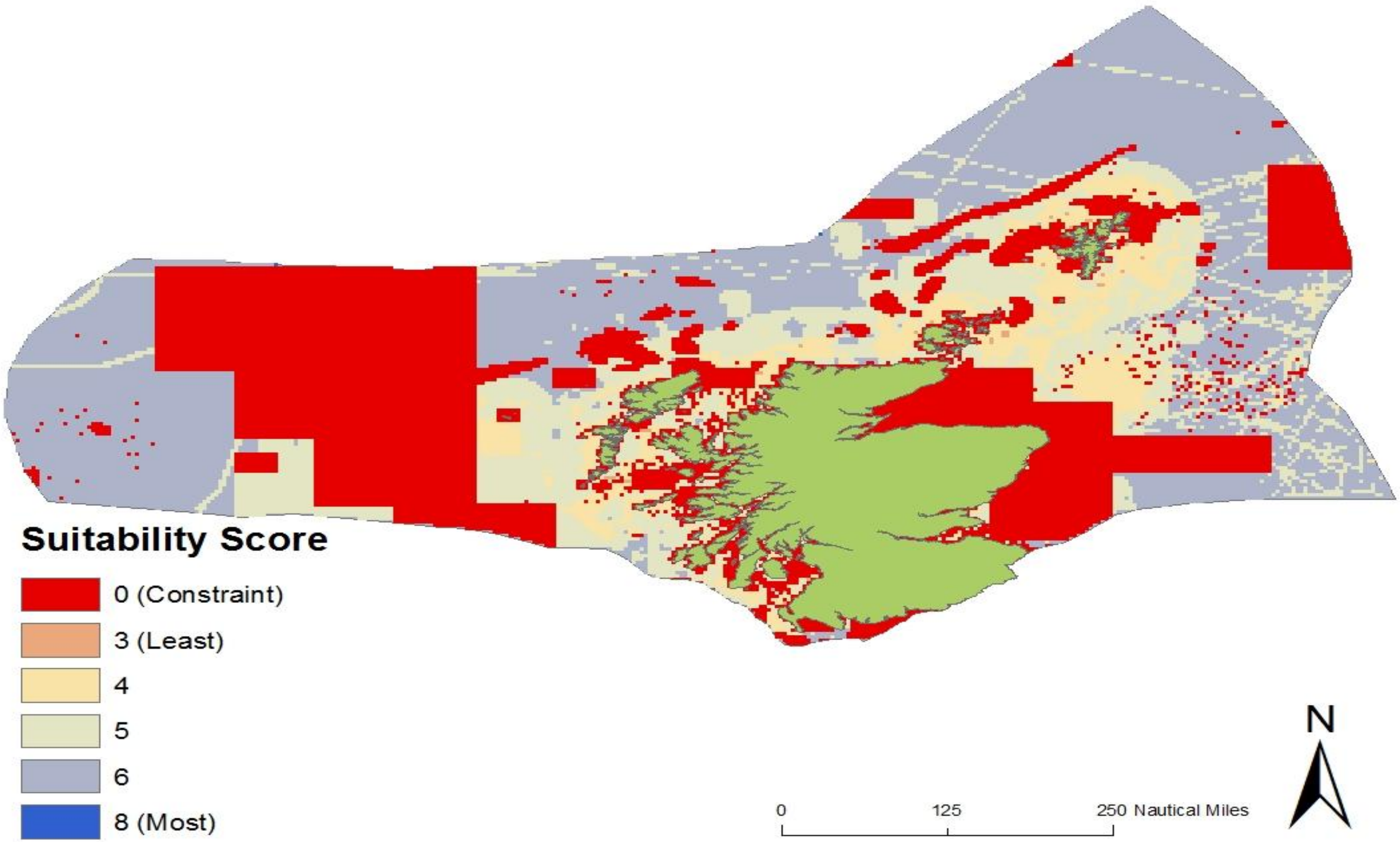

Figure 12 - Overall Site Selection map, with Constraints layer added, for Finfish Aquaculture in Scotland

In the final output for finfish aquaculture site suitability (see Figure 6.8), with the constraints layer applied, the model classified around 4% of this potential area had a score of 8 (most suitable). This small area is considered by the model to have ideal conditions for the criteria examined. Although no area was allocated to score 7, a further 3% was given to score 6. Roughly 57% of the area was ranked as being middle scoring (3, 4 and 5), while just over 1% was identified as belonging to lower scores (1 and 2).

6.5.1 Verification Analysis

The assessment of how robust this MCE site selection model is was done by comparing the location of existing finfish aquaculture operations and suitability of locations obtained from the MCE analysis. The results are shown in Table 6.3. It is important to note that a considerable number of the sites (45%) that have already been developed for finfish aquaculture were located in the constraints layer output.

Forty nine percent of the most suitable scores (6, 7, and 8) from the models output were matched with existing finfish aquaculture locations. Only 6% were present in moderate scoring areas (3, 4, and 5). No existing finfish aquaculture facilities were found within the lower scoring areas (1 and 2), see Table 6.3.

Table 6.3 - Model verification (expressed as percentage of the total potential area) between existing finfish aquaculture operations and suitability scores obtained from the MCE analysis

Suitability Scores	Percentage Area Coverage (%)
0	45
1 - 2	0
3 - 5	6
6 - 8	49

6.6 Discussion

In this study research was focused on the most suitable sites for finfish aquaculture. Different criteria were grouped into two sub-models (Biophysical and Social-Infrastructure), which were then combined to generate a final output showing the most suitable sites for finfish aquaculture development around Scotland. Although the total potential area in this study is 492,352 km^2 (sea area out to 200nautical miles), only around 65% (321,521km^2) could be classified as being suitable for finfish, while the remaining 35% (170,831km^2) was identified as a constraint area (see Figure 6.5 for details of constraints layers). Classification of suitability level using GIS techniques led to estimates that 11% of the remaining potential area had high scores (scores 6, 7 and 8) and middle scores (scores 4, 5 and 6) had 89% respectively, for finfish development. Areas with the highest scores were mostly distributed offshore but there are some smaller areas that are distributed along the inner waters of the west coast and islands, see Figure 6.8

The most suitable (highest sores) areas for finfish culture are those in which most of the variables coincide with each other and therefore there is a strong potential for finfish culture. The results of this GIS model are validated by using existing finfish aquaculture operation locations within the study area, Table 6.3. Existing culture locations cover around 49% of the area classified as being most suitable for finfish culture (score 8) in the study area. This indicates that further expansion of finfish culture into other areas is still possible. However, it should be noted that this does not take into account the fact that marine aquaculture is prohibited on the east coast and therefore potential sites located here will need to be removed also. While this study is based on site selection for finfish an attempt has been made to consider other potential users of the coastal space by including, and heavily weighting, a conflicting activities criteria layer within the social-infrastructure model. In some cases, management options will be required when activities overlap and these perhaps should be based on suitability analysis of the area. For example, in a study by Pérez et al. (2003), they looked at the potential area that was suitable to develop marine cage fish aquaculture in the Canary Islands in terms of their coexistence with the tourist industry.

This study showed the usefulness of how a GIS database and approach can bring together different data formats and use them effectively to identify and create a spatial model of suitability levels for finfish aquaculture. There are perhaps two obvious factors that can improve any site selection analysis, these are; adding more criteria and using site specific data for the area under consideration. The reality however, is that often the quality and quantity of the data available to decision makers can make precise site analysis difficult. In this study data was compiled from a variety of resources and where data were questionable in accuracy or resolution they were left out of the analysis.

Finfish aquaculture is one of the Scottish Government's priorities for further development in the future (Aquaculture Planning Taskforce, 2010). Finfish and in particular Atlantic salmon aquaculture, is already a well established industry throughout the west coast of Scotland. Significant advances have been made in recent years to reduce the impact made by this type of aquaculture. However, there is still much to be done to promote and improve public perception of this particular aquaculture sector throughout Scotland. There are still several aspects of finfish culture that need to be investigated further to ensure the long term sustainability of the industry. For example, different aspects of carrying capacity need further investigation. Other factors pertinent to site selection such as the optimum distance between farms should also be explored and better understood to avoid the effects of accumulative impacts and help avoid the spread of diseases and sea lice. Additionally some space will also need to be set aside for other activities such as navigation to occur between the culture sites. In this study one of the criteria built into the social-infrastructure sub-model was the distance between aquaculture sites. However there were difficulties when creating this criterion. When it was researched it was found that the distance left between farms varies greatly depending on the country, environmental characteristics, and the regulations and guidelines used. It was therefore the case that with this criterion and several of the other criteria layers this study had to use all the information gathered to make an informed decisions when creating the criterion layers.

In the future it is proposed by the Scottish Government that multi-trophic aquaculture is to be promoted and developed in Scotland. The aim of this new type of enterprise is to enhance culture production levels and lessen environmental impacts by farming two or more species at the same site. Multi-trophic aquaculture has already been demonstrated as being a viable option by several studies including Parsons et al. (2005) and Young et al. (2005). Integrating species such as shellfish and salmon or shellfish and seaweed can result in negating pronounced shifts in coastal processes. This is largely because the waste from one species becomes a resource for the others. This type of culture system is likely to be very applicable in Scotland and could result in more areas being suitable found to be suitable for this type of culture than have been identified solely for finfish. However, it would require further improvements and modifications to this site selection model in order to define the appropriate proportions between different co-culture organisms.

Site selection analysis as carried out by this study would benefit from further data improvements. It is already well known that other environmental criteria such as; dissolved oxygen, salinity, pH etc. are able to significantly influence finfish growth and survival. Furthermore they are also recognised as being extremely important when estimating the capabilities of the site to sustain production levels.

6.7 Conclusion

To summarise, this study demonstrated the use of GIS to model site selection for finfish aquaculture in Scotland based on certain important criteria and produced results that were deemed acceptable. GIS is a particularly useful tool for facilitating the decision making process for coastal planners in relation to aquaculture, allowing for the optimum use of natural resources. The predominant advantages of using GIS are the ability to update, integrate and analyse data and to easily be able to generate new results when better quality data becomes available. Implementation of a final decision must incorporate socio-economic factors as well as cultural and environmental factors which will allow coastal planners to make better informed decisions. In the past management of coastal resources, including aquaculture has given little consideration to the view of stakeholders. Therefore in the future this research hopes to involve stakeholders within the selection and weighting of the criteria when developing this model further. This we view as an important step towards the acceptability acceptance and success of sustainable management of finfish aquaculture in Scotland.

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Chapter 7
Shellfish Aquaculture Site Selection Model

7.1 Shellfish Culture

There are many different species used in aquaculture; however the most commonly farmed bivalve groups are oysters, clams and mussels (Dumbauld et al., 2009). Bivalves are most often cultured in brackish waters along more sheltered coastlines and bays (Diana, 2009). Adult broodstocks are often induced to spawn in hatchery facilities, where larvae are fed cultured phytoplankton until they reach a settlement stage at which point they are encouraged to attach to a substrate and are then moved out into coastal growing sites. Unlike the faster growth rates of popular finfish species, bivalve crops can often take between 1-6 years to mature to harvestable size but this is very dependent on site location, farming methods and culture species (Dumbauld et al., 2009). What makes bivalve culture perhaps more 'environmentally friendly' than finfish or crustacean culture, is that, as with seaweeds, it is predominantly carried out using far less intensive, and therefore less environmentally invasive, techniques (Diana, 2009). This said, bivalve culture, as with finfish culture can still be conducted in both an intensive (high densities and strong intervention) or extensive (low densities and low intervention) manner and this will of course influence the level of environmental impact individual sites will have on their environment.

Bivalves can be cultured in a number of ways; bottom culture, floating bags, rack systems, long lines, rafts and trays (Dumbauld et al., 2009). In general, all bivalve culture techniques can be divided into two groups: bottom and off-bottom methods (Pittenger et al., 2007). They may also be cultured intertidally, however, given the scope of this research these techniques will not be considered within this study. Instead this work will focus on culture techniques within the water column as harvesting off longlines or rafts has proven to have minimal environmental effects in comparison to harvesting from bottom systems (Goldburg et al., 2001). Off-bottom culture systems requires specialised apparatus such as cages, nets, bags and ropes (Pittenger et al., 2007) that enables the crop to be suspended within the water column, enabling the molluscs to access enhanced water circulation and therefore food supplies (Gibb, 2009). In the case of long line culture, species such as mussels are suspended in the top 10-15m of water (Christensen et al., 2003). Although this will be elaborated on in section 7.2, it is important to recognise that mussels and any other bivalves grown using this particular technique are consuming the particulate matter, phytoplankton and zooplankton found within the water column (McKindsey et al., 2006) therefore water quality is integral to their growth. In terms of environmental impact, this means that unlike finfish culture systems that require a feeding input and therefore the addition of nutrients to their aquatic environment, bivalve culture does not necessitate additional feeding and therefore reduces potential impact levels.

In addition to the lower impacts associated with bivalve culture compared to finfish production, the filter-feeding habit of the species can help control levels of plankton and thus potentially significantly improve an ecosystems' water quality (Goldburg et al., 2001). One potentially downside however, is that some of the organic matter they remove from the water column is excreted as ammonia and other amino-bound faeces or pseudo faeces. These are rejected particles that are wrapped in mucus that are expelled without having passed through the digestive system. Importantly, both faeces and pseudo-faeces have been found to quickly sink to the benthos bellow culture lines where they are incorporated into the sediment contributing organic matter, nitrogen and phosphorus to the system. As such bivalves, to a lesser degree perhaps, also have the potential to increase the organic material in the vicinity of farms (McKindsey et al., 2006; Dumbauld et al., 2009). There have been some instances where bivalve aquaculture enterprises have had a detrimental effect on their environment, through depriving wild shellfish species of food, altering the structure of planktonic communities and through deposition of their faeces and pseudo-faeces causing hypoxic benthic conditions (Goldburg et al., 2001).

7.1.1 Shellfish Aquaculture in Scotland

In Scotland there are five species of bivalves cultivated (here on referred to as shellfish for the purpose of this study), these are: mussels (*Mytilus edulis*), Pacific oysters (*Crassostrea gigas*), King scallops (*Pecten maximus*), Queen scallops (*Chlamys opercularis*) and Flat or European oysters (*Ostrea edulis*). However production is dominated by the mussel culture industry, the primary mussel growth areas are in Shetland and Strathclyde region (Smayda, 2006). Another area that has seen growth in its shellfish production over the past few decades has been the West coast of Scotland. This area is deemed very suitable for development of shellfish farming due to the presence of many sea lochs, inlets and islands which offer shelter and in many areas an environment almost free from pollution (Stirling and Okumus, 1995).

Shellfish aquaculture is usually operated in a far more traditional manner in comparison with finfish farms. Owners and staff are more likely to be residents of the local communities on the islands and around the shore of lochs where the farms are sited (The Highland Council 2011). The growth that has been seen in areas such as the West coast is seen by the government as a positive sign for the rural economy. Even more encouraging is the fact that shellfish cultivation is projected to continue to increase at least over the short-term particularly mussels and Pacific oysters (Smayda 2006). It appears to be a particular growth area of aquaculture, this is perhaps most likely due to the fact that the sector utilises the natural processing by filter feeders of the base of the food chain (Sequeira et al., 2008).

In Scotland *Mytilus edulis* are mostly cultured using floating rafts and longline systems, the mussel seeds used for suspended culture are obtained from natural settlement on spat collection ropes that hang from the rafts, longlines and salmon cages. The attached spat then continue to grow on the ropes suspended from longlines or rafts until marketable (Okumus and Stirling, 1998). King and Queen scallop cultivation also depends on natural spat settlement which is then on-grown in pearl and lantern nets suspended from longlines (Smayda 2006). These different production systems will be discussed in more detail in the following section. However, it should be noted that because the diversity associated with Scotland’s marine and coastal waters it is mostly the bathymetry of farm sites that dictates the type of culture system that is used and potentially the species of cultured organisms. For example, depth, in conjunction with turbidity and to a lesser extent light, may affect chlorophyll concentrations i.e. the amount of food available to a cultured organism at any given depth (Silva et al., 2011) and some species will be better suited to being cultured at certain depths.

The quality of farmed bivalves, which are sessile and rely on naturally supplied particulate organic matter (POM), is not affected by the textural and dietary issues which can occur in cultivated finfish such as salmon (Sequeira et al., 2008). Another difference between fin and shellfish cultivation is the heightened vulnerability of shellfish to naturally occurring blooms of indigenous harmful species and phytotoxin accumulation as a result of their filter feeding and the large filtration volumes processed (Smayda 2006). Fin and shellfish cultivation both impact the benthos and water column through their production of faecal and pseudo-faecal (by bivalves) waste.

Most shellfish farms have little environmental impact; however, there are some cases where, because of their location, or because of the techniques being used, significant environmental impacts can occur. Discharges from shellfish farms unlike with finfish are not subject to the Environmental Impact Assessment (Scotland) Regulations 2011 (EIA) or controlled by CAR (Controlled Activities Regulations), so any negative effects must primarily be taken into account at the pre-planning and planning application stage (SEPA 2012). Concerns regarding shellfish aquaculture are also reflected in legislation such as the E.U. Habitats Directive (92/43/EEC) and the E.U. Biodiversity Strategy and in more broader terms are covered by the United Nations Convention on the Law of the Sea (UNCLOS) (Sequeira et al., 2008). Furthermore the Shellfish Waters Directive 2006/113/EC has also been adopted to protect and improve the water quality in areas where shellfish are grown.

There are also no locational guidelines available to direct the development of shellfish farms. Developers usually propose shellfish farms within shellfish growing areas or harvesting areas in order to utilise the good water quality (SEPA 2012). This has also meant that in some areas the density of shellfish culture is such that it has resulted in reduced growth of shellfish and lower product yield, often linked to limitations on the supply of organic matter and phytoplankton (Grant et al., 2007).

Environmental modifications in shellfish-growing areas have been extensively documented and include the impact of over-exploitation and pollution on the cultivated species (Sequeira et al., 2008). Reports have indicated that there are varying levels of effects from shellfish farming activities on the benthic environment (Crawford et al., 2003). The magnitude of these impacts can be influenced by the dispersion of waste material from the farm and also by the assimilative capacity of the receiving sediments (Longdill et al., 2008). Organic enrichment of the seabed from shellfish farming are generally assumed to be small and far less then that caused by finfish farming (Crawford et al., 2003). However the build up of organic and other waste material (e.g. faeces, pseudo-faeces, shell-litter, ammonia) beneath and surrounding shellfish aquaculture sites can potentially lead to distinct changes in nutrient cycling characteristics, benthic species assemblages, and benthic bio-diversity (Longdill et al., 2008). As well as increased sediment deposition changes in the benthic community composition may also occur through other mechanisms such as excessive portioning of food resources and competition for space (Sequeira et al., 2008). The sustainable management of shellfish aquaculture must address some of these key concepts mentioned that all relate to the carrying capacity of the site and should also include the harmonious co-existence of cultured and naturally occurring (hence wild) species (Sequeira et al., 2008).

7.1.2 Production Systems

Most shellfish culturing depends on the use of natural spat because of the generally abundant supply but in some instances hatcheries are used to supply these early life cycle stages (see Figure 7.1). For example in Scotland there is only one commercial oyster spat producer located in Argyll, and this has the added advantage of producing spat that are free from diseases such as the Herpes virus that has affected oyster production in many parts of Western Europe (Ardtoe Marine Laboratory, 2011). Certain species, such as mussels, can be characterised by their high fecundity and mobile free living larval stages which greatly aid their dispersal. With species such as this it greatly influences the culture techniques employed but often spat collectors favour using polythene and palm-coconut fibre ropes. Hatchery production is accomplished by conditioning adult males through food and temperature control and then subjecting them to either a thermal shock to induce spawning or by stripping them. The larvae are fed and allowed to grow until they are ready to be placed onto ropes, which usually takes between 13-15 days, when they reach around 10mm in length they are then moved outdoors into grow-out systems.

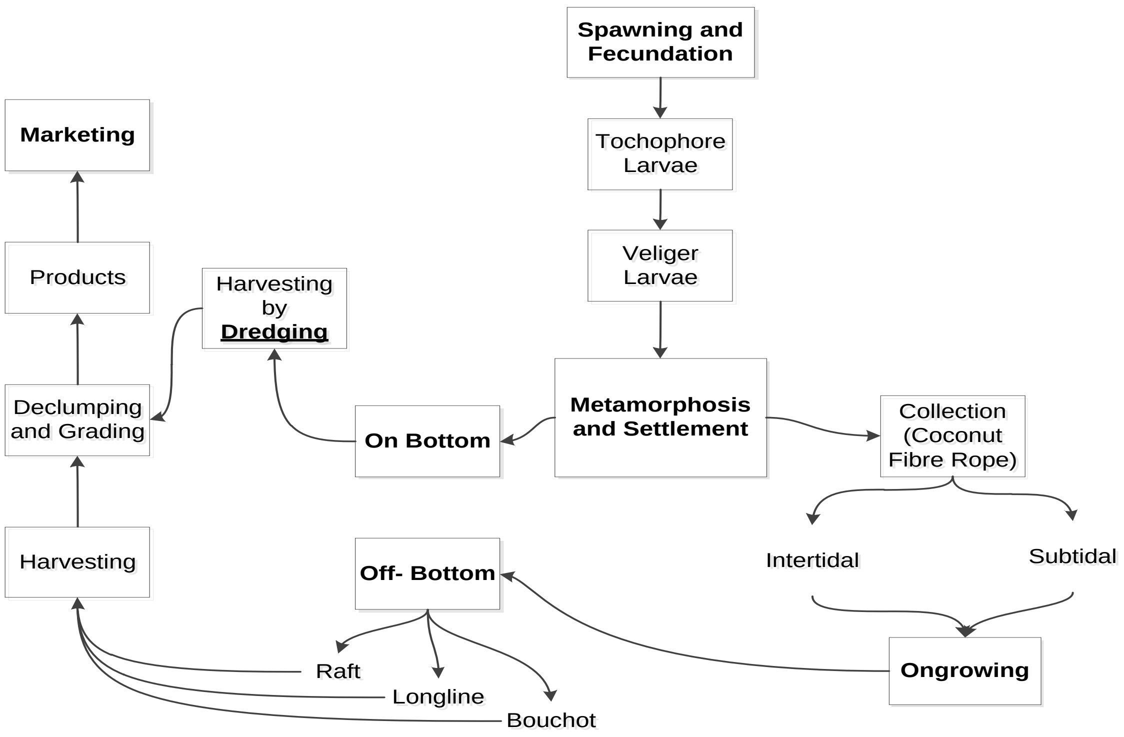

Figure 13 - Example of a typical bivalve production system.

Most farmed shellfish species have been selected for culture partly due to their fast growth rates which ensures that a marketable product can be reared in the shortest possible time period. Certain species, for example mussels, are also popular as they facilitate the ease of farming further by naturally being able to attach themselves to substrates provided via their byssus threads. In particular this can help with the ongrowing part of production. There are several methods used for ongrowing shellfish including tidal (on-bottom and bouchot) and subtidal (on-bottom, raft and longlines).

7.2 Methods

7.2.1 Study Area

This application of a Multi-Criteria site selection model (as with the previous finfish application), was carried out on both Scotland's territorial seas (from the coast out to 12 nautical miles) and for offshore waters (12 to 200nm). The total Scottish sea area out to the 200nm limit encompasses around 78,772km^2.

This study was developed specifically for identifying suitable long-line aquaculture sites for mussels within these waters; however suitable sites should only be given further consideration if they are situated in Northern waters and those to the West of the mainland in line with Planning Policy guidelines about siting farms on the East coast. However, once again, because the pre-consultation draft of the National Marine Plan covers both inshore area and offshore waters (out to 200nm), and the aquaculture industry is looking to expand into offshore waters in the future, given data availability, this study extended the site selection model out to cover this offshore area also, therefore the whole of the Scottish marine area has been analysed.

7.2.2 Site Selection Criteria

Mytilus edulis, or the Blue mussel is the main shellfish species currently being cultured within Scottish waters and is therefore the target species being used for the development of this model. The criteria chosen for use in this study can be viewed in Table 7.1, and have all been chosen for the target species *M. edulis,* it is recognised that for other species and culture techniques different criteria may be more appropriate.

The Blue mussel is widely distributed around the world mainly due to its abilities to withstand wide fluctuations in salinity, desiccation, temperature and oxygen levels. This species is highly tolerant of a wide range of environmental conditions, amongst other things it is considered euryhaline tolerating both marine and brackish waters, although it does not thrive in waters of less than 15 PSU and its growth is reduced below 18PSU. *M. edulis* is also eurythermal, being well acclimatised to water between 5 and 20 °C, thus making it well suited to Scottish waters. Although Blue mussels can live between 18-24 years in the wild, cultured mussels are often produced in less than 2 years.

All forms of aquaculture be it finfish, shellfish or algae rely on good water quality to support the growth of the species concerned (The Highland Council 2011). Open coastal regions are often popular locations for aquaculture as they are not subject to a high degree of salinity variation or to depressed dissolved oxygen concentrations which in particular can inhibit shellfish growth (Longdill et al., 2008) However, it has been well documented that other factors such sea temperature, food availability (measured as chlorophyll a), suspended sediment and bathymetry can also significantly influence bivalve growth (Radiarta et al., 2008). This is most likely due to growth of suspension feeding bivalves such as mussels as oysters being controlled by food availability and therefore indirectly phytoplankton dynamics. Therefore optimal shellfish aquaculture sites can primarily be characterised by having relatively high phytoplankton concentrations and therefore high productivity (Longdill et al., 2008). Water circulation not only delivers phytoplankton and other food particles to bivalves in culture it is also known to be beneficial as it supplies oxygen and aids in the dissipation of waste products (Silva et al., 2011). Several authors have correlated bivalve growth to current speed, but differ in their conclusions. Longdill et al. (2008) suggested that optimal aquaculture sites could be characterised by rapid flushing rates and efficient water exchange, i.e. persistently ‘high’ current speeds in open coast locations, through the infrastructural issues obviously limit areas of extreme hydrodynamism. However, other authors have also pointed out that slack water and strong currents or wave action can also have detrimental effects (Silva et al., 2011). In direct contrast Vincenzi et al. (2006) state that optimal sites for culture are usually characterised by weak water currents that allow for nutrient circulation. What must be considered further is the culture technique being employed and this may explain the discrepancies in these studies as off-bottom cultures will be far more likely to be affected by sedimentation brought about by high current velocity. Furthermore this will also be affected by the type of sediment located at the farm site. For example, rearing sites with high sand content have been found to be better for clam farming than muddy bottom sites in terms of both growth speed, maximum attainable size and success of juvenile settlement (Vincenzi et al., 2006). In contrast soft sediment habitats, comprised of fine, silty and muddy sediments with low organic content, are determined to be the most suitable benthic environments above which to site suspended shellfish aquaculture (Silva et al., 2011).

There are a number of different factors including those physical and biological factors that have just been outlined that will ultimately affect the suitability of a shellfish aquaculture site however another group of factors that must also be considered are those related to socio-economic influences (Buitrago et al., 2005). Data relating to habitat distribution, shellfish harvesting areas, navigational channels and transportation routes should all be considered and included where possible within a site selection appraisal (Arnold et al., 2000). For example, when siting shellfish farms it will be particularly important to ensure that developments are not close to any significant effluent discharges, including discharges from septic tanks (The Highland Council 2011) so as not to risk contamination of the product. Other perhaps less imperative social issues should also be considered such as avoidance of naturally occurring shellfish beds so as to reduce conflict with local fisherman (Arnold et al., 2000).

Table 7.1 - Criteria used for Scottish shellfish aquaculture site selection

Submodel	Criteria	Interpretation of Criteria	Data Source
Biophysical	Water Depth	Water depths in excess of 12m at extreme low water on spring tides are optimal, although shallower sites can be utilised.	GEBCO
	Current Velocity	50-100 cm sec is acceptable to provide sufficient food although less is also acceptable. At >70cm/sec resultant suspended sediment begins to reduce feeding rate.	IMR-Norway
	Chlorophyll a	Availability of natural food (phytoplankton). Levels above 10 mg/ m^3 are eutrophic conditions.(Tett et al., 2002)	SAHFOS
	Temperature	Above 8-9 degrees Celsius for much of the year are preferable for fastest growth.	NOAA
	Sediment Type	Farms located over highly oxygenated sediment (those with larger grain size) are likely to increase benthic productivity.	JNCC
	Turbidity	<50mg/l any more than this and feeding rate is reduced	MSS
Social Infrastructure	Distance from Beaches and Heritage Sites	Pollution threat and Viewshed	MSS,RCHAMS Historic Scotland
	Designated Protected Areas	Dependant on site designation aquaculture may be permitted within this area	SNH and JNCC
	Distance from Aquaculture Sites	Pollution, Navigation, Spread of Disease and Potential Accumulative Effects of Competition for Natural Resources	Crown Estate
	Distance from Towns and Transport Links	Support Services and Transport to Markets	OS data
	Distance from Important Fishing Grounds	Hazard, avoidance of impact on important wild fishing stocks and sites	MSS
	Distance from Small Craft Facilities	Pollution and Navigation	Edina
Constraints	Distance from Pollution/ Discharge Sites and Industrial Areas	Pollution and Disease threat	SEPA and Variety of Sources
	Salmon River Mouths	Safe distance to ensure that wild salmonid migrations will not be displaced by farms	MSS
	Predators: Pinnipeds/Birds	Avoidance of stock loss and damage to infrastructure	MSS and DEFRA
	Species Sensitive to Aquaculture (PMFs)	Safe distance to ensure sensitive species are not put under stress	MSS

7.2.3 Database Generation and the Weighting Procedure

This model for identifying suitable sites for sustainable shellfish culture around Scotland was built based on a hierarchical structure (also sometimes referred to as value structure). The hierarchical structure allows for the breakdown of the criteria being utilised into smaller groups (or sub-models). At the highest levels are the most general of the objectives which can be further defined at still lower levels, while the lowest levels of hierarchy are attributes; see Figure 7.2. This study identified 16 criteria according to the basic requisites for shellfish aquaculture in Scotland. These criteria were organised into three sub-models (Biophysical, Social-Infrastructure and Constraint) and represented as either factors or constraints (contributing or restricting criteria).

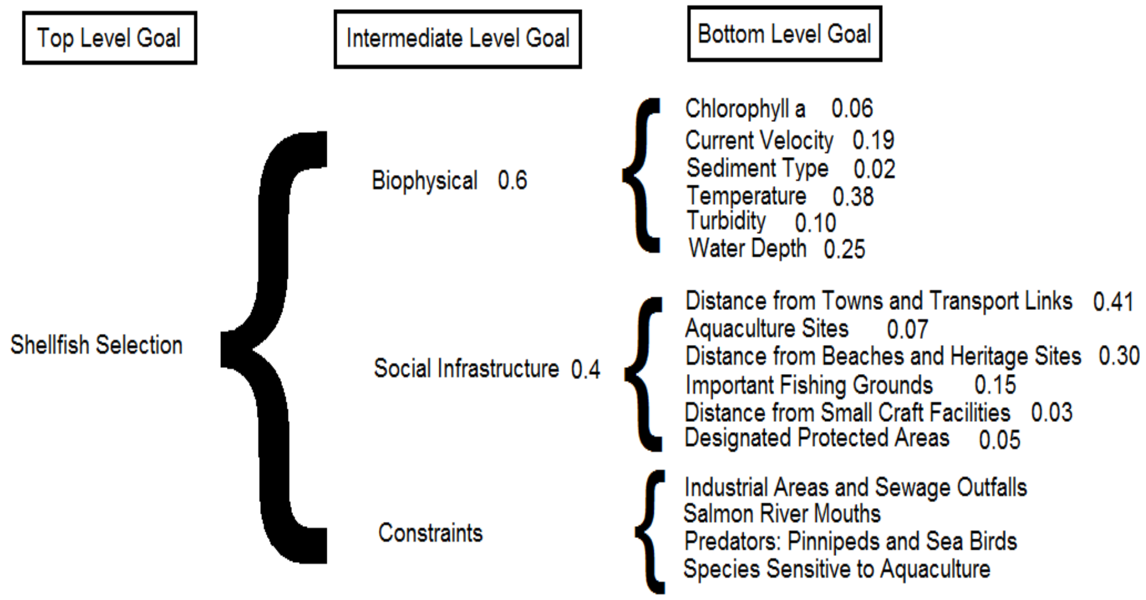

Figure 14 - A hierarchical modelling scheme to identify suitable sites for shellfish aquaculture in Scotland.

All data files gathered were integrated into a spatial database, where they all required some form of manipulation and reclassification to create a standard scoring method. Scoring of raw data was based on the requirements of the shellfish species cultured; in this instance *M. edulis* longlines were used as a benchmark culture system. A suitability score for each criterion was established according to Pérez et al. (2005) using a scoring system from 1 to 8, with 8 being the most suitable and 1 being the least suitable for developing shellfish culture. See Appendix 7, Tables A 7.0 and A7.1, for details of scores attributed to criteria values.

The next step was to ascertain a weighting for each criterion and factor. As discussed in the previous chapter, a variety of weighting techniques exist, however the pairwise comparison method developed by Saaty (1977) in the context of the Analytical Hierarchy Process (AHP) was used to develop a set of relative weights for each parameter in this model. Consequently, information regarding the relative importance of each criterion was required. At this point, decision-makers preferences regarding the evaluation criteria were incorporated into the decision model. The preferences were typically defined as a value assigned to an evaluation criterion that indicates its importance in relation to the other criterion under consideration. Criteria were rated according to an extensive literature review based on their relative importance using the pairwise comparison method (see Appendix 7 Tables A 7.2 and A 7.3)

The construction of pairwise comparison matrices and the extraction of weight values by using a principle eigenvector is central to the AHP design. With a pairwise comparison matrix for *n* criteria, the decision makers indicate how much importance criteria *i* has then criteria *j.* The 'verbal' intensity of importance is then translated into numbers: 1 for equal importance, 3 for moderate importance, 5 for strong importance, 7 for very strong importance and 9 for extreme importance; reciprocals for any inverse judgements are also used. For example if the decision maker decides that criterion *x* is of equal importance to criterion *y* the matrix will contain a value of $a_{xy} = 1 = a_{yx.}$ If they think that *y* is extremely more important than criterion *w* the value will be $a_{yw} = 9$; $a_{wy} = 1/9$; therefore criterion *x* should also be extremely more important than criterion *w* ($a_{xw} = 9$; $a_{wx} = 1/9$), see Appendix 7, Tables A 7.2 and A 7.3, for example.

Using Saaty's method allows for the consistency of the decision making process to be taken into the account also. This is important because unfortunately the decision maker is unable to express consistent preferences in the case of several criteria. In an ideal scenario the matrix (*A*) should be totally consistent and can be given a rank (*A*) = 1 and λ = *n,* where *n* equals the number of criteria. In this instance the following equation shows vector *x* representing the weights we are looking for:

$$A \times x \ = n \ \times x \ (where\ x\ is\ the\ Eigenvector\ of\ A)$$

However in non-consistent cases, (such as in this study), which are more common, the comparison matrix A may be considered as a perturbation of the previous, consistent example. Then the a_{ij} changes only slightly, with the *eigenvalues* changing in a similar fashion. Moreover, the maximum *eigenvalue* (λ_{max}) is closer to *n* while the remaining (possible) *eigenvalues* are closer to zero. Thus to extrapolate weights we are looking for the *eigenvector* which corresponds to the maximum *eigenvalue* (λ_{max}). In order to obtain weight values from the calculated *eigenvector* the values have to be normalised by the formula below (all the weights have to sum up to 1).

$$w_j = \frac{\widetilde{w}_j}{\sum_{i=l}^{n} \widetilde{w_\iota}}$$

The consistency index (CI) is calculated as follows:

$$Consistency\ Ratio(CR) = \frac{Consistency\ Index\ (CI)}{Random\ Consistency\ Index\ (RCI)}$$

$$CI = \frac{(\lambda max - n)}{n - 1}$$

$$\lambda\ \mathrm{max} = principle\ eigenvector$$

The consistency ratio (CR) is also calculated as the ratio of consistency index and random consistency index (RCI). The RCI is the random index representing the consistency of a randomly generated pairwise comparison matrix, it is derived as an average random consistency index see Table 7.2.

Table 7.2 - Random Consistency Indices for different numbers of criteria (n)

N	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

The random consistency index was calculated from a sample of 500 randomly generated matrices based on the AHP scale, see Table 7.3. If CR (A) ≤ 0.1, then the pairwise comparison matrix can be considered to be consistent and therefore acceptable as it demonstrates good and consistent judgement (Saaty, 1977). When the CR (A) is more than 0.1, the matrix needs to be re-evaluated and improved. The value of RCI depends on the number of criteria being compared.

Table 7.3 - Scale of relative importance for pair-wise comparison

1	**Same Importance**
2	Slightly More Importance
3	Weakly More Important
4	Weakly to Moderately More Important
5	Moderately More Important
6	Moderately to Strongly More Important
7	Strongly More Important
8	Greatly More Important
9	Absolutely More Important

By making a pair-wise comparison between each criterion, relative weights were developed that allowed us to account for the changes in the range of variation for each criterion and different degrees of importance that were attributed to these ranges in variation (Radiarta et al., 2008). .

7.2.4 Constructing the GIS Model

The model of site suitability has been constructed based on the MCE procedure known as weighted linear combination (WLC), in which the weight of relative importance assigned to each criterion and a total score, $V(x_i)$, is then obtained for each of the criteria by multiplying the weight assigned by the scale value for that particular criteria, and summing the product over all parameters as follows:

$$V(x_i) = \sum_j w_j r_{ij}$$

where w_j is a normalised weight, such that $\sum w_j = 1$ and r_{ij} is the attribute transformed into the comparable scale. The weights represent the relative importance of the attributes. The most preferred alternative is selected by identifying the maximum value of $V(x_i)$ for $i = 1, 2, , .., m$.

The final suitability map was created by averaging the two different sub-models. These models were derived using the different relative importance weight scenarios for Bio-physical and Social-Infrastructure sub-models, see Figure 7.3 and Appendix 7, Table A 7.4, to firstly prioritise the Biophysical sub-model and then the Socio-Infrastructure sub-model. The weightings for the sub-models were once again produced by using a pairwise comparison matrix.

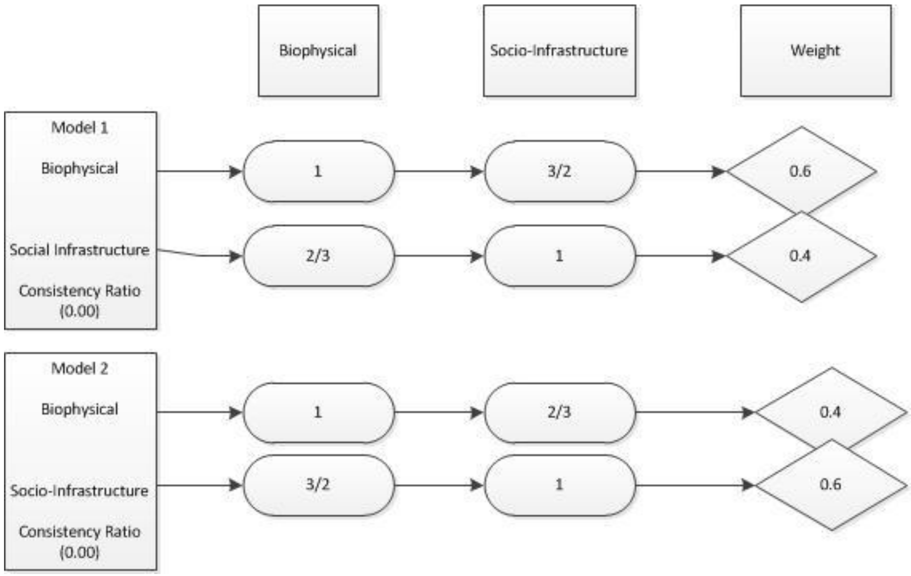

Figure 7.3 - A pairwise comparison matrix for assessing the relative importance of sub-models to final site selection model for shellfish aquaculture in Scotland.

The basic purpose of this analysis was to find out the influence of different criteria weights on the spatial pattern of the suitable sites. The relative importance weight scenarios were assigned according to the situation not only of the present day but also in the long run. It was therefore possible to change the weights of different preference criteria. For each scenario, a different decision factor is given the greatest importance. The Social-Infrastructure>Biophysical set were used as model 1 and the Biophysical>Social-Infrastructure set as model 2. This analysis can be particularly useful in situations where uncertainties exist in the definition of the importance of different factors (sub-model). In many instances it is also important to know how the result will change as a result of changing the weighting.

7.2.5 Results

Suitability maps for each parameter were made for the whole of the Scottish sea area (over 472,000 km^2) and the area distribution of suitability scores for each criterion was also calculated. The results for the 12 criteria (as factors) are presented separately in two sub-models; Biophysical and Social-Infrastructure, allowing for a more comprehensive analysis. The classification of surface areas for each criterion are summarised in Table 7.4, the corresponding spatial distributions of suitability are shown in Figures A 7.0- A 7.5 in Appendix 7. The spatial distribution of suitable sites for the sub-models can be seen in Figures 7.4 and 7.5.

Table 7.4 - Different suitability levels (expressed as a percentage of the total potential areas) for Shellfish aquaculture in Scotland.

Factors/Criteria	Suitability Score							
	1	2	3	4	5	6	7	8
Biophysical								
Water Depth	81	3.7	2	2	1.8	1.5	2	6
Current Velocity	83.6	1.8	1.6	1.7	2.9	3.1	2	3.3
Chlorophyll a	13	0.1		2.7	1.3	2.3	15.6	65
Temperature			2.6	0.3	0.3	0.4	0.4	96
Sediment Type	11.7	0.5	7.9	42.8	0.2	23	5	8.9
Turbidity	94.7	0.05	0.07	0.04	0.03		0.06	5.05
Sub-Overall	0.17	2.96	70.9	8.36	2.96	2.43	14.9	0.09
Social-Infrastructure								
Distance from Beaches and Natural/Social Heritage Sites	17.2	11.7	8	4.7	4	2.5	3.2	48.7
Distance from Protected Marine Areas	11.2	8.3	7.3	6	6	3.8	5	52.4
Distance from Aquaculture	2.6	3.7	3.5	3.2	3.7	2.7	3.6	77
Distance to Towns and Transport Links	3.6	4.8	4.2	3.2	3.5	2.6	3.4	74.7
Distance from Important Commercial Fishing Grounds	13	9.6	8.6	7	7.8	5.1	6.5	42.4
Distance from Small Craft Facilities	2	3.2	3.9	3.7	3.8	2.6	3.5	77.3
Sub-Overall	5.3	6.4	5.4	5.3	9.7	11.7	12.5	43.7
Overall Model 1		0.2	4.28	11.46	15.24	16.7	52.12	
Overall Model 2			0.2	8.88	24.8	27.33	38.76	
Overall Suitability		0.04	0.95	4.83	13.26	18.57	29.42	

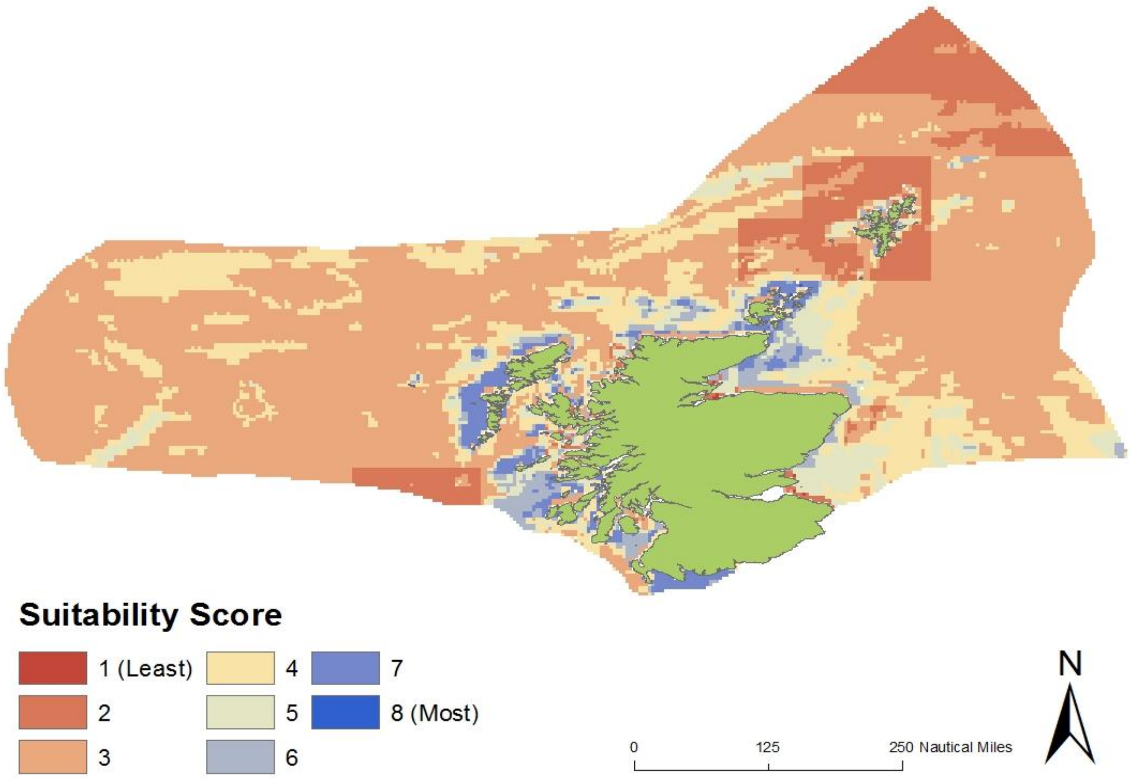

Figure 7.4 - Suitability map of Biophysical sub-model generated for Shellfish Aquaculture in Scotland.

The potential sites should have appropriate biophysical conditions including both biological habitat and physical environmental parameters in order to provide the optimum conditions for growth and survival of the mussels being cultured. In our model, bathymetry, current velocity, chlorophyll, water temperature, sediment type and turbidity were the criteria used to examine biophysical characteristics. Approximately 17.5% of the potential area was identified as having a score between 6 and 8 (most suitable), and this area was located close to inner shoreline of the mainland and in particular along the West coast, the Outer Hebrides and Orkney, see Figure 7.4 above. Approximately 65-96% of the potential area has scores of 8 (most suitable) for shellfish aquaculture in terms of sea temperature and chlorophyll a concentration. Areas that had the most suitable sediment type (score 8), accounted for almost 9% while the most suitable locations in terms of current velocity was almost a third less with just over 3% coverage. Areas with the most suitable water depth were again quite limiting with only 6% of the sea area being most suitable as were areas with the most suitable turbidity only accounting for 5%.See Table 7.4 for further details. This analysis allowed for identification of different relative limitations between the various factors within the Biophysical sub-model.

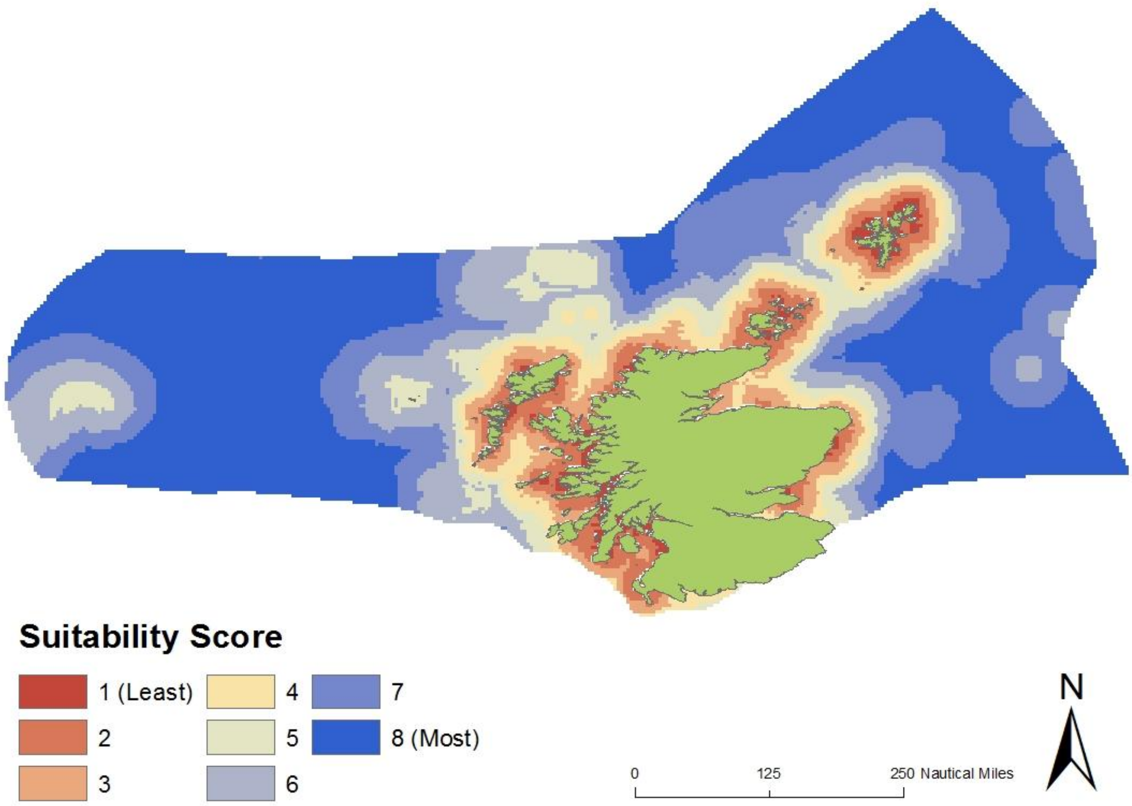

Figure 15 - Suitability map of Social-Infrastructure sub-model generated for Shellfish Aquaculture in Scotland.

Social-Infrastructure layers can be used to support improvement in product quality, for example by placing a farm near to good transport links which would speed up the product delivery process ensuring a fresher, potentially higher value, product and could also aid turnover rates between farms and processing plants. Social-Infrastructure layers such as distance to transport links and small craft facilities for example, are all relatively well supported for shellfish aquaculture development throughout Scotland (see Table 7.4). Almost 44% of the potential area was classified as score 8 (most suitable) for shellfish aquaculture in terms of social infrastructural factor. About 12% had a score of 7 and a further 12% had a score of 6. This amounts to approximately 68% of the Scottish sea area having a suitable score and then a further 20% of the potential area was classified as middle score (sum of 3, 4, and 5). The lower scores (1 and 2) made up less than 12% of the total area.

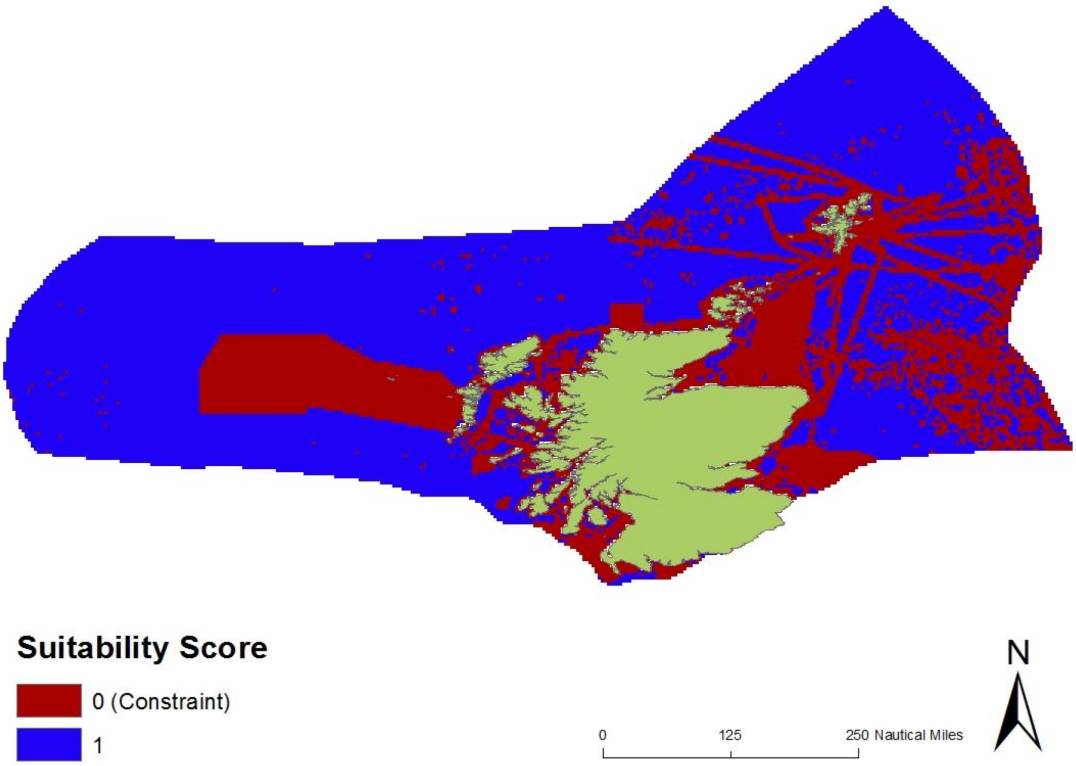

Figure 7.6 - Constraints map showing areas unsuitable for Shellfish Aquaculture

The constraints layer limits the area of suitable sites for shellfish aquaculture (see Figure 7.6). Locations that have a high concentration of legislated marine activities, waters that are near known pollution sources such as sewage outfalls, areas with known predator species, species sensitive to aquaculture and the mouths of salmon spawning rivers were all considered as constraints (score 0). They covered about 32% of the potential sea area in our site selection model.

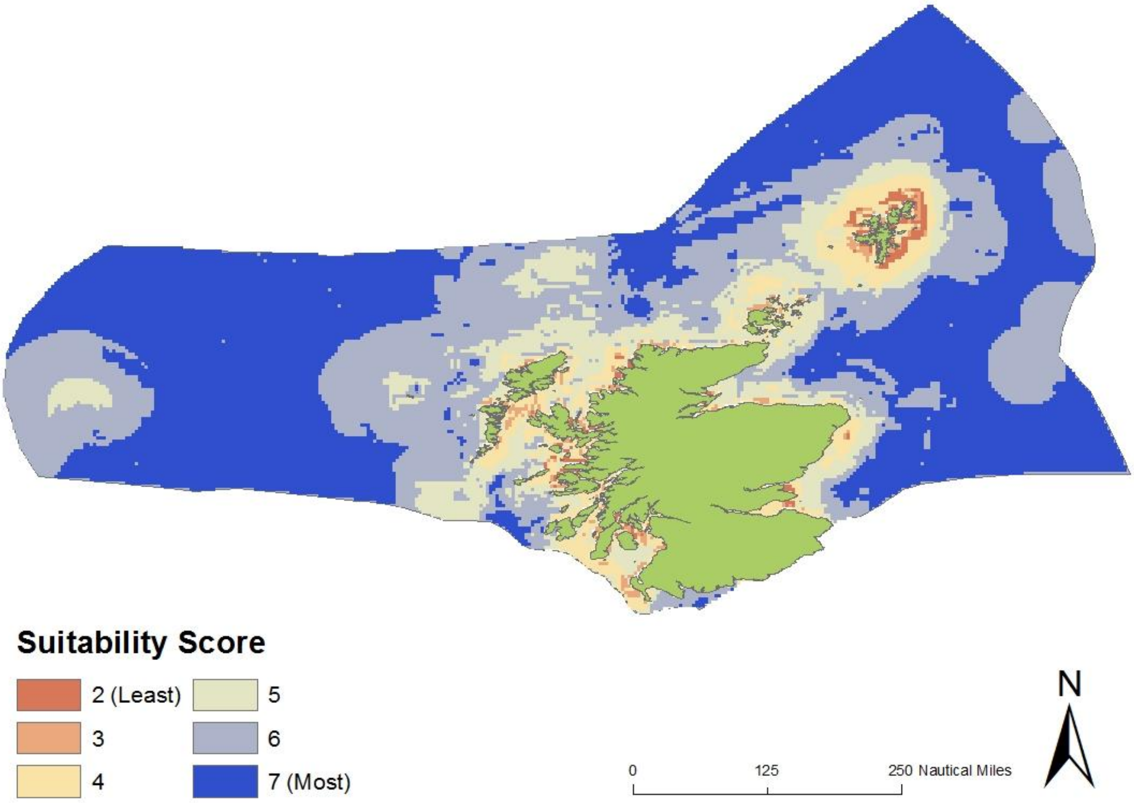

Figure 7.7 - Suitability map of model scenario 1 (Socio-Infrastructure>Biophysical)

Different relative importance weight scenarios were applied for two sub-models (Biophysical and Social-Infrastructure). This enabled the relative prioritisation of these different models to be incorporated in the process of producing the suitable area. They were also considered in order to investigate how changing the weight of various factors affected the determination of the preferred area. The different suitability scores for each model can be seen in Table 7.4, and the corresponding distributions of the suitable sites are shown in Figure 7.7 and Figure 7.8. In model 1, social-infrastructure is given the greatest relative importance (Figure 7.7). It was found that no areas were allocated a score of 8 (the most suitable), however, 52% had a score of 7. Around 32% of the potential area had scores of 5 and 6, and 16% with scores of 2, 3 and 4. There was no area identified as having the lowest score.

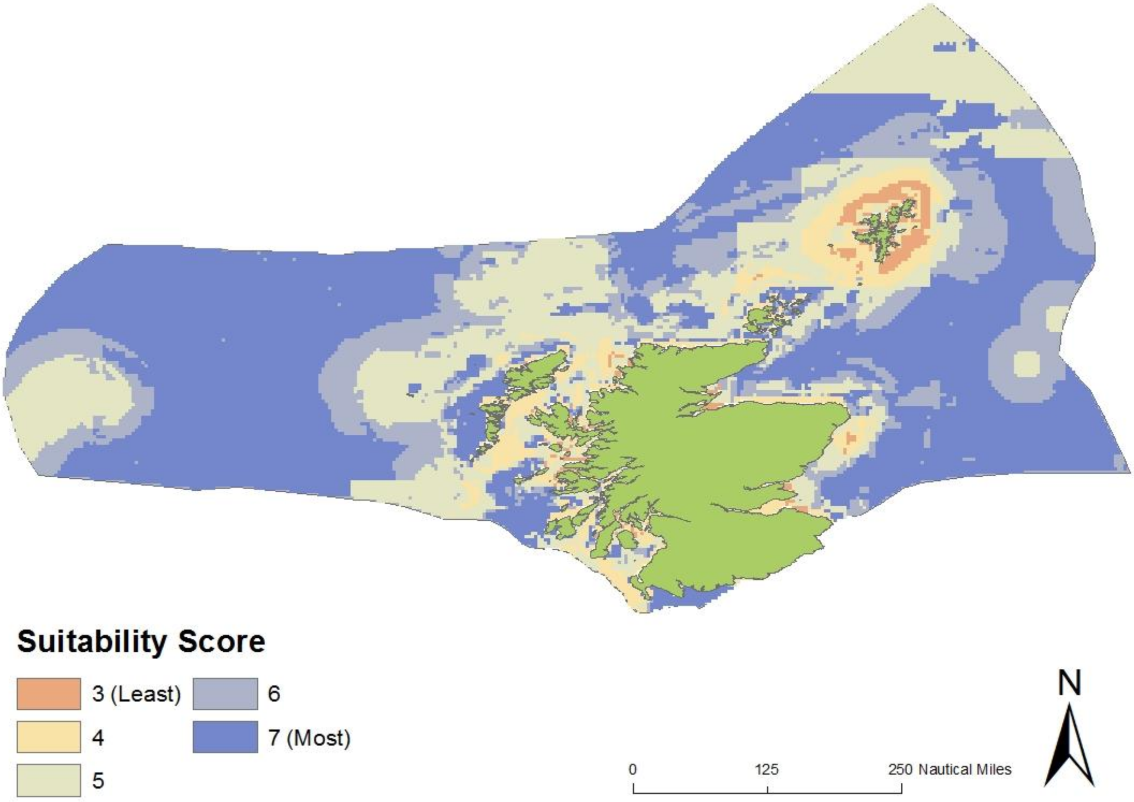

Figure 7.8 - Suitability map of model scenario 2 (Biophysical> Socio-Infrastructure

In model scenario 2, biophysical factors are given the greatest relative importance and consequently the output results were quite different (see Figure 7.8). Although again no area was identified as having a score of 1, in model 2 there was also no area allocated to score 2, and just 0.2% was allocated to score 3. Therefore these least suitable areas (scores 1, 2, 3 and 4) have decreased from 16% in Model 1 to less than 9% in Model 2. This, perhaps, can be mainly attributed to a high relative importance being placed on suitable growth factors rather than near shore activities that can often conflict with aquaculture enterprises. Furthermore, 52% was allocated to scores 5 and 6 in contrast to the 32% that was given to these scores in Model 1. However, once again no area was identified as belonging to score 8 and only 39% was found to have a score of 7, compared with 52% in Model 1. This said it is important to consider also the distribution of the areas scored as in Figure 7.8, showing model 1, the most suitable areas appear to be located further off shore in comparison to model 2 shown in Figure 7.9.

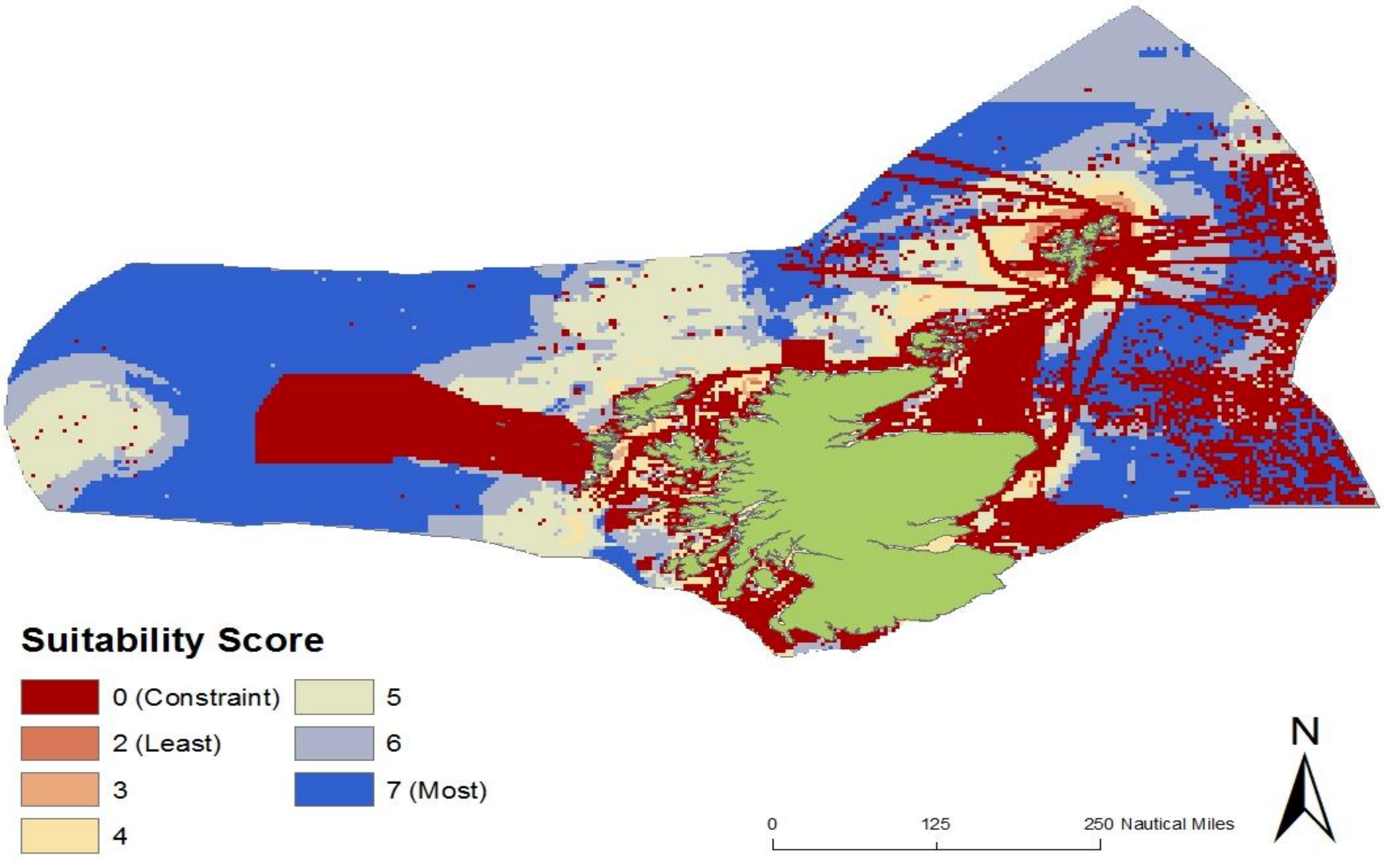

Figure 7.9 - Overall Site Selection map, with Constraints layer added, for potential Shellfish Aquaculture in Scotland.

In the final output for shellfish aquaculture site suitability (Figure 7.9) with the constraints layer applied, the model classified almost 30% of this potential area a score of 7 (in this case the most suitable). As can be seen in Figure 9 this ‘most suitable’ area is located further offshore, predominantly to the West with most of the inshore waters and areas surrounding Orkney and Shetland designated as being unsuitable by the constraints layer. This area is considered by the model to have good conditions for the criteria examined, although it should be noted that no areas were given a score of 8 and therefore considered ideal. A further 18% was given to score 6 and altogether roughly 32% of the area was ranked as being middle scoring (5 and 6), while just over 6% was identified as belonging to lower scores (2, 3 and 4). As previously mentioned 32% was accounted for by the constraints layer represented by the value 0 in Figure 7.9.

7.3 Revision of the Shellfish Model

The initial running of the shellfish site selection model in section 7.2 resulted in an output that placed most of the Scottish inshore waters (0-12nm) within its constraints layer. Therefore, since we know that there are currently successful aquaculture ventures happening within these coastal waters, it was decided that the model layout had to be revised before verification could be carried out.

7.3.1 Re-structuring the MCE model

The same model based on a hierarchical structure was once again used, however previous data layers that were used within the constraints sub-model were now moved to fall within one of the weighted sub-models. It was also decided with the inclusion of these extra criteria, that there should now be four sub-models; Physical, Biological, Social Infrastructure and Constraints (see Figure 7.10).

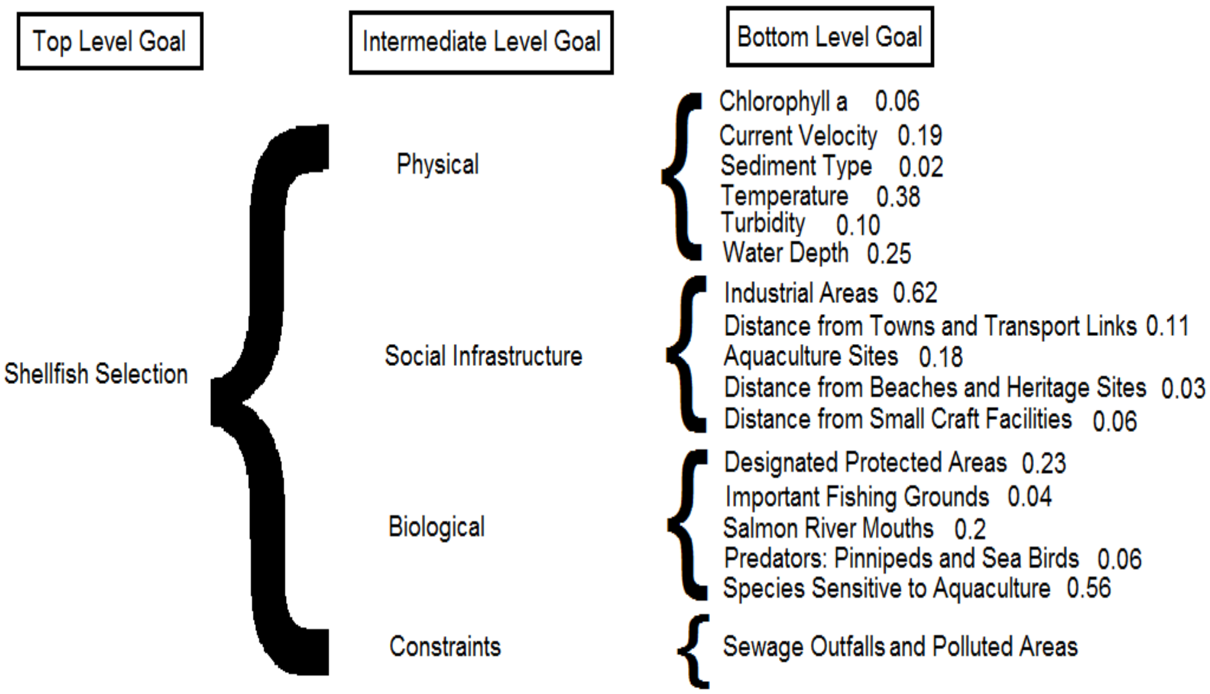

Figure 7.10 - A revised hierarchical model framework to identify suitable sites for shellfish aquaculture in Scotland

This revised model now identifies 17 criteria as being the basic requisites for shellfish aquaculture in Scotland, 16 of which fall within weighted sub-models and only 1(Polluted Areas) that falls within the Constraints model. Each of these criteria were once again given standardised scores between 1 and 8, the latter being the most suitable and 1 the least. More information on the criteria values assigned to each score can be found in Appendix 7, Table A 7.5, and once again all scoring was undertaken based on values derived from and extensive literature review.

Once again the Analytical Hierarchy Process (AHP) was used to develop a set of relative weights for each of the new parameter in this model. As for the previous models, criteria were rated according to an extensive literature review that informed the opinions of the authors in relation to the relative importance of each criterion using the pairwise comparison method (See Appendix 7, Tables A 7.6 – A 7.8)

Table 7.5 - A matrix for assessing relative importance of revised site selection model for shellfish aquaculture in Scotland

Factor requirement for assessment of finfish culture site selection	**Biological**	**Social-Infrastructure**	**Physical**
Model 1 (Physical>Social-Infrastructure>Biological	0.07	0.31	0.62
Model 2 (Social-Infrastructure>Biological>Physical)	0.31	0.62	0.07
Model 3 (Biological>Physical>Social-Infrastructure)	0.62	0.07	0.31

The revised model of site suitability was repeated using the same procedure (weighted linear combination). The new final suitability maps were created by combining the three different sub-models. These models were calculated using different relative importance weight scenarios for biological, physical and social-infrastructure sub-models (see Table 7.5 and Appendix 7, Table A 7.9). A more general purpose of this analysis was to find out the influence of increasing the number of sub-models with different criteria weights on the spatial pattern of the suitable sites. For each scenario, a different decision factor is once again given the greatest importance. The Physical>Socio-Infrastructure>Biological set were used as model 1, the Socio-Infrastructure>Biological>Physical as model 2 and the Biological>Physical>Social-Infrastructure set as model 3. This analysis can be particularly useful in situations where uncertainties exist in the definition of the importance of different factors (sub-model). In many instances it is also important to know how the result will change as a result of changing the weighting.

7.3.2 Revised Results

Again suitability maps for each parameter were made for the whole of the Scottish sea area and the area distribution of suitability scores for each criterion was also calculated. The results for the 16 criteria (as factors) is presented separately in three sub-models; biological, physical and social-infrastructure, enabling comprehensive analysis. The classification of surface areas for each criterion are summarised in Table 7.6, the corresponding spatial distributions of suitability sites are shown in Figures A 7.0 – A 7.7 in Appendix 7. The spatial distribution of suitable sites for the sub-models can be seen in Figures 7.11-7.13.

Table 7.6 - Different suitability levels (expressed as a percentage of the total potential areas) for shellfish aquaculture in Scotland.

Factors/Criteria	Suitability Score							
	1	2	3	4	5	6	7	8
Physical								
Water Depth	81	3.7	2	2	1.8	1.5	2	6
Current Velocity	83.6	1.8	1.6	1.7	2.9	3.1	2	3.3
Chlorophyll a	13	0.1		2.7	1.3	2.3	15.6	65
Temperature			2.6	0.3	0.3	0.4	0.4	96
Sediment Type	11.7	0.5	7.9	42.8	0.2	23	5	8.9
Turbidity	94.7	0.05	0.07	0.04	0.03		0.06	5.05
Sub-Overall	0.17	0.09	2.96	8.36	70.9	14.9	2.43	0.19
Biological								
Designated Protected Areas	11.2	8.3	7.3	6.0	6.0	3.8	5.0	52.4
Important Fishing Grounds	13	9.6	8.6	7	7.8	5.1	6.5	42.4
Predators	2.73	5.38	5.06	4.08	4.19	2.96	3.74	71.86
Sp. Sensitive to Aquaculture	15.78	14.10	13.32	11.8	12.58	7.87	7.31	17.24
Salmon River Mouths	0.32	0.73	1.36	3.68	1.54	2.2	1.78	88.39
Sub-Overall	1.31	7.31	11.35	14.96	18.09	14.22	11.34	21.42
Social-Infrastructure								
Distance from Beaches and Natural/Social Heritage Sites	17.2	11.7	8	4.7	4	2.5	3.2	48.7
Industrial Areas	38.5	3.6	16.9	2.9	7.0	4.6		26.5
Distance from Aquaculture Sites	2.6	3.7	3.5	3.2	3.7	3.7	3.6	77
Distance to Towns and Transport Links	3.6	4.8	4.2	3.2	3.5	2.6	3.4	74.7
Distance from Small Craft Facilities	2	3.2	3.9	3.7	3.8	2.6	3.5	77.3
Sub-Overall	0.05	2.92	8.27	35.86	15.59	5.1	7.25	24.96
Overall Model 1		0.17	6.28	41.95	37.92	13.68		
Overall Model 2	0.23	6.42	9.13	30.1	22.6	16.34	15.18	
Overall Model 3		2.83	16.66	25.59	22.29	25.32	7.31	
Overall Suitability		2.3	12.47	36.68	33.23	12.72		

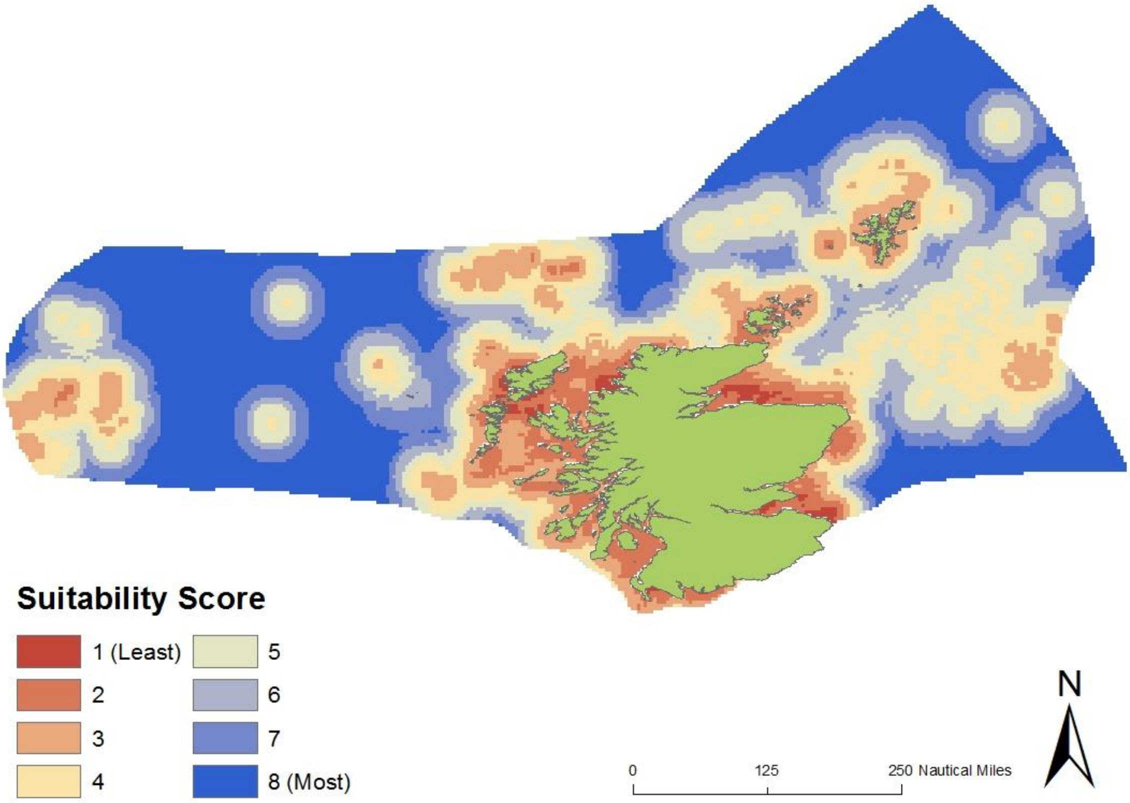

Figure 7.11- Suitability map of revised biological sub-model generated for Shellfish Aquaculture in Scotland.

Any potential sites will have to take into account the many biological variables that are present at different locations. Although considered to be a relatively low impacting form of aquaculture, mussel production can still affect wider biological communities that are present and to this end these biological factors must be given consideration during the site selection process. In our revised model, designated marine protected areas, important commercial fishing grounds, salmon river mouths, areas with known predators such as seals and seabirds and species sensitive to aquaculture were the criteria used to examine biological characteristics.

Almost 47% of the potential area was identified as having a score between 6 and 8 (most suitable), however most of this area was located further offshore, with smaller pockets to the west of the outer Hebrides, see Figure 7.11 above. Approximately 71-88% of the potential area has scores of 8 (most suitable) for shellfish aquaculture in terms of the location relative to predators and salmon river mouths. For the designated protected areas criterion almost 52% of the area was most suitable, for important fishing grounds just over 42% and species sensitive to aquaculture 17.24%. See Table 7.6 for further details.

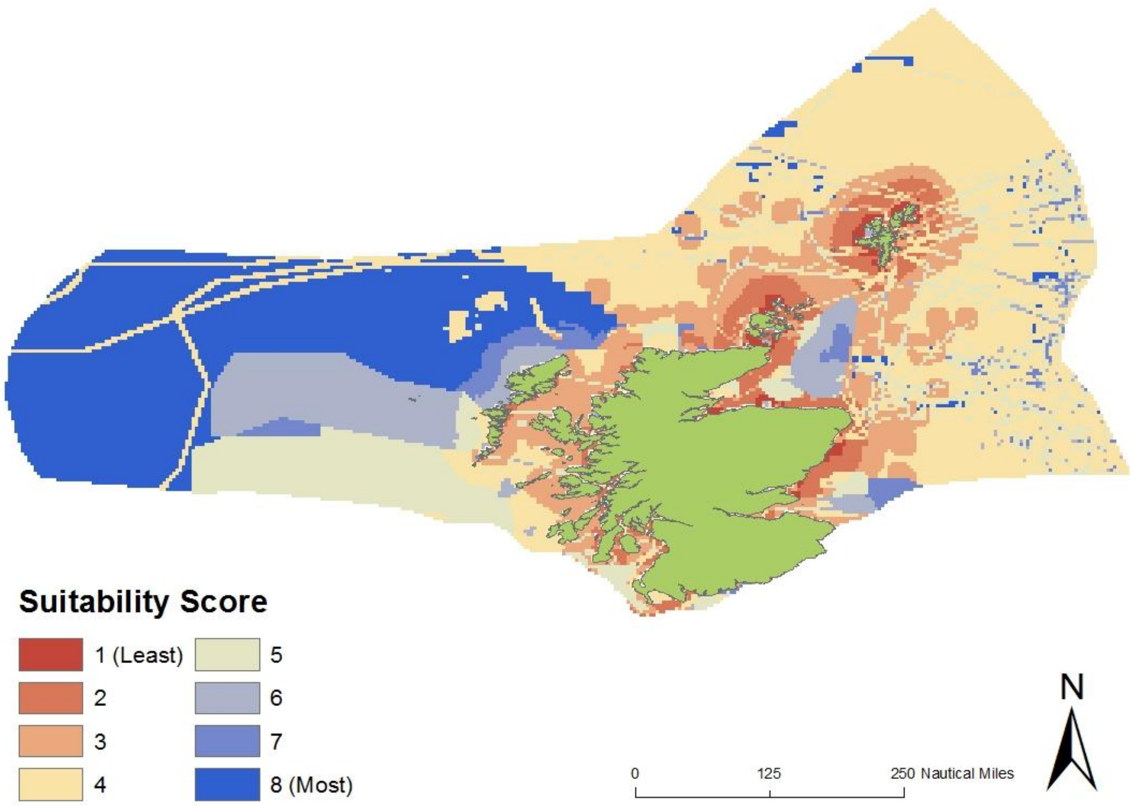

Figure 7.12 - Suitability map of re-run Socio-Infrastructure Sub-Model generated for Shellfish Aquaculture in Scotland.

In this revised model, industrial areas, beaches and heritage sites, aquaculture, towns and transport and small craft facilities were the criteria used to examine socio-infrastructure characteristics. Social-Infrastructure layers such as distance to transport links and small craft facilities for example, individually would not appear to be particularly limiting, given that relatively large areas scored highly (see Table 7.6). When taken together, almost 25% of the potential area was classified as score 8 (most suitable) for shellfish aquaculture in terms of social infrastructural factors. About 7% had a score of 7 and a further 5% had a score of 6. This amounts to approximately only 35% of the Scottish sea area having a suitable score and then a further 60% of the potential area was classified as middle score (sum of 3, 4, and 5). The lower scores (1 and 2) had less than 5%.

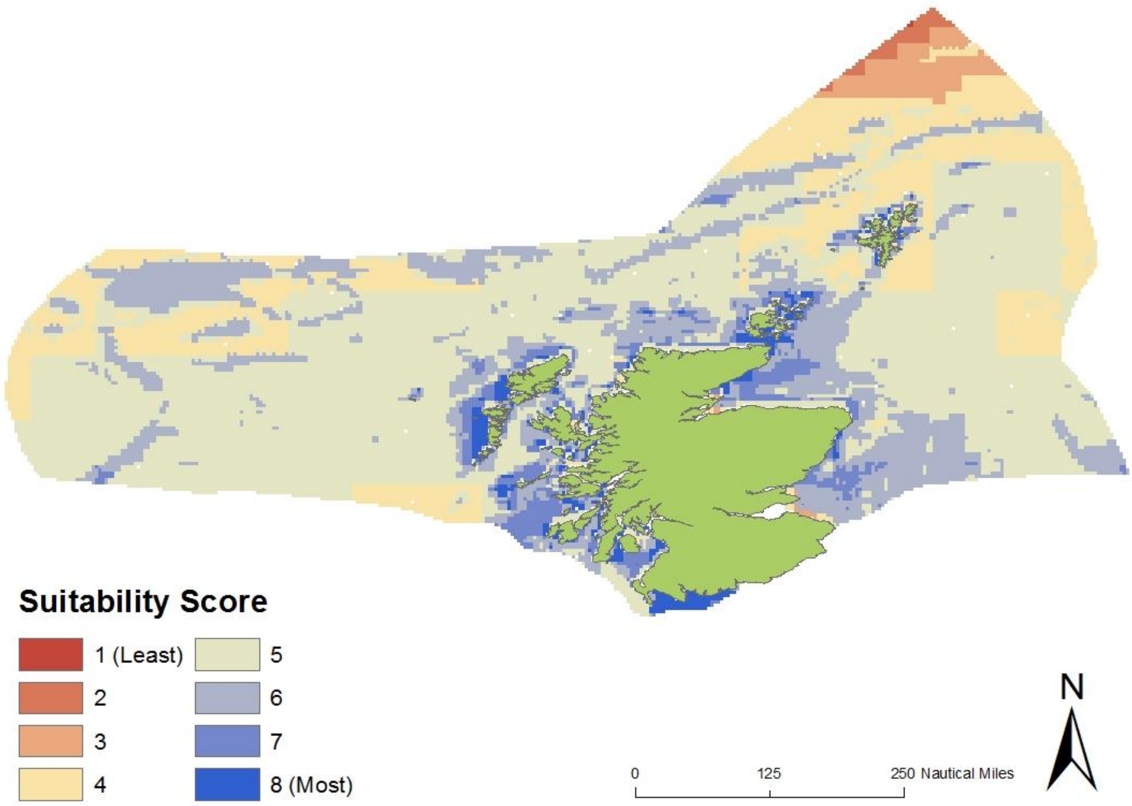

Figure 7.13- Suitability map of re-run Physical Sub-Model generated for Shellfish Aquaculture in Scotland.

The potential sites should have appropriate physical properties in order to provide the optimum conditions for growth and survival of the mussels being cultured. In our revised model, bathymetry, current velocity, chlorophyll, water temperature, sediment type and turbidity were the criteria used to examine physical characteristics. Approximately 17.5% of the potential area was identified as having a score between 6 and 8 (most suitable), and this area was located close to inner shoreline of the mainland and in particular along the West coast and the Outer Hebrides, Orkney and Shetland, see Figure 7.13. Approximately 65-96% of the potential area has scores of 8 (most suitable) for shellfish aquaculture in terms of sea temperature and chlorophyll a concentration. Sediment type showed that almost 9% was found to be most suitable, while current velocity just over 3% and turbidity 5% each and water depth for 6% respectively for the score of 8. See Table 6 for further details.

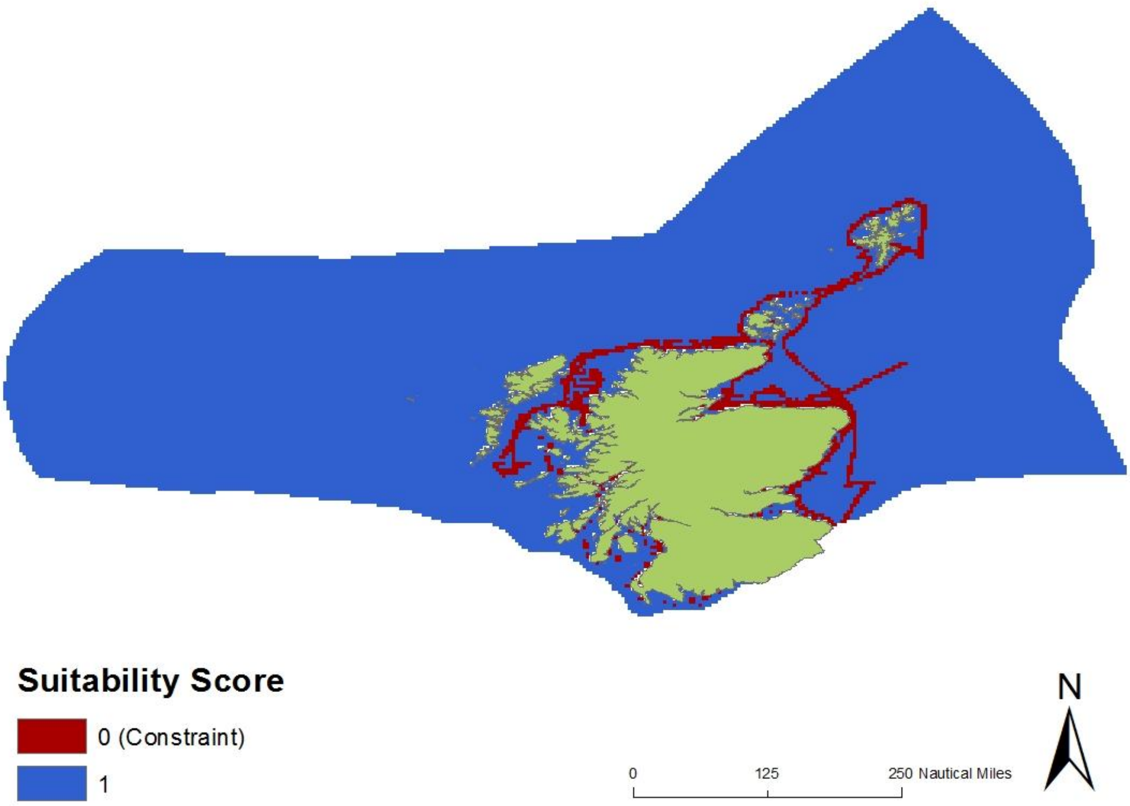

Figure 7.14 - Re-run Constraints map showing areas unsuitable for Shellfish Aquaculture

The constraints layer again limits the area of suitable sites for shellfish aquaculture, (see Figure 7.14). Locations that have waters that are near known pollutions sources such as sewage outfalls or known to be polluted or poor quality were considered as constraints (score 0). They covered about 2.5% of the potential sea area in our site selection model.

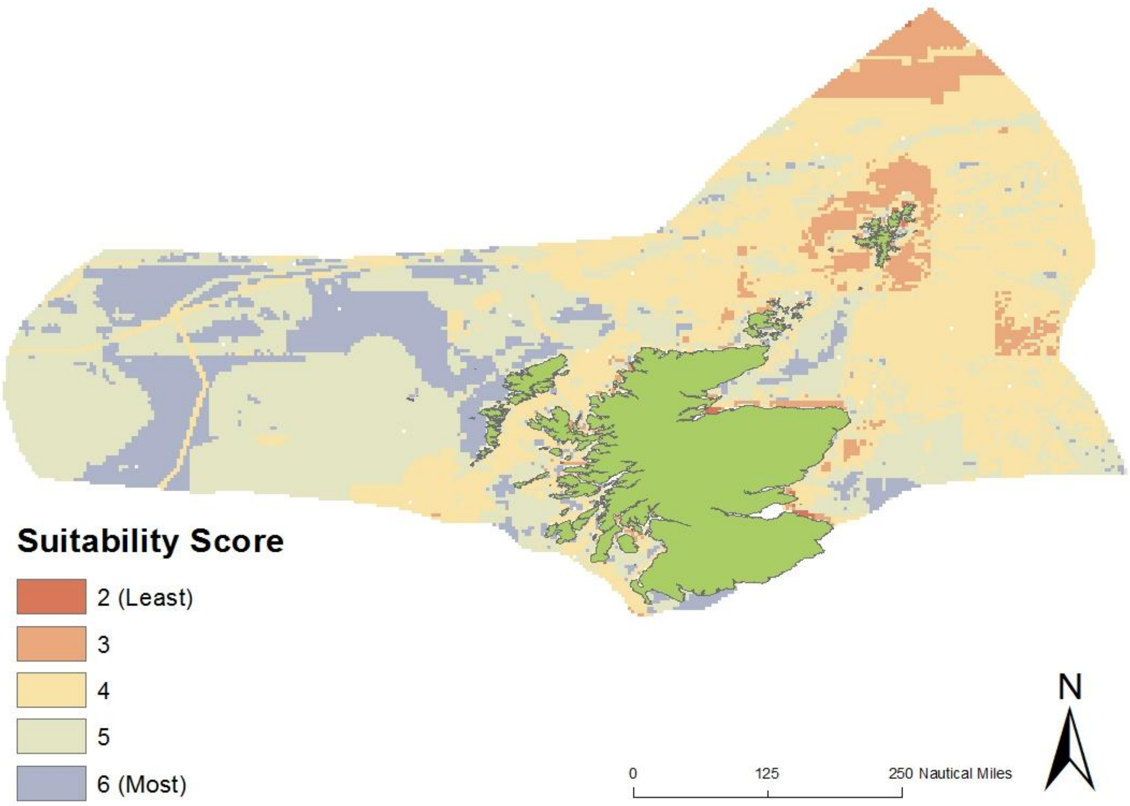

Figure 7.15 - Suitability map of re-run model scenario 1 (Physical>Socio-Infrastructure>Biological)

Different relative importance weight scenarios were applied to the three sub-models (Biological, Physical and Social-Infrastructure), this enabled the sensitivity analysis to be incorporated in the process of producing the suitable area. They were also considered in order to investigate how changing the weight of various factors affected the determination of the preferred area. The different suitability scores for each model can be seen in Table 7.6, and the corresponding distributions of the suitable sites are shown in Figures 7.15-7.17. In model 1, the Physical sub-model is given the greatest relative importance (Figure 7.15). It was found that no areas were allocated a score of 8 and less than 1% a score of 7 (the two most suitable), furthermore, only 14% had a score of 6. Around 38% of the potential area had scores of 5, and 48% with scores of 2, 3 and 4. There was no area identified as having the lowest score.

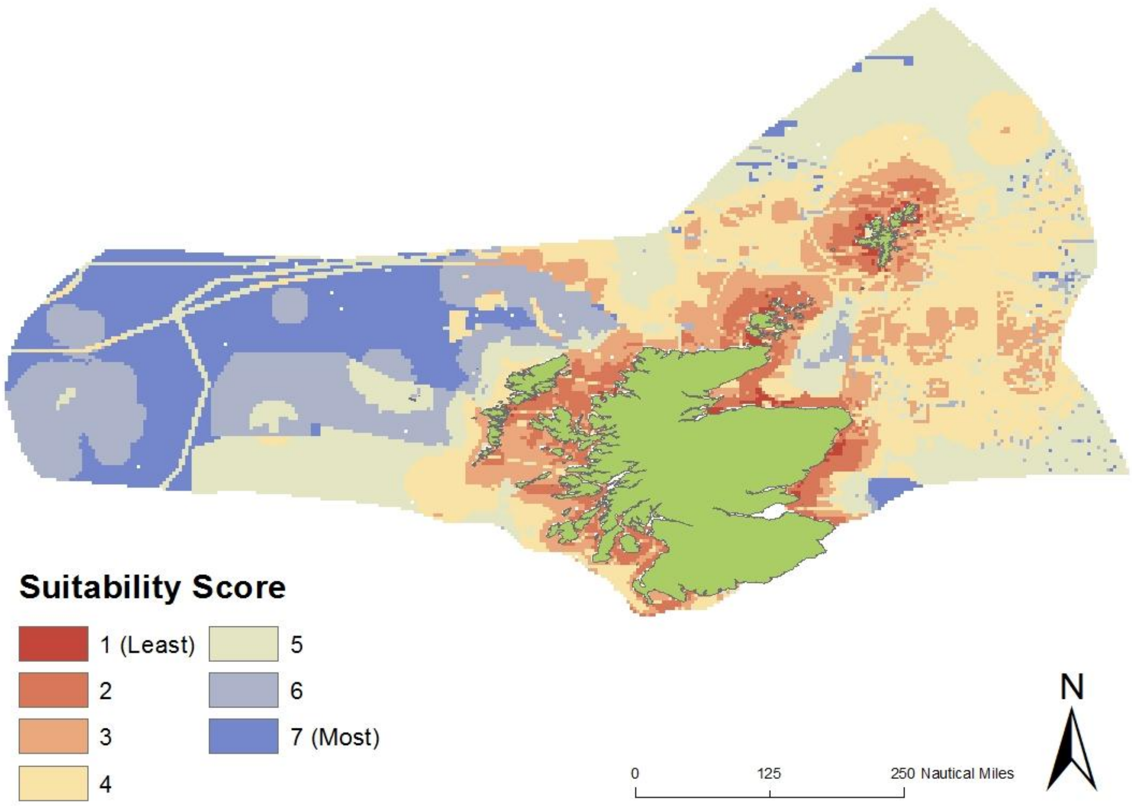

Figure 7.16 - Suitability map of re-run model scenario 2 (Socio-Infrastructure> Biological>Physical)

When socio-infrastructure factors are given the greatest relative importance the results are quite different (see Figure 7.16). Although again no area was identified as having a score of 8, in model 2 there was a very small area (0.23%) allocated to score 1. Just over 45% was allocated to scores 2, 3 and 4 in this model. Therefore these least suitable areas (scores 1, 2, 3 and 4) have marginally decreased from 48% in Model 1 to 45% in Model 2. A further 39% was allocated to scores 5 and 6 in contrast to the 52% that was given to these scores in Model 1. However, unlike in Model 1that had no area with a 7 score, in Model 2 over 15% was found to have a score of 7.

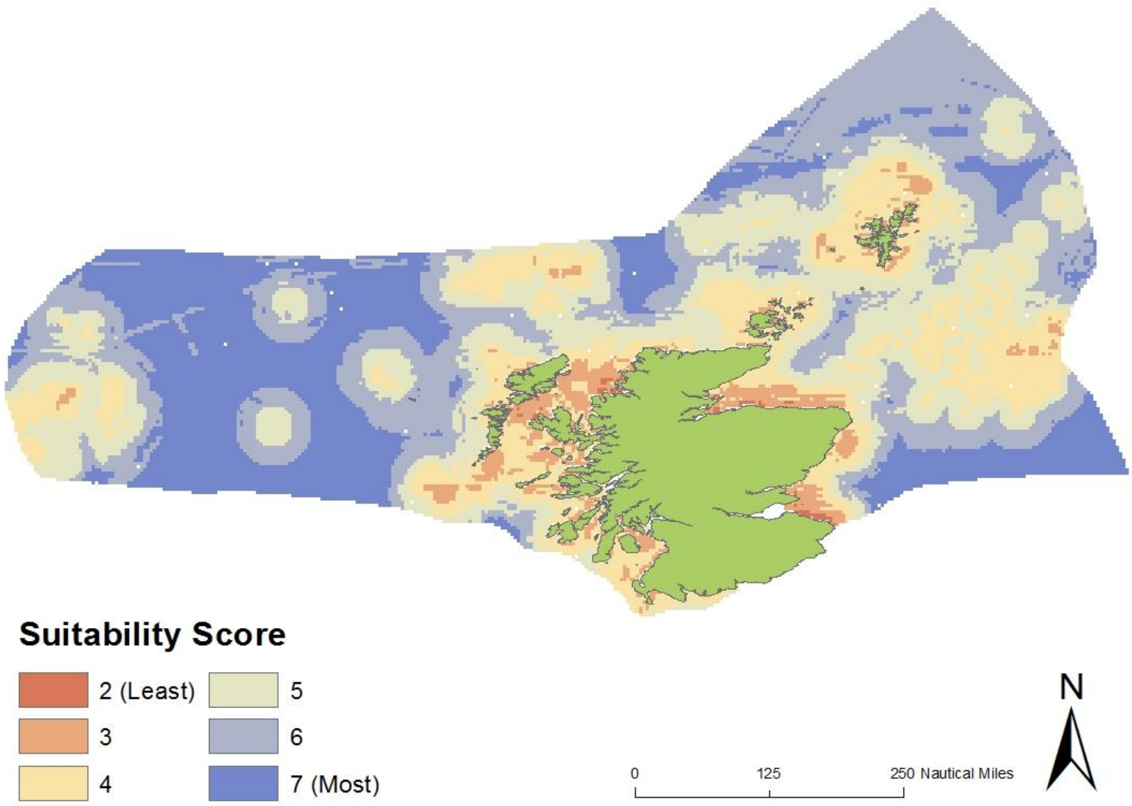

Figure 1.17 - Suitability map of re-run model scenario 3 (Biological>Physical>Socio-Infrastructure)

In model 3, the Biological sub-model was given the greatest relative importance (Figure 7.17). It was found that once again as with models 1 and 2, no areas were allocated a score of 8 (the most suitable), however, unlike model 1 that did not have a score of 7 either, model 3 had over 7% allocated a score of 7. A further 48% of the potential area had scores of 5 and 6, in comparison to 52% allocated to these scores in model 1 and 39% in model 2. Model 3 also has 45% with scores of 2, 3 and 4, the same as model 2, both therefore have marginally less unsuitable areas than model 1 that has 48%. As with model 1, model 3 also had no area identified as having the lowest score, 1.

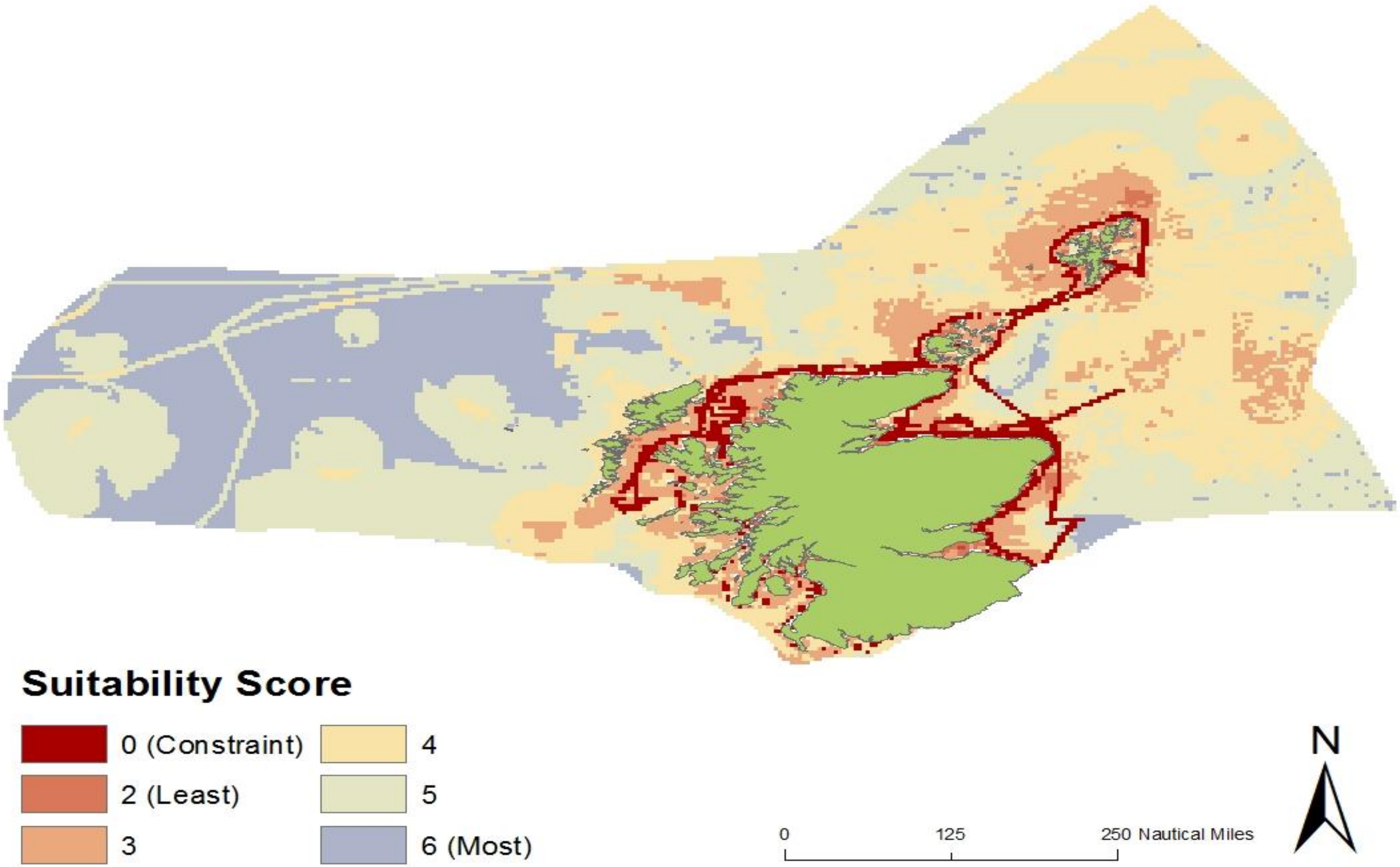

Figure 16 - Overall re-run site selection map, with Constraints layer added, for Shellfish Aquaculture potential in Scotland.

In the revised output for shellfish aquaculture site suitability (see Figure 7.18), with the constraints layer applied, the model classified almost 13% of this potential area had a score of 6 (in this case the most suitable). This area is considered by the model to have good conditions for the criteria examined, although it should be noted that no areas were given a score of 7 or 8 and therefore considered ideal. A further 34% was given to score 5 and therefore altogether roughly 45% of the area was ranked as being suitable, scoring (5 and 6), while just over 52% was identified as belonging to lower scores (2, 3 and 4). As previously mentioned almost 3% was accounted for by the constraints layer represented by the value 0 in figure 7.18.

7.4 Discussion

This study focused on identifying the most suitable sites for bivalve shellfish aquaculture based on a range of objective criteria. Different criteria were initially grouped into two sub-models (Biophysical and Social-Infrastructure), which were then combined to generate a final output showing the most suitable sites for this type of aquaculture development around Scotland. Although the total potential area in this study is 471,840 km^2 (sea area out to 200 nautical miles), only around 67% (316,516 km^2) could be classified as being suitable for shellfish, while the remaining 33% (155,321km^2) was identified as a constraint area (see Figure7. 6 for details of constraints layers). Classification of suitability level using GIS techniques led to estimates that 48% of the remaining potential area had high scores (scores 6 and 7) and middle scores (scores 4 and 5) had 18% respectively, for shellfish development. Areas with the highest scores were mostly distributed offshore but there are some smaller areas that are distributed along the inner waters of the west coast and northern islands, see Figure 7.9. The most suitable (highest scores) areas for shellfish culture are those in which most of the variables coincide with each other and therefore there is strong potential for expansion of shellfish culture.

When analysis of the total percentage cover of suitability was carried out for each of the criteria (see Table 7.4) it was found that most of the Socio-Infrastructure criteria were in themselves not limiting to aquaculture expansion. In contrast the lower values seen for Suitability Score 8 in the Biophysical layers would suggest that it is in fact these criteria that could prove restrictive for future aquaculture sites. This can be analysed further when looking at the revised shellfish model that additionally splits Biological and Physical features into two separate sub-models (see Figure 7.10). The extrapolation of these criteria and sub-models into their percentage cover of suitability score highlighted once again that Socio-Infrastructure factors are unlikely to be limiting (see Table 7.6). It also suggested that it was the Physical criteria associated with shellfish growth as opposed to Biological criteria that could prove significantly limiting to the industries growth and future site success.

While this study was based on site selection for shellfish long-line culture an attempt has been made within both models to consider other potential users of the coastal space. In the first model this was done by including an industrial areas criteria layer within the constraints sub-model. This layer was constructed from legislated activities occurring within Scottish waters and assessing where they were occurring in greatest concentrations. Then when the model was restructured this model was placed within the socio-infrastructure and heavily weighted to ensure it was given maximum consideration during the decision making process. Avoidance of these areas not only benefits the industry stakeholders but also safeguards shellfish producers from likely sources of product contamination. In some cases, management options will be required when activities overlap and these perhaps should be based on suitability analysis of the area.

This study showed the effectiveness of GIS-based approaches to identify and create a spatial model of suitability levels for shellfish aquaculture. There are perhaps two obvious factors that can improve any site selection analysis, these are: adding more criteria and using site specific data for the area under consideration. The reality however, is that often the quality and quantity of the data available to decision makers can make precise site analysis difficult. In this study data were compiled from a variety of resources and where data were questionable in its accuracy or resolution it was left out of the analysis. It is recognised that the site selection analysis as carried out by this study would benefit from further data improvements. This model was designed around the best possible datasets that were available for what were deemed to be the most important criteria relevant to shellfish culture. However it is recognised that other criteria such as dissolved oxygen, salinity, pH etc., are all able to significantly influence shellfish growth and survival and they are equally considered important when estimating the capabilities of the site to sustain production levels.

In this study two different site selection models were designed, both using the same basic principles of the MCE analytical hierarchy technique. The aim of re-structuring the initial model was to explore the effect that reducing the constraints layer would have on the overall suitability maps produced. Additionally, by adding a third sub-model to the re-structured model it allowed for a more detailed analysis of how the weighting of the sub-models influenced the final outputs. Often the difficulty with the site selection task is over complicating or simplifying the decision process too much. Exploring the different outputs from these two models served to highlight this fact, with the first model perhaps being considered more simplistic than the second. Referring to Tables 7.4 and 7.6, it was found that by re-structuring the model; introducing more criteria to the decision making process and increasing the number of sub-models actually reduced the area allocated to most suitable scores. Further analysis now perhaps needs to be undertaken to determine the optimum number of criteria, sub-models and constraints to be included for a site selection tool being applied to a large area such as the one used in this study.

Shellfish aquaculture is one of the Scottish Government's priorities for further development in the future (Aquaculture Planning Taskforce, 2010). Shellfish, and in particular *Mytilus edulis* aquaculture, is already a well established industry throughout the west coast of Scotland, Shetland and Orkney. Significant advances have been made in recent years to market the product and improve public perception of this type of aquaculture. However, there are still several aspects of shellfish culture that need to be investigated further to ensure the long term sustainability of the industry. For example, different aspects of carrying capacity need further investigation and the potential effects that harmful algal blooms can have on stocks and production. Other factors pertinent to site selection such as the optimum distance between farms and the potential for coupling shellfish production not only with other forms of aquaculture such as finfish production but potentially with renewable developments must also be explored. Additionally some space will also need to be set aside for other activities such as navigation to occur between the culture sites as mussel lines can be problematic for small boats in particular using inshore waters. In this study one of the criteria built into the social-infrastructure sub-model was the distance from beaches and natural and social heritage sites. However wide variation in the approaches adopted in different areas and by different stakeholders made generalisation difficult. It was therefore the case that with this criterion and several of the other criteria layers that this study had to use all the information gathered to make an informed decisions when creating the sub-model criterion layers.

In the future it is proposed by the Scottish Government that multi-trophic aquaculture is to be promoted and developed in Scotland. The aim of this new type of enterprise is to enhance culture production levels and lessen environmental impacts by farming two or more species at the same site. Multi-trophic aquaculture has already been demonstrated as being a viable option by several studies including Parsons et al. (2005) and Young et al. (2005). Integrating species such as shellfish and salmon or shellfish and seaweed can result in negating pronounced shifts in coastal processes. This is largely because the waste from one species becomes a resource for the others. This type of culture system is likely to be very applicable in Scotland and could result in more areas being suitable found to be suitable for this type of culture than have been identified solely for shellfish. However, it would require further improvements and modifications to this site selection model in order to define the appropriate proportions between different co-culture organisms.

7.5 Conclusion

To summarise, this study demonstrated the development and use of GIS to model site selection for shellfish aquaculture in Scotland based on specific important criteria and produced results that showed that the most suitable areas for shellfish aquaculture were located in offshore waters. It showed that GIS is a particularly useful tool for facilitating the decision making process for coastal planners in relation to aquaculture, allowing for the optimum use of natural resources. However, it also highlighted the importance model configuration and decision making preferences and how both can greatly affect a models outputs. To this end, the predominant advantage of using GIS is the ability to update and re-analyse data and then to easily be able to generate new results when a model is re-configured in light of new decision making evidence.

Implementation of a final decision must incorporate socio-economic factors as well as cultural and environmental factors which will allow coastal planners to make better informed decisions. In the past management of coastal resources, including aquaculture has given little consideration to the view of stakeholders. Therefore in the future this research hopes to involve stakeholders within the selection and weighting of the criteria when developing this model further. This we view as an important step towards the acceptability acceptance and success of sustainable management of finfish aquaculture in Scotland.

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Chapter 8
Stakeholder Informed Site Selection Model

8.1 Stakeholder Participation

As previously mentioned, aquaculture facilities are commonly located in busy coastal zones and therefore naturally conflict can also arise between other users of this space (Halwart et al., 2007 and Nimmo et al., 2011). Therefore, effective planning for, and management of aquaculture development should always take into account the range of perceptions and views of different stakeholders (Chu et al., 2010; Mazur and Curtis, 2008; Robertson et al., 2002 and Bacher et al., 2014).

Stakeholder participation in development projects is a recognised prerequisite for success (Bunting (2010). For example, the European Union (EU) Water Framework Directive (2000/60/EC) recommends stakeholder analysis as a method to support river basin management , a move that has been consistent with recent EU efforts to try and improve transparency and public participation within environmental decision making (refer to Directives 2003/4/EC and 2003/35/EC). Neglecting to consult or engaging an insufficient level of participation of relevant persons from stakeholder groups can result in mismanagement of resources and an increased likelihood of social/user conflict and decreased public support (Buanes et al., 2004 and Kaiser and Stead, 2002). Consequently there is a need to develop effective stakeholder involvement that aids both communication and understanding of the many complex issues related to aquaculture (Bacher et al., 2014). It has also been suggested that in order to be effective, stakeholder involvement in marine planning issues such as aquaculture site-selection, has to be initiated as early as possible (Douvere et al., 2007; Pomeroy and Douvere, 2008, and Maguire et al., 2012). However, it must also be assumed that it is impossible to include every stakeholder throughout the process (Maguire et al., 2012). Therefore it is important to determine just who to involve, at what stage to involve them and by what means in order to maximise the effectiveness of inclusion of stakeholder involvement.

8.1.1 GIS and decision making

The capabilities of Geographical Information Systems (GIS) in planning for aquaculture development have begun to be explored in recent years (Radiarta et al., 2008). In particular, within the last decade, the combination of GIS and Multi-Criteria Evaluation (MCE) has been routinely adopted as an approach to assess the suitability of areas for specific uses, and consequently to select optimal locations for activities (Geneletti, 2010). MCE can be utilised within a GIS environment to identify and compare solutions to spatial problems, in this case that are related to aquaculture site selection. It is able to do this by using a combination of multiple factors that are at least partially represented by maps (Malczewski, 2006 and Geneletti, 2010). In this study we aim to adopt an approach that takes advantage of both the capabilities of GIS to manage and process spatial information and the ability of MCE to combine quantitative data with value-based information derived from expert opinion gathered from a participant's survey. Although there is an extensive literature on how GIS have been used to indirectly support decision-making, but there have been far fewer studies that incorporate stakeholder opinions using GIS to help solve spatial problems (Nyerger et al., 1997 and Geneletti, 2010). In our past work using MCE and in most published applications of this methodology, the value-based inputs (e.g. weights of the individual criterion) are provided by the same authors. The aim here is to integrate the opinions of a panel of experts and stakeholders in order to generate results that are potentially more robust and defensible, being that they are delivered from a range of expert opinion rather than a single viewpoint (Handyside et al., 2006). Furthermore, a decision support process that is able to account for an extensive range of values and opinions can be presumed to be more successful at finding valid and acceptable solutions (Petts, 2001).

8.1.2 Production Systems

The Delphi methodology was chosen for this study, as a means of eliciting the perceptions of aquaculture stakeholders from informed but diverse backgrounds, and exploring the general consensus concerning relative importance of specific criteria and types of criteria to the site selection process. This technique was originally developed in the early 1950s by the RAND cooperation (Orsi et al., 2011) and is a method that can be used to structure group communications that allows individuals to deal with a complex problem (Lindstone and Turoff, 1975). In this same publication, Ludlow (1975), defined the Delphi methodology as; judgement, analytical ability and predictive powers of experts being elicited through an iterative series of questionnaires to reach outcomes on possible future events. Delphi surveys aim to incorporate the advice of a panel of experts or people directly involved (stakeholders) and whenever possible forge a consensus (Oliver 2002). The process is based on structured questionnaires to which participants answer anonymously. All responses are summarised and reported back to participants who then have the opportunity to revise their judgements (Orsi et al., 2011). The Delphi study presented here marks a slight departure from a classic 'Stakeholder Delphi' in two key ways, firstly, the opinions of experts from various aquaculture related organisations were sought rather than stakeholders alone. This was done in order to ensure to ensure that the knowledge and experience of researchers, environmental advocates, managers and regulators were captured. Secondly, we did not carry out the process in isolation or anonymously as those involved were allowed to discuss and debate issues prior to the decision making process. Our Delphi study recognises that some of the participants, although not classified as stakeholders or experts, can be highly influential or possess knowledge that may better inform the process. It was therefore hoped that by inviting a diversity of participants, a larger spectrum of perspectives would be achieved. Studies using the Delphi technique have already been conducted to help develop sustainability indicators for aquaculture in the South East of America (Caffey 2001) and to assess prospects for horizontally integrated aquaculture by Bunting (2008). Additionally, Haylor et al., (2003) in a study looking at aquaculture provisions noted that the Delphi approach is particularly appropriate when decision-making is required in a political or emotional environment, or when the decisions affect strong factions with opposing preferences. Additionally, in a review of aquaculture prospects, Brugere and Ridler, (2004) concluded the planning will be integral to sustainable aquaculture development they also advised upon the adoption of a planning framework that was further underpinned by the application of the Delphi method.

8.2 Methods

The aim of this particular exercise was to further develop a GIS-based model for identifying suitable finfish cage sites, specifically for Atlantic salmon culture, within Scottish waters through the incorporation of stakeholder participation to inform the value-based inputs. The intention was to refine the model and potentially produce results that are both technically more accurate and robust than those derived solely from the authors' interpretation of the relevant literature as utilised in the previous two chapters.

8.2.1 Study Area

As with the models used in the previous chapter, the application of this site selection model was carried out for both offshore waters (12-200nm) and Scottish territorial waters (from the coast out to 12nm), covering a total area of some 78,772km^2. Again, this site selection model only considered results for Northern waters and those to the West of the mainland in line with Planning Policy guidelines about the siting of farms on the East coast. However, owing to the plans outlined for aquaculture in the pre-consultation draft of the National Marine Plan and the fact that planning will cover both inshore and offshore waters in the future, this model analysed the whole of the Scottish marine area out to 200nm.

8.2.2 Site Selection Criteria for Atlantic Salmon

This model build on the first finfish model developed in chapter 6 and as such is uses the same criteria and data sets that were previously identified as being pertinent to the success of this GIS-MCE model. Once again, consideration was given to the natural conditions present, the requirements of the type of aquaculture operation, and the particular needs of the species to be cultured. In using these criteria we also hope to have recognised development in dependent factors which can influence the growth quality of culture species such as economic stability. They also aim to consider the potential level of impacts from cultured species (environmental sustainability) and the existing users, alongside societal values relating to their marine region.

Optimal sites for sustainable and economically viable aquaculture have also been acknowledged as having conditions leading to relatively enhanced growth rates and high quality products whilst minimising environmental impacts.

Comparable economic returns can additionally be achieved at optimal sites with relatively low stock densities (hence less environmental stress) as at a less optimal site supporting higher stock densities importantly depends on the culture system being utilised by the farmers (Longdill et al., 2008). The influence of biological factors such as sea temperature, food availability (chlorophyll a), wave heights and bathymetry on the growth of farmed fish are all widely recognised as is the additional effects of social and infrastructure operations. Therefore, these factors were all used for identifying suitable sites for sustainable finfish aquaculture around Scotland (see Table 8.1).

Table 8.1 - Criteria used for Scottish finfish aquaculture site selection

Criteria	Interpretation of Criteria	Data Sources
Water Depth	Favourable depth for salmon culture as cage nets can drop between 18 and 20m	JEBCO
Current Velocity	Current speed fast enough to prevent degradation of the surrounding area	IMR-Norway
Chlorophyll a	Availability of Natural Food (Phytoplankton)	SAHFOS
Temperature	Favourable Temperature for Finfish Culture	NOAA
Sediment Type	Least sensitive to benthic impacts from cages	JNCC
Maximum Wave Height	Wave height that will not increase the chances of damage/escapees	DECC
Distance from Beaches	Pollution threat	MSS
Distance from Pollution/ Discharge Sites	Pollution threat	SEPA
Distance from Aquaculture Sites	Pollution, Navigation, Spread of Disease and Potential Accumulative Effects of Competition for Natural Resources	Crown Estate
Distance to Roads	Support Services and Transport to Markets	OS data
Distance from Towns and Natural/Social Heritage	Support Services and Viewshed	RCHAMS, Historic Scotland and OS data
Distance from Conflicting Activities	Hazard	Multiple Data Sources
Distance from Small Craft Facilities	Pollution and Navigation	Edina
Distance from Ports and Harbours	Support Service but also Pollution and Navigation	MSS
Fish nursery and Spawning Grounds	Ensure no negative impact on wild fisheries	CEFAS
Designated Protected Areas	Dependant on site designation aquaculture may be permitted within this area	SNH and JNCC
Predators: Cetaceans/Pinnipeds/Birds	Avoidance of stock loss and damage to cages	MSS and DEFRA
Species Sensitive to Aquaculture (PMFs)	Safe distance to ensure sensitive species are not put under stress	MSS
Important Fishing Grounds	Ensure no negative impact on wild fisheries	MSS
Salmon River Mouths	Safe distance to ensure that wild salmonids will be exposed to farms	MSS

8.2.3 Constructing the GIS Model

As explained in Chapter 6, the original model structure for identifying suitable cage sites (see Figure 8.1) was built based on a hierarchical structure (also sometimes referred to as a value structure) and contained 20 criteria according to the basic requisites for salmon aquaculture in Scotland. Hierarchical structures breakdown all the criteria being utilised into smaller groups or sub-models. At the highest levels are the most general of the objectives which can be further defined at still lower levels, while the lowest levels of hierarchy are attributes.

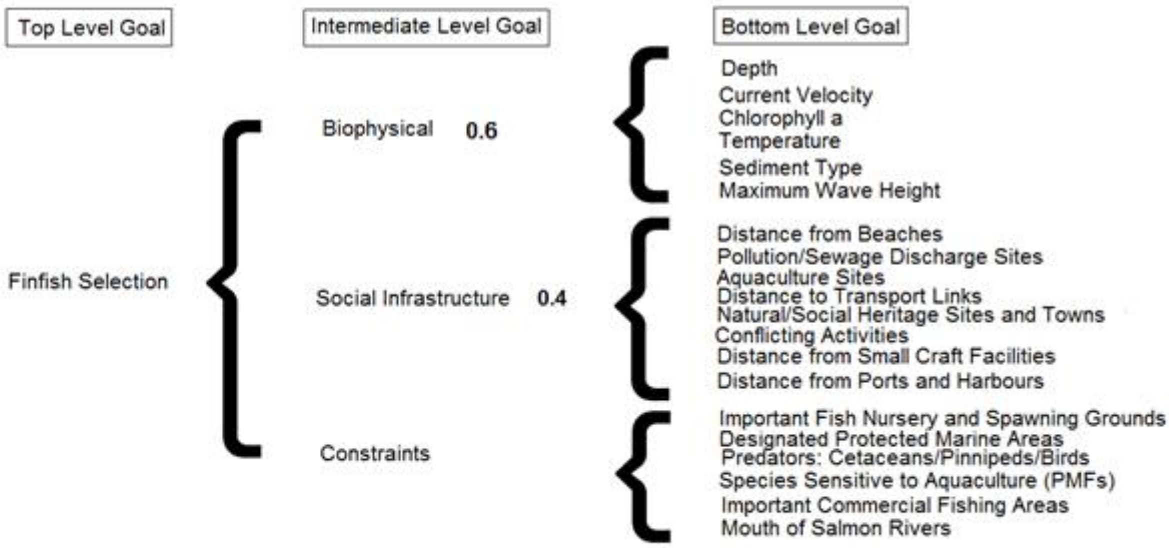

Figure 8.1 - The original hierarchical modelling scheme to identify suitable sites for finfish aquaculture in Scotland.

Unlike the original model shown above, and subject to further exploration (explained in chapter 7), it was decided to add an additional sub-model to the design, so there were now four sub-models; Physical, Biological Socio-Infrastructure and Constraints. The placement of the same original 20 criteria layers within these models was to be guided by a questionnaire supplied as part of the accompanying stakeholder workshop and can be viewed in Table 8.7 of the Results section. However, when presented to the stakeholders, and after further discussion, it was decided to add yet another sub-model see below in Fig 8.2.

Each of the components (Biological, Environmental, Physical, Social-Infrastructure and Constraints) are represented as individual sub-models which themselves can be used to investigate particular limitations placed on aquaculture before being combined in the main model to give an overall indication of suitability. The criteria of the sub-models and the sub-models themselves can be included /excluded and combined with different weightings in a number of combinations to ask different questions of the database. The aim of this site suitability assessment is to highlight areas that are likely to be most suitable for cage culture and hence require further exploration. At present this still needs to be considered as an indicative tool as limitations on what can be achieved are inherently linked to data resolution, quality and availability issues.

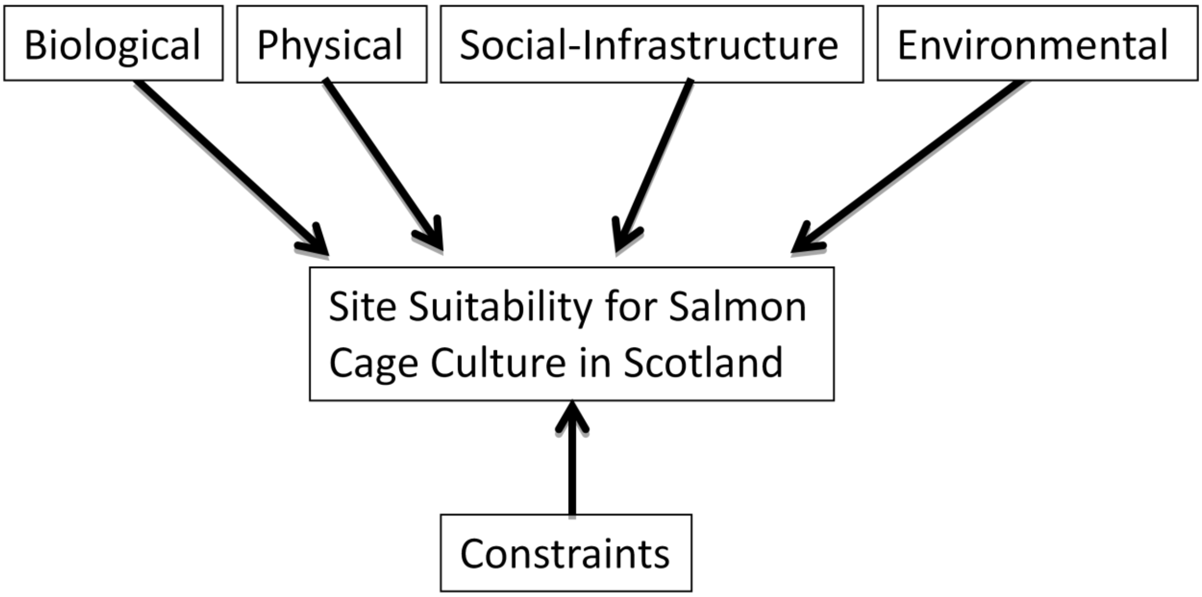

Figure 8.2 - Schematic representation of the Site Suitability Sub-Models

8.2.4 Database Generation and Reclassification

As with previous models, data at a variety of different resolutions were used in the criteria layers that are compiled within this model. Consistent and even coverage of the entire Scottish sea area was once again a priority for data selection to allow for direct and accurate coverage across marine regions. As a result this did in some instances limit the resolution available for use. For the purpose of combining data by multi-criteria evaluation all the data were converted into raster images with a cell size of 0.05 decimal degrees in line with our other studies.

ESRI's ArcGIS (version 9.3) was used for all the spatial modelling and data presentation. All data used in the modelling process was in the form of raster images and converted to a common georeference (WGS1984). Raster is a term used to describe an image which consists of small uniform cells, or pixels, arranged in a grid. Each cell can represent a unique numeric value e.g. temperature or wave height. The image is also georeferenced so that cells correspond accurately with points on the earth's surface. This makes it possible to combine data layers using a number of mathematical operations on cells that occupy the same grid location.

Once again all layers used in the model were reclassified to have a scale ranging from one to eight. Scoring of raw data was based on the requirement of the finfish species in culture; in this instance we used salmon cage culture as our benchmark culture system. Following Pérez et al., (2005), the suitability score for each criterion ranged from 8 (the most suitable) to 1, the least suitable for developing finfish culture. For each criteria layer, details of this scoring are given in Appendix 8, Table 8.0. Due to the varied nature of each data set used within the model, it was not possible to use one standard method of reclassification. In all instances objective reclassification decision were made by based on information provided in literature accompanying the data and on the author's knowledge of the data and issues involved.

8.2.5 Construction of the GIS-MCE Model

Data layers were combined in the sub-models and main model using Multi-Criteria Evaluation and weighted linear combination. In this process different weightings (levels of importance) are assigned to each input layer which in turn controls their level of influence in the final layer produced. In the original study weightings were assigned by the author based on knowledge of the factors involved and an extensive literature review. In this investigation the consensus of a panel of experts obtained from a focus group meeting and questionnaires was used to inform the weighting scheme.

Weightings were assigned so that when combined they have a total value of 1, for example for a combination of three layers: Layer 1 = 0.5, Layer 2 = 0.25 and Layer 3 = 0.25. The value assigned to each cell in each data layer is then multiplied by the weight value given to that layer. Corresponding cells in each layer are then added together to produce a final combined raster image. An example of this process using the three layers and weightings mentioned previously can be seen in Fig 8.3.

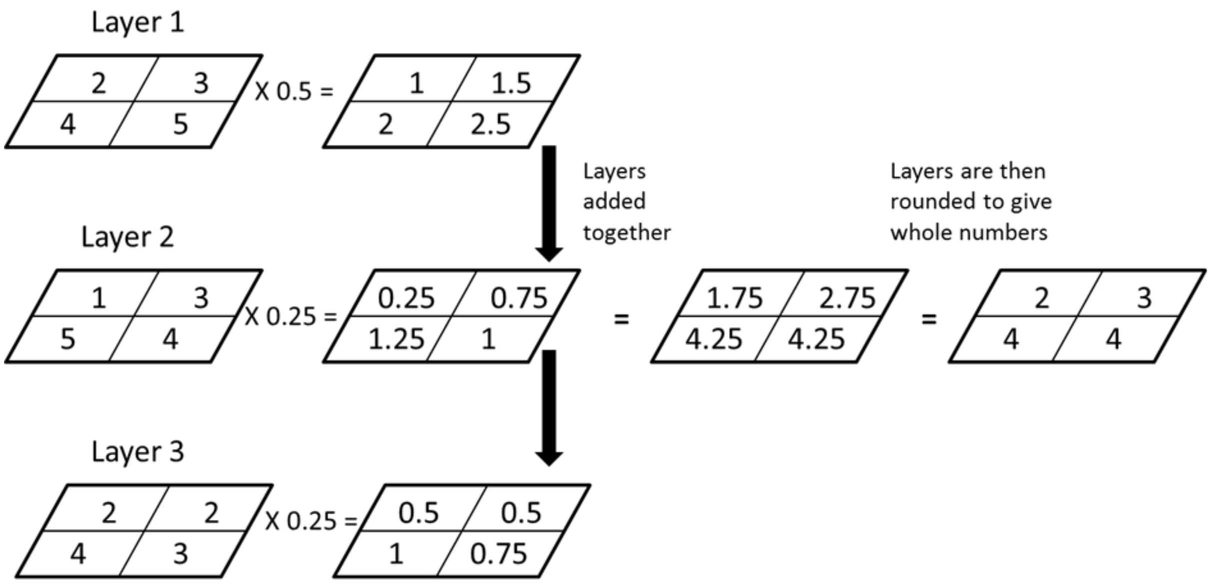

Figure 17 - Example of combining layers using MCE and Weighted Linear Combination

The weightings used when combining data layers are inherently crucial to the outcome of the model. A focus group of 7 individual stakeholders from several organisations including Marine Scotland Science, Scottish Environment Protection Agency, Scottish Natural Heritage, Scottish Aquaculture Research Forum and the Scottish Association for Marine Science, who all have a broad range of expertise relating to aquaculture were invited to attend an interactive workshop held at Heriot-Watt University in Edinburgh. Firstly they were asked to guide the placement of the criteria layers within the sub-zones they felt were most appropriate. Then they were asked to fill in two guided questionnaires in the form of Pair-wise Comparison Matrices to give their views on the weightings to be used when combining both data layers and sub-models. Final placement of layers within the model was dictated by the most frequent choice of stakeholders and then the mean values derived from the pair-wise comparisons were used for further derivation of the model. Having had a chance to see the outputs from the model and the weightings they had chosen to assign, stakeholders were then given the chance to review the decision matrices they had filled out for each of the criteria. They were given a new matrix and allowed to re-do the first of the questionnaires following the Delphi Process which was then analysed after the workshop had concluded, the findings of which are also presented within this report. It is fully accept that a larger focus group would have perhaps been more beneficial, providing a greater range of opinions and expertise. The aim of the group assembled was to target key individuals who would be able to represent the range of potential stakeholder views and the number used would suffice to provide more statistically robust results than the previous running of this model had allowed for.

Table 8.2 - Scale used for assigning weightings using the pair-wise comparison matrix (Saaty, 1977).

1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
Extremely		Very Strongly		Strongly		Moderately		Equally	Moderately		Strongly		Very Strongly		Extremely	
Less Important									More Important							

Each matrix used a scale dividing the level of importance originally developed for use by Saaty, (1977), see Table 8.2. The group were asked to fill in a series of matrices for the different layer combinations used in the model, see Table 8.3 for an example. It was suggested to those participating that they should rank the layers in order of importance before filling in the matrix. A presentation was given by the authors at the beginning of the workshop to explain the process fully and examples were used to demonstrate and aid understanding of the weighting system and the matrix as much as possible.

Table 8.3 - Example of a pair-wise comparison matrix (developed by Saaty 1977) used to assign weightings to groups of criteria.

	Wave Height (m)	Temperature (°C)	Sediment (grain size)	Chlorophyll (mg/m²)
Wave Height (m)	1			
Temperature (°C)	1/2	1		
Sediment (grain size)	1/2	1/2	1	
Chlorophyll (mg/m²)	1/4	1/3	1/2	1

The example matrix shown in Table 8.3, shows four layers for a potential Physical sub-model; Wave Height, Temperature, Sediment and Chlorophyll. A row-by-column comparison of different combinations is then undertaken; in this example, Sediment is considered 1/2 as important as Wave Height, Chlorophyll is considered 1/3 as important as Temperature and so on. Using Saaty's methodology allows for the consistency of the decision making process to also be taken into account. This is important to consider as the decision maker may not be able to express consistent preferences when faced with multiple criteria. Ideally a matrix (*A*) should be consistent and be awarded a rank (*A*) = 1 and λ = *n*, where *n* is equal to the number of criteria. In this instance the following equation would show vector B representing the weights:

A X B = *n* X B (where B is the Eigenvector of *A*)

However, in non-consistent cases, such as this study, the importance placed on different criteria may be changed only slightly but this causes the eigenvectors (values that allow for the understanding of linear transformation) to change in a similar manner. More importantly, the maximum eigenvector value (λmax) moves closer to *n* while the remaining possible eigenvalues are closer to zero. Therefore to extrapolate the weight, the eigenvector which corresponds to the maximum eigenvalue (λmax) must be used. The calculated eigenvector values have to be normalised in order to obtain the weights using the formula below, and all weights must sum up to 1.

$$w_j = \frac{\widetilde{w}_j}{\sum_{i=l}^{n} \widetilde{w_\iota}}$$

Saaty (1977) proved that for a consistent reciprocal matrix, the largest Eigen value is equal to the size of the comparison matrix. Then he gave a measure of consistency, called the Consistency Index (CI) as a deviation or degree of consistency calculated as follows:

$$CI = \frac{(\lambda max - n)}{n - 1}$$

$$\lambda \max = principle\ eigenvector$$

$$Consistency\ Ratio(CR) = \frac{Consistency\ Index\ (CI)}{Random\ Consistency\ Index\ (RCI)}$$

The consistency ratio (CR) is also calculated as the ratio of consistency index and random consistency index (RI). The RI is the random index representing the consistency of a randomly generated pairwise comparison matrix, it is derived as an average random consistency index; see Table 8.4.

Table 8.4 - Random Consistency Indices for different numbers of criteria (n)

N	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

The random consistency index was calculated from a sample of 500 randomly generated matrices based on the AHP scale, see Table 8.4. If CR (A) ≤ 0.1, then the pairwise comparison matrix can be considered to be consistent and therefore acceptable as it demonstrates good and consistent judgement (Saaty, 1977). When the CR (A) is more than 0.1, the matrix needs to be re-evaluated and improved. The value of RI depends on the number of criteria being compared.

8.3 Analysis and Evaluation of Stakeholder Feedback

To summarise, weights were calculated from the scores given in the matrices using the previously mentioned calculations. Along with the weights consistency ratios (CR) were also calculated, which indicated the consistency of logic between values in the matrices i.e. to what extent the values given in the matrices contradicted each other.

In the example matrix shown in Table 8.5, the CR was 0.02 which indicates a very good agreement between the values used, as explained previously. Furthermore this threshold has been used in a number of studies, such as those by Aguillar-Manjarrez, (1996) and Radiarta et al., (2008).

Table 8.5 - An example of a pair-wise comparison matrix and calculated CR

	Wave Height (m)	Temperature (°C)	Sediment (grain size)	Chlorophyll (mg/m^2)	Weightings
Wave Height (m)	1				0.435
Temperature (°C)	1/2	1			0.286
Sediment (grain size)	1/2	1/2	1		0.182
Chlorophyll (mg/m^2)	1/4	1/3	1/2	1	0.097

Consistency ratio = 0.02

Table 8.6 - Example of the results Table from the completed Matrix Questionnaires.

Components	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Mean Weighting Using all Five Decision Makers
	Weighting	Rank	Weighting	Rank	Weighting	Rank	Weighting	Rank	Weighting	Rank	
Wave Height (m)	0.2836	2	0.5	1	0.1342	3	0.1728	3	0.0879	3	0.236
Temperature (°C)	0.1343	3	0.25	2	0.2622	2	0.0618	4	0.2862	2	0.199
Sediment (grain size)	0.4992	1	0.125	3	0.5119	1	0.5656	1	0.5791	1	0.456
Chlorophyll (mg/m²)	0.0828	4	0.125	3	0.0866	4	0.1998	2	0.0468	4	0.108

Table 8.6 is an example of a table that was composed from the outputs of the stakeholder workshop. For the final tables of results see section 8.4. They are designed to show the weightings produced by each decision maker using the pair-wise comparison matrix along with the order in which these weightings 'rank' in each instance. Confidence in the level of agreement was therefore assessed using Kendall's coefficient of concordance (*W*).

When a sufficient number of decision makers (*k*) and variables (*N*) are involved, Kendall's Coefficient of concordance (*W*) can be used to measure the level of agreement between the different rankings based on the equation given below:

$$W = \frac{\sum_{i=1}^{N}(R_i - R)^2}{N(N^2 - 1)/12}$$

Where R_i is the average of the ranks assigned to the *i*th item, and *R* is the average of the ranks assigned across all items. *W* can range from 0 (no agreement between rankings) to 1 (total agreement between rankings). This measure of rank convergence was recommended for interpreting data from Delphi investigations, providing a measure of the degree of agreement achieved and the level of confidence in mean ordinal ranks (Schmidt., 1997). The null hypothesis (H_0) that the rankings are not related can then be rejected for values of W that are above a critical value. In the current this study critical values for the rejection of the H_0 at the 95% confidence level were taken from (Siegel & Castellan, 1988). It should be noted that only those decisions involving four or more variables and at least four decision makers were deemed to be of a sufficient sample size for the reliable use of *W*. In cases where there are only three variables for example, then eight or more decision makers would be required before a critical value with a probability of occurrence less than 0.05 is available (Siegel & Castellan, 1988). Although Kendall's W fails to provide any indication concerning the relative importance participants place on each factor, the mean ranks were used for this purpose.

SPSS statistical software was used to calculate values for *W*. A value above the critical value of 0.619 will indicate an agreement between decision makers. The results from the workshop pair-wise comparisons, including values for *W* where appropriate, are shown and discussed for each combination of layers in the following results section, that also describe the final layout , construction of the four sub-models along with the final outputs. In each case the contribution of the workshop participants including any comments made, is discussed in conjunction with the rationale behind the eventual weightings used.

It should be noted that care was taken not to influence the focus group in relation to individual weighting decisions, and it was also considered important to discuss the concepts behind the model with the group in as much detail as was feasible given the limited time. The intention was that by providing the participants with a good understanding of the model design and principals this would make for better informed decisions regarding weightings. The participants were also encouraged to give constructive criticism about any aspects of the model where they felt it was appropriate to do so.

8.4 Results

Following an extensive discussion about each of the criteria, stakeholders were asked to place each data set within one of the sub-models they had decided upon. Table 8.7 illustrates the results of this vote, with highlighted boxes displaying the majority of votes and therefore the sub-model that criteria was then attributed to. It should be noted that stakeholders chose not to place any criteria within the Constraints model.

Table 8.7 - Division of Criteria between the different Sub-Models as voted for by Workshop Stakeholders. Shading shows final placement, based on majority view.

Criteria	Sub Model (No. of Votes)				
	Biological	Physical	Socio-Infrastructure	Environmental	Constraint
Water Depth		7			
Current Velocity		7			
Chlorophyll a	1			6	
Temperature	7				
Sediment Type		4		3	
Maximum Wave Depth		7			
Distance from Beaches			7		
Pollution/Sewage Discharge Sites	5		1	1	
Aquaculture Sites	2		3	2	
Distance to Transport Links		4	2		
Natural/Social Heritage Sites and Towns			7		
Conflicting Activities		3	4		
Distance from Small Craft Facilities			7		
Distance from Ports and Harbours		6	1		
Important Fish and Nursery and Spawning Grounds				7	
Designated Protected Marine Areas				7	
Predators: Cetaceans/Pinnipeds/Birds	7				
Species Sensitive to Aquaculture (PMFs)				7	
Important Commercial Fishing Areas			7		
Mouth of Salmon Rivers			7		

8.4.1 Biological Sub-Model

Table 8.8 shows the standardised aquaculture scores assigned to each of the criteria layers and those layers which are present within the Biological Sub-Model alongside the justification for the divisions made for that data layer. This standardisation was carried out by the authors and not the stakeholders based on an extensive literature review and their own judgement where knowledge gaps were present. It is accepted that this is a potential source of controversy within this model and in the future the standardisation would perhaps be better informed by also being subject to relevant stakeholder scrutiny. Time limitations in this case study however prevented such analysis and it is therefore accepted as an area in which this assessment model could be further improved.

Table 8.8 - Data Layers used in the Biological Sub-Model alongside details of their Classification in terms of Suitability Construction and Significance.

Criteria Layer	Data Source and Reclassification	Description and Significance
Temperature	Data Source : NOAA (0-7)= 5, (7-8)=6, (8-9 and 10-11)=7 and (9-10)=8	Shows surface water temperature in (°C). Favourable temperature for salmon culture based on optimum growth values.
Pollution	Data Source : SEPA (0-0.5)= 1, (0.5-1)=2, (1-2)=3, (2-3)= 4, (3-4)=5, (4-5)=6, (5-6)=7and (6-63)=8	Shows distance from Pollution (sewage outfall) sites in km. Threat of contamination of finfish product and potentially harmful to health of fish.
Predators	Data Source : MSS & DEFRA (0-1)= 1, (1-2)=2, (2-3)=3, (3-4)= 4, (4-5)=5, (5-6)=6, (6-7)=7and (7-86.9)=8	Shows distance from Seal Haul out sites, areas with high intensity of cetaceans and nesting sites of selected bird species. Avoidance of stock loss and damage to cages.

Model Outputs

As shown in Figures 8.4 and 8.5, and the weightings below, the stakeholders did not alter the ranking of their weightings only the relative strength of the weight they gave each criteria.

Constructed by MCE using layers: Original Weighting: Reviewed Weighting:

	Original Weighting	Reviewed Weighting
• Temperature	0.401	0.296
• Pollution	0.31	0.368
• Predators	0.289	0.336

As expected the biological sub-model (see Fig. 8.4) was found to not favour inshore waters. This could be predicted due to the fact that the stakeholders chose to weight temperature, pollution and predators all relatively highly in this Model. The pollution sites were illustrated using data layers that included sewage outfalls that are also located inshore. They also heavily weighted predator layer which included seal haul out areas and bird nesting sites which are predominantly located around the shoreline, see below for individual criteria weightings.

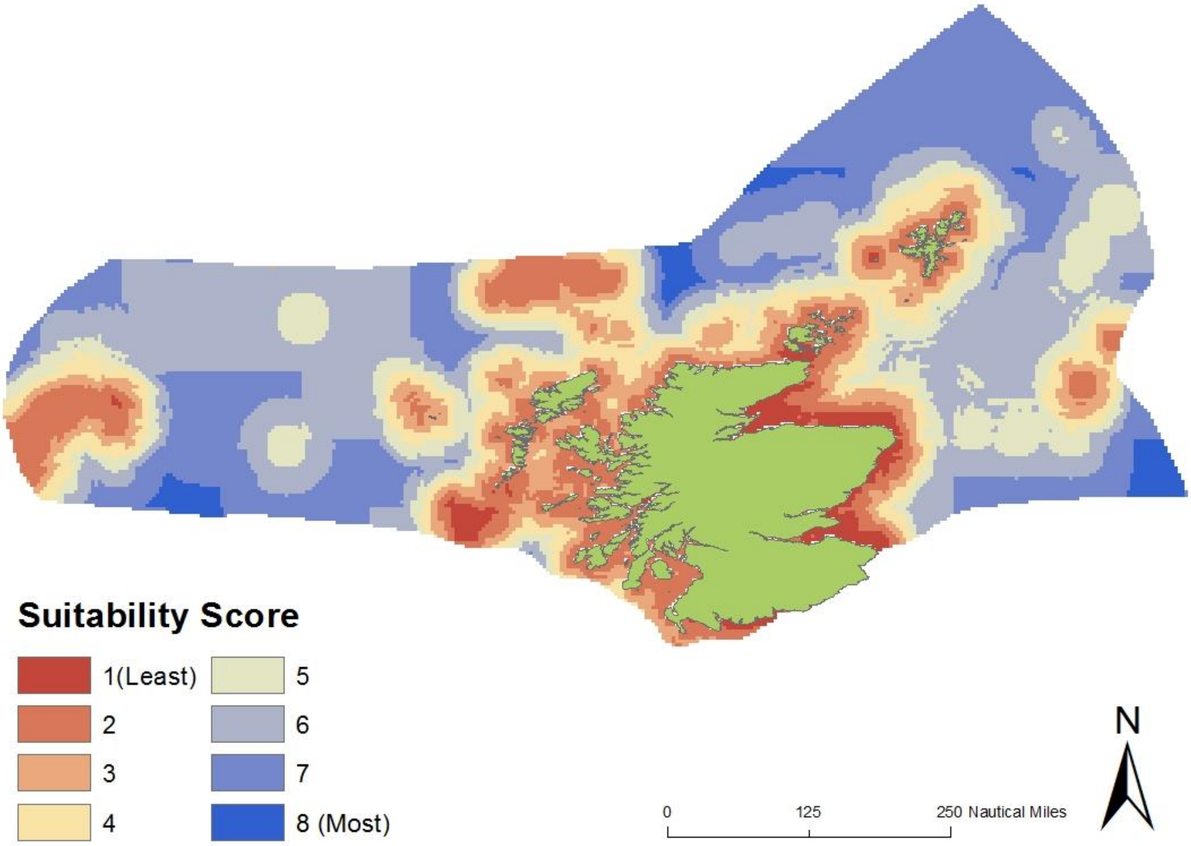

Figure 8.4 - Biological Sub-Model - Areas most suitable for cage salmon aquaculture in Scotland.

After being shown the map output in Figure 8.4, stakeholders were then asked to repeat the weighting process using a new pair-wise comparison matrix, this time informed by the knowledge of their previous decision making output. The result of this second round of decision making can be seen below in Figure 8.5. The increase in less suitable sites should be noted as a result of an increase in the weighting of predator and pollution sites that are located within inshore waters primarily.

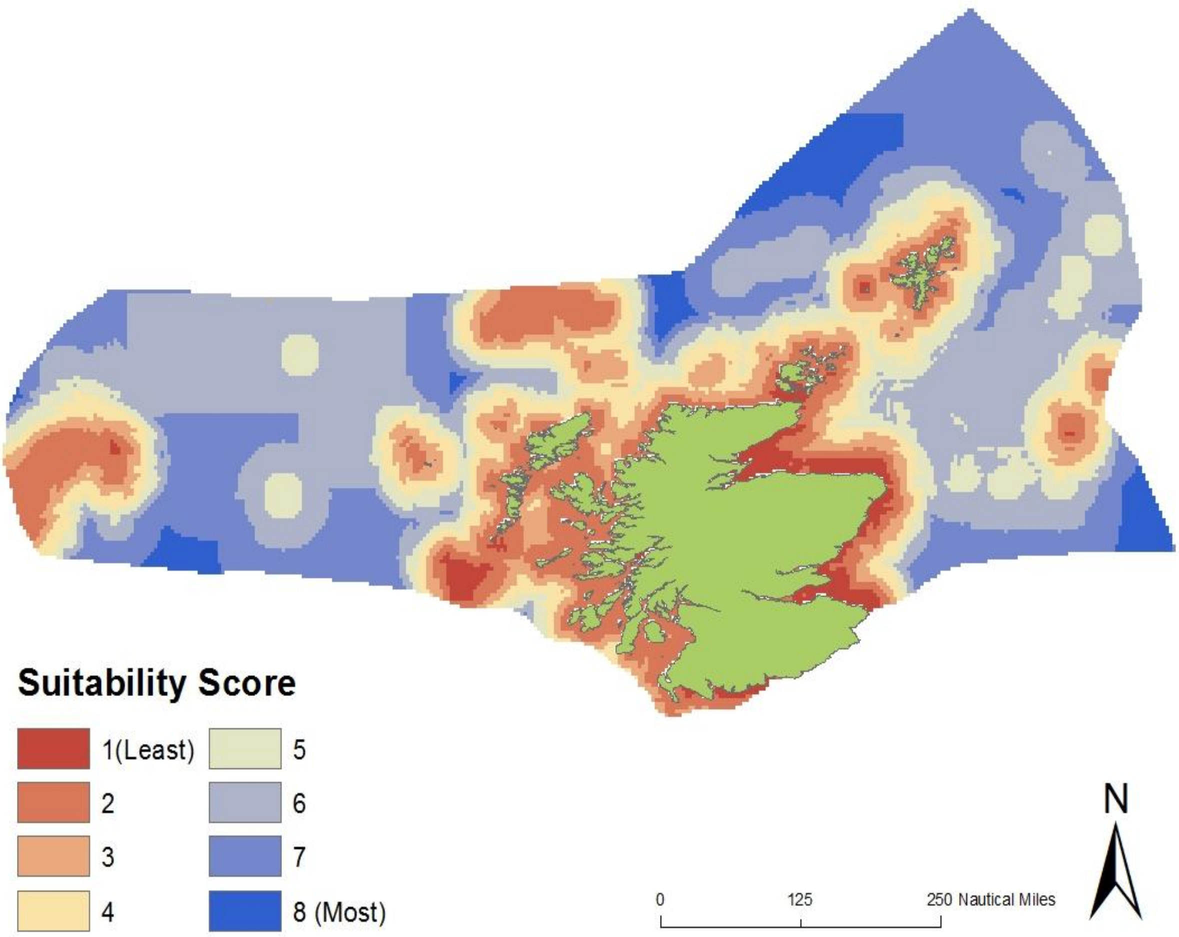

Figure 18 - Reviewed Biological Sub-Model

This Sub-Model was designed to investigate the significance of biological variables in terms of restricting the suitability of areas to cage aquaculture by combining various data layers reflecting different aspects of marine biological growth that can be influenced or have effects on or from aquaculture facilities.

Weighting of Components

Table 8.9 - Original Weighting of Component Layers by the Workshop Participants for the Biological Sub-Model

Criteria	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Decision Maker F		Decision Maker G		Mean Weighting Using all Seven Decision Makers
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	
Temp	0.07	3	0.09	3	0.13	3	0.82	1	0.7	1	0.57	1	0.43	2	0.401
Pollution	0.18	2	0.22	2	0.69	1	0.09	2	0.2	2	0.32	2	0.47	1	0.31
Predators	0.75	1	0.69	1	0.18	2	0.09	2	0.1	3	0.11	3	0.10	3	0.2885

Referring to both tables 8.9 and 8.10 it should be noted that due to there being less than 4 variables used within the biological sub-model, there was not a sufficient sample size for the reliable use of W. Siegel and Castellan (1988) also stated that where 3 variable such as in this case are used, then 8 or more decision makers are required before a critical value of occurrence less than 0.05 is available.

Table 8 - Reviewed Weighting of Component Layers by the Workshop Participants for the Biological Sub-Model

Criteria	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Decision Maker F		Decision Maker G		Mean Weighting Using all Seven Decision Makers
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	
Temp	0.08	3	0.09	3	0.11	3	0.17	3	0.64	1	0.33	2	0.65	1	.2957
Pollution	0.23	2	0.22	2	0.68	1	0.39	2	0.26	2	0.57	1	0.23	2	0.3685
Predators	0.69	1	0.69	1	0.21	2	0.44	1	0.1	3	0.1	3	0.12	3	0.3357

8.4.2 Environmental Sub-Model

It was decided during the course of the stakeholder meeting to create an additional fourth sub-model which we have called the Environmental Sub-Model. The selection of criteria in this current study was made through the identification of those datasets that were most likely to be affected by the wider, water body impacts that can occur as a result of finfish cage culture. Table 8.11

lists the criteria layers used in this Environmental sub-model and gives details on their construction and significance.

Table 8.11 - Data Layers used in the Environmental Sub-Model alongside details of their Construction and Significance.

Criteria Layer	Data Source and Reclassification	Description and Significance
Chlorophyll	Data Source : SAHFOS (11-11.4)= 1, (0-3)=2, (3-6)=3, (6-7)= 4, (7-8)=5, (8-9)=6, (10-11)=7and (9-10)=8	Indicative of availability of natural food and areas potential more at risks from HABS (mg/m^2). Areas above 10mg/m^2 considered at greater risk for eutrophication
Nursery & Spawning	Data Source : CEFAS (0-0.1)= 1, (0.1-0.2)=2, (0.2-0.3)=3, (0.3-0.4)= 4, (0.4-0.5)=5, (0.5-0.6)=6, (0.6-0.7)=7and (0.7-5.51)=8	Insurance against no negative impact on wild fisheries, measured in km. High intensity spawning and nursery grounds of important commercial species used.
Protected Marine Areas	Data Source : SNH and JNCC (0-0.1)= 1, (0.1-0.2)=2, (0.2-0.3)=3, (0.3-0.4)= 4, (0.4-0.5)=5, (0.5-0.6)=6, (0.6-0.7)=7and (0.7-3.04)=8	Distance from already designated areas (excluding MPAs) in km. Dependent on the type of site designation aquaculture may still be permitted within this area.
Sensitive Species	Data Source : SNH (0-0.1)= 1, (0.1- 0.2)=2, (0.2- 0.3)=3, (0.3- 0.4)= 4, (0.4- 0.5)=5, (0.5-0.6)=6, (0.6- 0.7)=7and (0.7-5.09)=8	Distance from Benthic Habitat forming Priority Marine Features in km. Safe distance to ensure sensitive species are not put under stress.

Model Output

Constructed by MCE using layers:	Weighting:	Reviewed
• Chlorophyll	0.114	0.101
• Nursery and Spawning Areas	0.225	0.124
• Protected Areas	0.411	0.47
• Species Sensitive to Aquaculture	0.36	0.304

We can see in the Environmental sub-model output map in Figure 8.6, that the majority of the most suitable areas (scores 7 and 8) were located offshore, with inshore areas being less suitable and having lower scores.

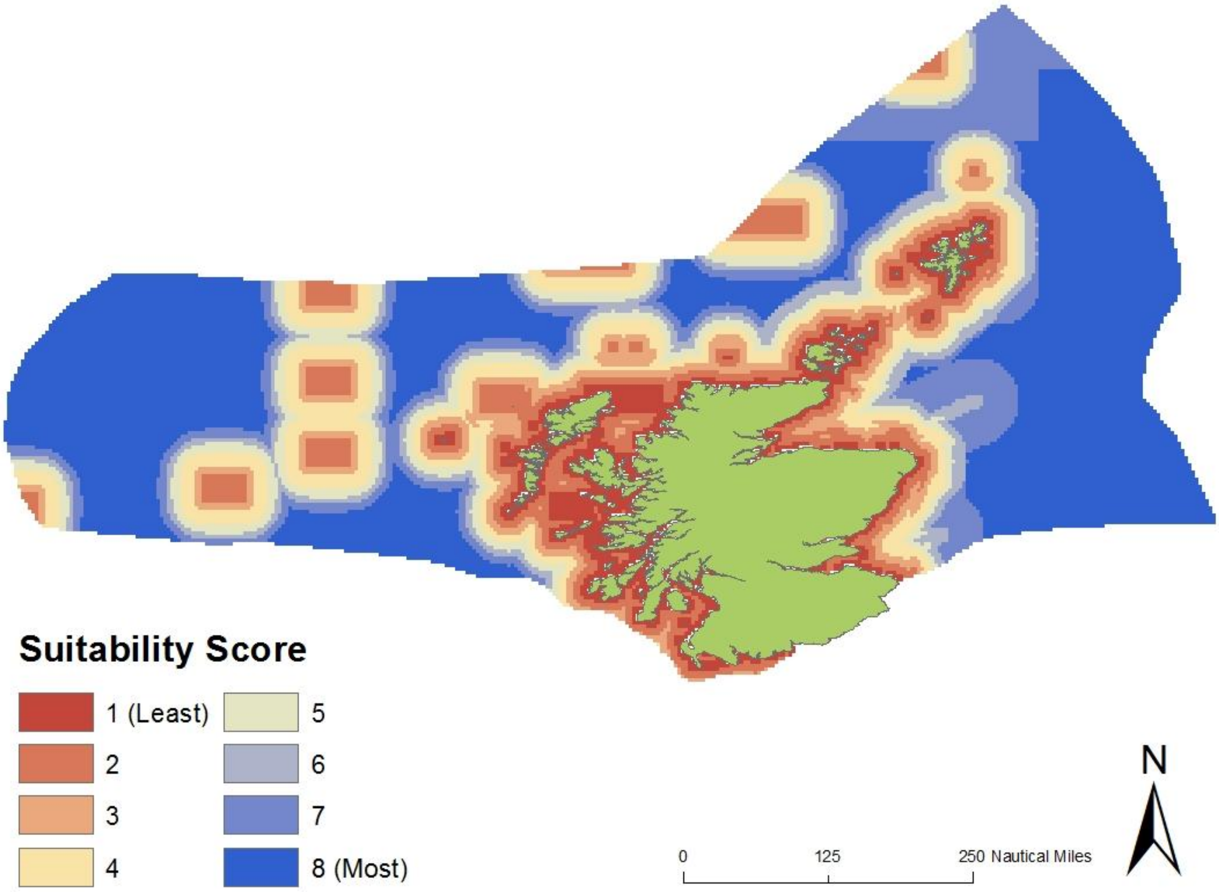

Figure 8.6 - Environmental Sub-Model - Areas most suitable for cage salmon aquaculture in Scotland.

Referring to Table 8.21, it can see that the Environmental sub-model, from all of the four sub-models analysed, had the highest percentage area dedicated to score 8, the most suitable being allocated 41.39%. Which can be seen from Figures 8.6 and 8.7, was always located offshore. A further 17% was then also found to belong to scores 6 and 7, the next most suitable areas. From these results it could be assumed that the Environmental sub-model was the least limiting in terms of area coverage for salmon age culture.

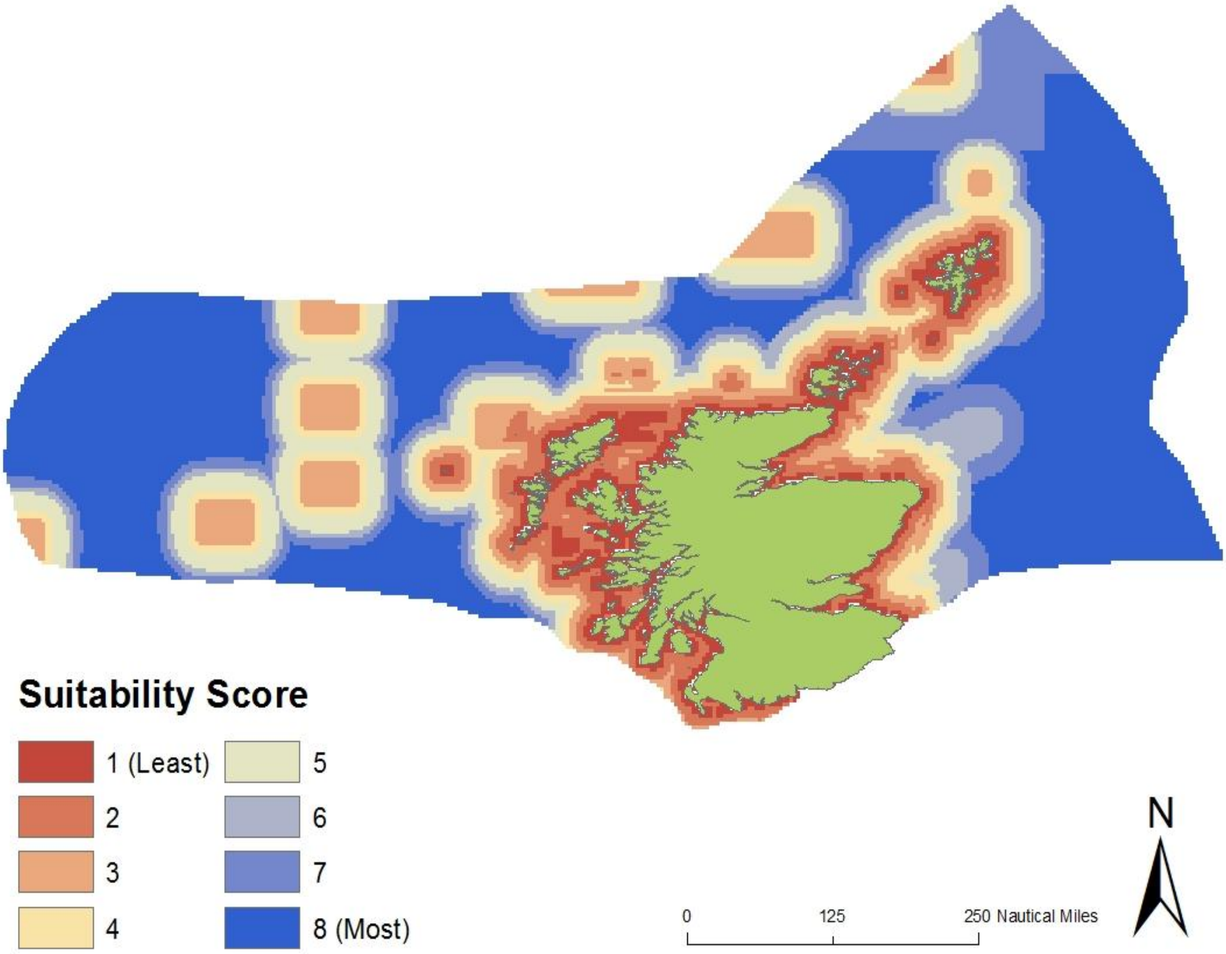

Figure 8.7 - Reviewed Environmental Sub-Model

This Sub-Model was designed to investigate the significance of environmental variables in terms of restricting the suitability of areas to cage aquaculture by combining various data layers reflecting different aspects of marine environmental communities that can be influenced or have effects on or from aquaculture facilities.

Weighting of Components

Table 8.129 - Weighting of Component Layers by the Workshop Participants for the Environmental Sub-Model

Criteria	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Decision Maker F		Decision Maker G		Mean Weighting Using all Seven Decision Makers
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	
Chlorophyll	0.03	4	0.05	4	0.08	4	0.04	3	0.1	3	0.42	1	0.08	3	0.114
Nursery & Spawning	0.14	3	0.1	3	0.12	3	0.04	3	0.06	4	0.1	4	0.23	2	0.225
Protected Areas	0.58	1	0.59	1	0.27	2	0.23	2	0.65	1	0.33	3	0.23	2	0.411
Sensitive Species	0.25	2	0.26	2	0.53	1	0.68	1	0.2	2	0.15	2	0.45	1	0.36

W= 0.14

After the stakeholders re-considered their decisions for this sub-model we saw only a slight difference in their weightings, with no change to the ranks assigned and this was reflected in the second map output see Figure 8.7. What is interesting to note is the *W* value for the original output was 0.14 which is very low and suggests a poor level of agreement between decision makers. This already poor value became substantially worse after the stakeholders made their second attempt at the decision matrix falling to 0.08, see Tables 8.12 and 8.13 respectively. Although overall agreement was not strong there did appear to be a high significance trend for protected areas in both the original and second set of weights, see Tables 8.12 and 8.13.

Table 8.13 - Reviewed Weighting of Components Layers by the Workshop Participants for the Environmental Sub-Models

Criteria	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Decision Maker F		Decision Maker G		Mean Weighting Using all Seven Decision Makers
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	
Chlorophyll	0.02	4	0.05	4	0.07	4	0.03	4	0.1	3	0.34	2	0.1	4	0.101
Nursery & Spawning	0.14	3	0.12	3	0.16	3	0.08	3	0.05	4	0.1	4	0.22	3	0.124
Protected Areas	0.6	1	0.67	1	0.23	2	0.52	1	0.6	1	0.37	1	0.30	2	0.47
Sensitive Species	0.24	2	0.16	2	0.54	1	0.37	2	0.25	2	0.19	3	0.38	1	0.304

W= 0.08

8.4.3 Physical Sub-Model

Within this Sub-Model those individual criteria chosen by the stakeholders (see Table 8.14 below), were brought together to provide some insight as to where physical factors may be limiting to salmon cage culture.

Table 8.14 - Data Layers used in the Physical Sub-Model alongside details of their Construction and Significance.

Criteria Layer	Data Source and Reclassification	Description and Significance
Water Depth	Data Source : JEBCO (512 --10 and -2391--80)= 1, (-10--20 and -80--75)=2, (-20 -- 25 and -75--80)=3, (-25--30 and -70--75)= 4, (-30--35 and -65--70)=5, (-35--40 and -60--65)=6, (-40--45 and -55--60)=7and (-45--55)=8	Shows depth from water surface in (m). Favourable depth for salmon culture as cage nets can drop between 18 and 20m
Current Velocity	Data Source : IMR Norway (0-4 and 40-59)= 1, (4-5 and 38-40)=2, (5-6 and 36-38)=3, (6-7 and 34-36)= 4, (7-8 and 32-34)=5, (8-9 and 31-32)=6, (9-10 and 30-31)=7and (10-30)=8	Current Velocity measured in (ms^1). Current speed fast enough to prevent degradation of the surrounding areas.
Sediment Type	Data Source : JNCC (Fine)= 1, (Fine/Deep)=2, (Mixed/Upper)=3, (Mixed)= 4, (Mixed/Deep)=5, (Course/Upper)=6, (Course/Deep)=7and (Rock/Deep)=8	Sediment type least likely to be heavily impacted by the fallout from cage culture.
Max Wave Height	Data Source : DECC (0-0.5)= 1, (0.5-1)=2, (1-1.2)=3, (1.2-1.4)= 4, (1.4-1.6)=5, (1.6-1.8)=6, (1.8-2)=7and (2-2.2)=8	Shows Maximum wave height in (m). Wave height that will not increase the chances of damages /escapees.
Transport Links	Data Source : OS data (0-1)= 1, (1-2)=2, (2-3)=3, (3-4)= 4, (4-5)=5, (5-6)=6, (6-8)=7and (8-74)=8	Distance recorded from major A roads and towns with train stations in (km). Support services and transport to market also commuting workforce.
Ports & Harbours	Data Source : MSS 0-1)= 1, (1-2)=2, (2-3)=3, (3-4)= 4, (4-5)=5, (5-6)=6, (6-7)=7and (7-94)=8	Distance from major ports and harbours in (km). Support services but also pollution and navigation.

Model Outputs

Constructed by MCE using layers: Weighting: Revised

Layer	Weighting	Revised
• Water Depth	0.144	0.137
• Current Velocity	0.215	0.294
• Sediment Type	0.108	0.1
• Max Wave Height	0.354	0.297
• Transport Links	0.07	0.068
• Ports & Harbours	0.011	0.1

The initial model output for the Physical Sub-Model can be seen in figure 8.8. Many of the most suitable areas can be seen located within inshore waters. However, the highest suitability score allocated by this Sub-Model is 5, which is substantially less than others such as the Environmental Sub-Model. This could suggest that overall physical aspects of site selection may be more limiting to salmon cage culture in the future.

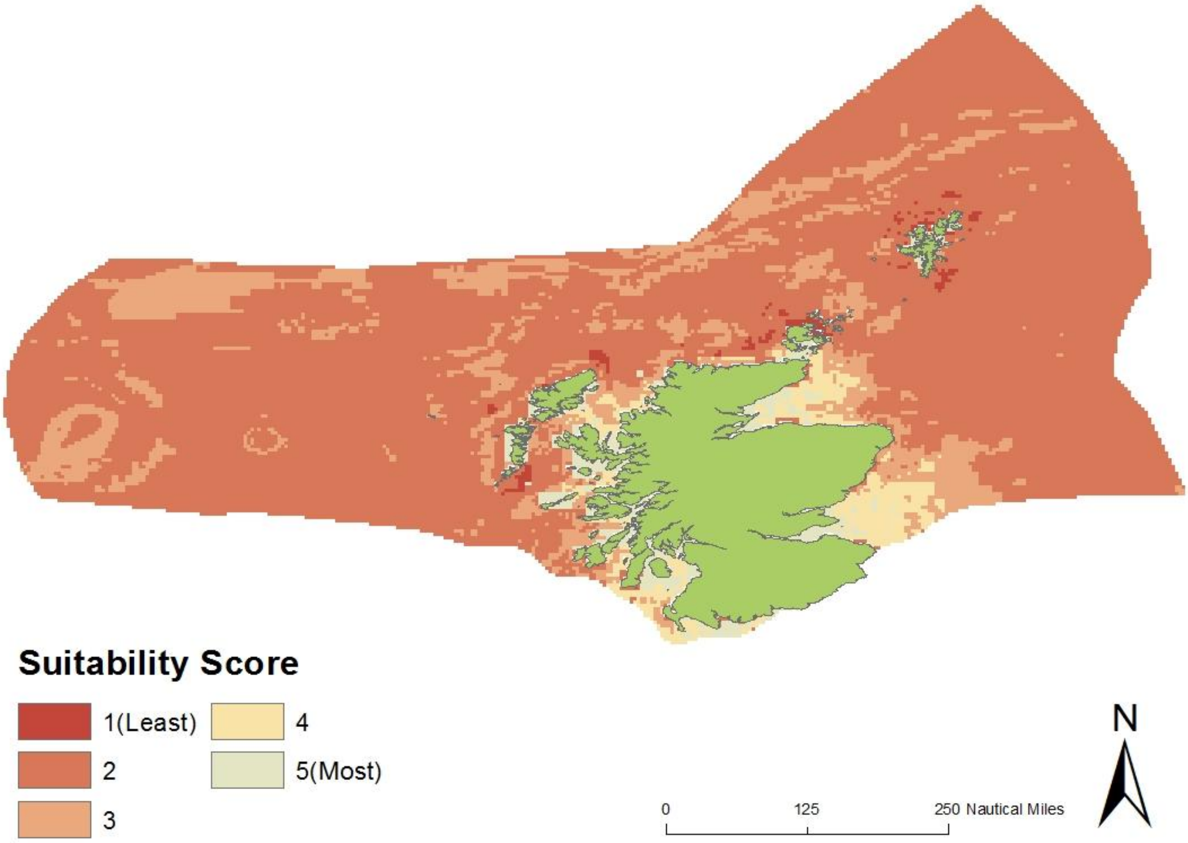

Figure 8.8 - Physical Sub-Model - Areas most suitable for cage salmon aquaculture in Scotland.

When we view the second output map for the Physical Sub-Model in figure 8.9, we can see slight differences in the distribution of the most suitable areas particularly on the West coast, many areas which in the first output rated a score of 2 are now given a score of 3.

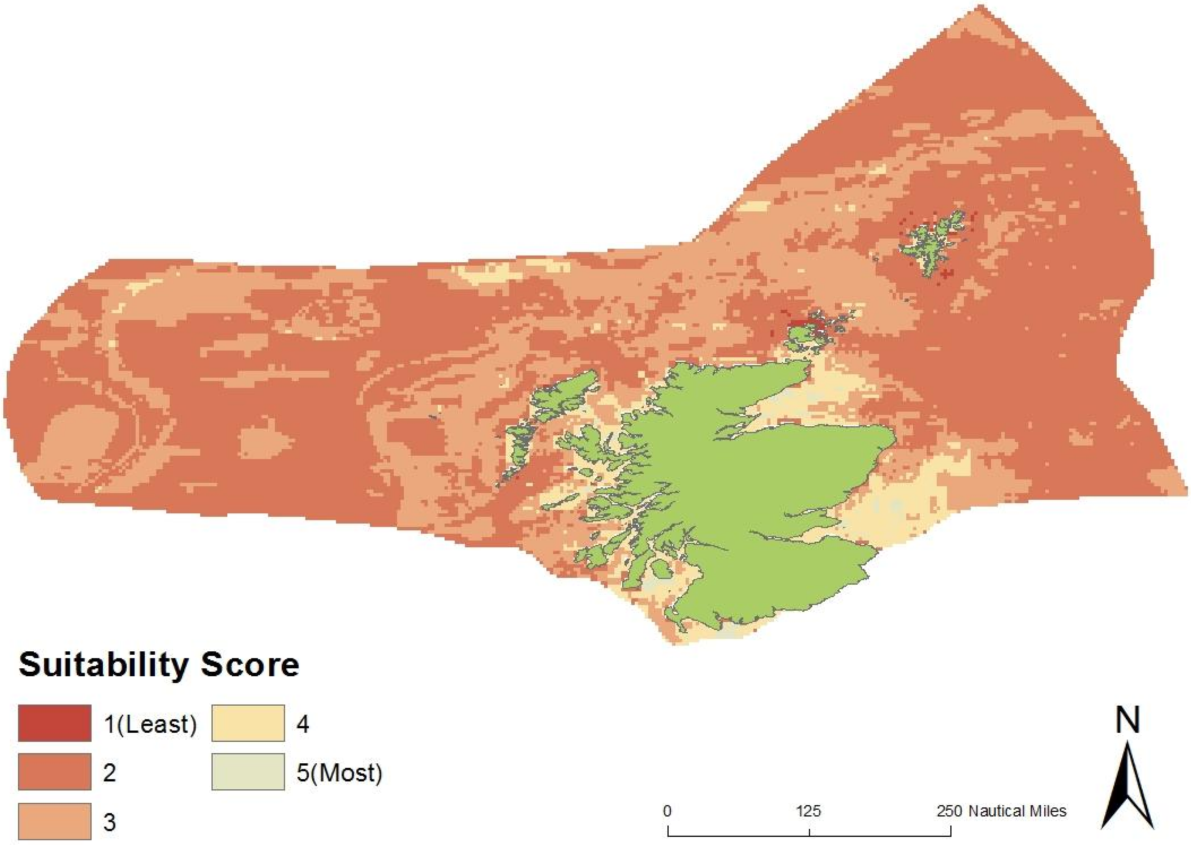

Figure 8.9 - Reviewed Physical Sub-Model

This Sub-Model was designed to investigate the significance of physical variables in terms of restricting the suitability of areas to cage aquaculture by combining various data layers reflecting different aspects of the physical environment that can be influenced or have effects on or from aquaculture facilities.

Weighting of Components

Unlike with the previous Sub-Model the ranking of the layers within the Physical Sub-Model was altered after the first set of decisions were carried out, see Tables 8.15 and 8.16 below. Interestingly both the transport links and the sediment criterion have changed their weights, becoming less heavily weighted and yet this has resulted in them being ranked lower within the model overall.

Table 8.15 - Weighting of component layers by the workshop participants for the Physical Sub-Model

Criteria	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Decision Maker F		Decision Maker G		Mean Weighting Using all Seven Decision Makers
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	
Depth	0.11	2	0.2	2	0.04	5	0.23	3	0.19	2	0.11	4	0.13	2	0.144
Current	0.1	3	0.08	4	0.28	2	0.41	1	0.15	3	0.24	2	0.25	1	0.215
Sediment	0.09	4	0.04	6	0.12	3	0.05	4	0.03	5	0.30	1	0.13	2	0.108
Wave	0.5	1	0.43	1	0.38	1	0.25	2	0.49	1	0.18	3	0.25	1	0.354
Transport	0.1	3	0.06	5	0.06	4	0.03	5	0.03	5	0.08	6	0.13	2	0.07
Ports	0.1	3	0.19	3	0.12	3	0.03	5	0.11	4	0.09	5	0.13	2	0.11

W =0.31

Referring to Table 8.15, we can see that the *W* value of 0.31 suggest that there wasn't a great deal of agreement between the stakeholders. This is best illustrated by the Sediment Type criteria layer, where decision maker B placed it as least important and decision maker D voted it as the most important.

Table 8.16 - Reviewed Weighting of component layers by the workshop participants for the Physical Sub-Model

Criteria	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Decision Maker F		Decision Maker G		Mean Weighting Using all Seven Decision Makers
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	
Depth	0.14	2	0.2	2	0.04	6	0.21	2	0.18	3	0.09	4	0.1	4	0.137
Current	0.12	3	0.11	4	0.29	2	0.48	1	0.42	1	0.38	1	0.26	2	0.294
Sediment	0.1	4	0.03	6	0.12	4	0.04	4	0.03	5	0.26	2	0.12	3	0.1
Wave	0.4	1	0.41	1	0.35	1	0.20	3	0.28	2	0.13	3	0.31	1	0.297
Transport	0.12	3	0.06	5	0.06	5	0.04	4	0.03	5	0.07	5	0.1	4	0.068
Ports	0.12	3	0.19	3	0.13	3	0.04	4	0.06	4	0.07	5	0.1	4	0.1

W = 0.09

As with the Environmental Sub-Model it was found that the second output resulted in stakeholders being in even less agreement (W=0.09) after reviewing the output of their original weighting and revising their scoring.

8.4.4 Socio-Infrastructure Sub-Model

The Social-Infrastructure Sub-Model configured by this workshop had the greatest number of criteria (7) present, see table 8.17, having more than double the number of criteria that make up the Biological Sub-Model.

Table 8.17 - Data Layers used in the Social-Infrastructure Sub-Model alongside details of their Construction and Significance.

Criteria Layer	Data Source and Reclassification	Description and Significance
Beaches	Data Source : MSS (0-1)= 1, (1-2)=2, (2-4)=3, (4-6)= 4, (6-8)=5, (8-10)=6, (10-15)=7and (15-95)=8	Shows distance in km from Blue Flag beaches. Avoidance of any visual impact or pollution threat.
Aquaculture	Data Source : Crown Estate (0-1)= 1, (1-2)=2, (2-3)=3, (3-4)= 4, (4-5)=5, (5-6)=6, (6-7)=7and (7-77)=8	Shows distance from active aquaculture sites in km. Pollution, Navigation, Spread of Disease and Potential Accumulative effects of competition for natural resources.
Heritage Sites	Data Source : RCHAMS, Historic Scotland and OS data (0-0.2)= 1, (0.2-0.5)=2, (0.5-0.75)=3, (0.75-1)= 4, (1-1.25)=5, (1.25-1.5)=6, (1.5-2)=7and (2-54)=8	Show the distance from wreck sites and historical marine monuments often located in popular tourist towns in km. Support services and viewshed.
Conflicting Activities	Data Source : Multiple Data Source (High)= 1, (High)=2, (Medium)=3, (Medium)= 4, (Low)=5, (Low)=6, (Low)=7and (Low)=8	Shows areas where the is a high concentration of overlapping legislated activities, 2<=low, 3-4=medium and 4>=high. Hazards.
Small Craft	Data Sources : Edina (Marine Digimap) (0-1)= 1, (1-2)=2, (2-3)=3, (3-4)= 4, (4-5)=5, (5-6)=6, (6-7)=7and (7-76)=8	Distance from small craft facilities in km. Pollution and navigation issues may result however aquaculture facilities will also rely on these for their own boating requirements.
Commercial Fishing	Data Sources : MSS (0- 0.1)= 1, (0.1-0.2)=2, (0.2-0.3)=3, (0.3-0.4)= 4, (0.4-0.5)=5, (0.5-0.6)=6, (0.6-0.7)=7and (0.7-3.12)=8	Distance from important commercial fishing grounds in km for all the major fishing types high intensity areas have been selected. Ensure no negative impacts on wild fisheries.
Salmon Rivers	Data Source : MSS (0-0.1)= 1, (0.1-0.2)=2, (0.2-0.3)=3, (0.3-0.4)= 4, (0.4-0.5)=5, (0.5-0.6)=6, (0.6-0.7)=7and (0.7-9.74)=8	Distance from the mouth of salmon and sea trout rivers in km. Safe distance to ensure that wild salmonids will be exposed to farms.

Model Output

Constructed by MCE using layers:	Weighting:	Reviewed
• Beaches	0.077	0.154
• Aquaculture	0.184	0.125
• Heritage Site	0.112	0.14
• Conflicting Activities	0.198	0.2
• Small Craft	0.08	0.088
• Commercial Fisheries	0.157	0.13
• Salmon River Mouths	0.207	0.208

The first output map from the Socio-Infrastructure Sub-Model can be seen in Figure 8.10. The suitability of most areas, especially offshore appears to be fairly good, particularly on the West coast. Inshore waters would suggest a poorer level of suitability in terms of Social-Infrastructure factors particularly on the East coast and the Eastern side of the Outer Hebrides.

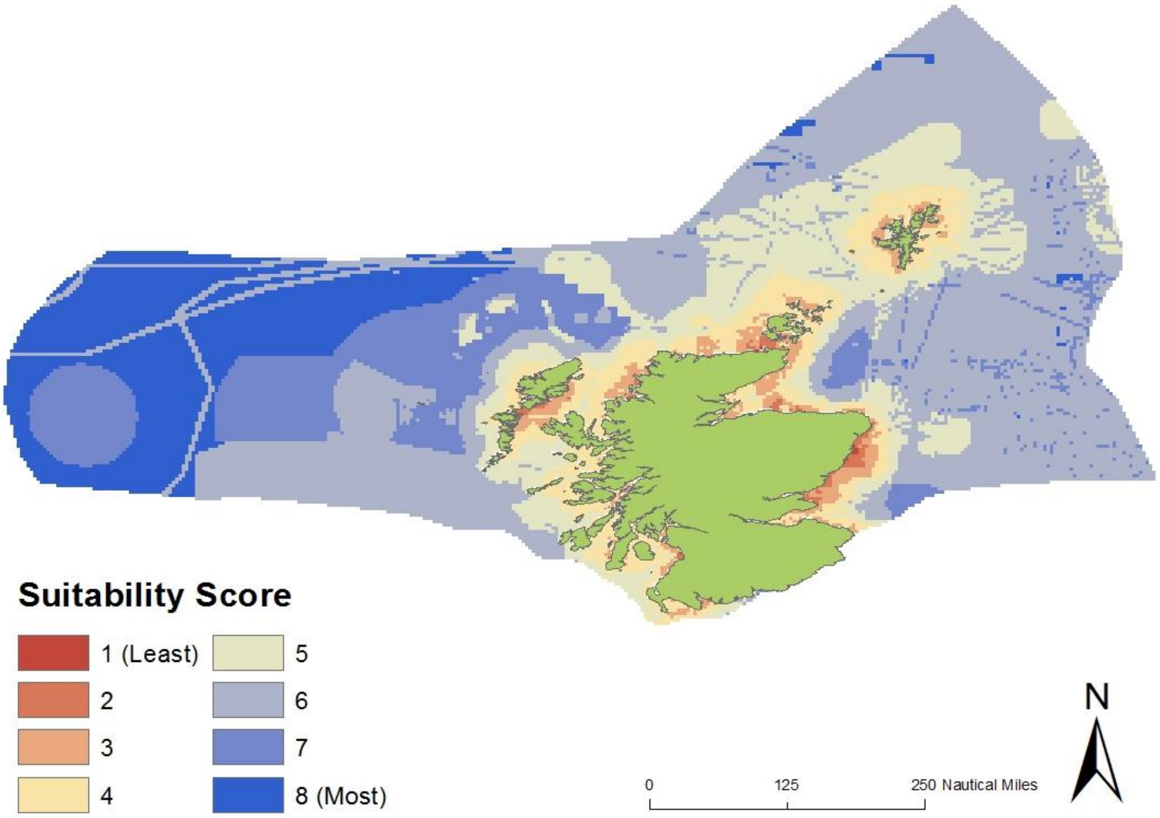

Figure 8.10 - Social-Infrastructure Sub-Model - Areas most suitable for cage salmon aquaculture in Scotland.

The general pattern of suitability score distribution did not change greatly when the decision makers were allowed to re-evaluate their choices. What does change quite notably however, is the degree of suitability in certain areas, but perhaps most notably on the West coast, see Figures 8.10 and 8.11. After the second round of decision making no areas were found to have the most suitable score, 8.

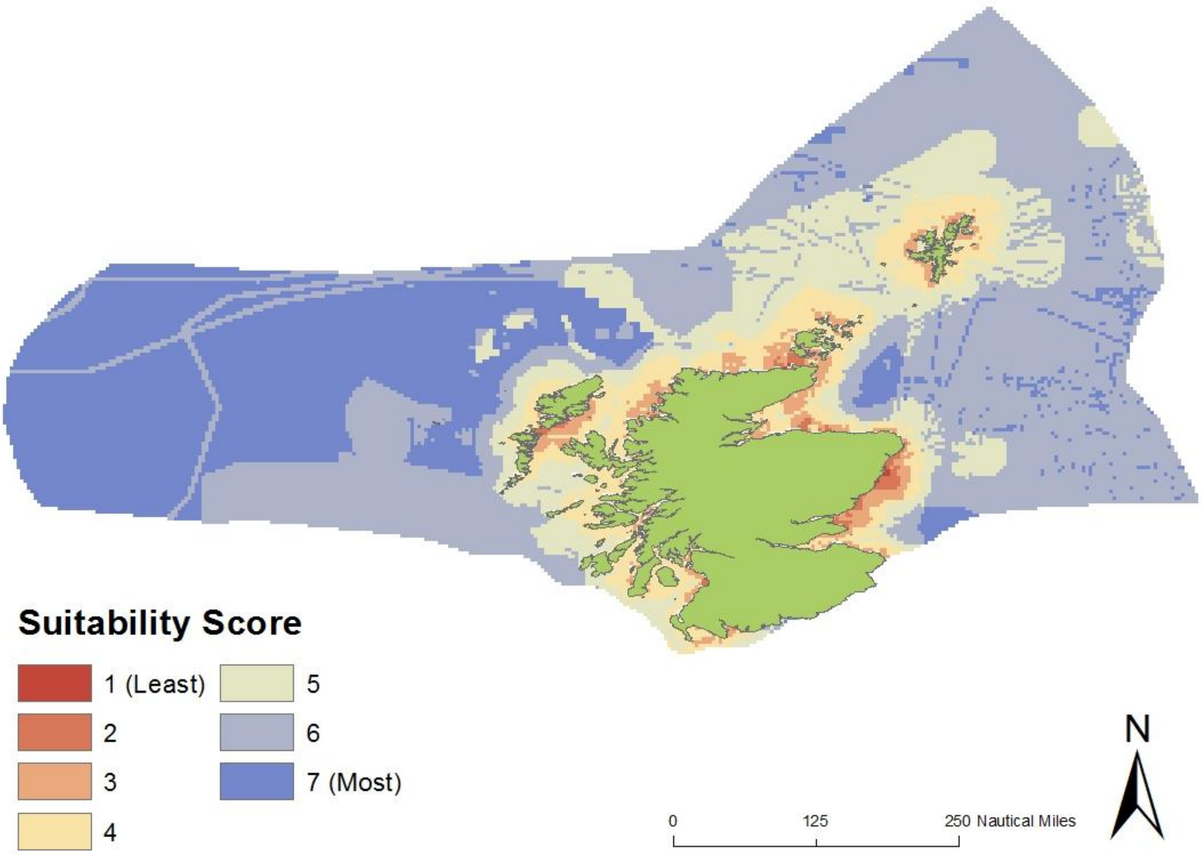

Figure 8.11 - Reviewed Social-Infrastructure Sub-Model

This change in suitability can perhaps be explained by changes to the weighting values between the two model runs as can be seen above there was some considerable variance in the weight values assigned in particular to the Beaches and Aquaculture layers.

This Sub-Model was designed to investigate the significance of Social-Infrastructure variables in terms of restricting the suitability of areas to cage aquaculture by combining various data layers reflecting different aspects of surrounding infrastructure and current settlement that can be influenced or have effects on or from aquaculture facilities.

Weight Components

When we look at the order of ranking of the criteria in the original Socio-Infrastructure Sub-Model, Table 8.18, and compare it with the order of ranking in Table 8.19 it is notable that Beaches and Aquaculture move their ranks by three or more places, while the two highest ranked layers; Rivers and Conflicting Activities stay in the same place.

Table 8.18 - Weighting of Component Layers by the Workshop Participants for the Social-Infrastructure Sub-Model

Criteria	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Decision Maker F		Decision Maker G		Mean Weighting Using all Seven Decision Makers
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	
Beaches	0.08	5	0.03	5	0.08	5	0.12	3	0.03	7	0.11	4	0.09	5	0.077
Aquaculture	0.2	3	0.02	6	0.27	1	0.11	4	0.26	1	0.17	2	0.26	1	0.184
Heritage	0.06	6	0.2	2	0.05	7	0.11	4	0.11	5	0.06	5	0.09	5	0.112
Conflict Act	0.23	2	0.2	2	0.21	2	0.13	2	0.24	2	0.24	1	0.14	3	0.198
Small Craft	0.05	7	0.05	4	0.07	6	0.12	3	0.05	6	0.15	3	0.07	6	0.08
Fishing	0.11	4	0.18	3	0.18	3	0.29	1	0.13	4	0.11	4	0.1	4	0.157
Rivers	0.26	1	0.33	1	0.14	4	0.13	2	0.17	3	0.17	2	0.25	2	0.207

W = 0.2

The value for *W* for the original output was 0.2, indicating a low level of agreement between the decision makers, see Table 8.16. Notably individuals C, E, F and G all indicated that aquaculture was very important while individuals B and D ranked it as fairly insignificant.

Table 8.19 - Reviewed weighting of component layers by the workshop participants for the Social-Infrastructure Sub-Model

Criteria	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Decision Maker F		Decision Maker G		Mean Weighting Using all Seven Decision Makers
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	
Beaches	0.08	5	0.03	5	0.21	2	0.15	4	0.4	1	0.13	3	0.08	3	0.154
Aquaculture	0.19	3	0.02	6	0.05	6	0.04	6	0.23	3	0.13	3	0.22	2	0.125
Heritage	0.06	6	0.2	2	0.32	1	0.17	2	0.08	6	0.07	5	0.08	3	0.14
Conflict Act	0.23	2	0.2	2	0.19	3	0.16	3	0.32	2	0.22	1	0.08	3	0.2
Small Craft	0.05	7	0.05	4	0.03	7	0.16	3	0.05	7	0.20	2	0.08	3	0.088
Fishing	0.11	4	0.18	3	0.09	5	0.18	1	0.17	4	0.1	4	0.08	3	0.13
River	0.26	1	0.33	1	0.11	4	0.13	5	0.11	5	0.13	3	0.39	1	0.208

W = 0.28

Having reviewed the initial output the decision makers were found to have a slightly higher level of agreement (*W* = 0.28) after they had reconsidered their choices for a second time, see table 8.19. What was also interesting to note was the change in the ranking afforded to aquaculture by some decision makers, while its overall rank remained unchanged, decision makers D altered its rank most significantly from 1st to 6th place.

8.4.5 Final Model Configuration

Constructed by MCE using Sub-Models: Weighting:

- Social-Infrastructure 0.13
- Physical 0.0.267
- Biological 0.334
- Environmental 0.271

Here the outputs from all the Sub-Models are weighted and brought together with the aim of investigating suitability for salmon cage culture. The aim is not to produce a definitive model, but rather to provide some insight as to where and why areas may be more or less suitable for this type of aquaculture. These results can then be used as a guide in conjunction with other available data, reports and information guidelines and sources to make sensible informed decisions regarding site suitability and as a basis for further investigation.

As can be seen in Figure 8.12, the final output from this model showed there to be more suitable areas offshore than inshore. This said there are still potentially areas on the West coast that could prove potentially suitable. When shown the results the decision makers were all in agreement over the weights and rankings they had given each Sub-Model so it was decided that a second review was not necessary.

This Final Model output was designed to investigate the significance of weighting each of the various Sub-Models in terms of their overall importance to aquaculture site selection.

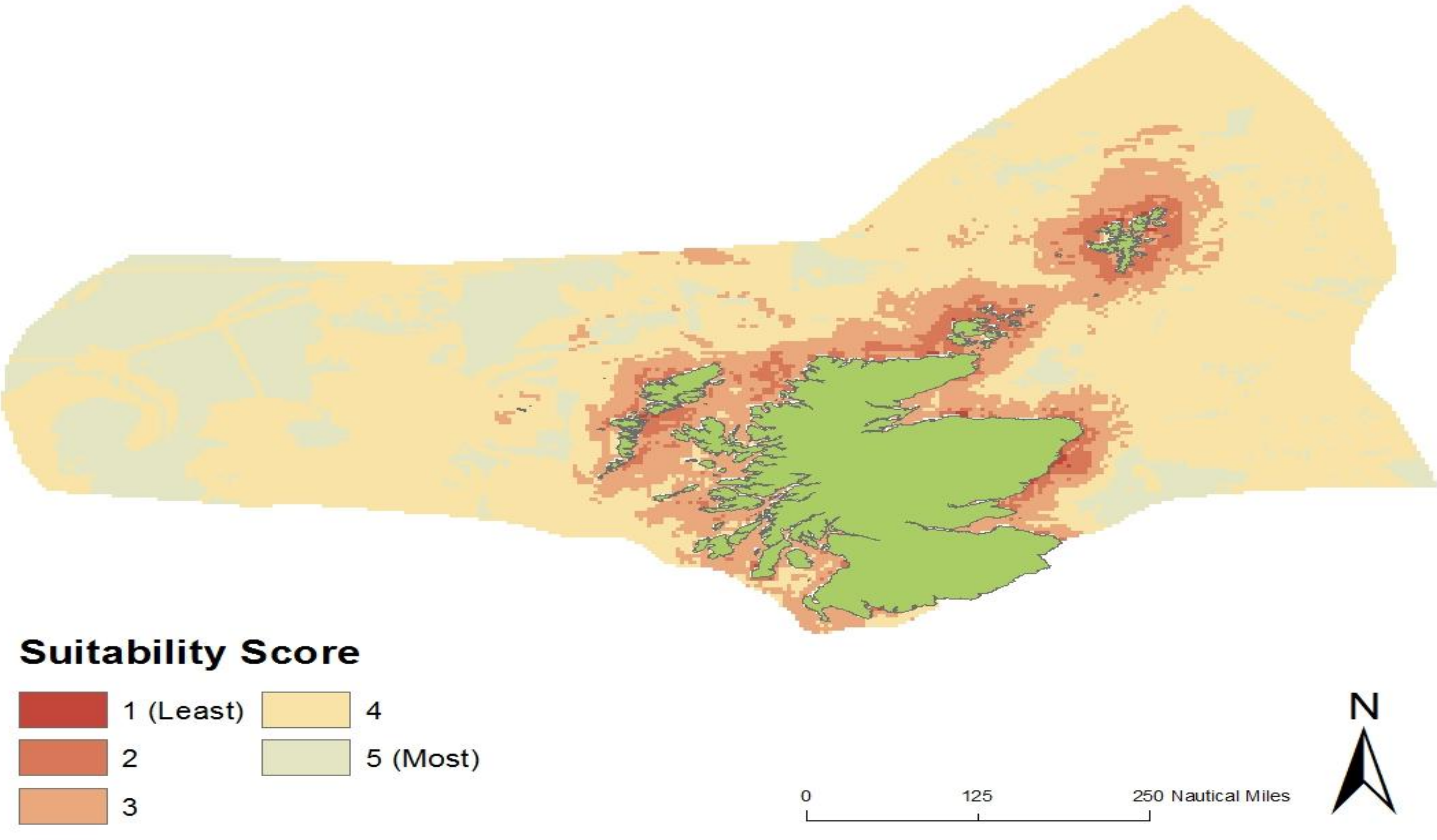

Figure 8.12 - Final Output – Areas most suitable for salmon cage culture in Scotland

Weighting of Sub-Models

Table 8.20 shows the final output from the decision makers, agreement between them was generally poor (*W* = 0.28). There seemed to be a trend, however, for high significance in the case of Physical criteria and low significance for Biological criteria. It is agreed here that both Physical and Socio-Infrastructure criteria are very important components, but it was also verbalised that Socio-Infrastructure criteria at certain locations would often need to be weighted more strongly.

Table 8.20 - Weighting of Components Sub-Models by Workshop Participants

Criteria	Decision Maker A		Decision Maker B		Decision Maker C		Decision Maker D		Decision Maker E		Decision Maker F		Decision Maker G		Mean Weighting Using all Seven Decision Makers
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank	
Biological	0.04	4	0.05	4	0.11	4	0.25	1	0.07	3	0.33	2	0.06	3	0.13
Environmental	0.1	3	0.21	3	0.27	2	0.25	1	0.39	1	0.09	4	0.56	1	0.267
Physical	0.4	2	0.5	1	0.42	1	0.25	1	0.15	2	0.43	1	0.19	2	0.334
Social-Infrastructure	0.46	1	0.24	2	0.21	3	0.25	1	0.39	1	0.16	3	0.19	2	0.271

Table 8.21 - Different Suitability levels (expressed as a percentage of the total potential areas) for Salmon Cage Aquaculture in Scotland

Factors/Criteria	Suitability Score 1	2	3	4	5	6	7	8
Physical								
Original Weights	0.62	77.08	15.15	3.84	3.31			
Reviewed Weights	0.19	59.48	32.19	7.59	0.55			
Social-Infrastructure								
Original Weights	0.04	0.50	2.84	8.45	15.59	42.01	14.63	15.94
Reviewed Weights	0.04	0.51	2.83	8.48	15.60	41.95	30.57	
Biological								
Original Weights	2.54	11.76	10.18	9.88	12.57	28.59	22.15	2.32
Reviewed Weights	2.63	12.46	9.69	9.62	100.72	28.87	21.87	4.14
Environmental								
Original Weights	7.35	8.77	7.07	10.38	7.86	6.23	10.95	41.39
Reviewed Weights	6.49	7.21	9.08	7.25	11.49	6.95	10.15	41.9
Final Output								
Original Weights	0.18	5.06	16.39	57.66	20.17			
Reviewed Weights	0.15	3.47	14.86	60.98	20.55			

8.5 Discussion

This study focused on identifying the most suitable sites for salmon cage aquaculture based on a range of objective criteria, organised and weighted according to informed stakeholder input. After considerable discussion the different criteria were placed within four Sub-Models (Biological, Environmental, Physical and Social-Infrastructure). These were then combined to generate a final output showing the most suitable sites for this type of aquaculture development around Scotland. Referring to map in Fig 8.12 showing the final output from suitability model, inshore waters had the highest coverage of unsuitable areas for cage culture.

Although the total potential area in this study is 469,605 km^2 (sea area out to 200 nautical miles), only around 21% (97, 213 km^2) could be classified as being potentially suitable for salmon cage culture with a suitability score of 5, while the remaining 79% (372, 204km^2) was identified as having a suitability score less than 4 (see Table 8.21 for percentage coverage of each suitability score).

To understand the relationship between the decision making and the final output was analysed each of the individual sub-models both during and after the workshop in order to identify an areas that need to be re-addressed and where improvements could be made.

Looking firstly at the Biological Sub-Model, the smallest model component containing only three criteria, it was recognised that the weightings assigned would be most influential to this models output. This was demonstrated (see Figures 8.5 and 8.6) by the resultant maps that designated most of the inshore waters as being unsuitable due to the high weighting of both predators and pollution criteria that were both located within inshore waters. What was interesting to note from this map (Fig. 8.5), was that the East coast had a higher degree of unsuitability in many more areas than the West coast. Aquaculture in Scotland is not permitted on the East coast due to planning policy, primarily to protect wild salmon runs, however these result would also suggest this coast is additionally less suitable for other biological reasons too. From the second set of results produced from the Delphi it is also possible to ascertain that stakeholders agreed with the original weighting rank that they awarded each of the criteria. Given the data this could indicate that they agreed with the output map from this model, however thanks to the workshop discussions it was possible to ascertain that this was not the case. Although stakeholders largely agreed with the order of their rankings, they felt that the maps did not necessarily reflect their choices and therefore perhaps the standardisation of each of the criteria layers should be re-assessed.

In the results section it was identified that the Environmental sub-model was least limiting in terms of % area coverage of suitability scores when comparing all the different sub-models, see Table 8.21. However, when looking at the maps in Figures 8.7 and 8.8 it can be seen that most of this area is located offshore where aquaculture has not yet been developed. In fact when we consider all of the maps produced by the different sub-models it becomes apparent that the physical and social-infrastructure sub-models that are perhaps in actual fact less limiting as they show more suitability in inshore waters. Considering all the sub-models the maps produced would suggest that the biological and environmental criteria seem to place the most constraint on the industries coastal development.

Considering next the layers and their set up (Table 8.11) within the Environmental sub-model it is perhaps unsurprising that inshore waters have been judged to be less suitable for aquaculture. It can be seen that protected areas were the most heavily weighted or limiting of the four criteria, many of these designated areas can even be clearly distinguished on the map, due to them exerting significant suitability strength in more remote areas. What is important to acknowledge here is that just because areas have a conservation designation associated with them, this does not automatically mean that they are unable to also have aquaculture ventures present within them. The fact that protected areas were weighted quite so heavily was unexpected with only one out of the possible decision makers ranking it third most important as opposed to the remaining decision makers who placed it as the first or second most important criteria. This decision was solidified during the second round of the Delphi when all the decision makers placed the protected areas as being either the most or second most important criteria in this sub-model.

The outputs from the Physical Sub-Model were heavily influenced by the strong weighting of wave height and to a slightly lesser extent, current and water depth. These are the three obvious criteria that dramatically reduced the suitability of offshore waters, however in contrast they leave inshore waters more suitable. The dominance of these three layers within this Sub-Model is perhaps a direct result of the criteria chosen by stakeholders to represent this Sub-Model. It was interesting to note that there was a considerable amount of discussion generated amongst stakeholders surrounding the placement of criteria within this particular Sub-Model. Transport Links and Ports and Harbours criteria layers in particular were discussed at length, and whether or not they should be placed within the Social-Infrastructure or Physical Sub-Models. Eventually a vote was undertaken and the Physical Sub-Model was decided upon, however given the weightings they seem to be somewhat lost from the final outputs and perhaps their placement within this model could do with revision. Another criteria layer that sparked debate for another reason entirely within the Physical Sub-Model was Sediment Type. It was suggested that this layer could belong in multiple Sub-Models and should/could appear twice within the Models design. The point was raised following a point made that the ideal sediment type for moorings is not necessarily the same as the type of sediment that limits the amount of environmental stress placed on the benthos. Therefore perhaps this is an area that should be explored further in the future, can the same layer appear effectively within the same or different Sub-Models given that the criteria layer is standardised differently to represented different factors.

The maps produced by the Socio-Infrastructure Sub-Model could be considered largely unsurprising given that the majority of the criteria layers present were located within inshore waters. Thus it was conceivable that coastal waters were shown to be less suitable as aquaculture could conflict with these already established socio-economic interests. What was unexpected was the amount of areas still considered to be suitable on the West coast. Given that planning policy has already precluded aquaculture development in the East, the greater distribution of unsuitable areas along this coast is perhaps of less concern. Upon further investigation, however, it is the case that this model will require further investigation as areas of known high socio-infrastructure, i.e. the Clyde are not highlighted as being highly unsuitable. It could be that the layers need to be restructured or again, as mentioned earlier, the criteria may need to be reclassified or/and the standardisation edited. There are no guarantees that any of these things will have a considerable affect on the final models output however it would still prove a very worthwhile exercise. Indeed it is one of the major findings of this study that all the criteria layers would greatly benefit from reclassification with the addition of knowledge gained from these studies and output maps coupled with stakeholder participation.

It was the general feeling when considering the final overall output from the site suitability model, refer to Figure 8.13, that the mean weighting for the Biological Sub-Model may be a little weak when compared with the Environmental criteria dealing with the wider impacts. While the biological layers may only affect the suitability in specific areas many of these are home to significant aquaculture producing locations. Although all the decision makers when confronted with the final weights were in agreement with the importance placed on each Sub-Model, they felt that the overall output was perhaps still not reflective of their decision making choices. This was acknowledged as being largely thought to be due to the criteria layers not being standardised to reflect their opinions.

It should also be noted that there were some difficulties encountered regarding a lack of understanding amongst the decision makers as to the direction of the information requested of them, i.e. is it their personal opinions or those of the organisation they are representing, are they looking at this from the prospective of a producer or an environmentalist etc. This served to highlight both the difficulty of communicating the research objectives and scope (which also may account for some of the variation in responses) and also the advantage of having a face-to-face workshop whereby these issues can be easily clarified as opposed to a mailed questionnaire. A further issue that should be acknowledged, is that the use of an ‘expert panel approach’ that was adopted here can still result in biased or flawed understanding of the issue. This can always result regardless of how experts are chosen and how representative their views of current scientific opinion are. However, the relatively small working group assembled was considered to be as well informed as possible but acknowledge that this can be viewed as a possible issue.

Overall this study showed the effectiveness of incorporating stakeholder feedback with a GIS-based approach for identifying and creating a spatial model of suitability levels for salmon cage aquaculture. There are some additional factors not previously mentioned here that can also improve any site selection analysis, these are; adding more criteria and using site specific data for the area under consideration. The reality however, is that often the quality and quantity of the data available to decision makers can make precise site allocation analysis difficult. In this study data were compiled from a variety of resources and where data were questionable in accuracy or resolution it was left out of the analysis. It is also recognised that the site selection analysis as carried out by this study would benefit from further data improvements. This model was designed around the best possible datasets that were available for what were deemed to be the most important criteria relevant to salmon culture. However it is recognised that other criteria such as; dissolved oxygen, salinity, pH etc. are all able to significantly influence salmon growth and survival and they are equally considered important when estimating the capabilities of the site to sustain production levels.

8.6 Conclusion

In aquaculture site selection, expert knowledge can provide an invaluable contribution towards the solution of highly complex problems involving multiple decision making criteria. This study showed that the identification of criteria within Sub-Models and their relative weights to highlight their importance can be informed by a Delphi process. Moreover, a Delphi interactive workshop was shown to have potential in helping to obtain weights that are suitable for informing spatial analysis and mapping. The research has produced a provisional model framework that could be used to support the site selection process for cage aquaculture of salmon in Scotland. However, this approach developed here has also identified the need for further clarification to be given to each of the standardised criteria that combine to inform this models output. Although the Sub-Models and weights identified here are directly applicable to support salmon site selection through the use of GIS-based techniques, their validity should also be further tested perhaps through validation using established salmon cage site data.

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Chapter 9

Suitable Sustainable Aquaculture Sites - Conclusions

9.1 Introduction

Outcomes of these studies set out to evaluate and explore the application of different approaches, using GIS, to develop a marine spatial planning framework in Scotland, with a particular focus on decision making for future aquaculture sites. The Scottish government have set out clear targets for aquaculture in Scotland, aiming to increase finfish production by 100% in 2020. Therefore, the findings from this study could be used to inform the planning of future aquaculture locations and areas for expansion, thus helping to address the future goals set out for the industry in a sustainable manner. Optimising the site selection process in this manner is of particular importance as poor choices made at the planning stage can result in adverse environmental conditions and eventually in the failure of the site.

9.2 Empirical Findings

The main findings of these studies are chapter specific and can be found laid out within Chapters 2 to 8. Bringing together these individual findings allows this study to begin to address the main research questions posed in Chapter 1, Figure 1.1.

1. What degree of protection do different zoning schemes afford?
   Through the application of different zoning schemes it was evident that the level of protection along with the area coverage of protective zones varied greatly. This could largely be attributed to the data sets being utilised to derive the zones along with the rules devised to dictate the production of zones (Chapters 2, 3, 4 and 5).
2. Can activities be allowed to occur in the same area through similar management levels?
   All of the zoning schemes that were selected for application to the Scottish marine area in this study were effectively multiple-use in design. Schemes designed to allow for multiple activities to occur and be managed within a zone are, if devised carefully, a logical and effective means of designating marine space. They can be seen as a mechanism for implementing integrated management practices and

are perhaps the only solution for managing marine areas that already have many existing users and activities. (Chapters 2, 3 and 4)

3. Is it possible to design adaptive zoning schemes which can cope with climate change scenarios?

Given prioritisation within a zoning scheme it was shown in Chapter 5, that it is possible for important environmental features to be given significant and specified levels of protection. A zoning scheme that is adaptable and structured so that given new or improved data can be easily updated, can be seen as the basic starting point for the design of any adaptive management tool. Therefore, it has been demonstrated that it is possible to design tools that can be considered as ‘adaptive’, thus can help in terms of planning and conservation and mitigate against some of the effects of climate change. (Chapter 5)

4. Do current protective legislation measures in Scotland afford sufficient protection to important marine species?

The zoning scheme applied in Chapter 2 describes the development and testing of a multiple-use scheme. Given that the scheme applied was based on existing legislative controls and implemented for a wide variety of reasons it was unsurprising that the levels of protection it provided important marine species and features was relatively weak. (Chapter 2).

5. Which features/variables are more important to consider when selecting a suitable site for aquaculture?

Following an extensive literature review a list of key criteria were drawn up for use in both the shellfish and finfish models. However, it should be noted that the criteria used were restricted due to data quality and availability. Following stakeholder discussion however it was the consensus that all significant criteria were included, for a final list of criteria and their relative importance please see Chapter 8.

6. Can aquaculture be coupled with other industries that are managed at an equivalent level?

The application of our Prototype zoning scheme places aquaculture within Zone 3A the Limited Exclusion Zone where it would be managed alongside other activities such as sub-marine cables and pipelines, shipping and ferry routes, small craft facilities and MOD activities such as practice areas and firing danger areas. (Chapter 4).

7. How will stakeholder participation potentially affect the location of aquaculture sites?

   Inclusion of stakeholder opinion was found to greatly affect the site selection model output, reducing the overall level of suitability score assigned to the Scottish sea area. This could have resulted from two major changes that their input 'triggered'; one was the alteration of the models structure and secondly the weights assigned to the individual criteria. (Chapter 8).

8. Can areas suited to aquaculture be found within suitably managed areas as dictated by the Prototype zoning scheme?

   To attempt to answer this question this study can take Zone 3A (Limited Exclusion zone), the zone deemed suitable for aquaculture management from the Prototype zoning scheme produced in Chapter 4, and overlay it with the outputs from the stakeholder site selection model, see Chapter 8. Only the areas with the most suitable scores were extracted from the Stakeholder Site Suitability model and combined with Zone 3A for further analysis. Through combining the outputs from the two layers, see Figure 9.1, it was then also possible to calculate the potential area that was potential suitable within both inshore (12nm) and offshore (12-200nm), see Table 9.1.

Table 9.1 - Area in km of most suitable aquaculture scores within Zone 3A

Data Layer	Area (km^2)
Prototype Zone 3A	323,536
Aquaculture Suitability Score 4	286,342
Aquaculture Suitability Score 5	96,497
Aquaculture Suitability Score 4 within Zone 3A	203,978
Aquaculture Suitability Score 5 within Zone 3A	76,442
Aquaculture Suitability Score 4 within Zone 3A – 12nm	8,735
Aquaculture Suitability Score 5 within Zone 3A – 12nm	243
Aquaculture Suitability Score 4 within Zone 3A – 12-200nm	195,242
Aquaculture Suitability Score 5 within Zone 3A – 12-200nm	76,198
Aquaculture Suitability Score 4 within Zone 3A – West Coast	8,657
Aquaculture Suitability Score 5 within Zone 3A – West Coast	243

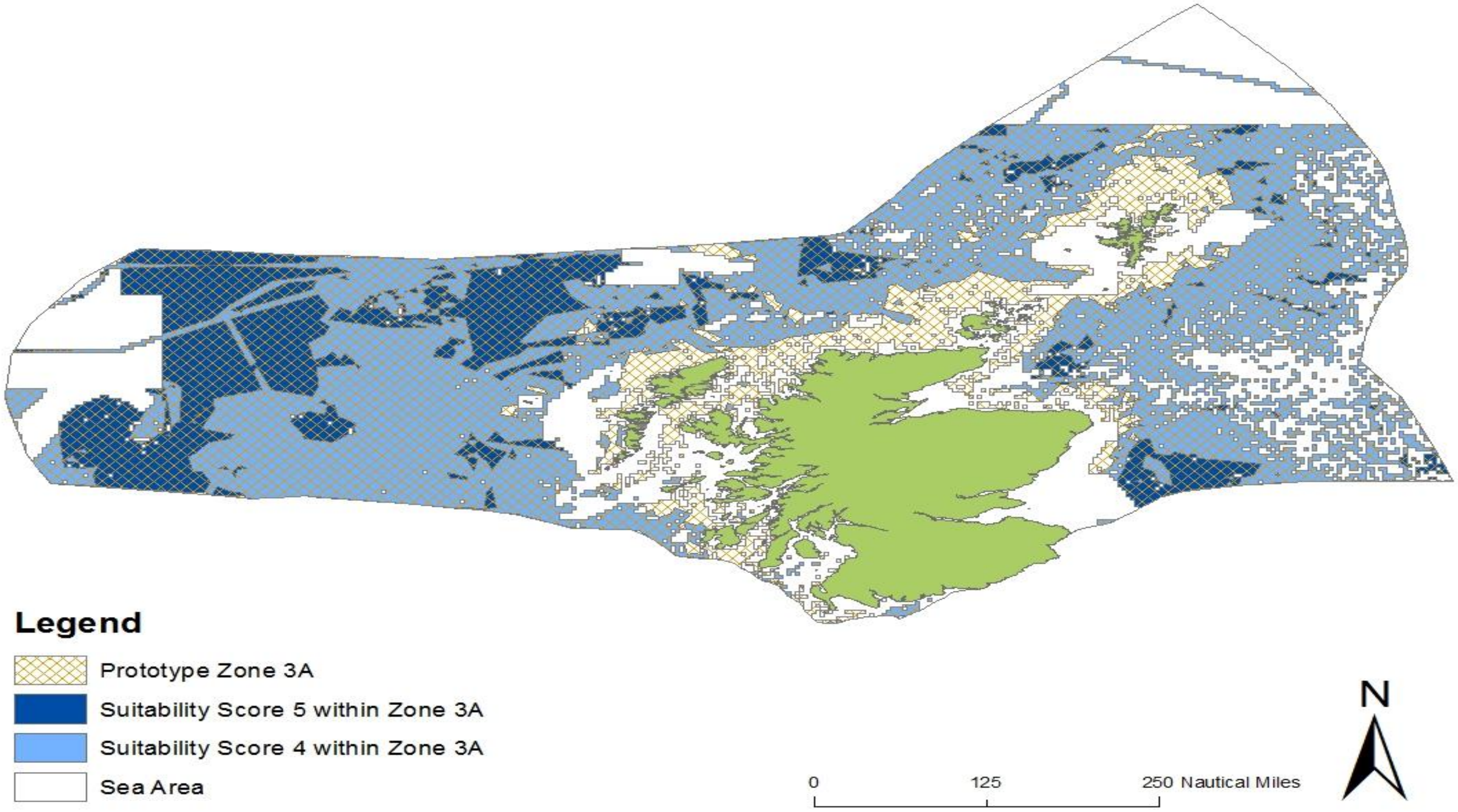

Figure 9.1 - The location of the Suitability Scores 4 and 5 within Prototype Zone 3A

9. Are there still suitable sites that will accommodate the potential future expansion of aquaculture in Scotland?

While Figure 9.1 shows areas that are theoretically most suitable, realistically this area is greatly reduced due to both existing planning policy with restrictions on East coast aquaculture development and the capabilities of the current industries infrastructure to locate offshore. Therefore, when looking at the most suitable areas within Zone 3A, within 12nm of the coast and only bordering northern and western shorelines (see Table 9.1 and Figure 9.2), it is possible to get a more realistic idea of which areas are most suitable. As can be seen in Figure 9.2 many of the areas identified are of a reasonable size and it could even prove to be the case that when explored further they are suitable for locating multiple farms. Furthermore, with developments in aquaculture practices such as multi-trophic culturing, where different organisms are cultured together to effectively reduce their environmental impact, the concentration of farms in areas could potentially be increased or result in higher product yields.

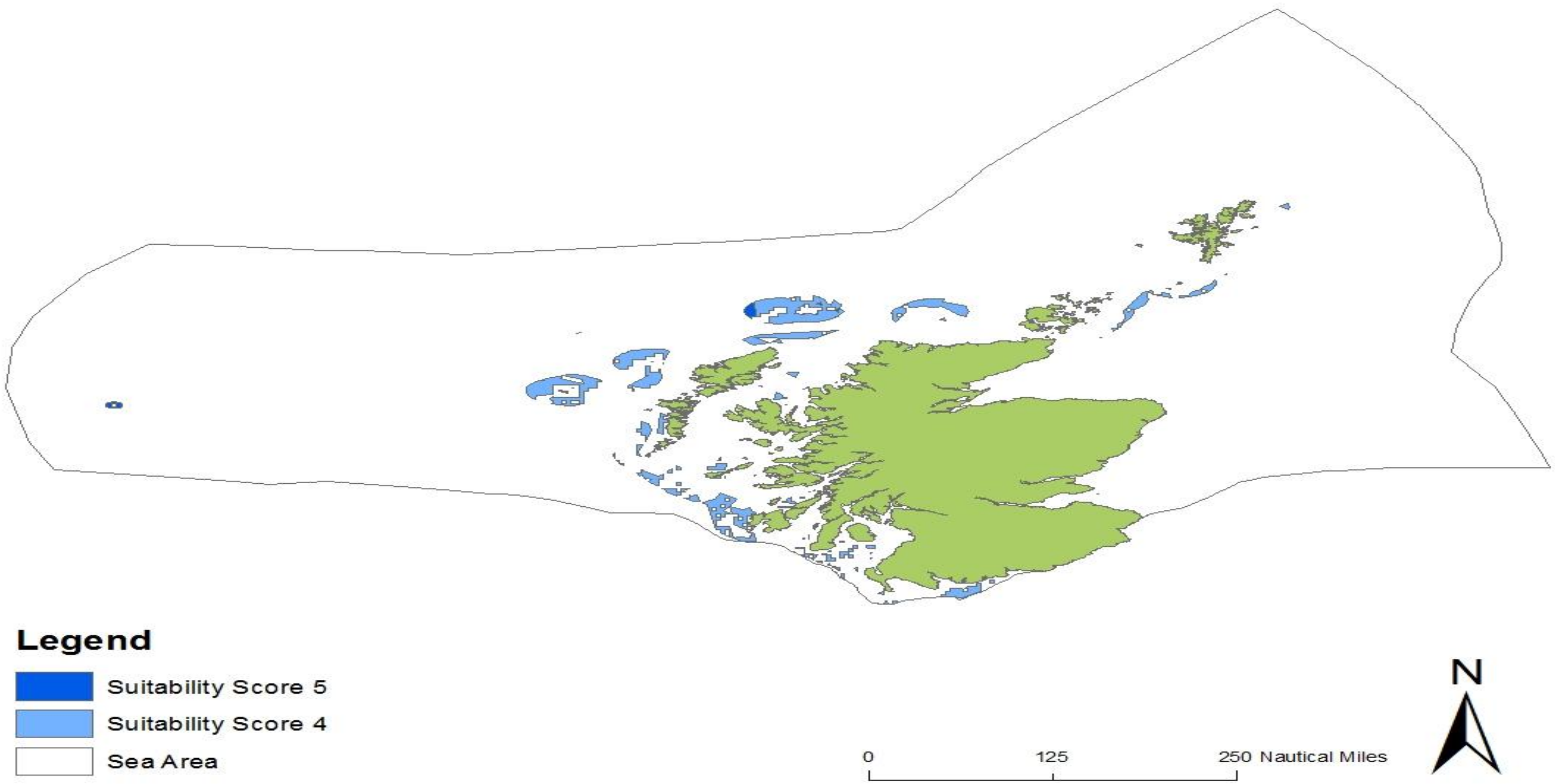

Figure 9.2 - The location of the Suitability Scores 4 and 5 within Prototype Zone 3A, 12nm of the coast and not located along the restricted East Coast sites.

9.3 Theoretical Findings

The need for a strategic approach to siting farms to facilitate sustainable expansion of aquaculture has been recognised nationally, as has the need to integrate any new approach within a marine planning framework. While this study has demonstrated that developing such an approach is possible it has also identified, and confirmed a far more pertinent issue. Namely that there is little space left within Scotland's inshore waters that is still both available and suitable for further sustainable aquaculture development. Pérez et al (2005) and Black et al. (2008) have also both identified that there are only a finite number of suitable sites left, and that this can largely be attributed to prime production sites being located in areas that have high concentrations of other marine activities. However, this study has also highlighted that there could potentially be a significant number of available sites (within suitable areas in terms of management) located in offshore waters. Moving aquaculture production offshore is a controversial and much talked about subject with proponents stating that mounting spatial pressures make the move offshore inevitable, meanwhile, detractors argue that there is not a big enough profit margin to drive capital investment. At present there are plans and committed investment from aquaculture companies like Marine Harvest to start new ventures in more exposed and remote sites on the West coast. None of these sites can be considered truly offshore, however as technologies advance, it is likely that Scotland's offshore waters will be highly suitable for such enterprises.

While this work has identified the potential for expansion exists, it also recognises that there is a large hurdle that stands in its way and that is the relationship between scientists and policy makers. For developments to continue in terms of management of the marine sector, be it aquaculture or any other industry or planning framework, a common language will need be devised. It is widely accepted now that science should be the foundation and underpin any future ventures in the marine environment; however the evidence produced may not always fall in line with Government plans and objectives. The 'battleground' that often results between science and policy can take up considerable resources and a significant amount of time to resolve. Therefore in terms of future marine planning and management perhaps the most essential tool to develop is one which aids the dialog between those that inform and those that enforce.

The communication difficulties that exist between policy makers and scientists also extend to marine stakeholders and users. While it is widely acknowledged that stakeholders should be involved as soon as possible in the planning and policy processes, the reality often is that they are not included until the later consultations stages. Exploring tools such as those developed in this study, that utilise stakeholder involvement at the earliest stages when scientific evidence is still being compiled may go a ways to aid the flow of dialogue between all three groups. Indeed, it is far more likely that harmonisation of the relationships and communication between policy makers, scientists and stakeholders will result in the realisation of effective MSP and the potential for sustainable development. This harmonisation can only be achieved through open and honest communication channels and greater engagement and interaction between all those involved in the process.

9.4 Policy Implications

There are several policy documents that have outlined their goals and respective intent towards management practices, environmental standards and production targets. Many of these documents have theoretical underpinnings that evidence from this study informs and supports; these can be found initially outlined in Chapter 1 section 1.2.2. but are listed further here:

1. A Fresh Start – The renewed strategic framework for Scottish aquaculture (2008)
   This study attempts to explore the possibility of incorporating climate change scenarios into planning. The inclusion of such scenarios are noted as being key to the future development of the aquaculture industry within this document as is the need for a strategic approach to facilitate sustainable expansion. Work undertaken by this study has attempted to combine a site selection model within a planning framework and to this end show the possibility for developing novel new approaches that fulfil this objective.

2. Charting Progress 2 (2011)

In Chapter 5 of this document, the need to streamline licensing involved with the aquaculture industry is raised. Although this study does not directly deal with licensing, the introduction of a more straight forward management framework such as the one developed by this study, could additionally serve to refine this process too.

This same document also outlines some key areas of research for the future which include the following that have all been considered during the course of this study:

- Knowledge and appreciation of spatial and temporal distribution of species, activities and marine features is required to support the assessment of Good Environmental Status.
- Need a better understanding of pressures related to each activity and cumulative impacts
- Require a better centralisation of collated data on the distribution of activities and pressures

3. EU Strategy for the Sustainable Growth of Aquaculture (2009)

The overall aim of this document is to promote and encourage the aquaculture industries growth while safeguarding environmental and quality standards. One of the major considerations when designing the site selection model developed during the course of this study was to ensure that the parameters for sustainable aquaculture were included. This was largely done by including standardised scores, preference weightings and constraints which allowed for an 'element of sustainability' to be included whilst still aiming to identify suitable areas.

4. UK Marine Policy Statement (2010)

Within this piece of policy it calls for marine plans to be based following an ecosystem-based approach. We have included environmental datasets within our Prototype zoning scheme with the intention of including this principle as proven through the application of the Environmental zoning scheme (Chapter 3). The same document also expresses the need to include the precautionary principle. Again the Prototype scheme aims to incorporate this principle through the ‘upgrading’ of its PUs when the activities and environmental layers are combined, for a more detailed explanation see Chapter 4.

Later in this document it also highlights the need for co-existence between aquaculture and other marine activities. This study considers the inclusion of aquaculture within a multiple-use (such as the Prototype zoning scheme demonstrated here) as a practical means of addressing this integration with other activities.

5. Scottish Marine Science Strategy (2010)

This science strategy lists sustaining and increasing ecosystem benefits and responding to climate change as two of its three high level priorities. The tools developed by this study attempts to start addressing both of these priorities. This same document also identifies working across disciplinary boundaries to bridge the gap between natural and social sciences. Although this project did not have the time to elaborate further on the stakeholder engagement, initial attempts have now been made to develop tools that address this void.

This study also addresses the document’s call to develop decision making tools to inform marine spatial planning and attempts to identify sustainable management scenarios by using GIS. This is notable as GIS itself is mentioned specifically as a potential means of improving data interpretation within this document.

9.5 Recommendations for Future Research

The scale of this work is extensive and multifaceted even when approached at a regional level. Therefore, for this work to better inform policy strategies and development targets with regards to sustainable aquaculture and future management practices there is a need for more case studies at local and regional level. This relates directly to the future developments of the regional marine plans (RMP) that will be evolving over the coming years, many of which would greatly benefit from localised case studies such as those proposed. It is unlikely that a ‘one size fits all’ approach to management will appropriate for RMPs as each plan will have to be unique due to the diversity of activities and environments that occur within Scotlands coastal waters. However, they should have a common set of goals and objectives even if the means for achieving them are devised to best suit that specific region, furthermore, examples from case studies, should help to inform these different plans. Exploring the following as future research strategies can also fulfil the attainment of this goal and better inform future RMP:

- Can cumulative impacts be better assessed and integrated within Marine Spatial Planning tools?
- Can site success probability be calculated and incorporated within site selection tools?
- Is there any potential for combining carrying capacity models with the results from the site selection work?
- Given new evidence and framework, can the regulation process and planning policy be refined in this area?
- Are there additional aspects of climate change that can be used to test the adaptability of zoning schemes and planning tools?
- How do the locations of the new potentially suitable sites identified by this study serve to achieve the expansion targets set out by the Scottish government and will they be sufficient to meet the 2010 production quotas?

9.6 Limitations of this Study

This work has attempted to evaluate and explore novel approaches to marine spatial planning and aquaculture site selection across the entire Scottish marine area. All of the aims set out at the beginning were achieved, however, as a direct consequence of the scale of this project and some of the methodologies adopted, the study encountered a number of limitations which must s be considered and are mentioned in the various chapters they are associated with. Regardless of the methodology being adopted, the major limitation that repeatedly surfaced during the course of the study was regarding data quality and availability. This study fully acknowledges that the outputs from both the zoning scheme and the models could be further improved through the inclusion and substitution of better data. In saying this the importance of this work was in developing the tools themselves, and the advantage of using GIS is that when new data become available it is a relatively straightforward job to substitute datasets.

9.7 Conclusion

In spite of the concerns often reported about aquaculture and its associated effects on the environment, its future expansion is now inevitable given the condition of world capture fisheries. However, the industry’s growth is set to be limited by the increasing pressures and competition for coastal space by other users and activities. The adoption of an overarching comprehensive management framework for marine space will be integral to the future success of the industry. Further challenges related to sustainability and planning in an ever changing climate need to be addressed now in order to mitigate against the potentially negative environmental consequences that poor planning and site selection have historically resulted in. development of models and frameworks such as those featured in this study, that utilise the many qualities of GIS can be seen as the first step on a pathway to securing the future of sustainable aquaculture production in Scotland.

9.8 References

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Aquaculture Site Selection: A GIS-based Approach to Marine Spatial Planning in Scotland.

Thesis submitted for the Degree of Doctor of Philosophy – Volume 2

By
Lauren Helen McWhinnie
BSc (Hons)
May 2015

Centre for Marine Biodiversity and Biotechnology, School of Life Sciences
Heriot-Watt University

ACADEMIC REGISTRY
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2) where appropriate, I have made acknowledgement of the work of others and have made reference to work carried out in collaboration with other persons
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Appendix 1

Table A 1.0 - National Legislation and Location of Activities Regulated within Scottish Waters

Activity	Legislation	Location
Archaeology	The Merchant Shipping Act (MSA) 1995, The Protection of Wrecks Act (PWA) 1973 the Protection of Military Remains Act (PMRA) 1986 (Maritime and Coastguard Agency, 2007) (SEA, 2007) and the Ancient Monuments and Archaeological Areas Act (AMAA) 1979.	There are many wrecks currently protected under the PWA (Part 1) in Scottish coastal waters, including Dartmouth in the Sound of Mull, Kinlochbervie in Sutherland and Wrangels Palais off the coast of Shetland. There are also several wrecks designated under the PMRA act including HMS Dasher an escort aircraft carrier in Strathclyde and the battleship HMS Vanguard in Scapa Flow, Orkney.
Aquaculture	The Aquaculture and Fisheries (Scotland) Act 2007 and the Water Environment (Controlled Activities) (Scotland) Regulations 2011(CAR).	Most aquaculture facilities can be found along the more sheltered west coast of Scotland, Orkney and Shetland. The majority of sea lochs have aquaculture ventures taking place within them.
CO_2 Storage	The European Directive 2009/31/EC relating to licensing of CO_2 storage and The Storage of Carbon Dioxide (Scotland) Regulations 2011	Ten saline aquifers have been identified as having CO_2 storage potential. A further 29 hydrocarbon fields (21 oil, 7 gas condensate and 1 gas field) have also been identified as having CO_2 storage potential within the North Sea.
Dredging Disposal Sites	The Food and Environment Protection Act (FEPA) (1985)..	There are 66 open sites used for disposing dredged materials around Scotland. The largest dredging operation in Scotland is at Grangemouth, and it is licensed to dispose 1.15M tonnes

		equivalent (Te) of sediment materials annually.
Military Activities	The Military Lands Act 1892 and 1900, The Land Powers (Defence) Act 1958 section 7 extended this previous regulation to any sea areas not bordering on defence land or subject to firing from said land.	MOD activity is a reserved issue for reasons of confidentiality; however the MOD mainly uses Scotland's Seas for training purposes.
Nature Conservation	Although there are many designations that have been made to protect both habitats and species within the marine environment, this research has chosen to focus on six of the main designations that give protection to marine areas. SACs - Sites that are designated under the European Habitats Directive (92/43/EEC). SPAs – Sites that are designated under the European Birds Directive (79/409/EEC). SSSIs - They are designated and managed under the Wildlife and Countryside Act 1981 (as amended). World Heritage Site - The United Nations Education, Science and Cultural Organisation (UNESCO) under the Convention Concerning the Protection of the World Cultural and Natural Heritage, adopted in 1972 by the General Conference of UNESCO and ratified by the UK Government in 1984. Ramsar sites are designated under the Convention on Wetlands of International Importance 1971.	SACs - In total there are currently 239 designated SACs in Scotland, two of which straddle the border with England. Combined they cover an area of some 963 thousand hectares. SPAs - In total there are 153 designated SPAs in Scotland these include the Upper Solway Flats and Marshes that partly straddle the border with England. There are more than fifty National Nature Reserves in Scotland, combined they cover an area of less than 1.5% of Scotland's total land mass. Although not all National Nature Reserves are found by the coast many have a marine component and it is these reserves that have been highlighted. Scotland has one designated World Heritage Site, the islands of St. Kilda, which is both a natural and cultural world heritage site, located around 66 km north west of North Uist, in the Outer Hebrides. There are currently 51 Ramsar sites

		designated across Scotland that cover a total area of around 313 thousand hectares although Figure 75 only illustrates those Ramsar sites with a marine component.
Oil and Gas	Petroleum Act 1998, the Continental Shelf Act 1964. Also under the Petroleum Act of 1998, Petroleum (Production) (Seaward Areas) Regulations 1988, Coast Protection Act 1949	Oil and gas exploration takes place in Scottish offshore waters, the only exception to this being the Beatrice Field in the Moray Firth, within 12nm of the shore.
Ports, Harbours and Shipping	Merchant Shipping (Distress Signals and Prevention of Collisions) Regulations 1996, this piece of legislation gives force in the UK law to the International Regulations for the Prevention of Collisions at Sea 1972. The IMO's responsibility for ship routeing is enclosed in SOLAS chapter V, which identifies the organisation as the only international body for establishing such systems. Transport Scotland has responsibility for legislation and policy relating to ports and harbours in Scotland, they administer provisions under the Harbours, Pilotage and Ports Act and other related local legislation. Any licensing for Ports and Harbours is dealt with in accordance to the	Shipping traffic passing through the Pentland Firth and the Minches is of particular importance and interest as the majority of these passing vessels do not make land at Scottish ports. Scotland has several major ferry terminals that provide a connection for the country with Northern Ireland, Orkney, Shetland and the Continent. There are also numerous minor ferry ports that serve sixty plus inhabited islands. Altogether there are over 50 ferry routes, mainly concentrated along the west coast for example between the mainland

	Marine (Scotland) Act 2010. A Harbour Empowerment or Revision Order is a set of local legislation that governs a port. It was made a Scottish Statutory Instrument under the 1964 Harbours Act by Scottish Ministers.	and the Outer Hebrides. Ferries regularly leave Aberdeen for Lerwick in the Shetlands and Stromness in Orkney, with regular crossings from Jamieson's Quay in the harbour.
Renewables	The Climate Change (Scotland) Act 2010, the Marine and Coastal Access Act in 2009, the Marine (Scotland) Act 2010, the Environmental Assessment (Scotland) Act 2005 the Electricity Act 1989 and the Energy Act 2004.	Scotland has granted six wave and five tidal schemes within the Pentland Firth and Orcadian waters. Currently there are eight new Scottish offshore sites that have been agreed for wave and tidal energy projects The first examples of offshore wind developments in Scotland include: Robin Rigg, a 180 MW project in the Solway Firth, and the offshore wind demonstrator at the Beatrice oilfield in the Moray Firth.
Sea Fisheries	EU law is generally directly transferred into Scottish waters through subordinate legislation by the Scottish Statutory Instrument (SSI). Laws made under the Fisheries Act 1981, the Fishery Limits Act 1979 and the European Communities Act 1972 fundamentally deal with European issues where as the Acts listed below deal with measures more closely related to Scottish fisheries. Marine(Scotland) Act 2010/Marine and Coastal Access Act 2009/Aquaculture and Fisheries (Scotland) Act	The majority of activity by the Scottish fishing fleet takes place within the Scottish fisheries zone (out to 200 nm). Scottish fleets predominantly target mackerel and herring (pelagic), haddock, cod and monkfish (demersal) and *Nephrops*, scallops and crabs (shellfish). The Scottish fleet can be broadly divided into two main sectors, as described below. The Pelagic Fleet – This sector is made up of a

	2007/Inshore Fishing (Scotland) Act 1994/Sea Fish (Conservation) Act 1992/Merchant Shipping Act 1988/Territorial Sea Act 1987/Inshore Fishing (Scotland) Act 1984/British Fishing Boats Act 1983/Fisheries Act 1981/Fishery Limits Act 1976/European Communities Act 1972/Sea Fisheries Act 1968/Sea Fish (Conservation) Act 1967/Sea Fisheries (Shellfish) Act 1967/Oyster Fisheries (Scotland) Act 1840/Fisheries Act 1705.	relatively small number of vessels that are physically large and very profitable. They mainly target species such as mackerel and herring. The Demersal Fleet – this sector targets bottom dwelling species, there are two types of fishery: the round-fish fishery that targets species such as cod, haddock and saithe in the North Sea and off the West of Scotland and the deep water fisheries that target monkfish to the far North and West of Scotland.
Pipelines and Cables	Coast Protection Act 1949 (CPA), the Transport and Works Act (1992), the Petroleum Act (1998) and the Telecommunications Act 1984).	An international network of submarine cables passes north and south of Shetland that connects Europe to North America, however these do not make landfall in Scotland. Other cables connect Shetland and Orkney to mainland Scotland and mainland Scotland to Northern Ireland and the Faroe Islands; some also connect to oil and gas fields. Scottish Islands are generally connected to the mainland by microwave transmission rather than cables.

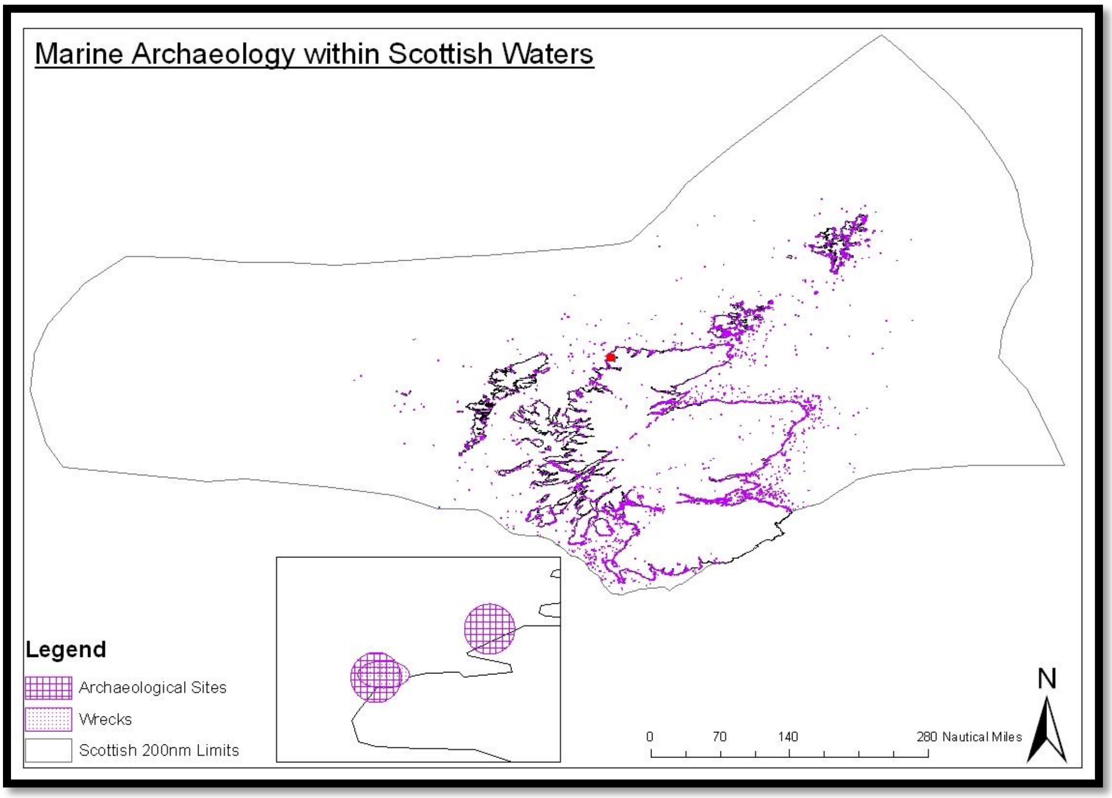


Figure A 1.0 – Archaeological Sites and Designated Wrecks within Scottish Waters in 2011 © Crown Copyright 2015. An Ordinance Survey/EDINA supplied service. Data supplied by Royal Commission on the Ancient Historic Monuments of Scotland (RCAHMS) and Historic Scotland.

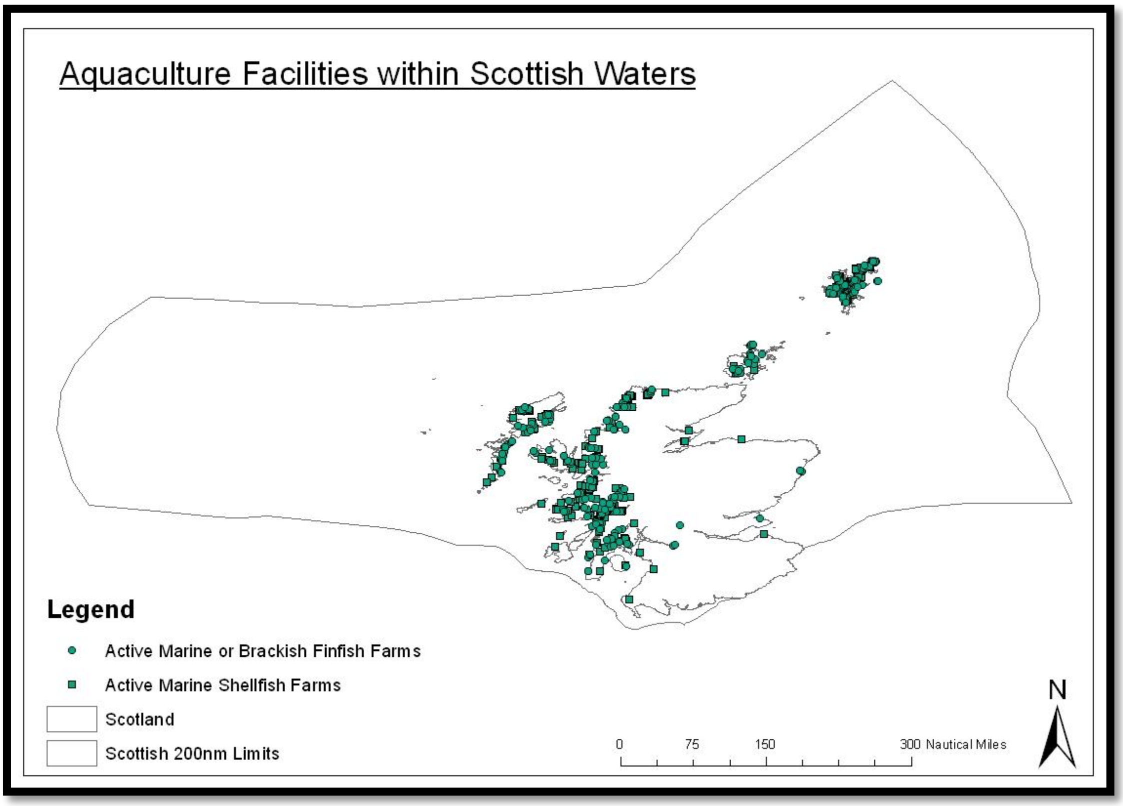
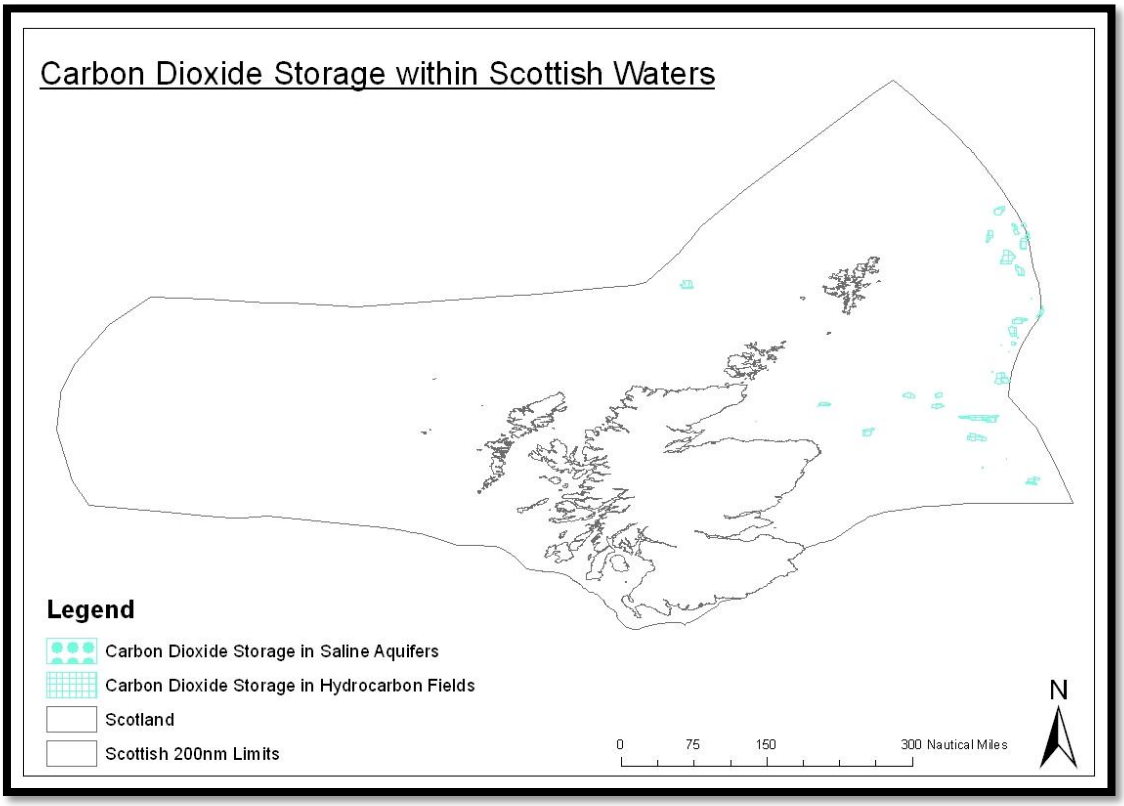


Figure A 1.1 – Aquaculture Facilities within Scottish Waters in 2011 © Crown Copyright 2015. A Scottish Executive GIS supplied service.



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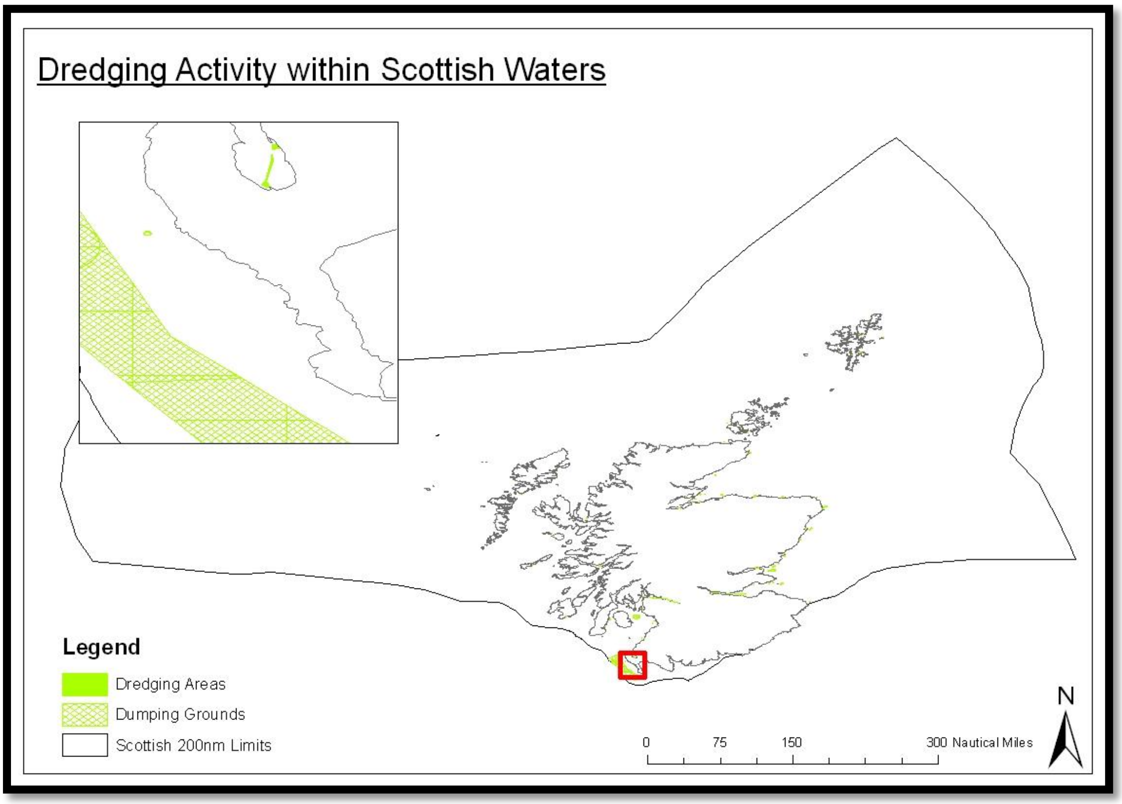
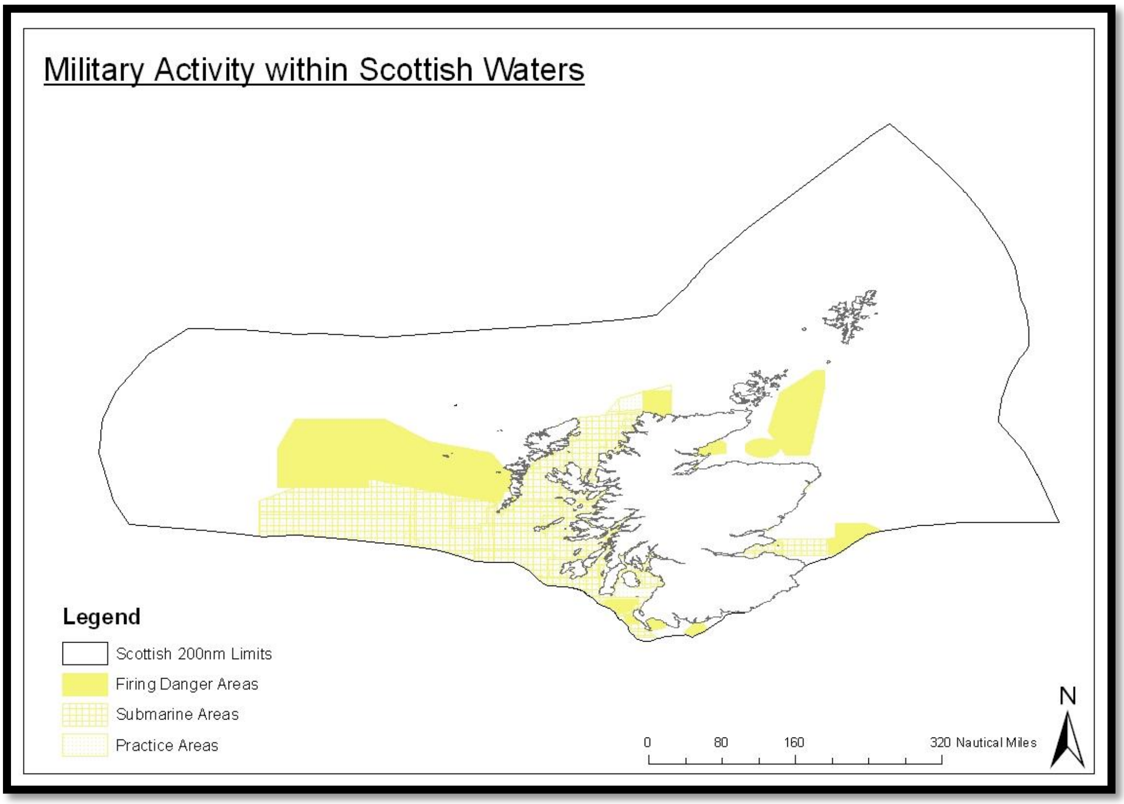


Figure A 1.3 – Licensed Dredged Disposal Sites and Dumping Grounds within Scottish Waters in 2011 © Crown Copyright 2015. Ordnance Survey/EDINA and a Scottish Executive GIS supplied service.



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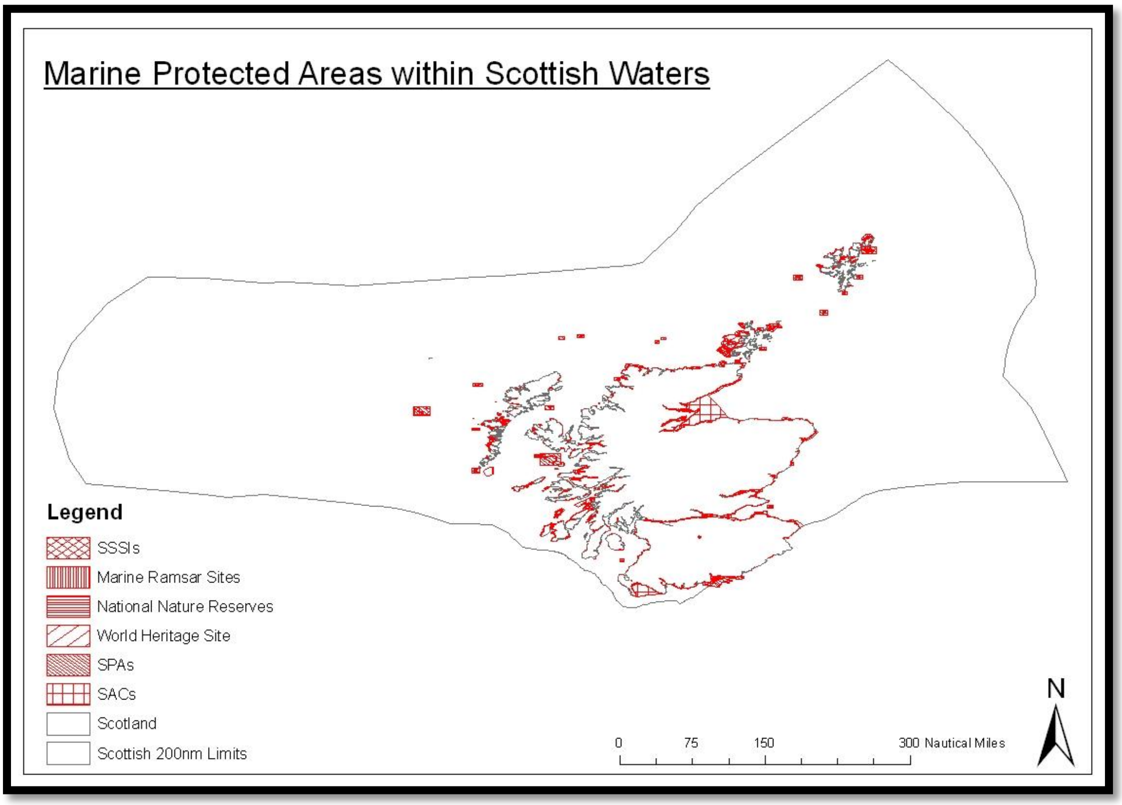


Figure A 1.5 – Marine Protected Areas within Scottish Waters in 2011 © Crown Copyright 2015. Ordnance Survey/EDINA supplied service. Data available online from Scottish Natural Heritage at *http://www.gateway.snh.gov.uk*

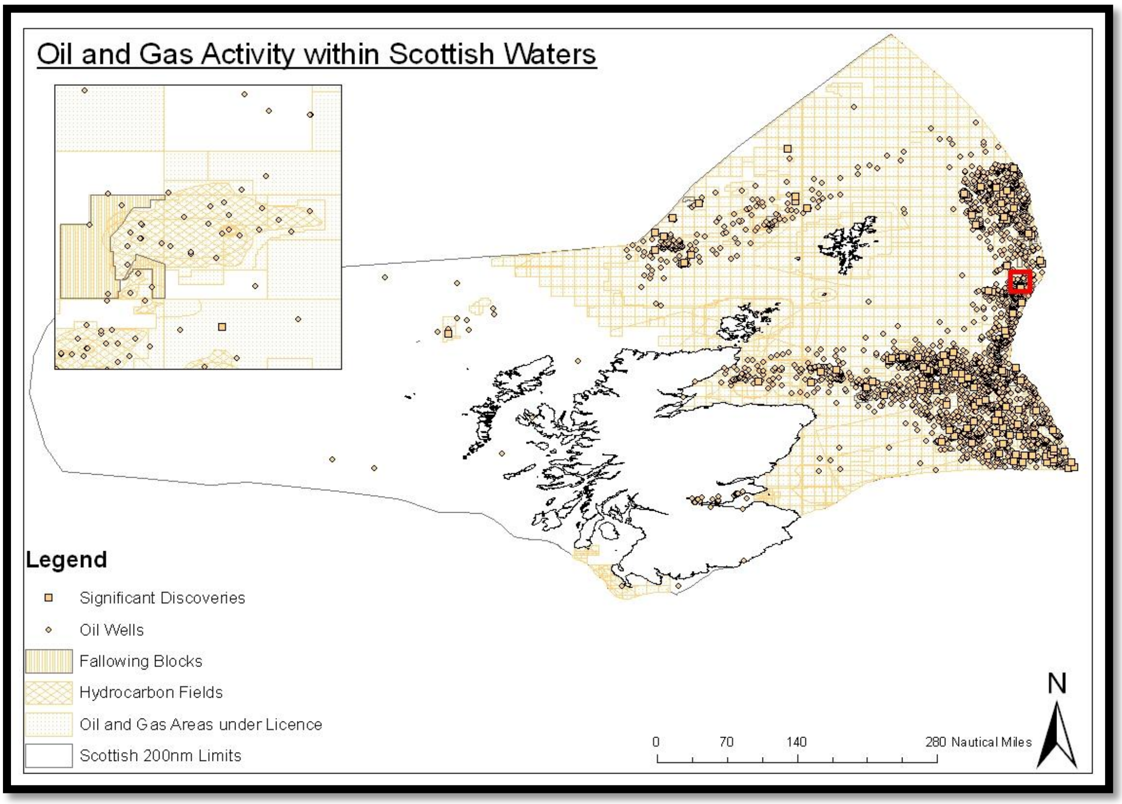


Figure A 1.6 – Legislated Oil and Gas Activity within Scottish Waters in 2011 © Crown Copyright 2015. An Ordnance Survey/EDINA supplied service. Data available online at *http://www.og.decc.gov.uk*

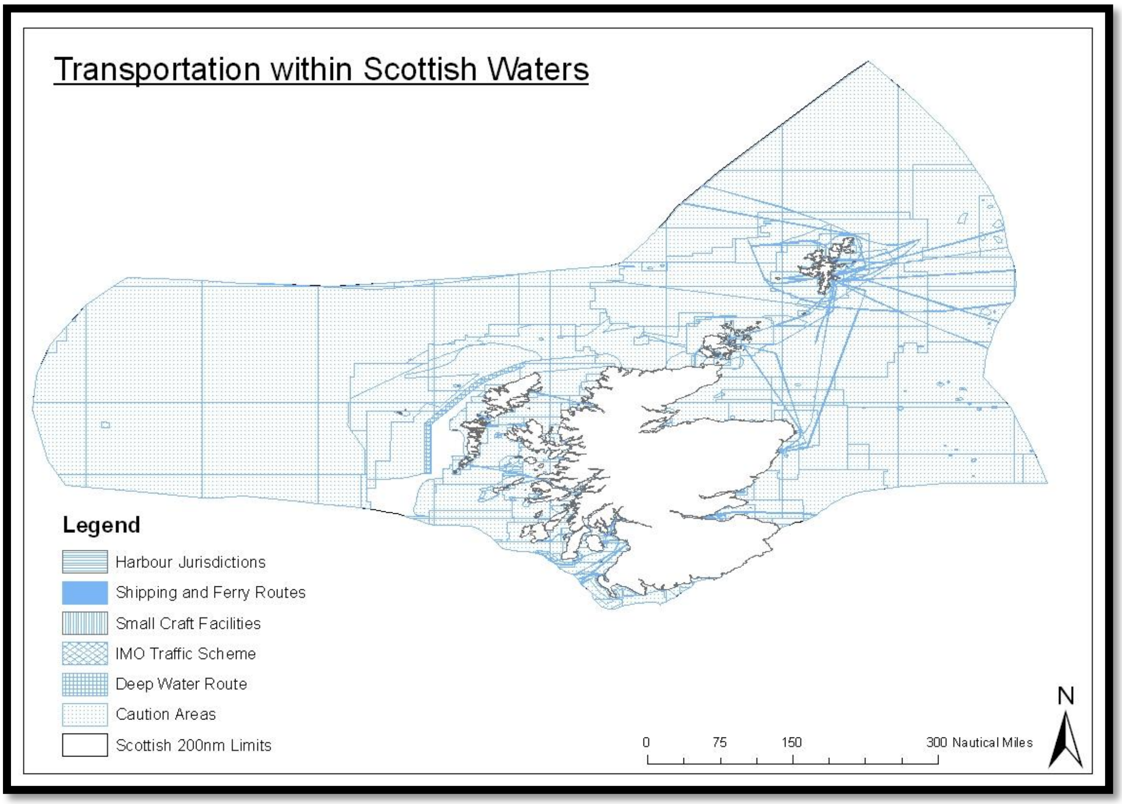
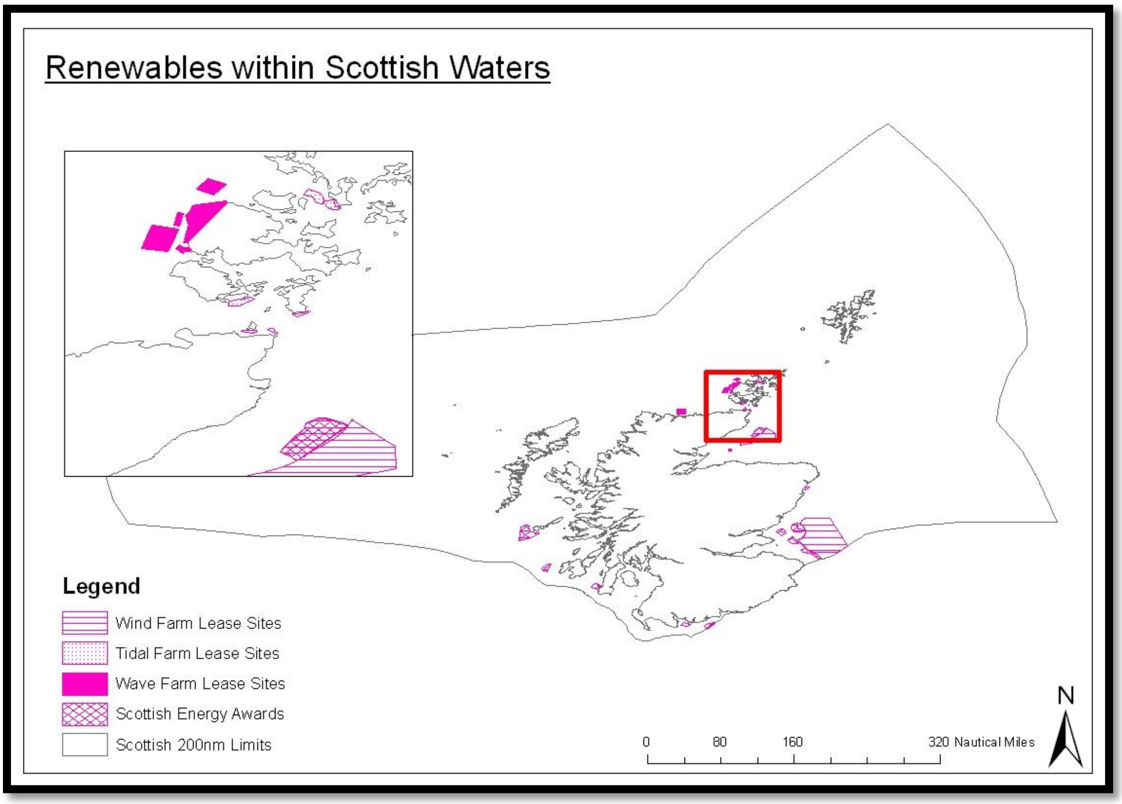


Figure A 1.7 – Ports, Harbours and Shipping within Scottish Waters in 2010 © Crown Copyright 2015. An Ordnance Survey/EDINA and a Scottish Executive GIS supplied service.



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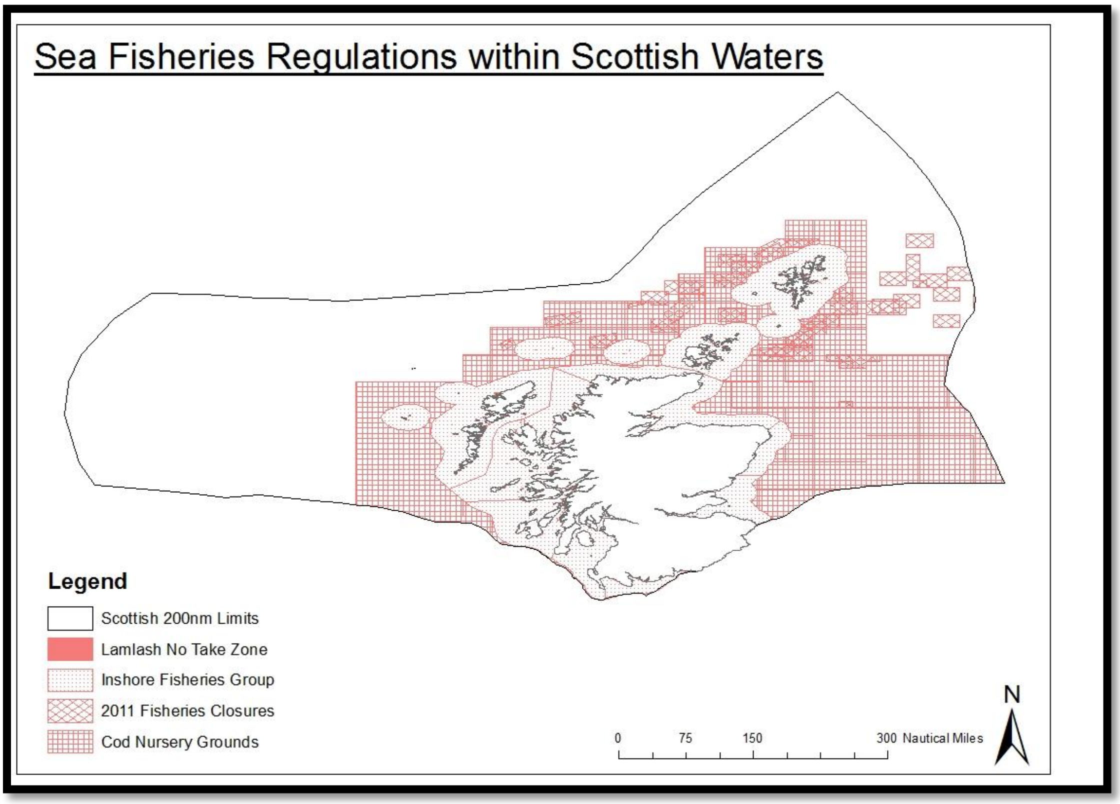

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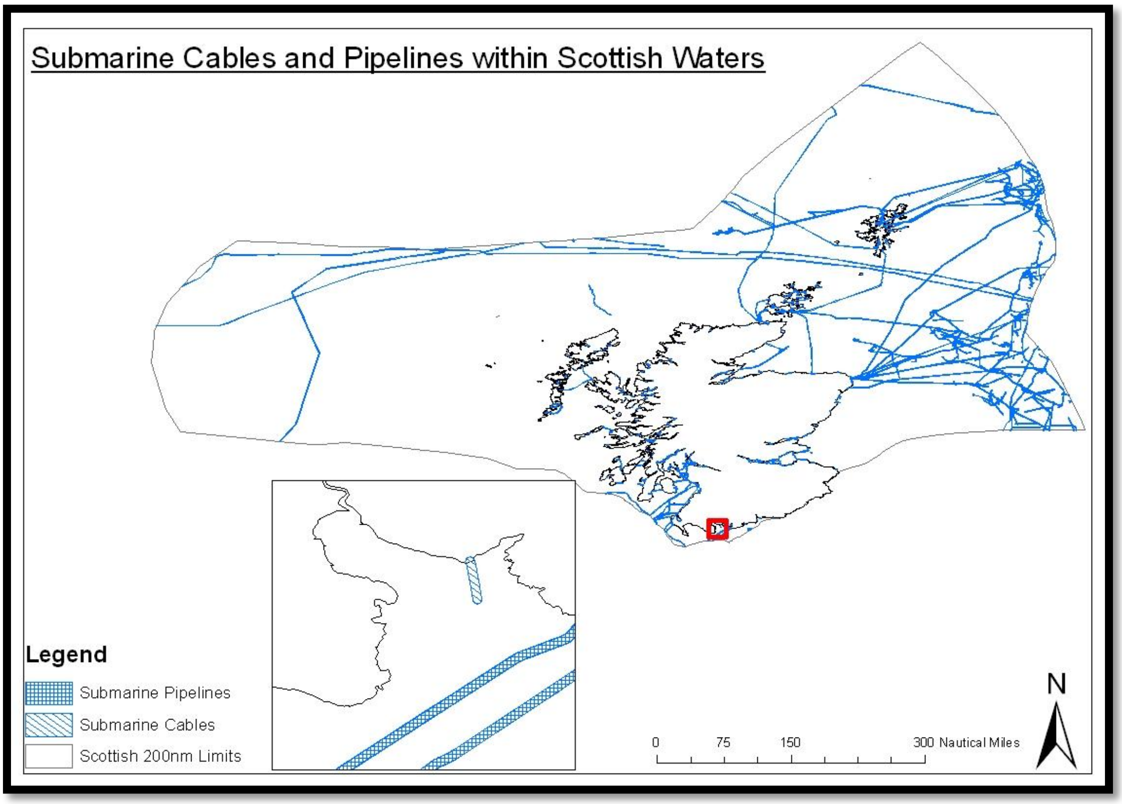


Figure A 1.10 – Submarine Cables and Pipeline within Scottish Waters 2011 © Crown Copyright 2015. An Ordnance Survey/EDINA supplied service.

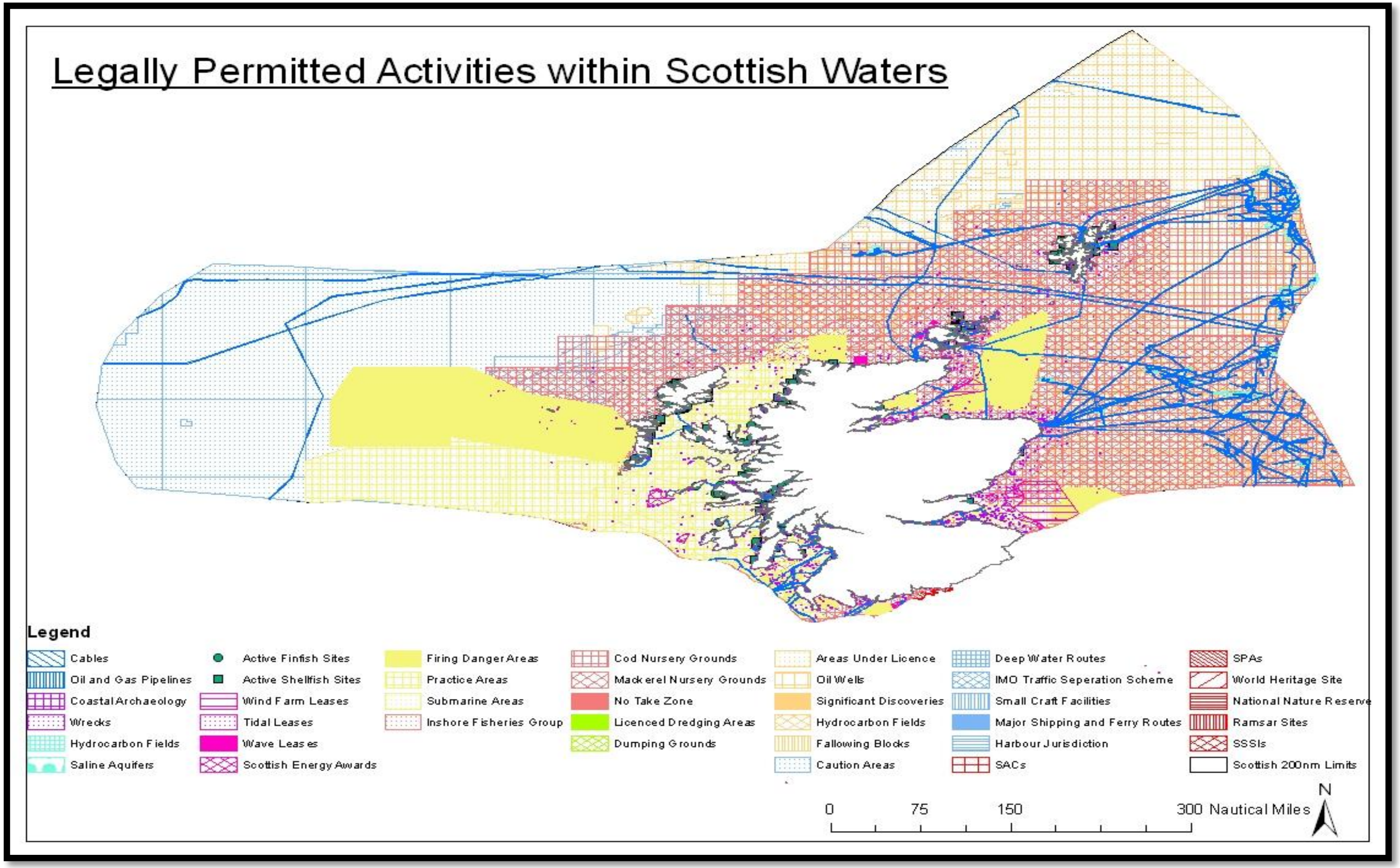


Figure A 1.11 – Legally Permitted Activities within Scottish Waters © Crown Copyright 2015. Data from various sources.

Table A 1.1- Derived Multiple-Use zones and the legally permitted activities occurring within each zone in Scottish waters.

Activity	Multiple-use Zones			Partial-use Zone	Exclusive-use Zone	
	General-use Zones (GUZ)		Conservation Priority Zone (CPZ)	Exclusion Zone (EZ)		Protected Zone (PZ)
	Minimal Management Zone (MMZ)	Targeted Management Zone (TMZ)		Limited Exclusion Zone (LEZ)	Significant Exclusion Zone (SEZ)	
Aquaculture	✓ (Consent Required)	✓ (Consented Areas)	✓ (Consented Areas)	✗	✗	✗
CO_2 Storage	✓ (Consent Required)	✓ (Consented Areas)	✓ (Consented Areas)	✗	✗	✗
Dredging and Disposal	✓ (Consent Required)	✓ (Consented Areas)	✓ (Consented Areas)	✗	✗	✗
Military Activities	✓	✓	✓	✓ (1)	✗	✗
Oil and Gas	✓ (Consent Required)	✓ (Consented Areas)	✓ (Consented Areas)	✗	✓ (2)	✗
Ports, Harbours and Shipping	✓	✓	✓	Limited (4)	✗	✗
Renewables	✓ (Consent Required)	✓ (Consented Areas)	✓ (Consented Areas)	✗	✓ (2)	✗
Sea Fisheries - closures	✓	✓	✓	✓ (5)	✗	✗
- Inshore Fisheries	✓	✓	✓	✗	✗	✗
Submarine Cables and Pipelines	✓ (Consent Required)	✓ (Consented Areas)	✓ (Consented Areas)	✓ (3)	✗	✗

Footnotes:

(1) Activity within danger areas is only restricted during MOD activity
(2) Includes a safety zone around the activity
(3) Dredging prohibited 250m either side but other activities still permitted
(4) Limited – Dependant on the size of vehicle, for example tankers will have to avoid shallow areas
(5) Areas included that are closed for a defined period of time, creating a partial exclusion zone

Appendix 2

Table A 2.0 - The definitions, goals and allowable impact definitions for each of the Ecologically Rated (ER) Zones (Day et al., 2008).

ER Zone	Definition	Goals and Objectives	Permitted Impact: Definition
ER Zone 1	This zone contains the highest level of diversity of all marine, coastal and estuarine species and habitats.	Both development and use are managed so that they will cause negligible impacts on biodiversity, habitats and ecological processes that are important to the health and productivity of the ecosystem.	Negligible: will not exceed negligible impacts to habitats or populations. Unlikely to be measurable against background variability. Habitat and ecosystem interactions may occur but it is unlikely that there would be any change outside of natural variation. Recovery will be measured in days to weeks.
ER Zone 2	Has a high level of diversity (marine, coastal, and estuarine, species and habitats).	Development and use are managed to ensure only minor impacts	Minor: will not exceed minor impacts to habitats or populations measurable against background variability. Recovery measured in weeks to, not more than 6months.
ER Zone 3	Contains a moderate level of diversity (marine, coastal and estuarine, species and habitats).	Development and use are managed to ensure only moderate impacts	Moderate: will not exceed moderate impacts to habitats or population. Measurable changes to ecosystem components without there being a major change in function (i.e. no loss of components). Recovery measured in months to, not more than 2 years.
ER Zone 4	Available scientific data is inadequate in order to identify these areas importance to the maintenance of biodiversity, ecological health and productivity of the ecosystem.	Development and use are preceded by research to improve knowledge of the area.	Precautionary Principle: research will determine allowable consequences to habitats.

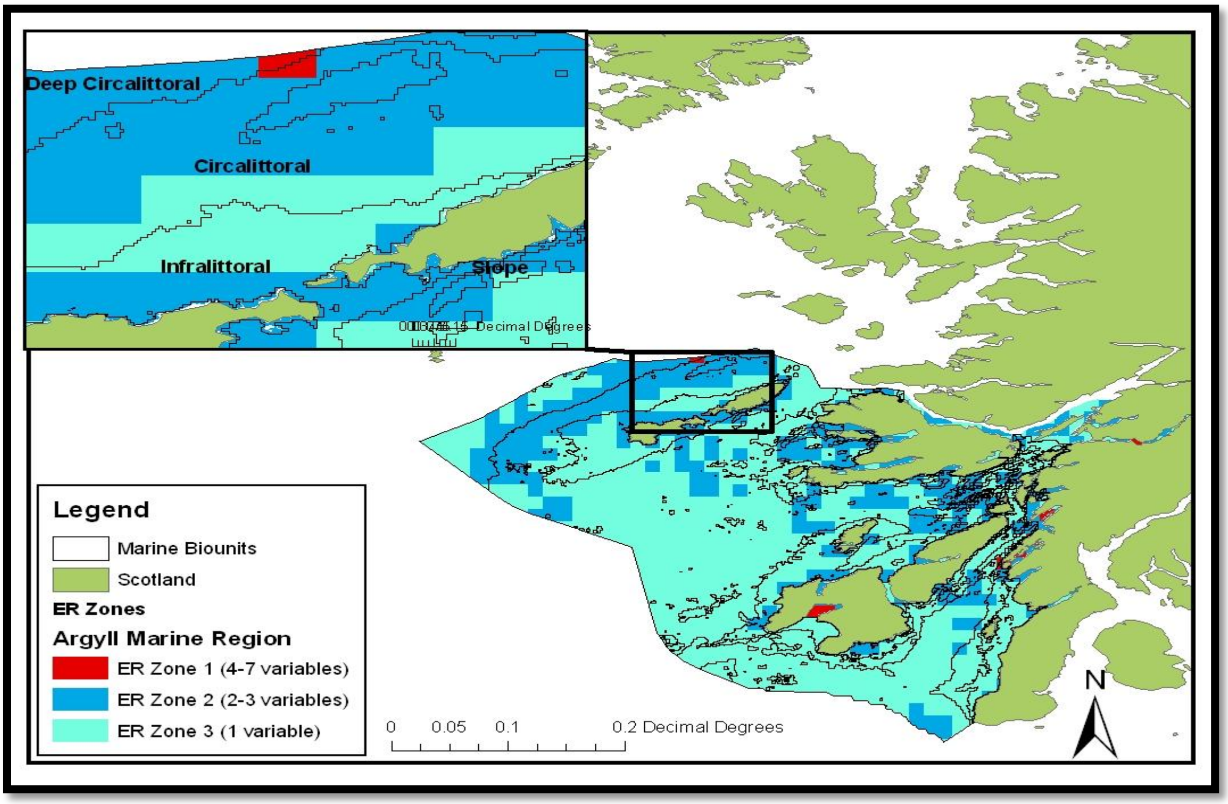


Figure A 2.0 - Argyll Marine Planning Area with Ecologically Rated Zones and Marine Biounits

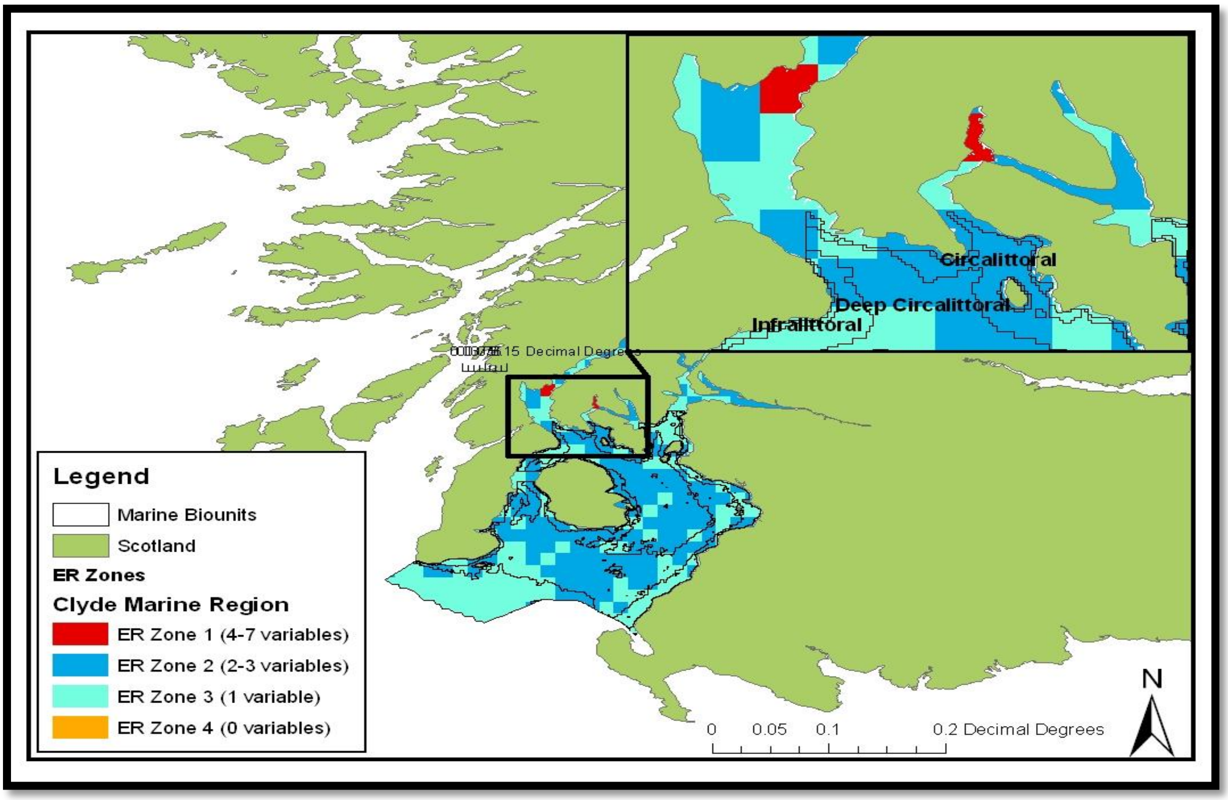


Figure A 2.1 - Clyde Marine Planning Area with Ecologically Rated Zones and Marine Biounits

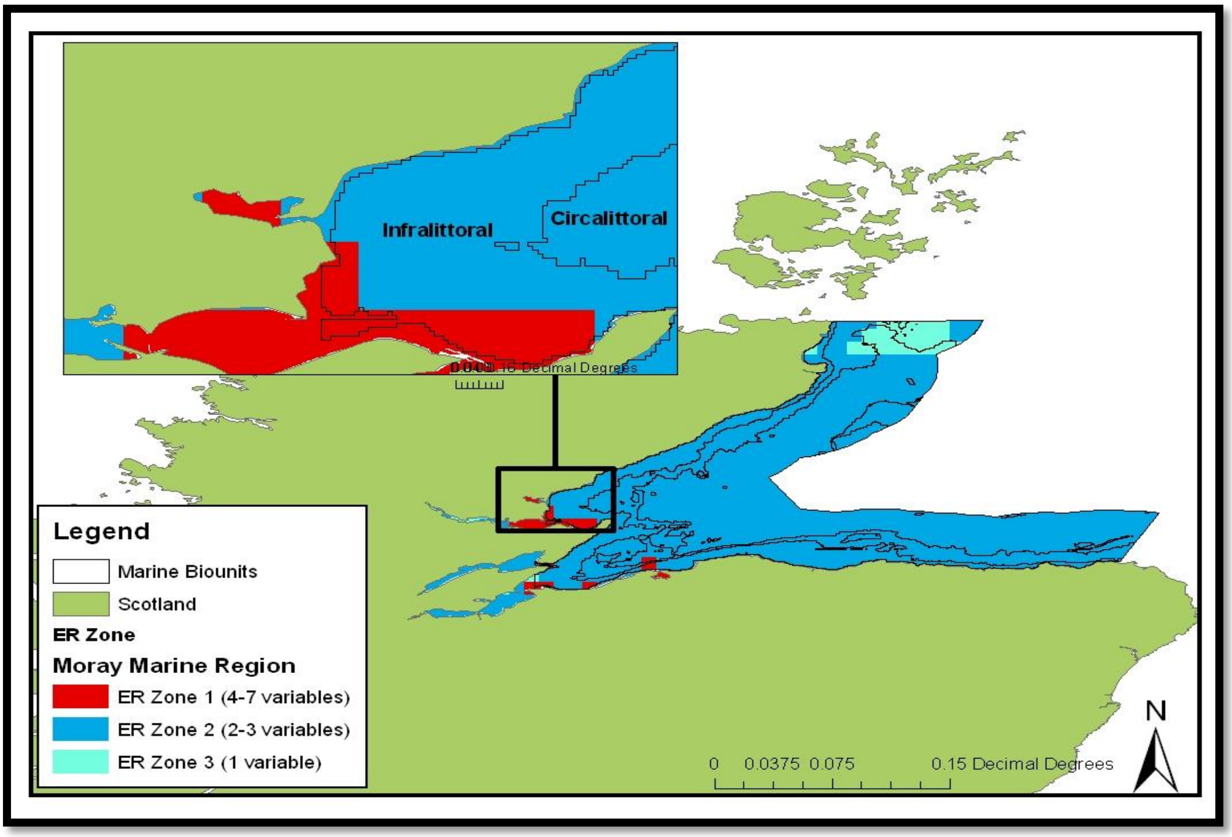


Figure A 2.2 - Moray Marine Planning Area with Ecologically Rated Zones and Marine Biounits

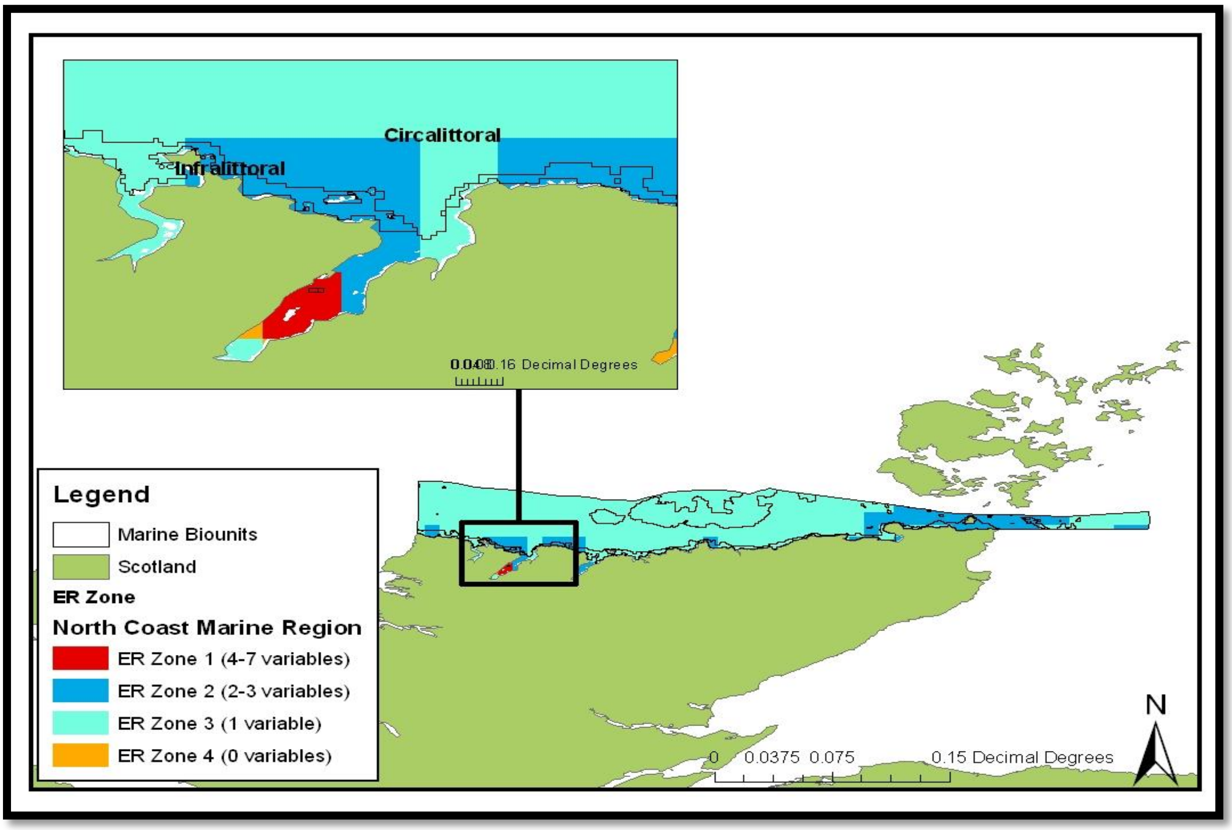


Figure A 2.3 - North Coast Marine Planning Area with Ecologically Rated Zones and Marine Biounits

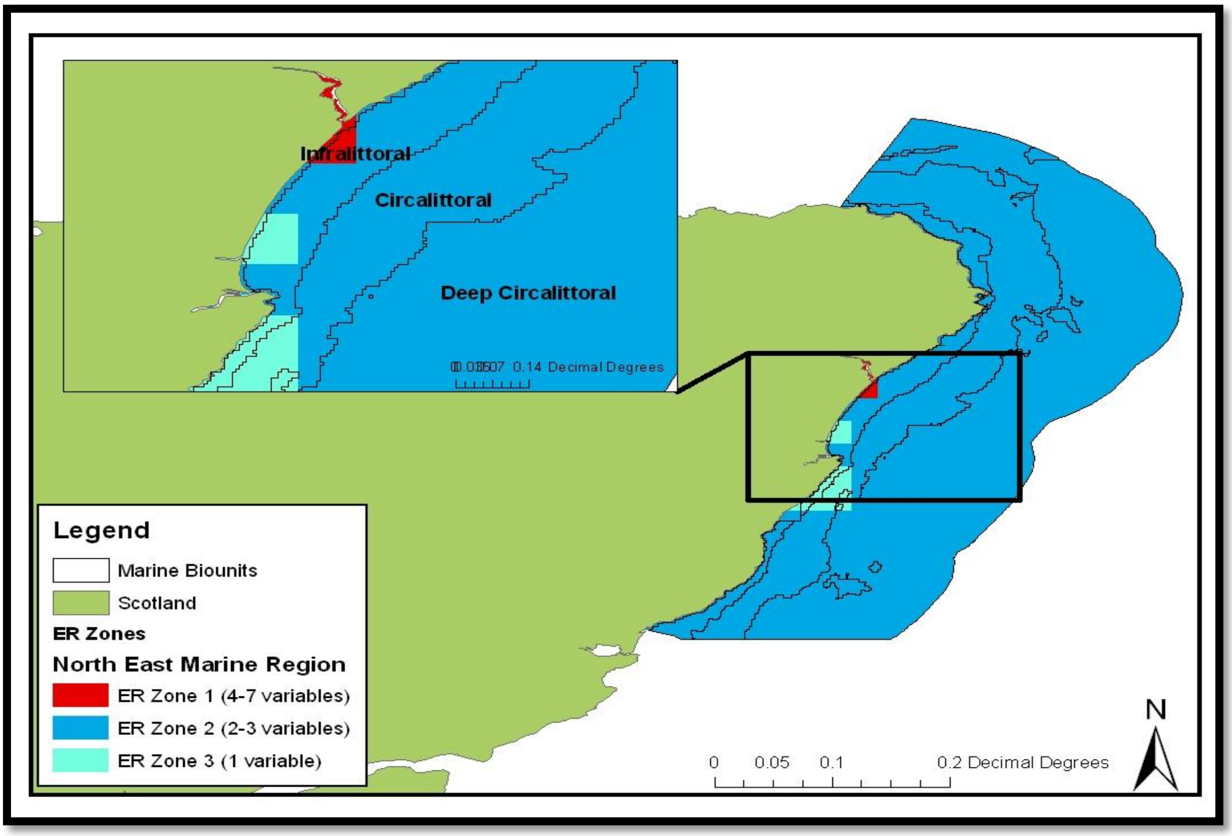


Figure A 2.4 - North East Marine Planning Area with Ecologically Rated Zones and Marine Biounits

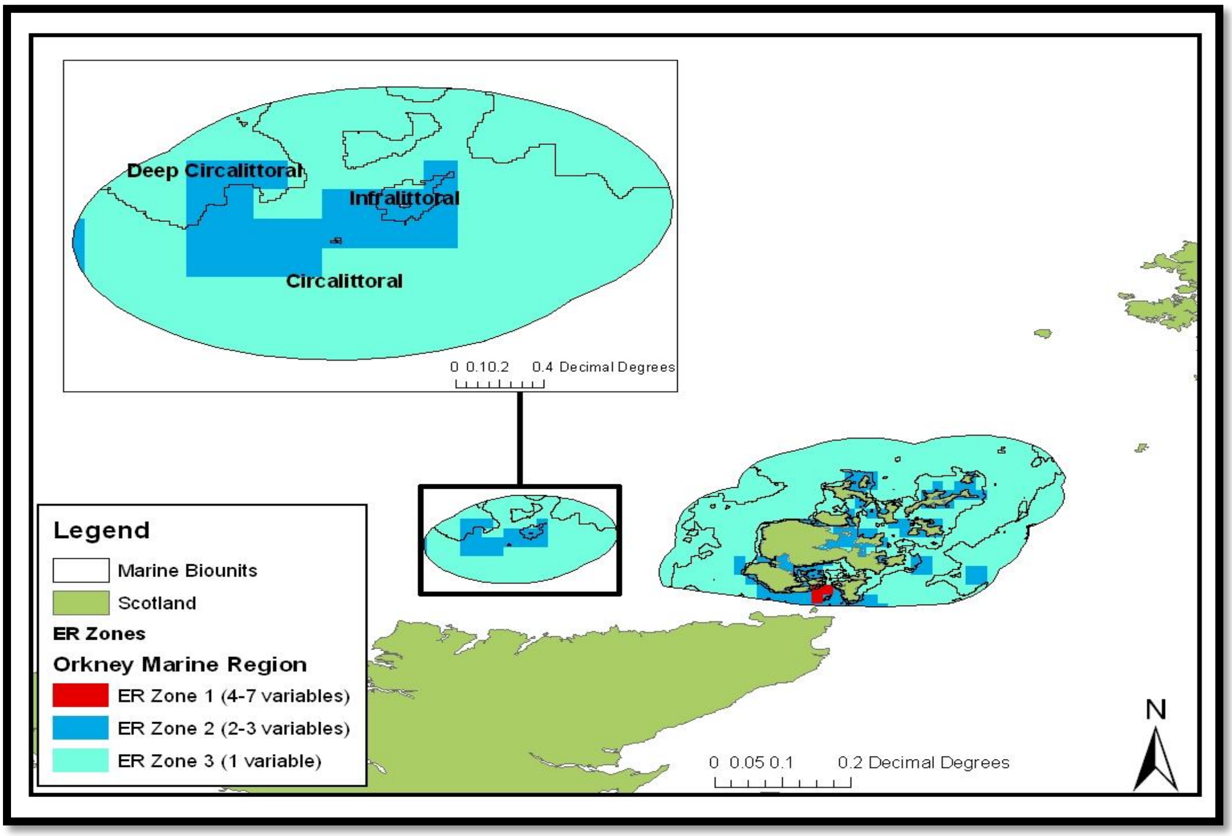


Figure A 2.5 - Orkney Marine Planning Area with Ecologically Rated Zones and Marine Biounits

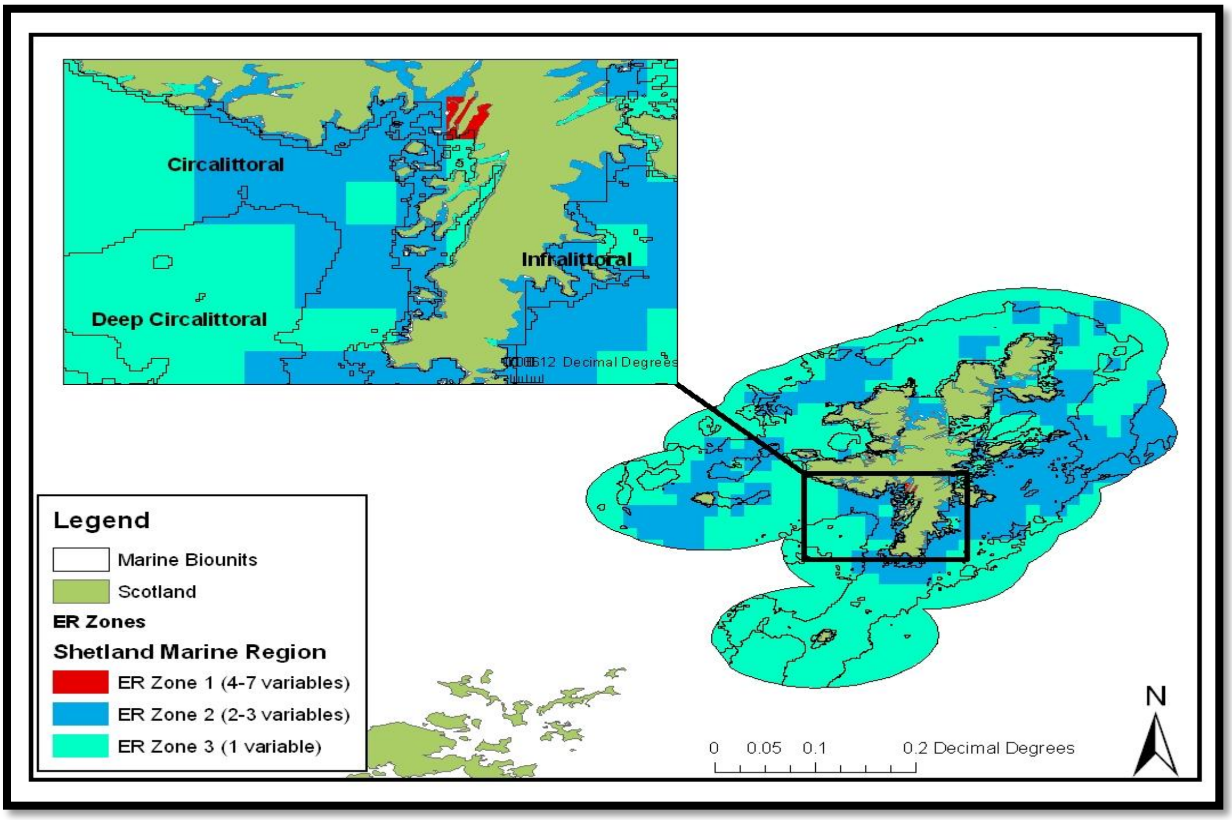


Figure A 2.6 - Shetland Marine Planning Area with Ecologically Rated Zones and Marine Biounits

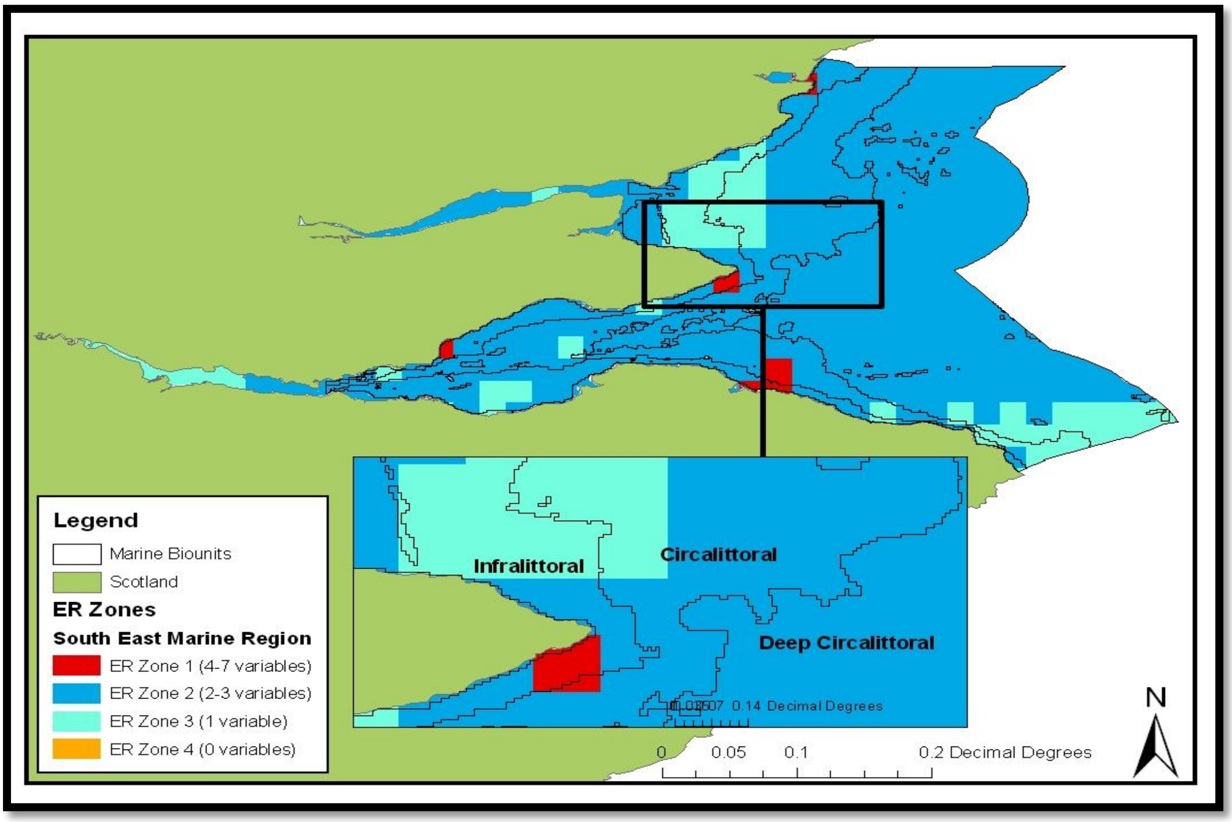


Figure A 2.7 - South East Marine Planning Region with Ecologically Rated Zones and Marine Biounits

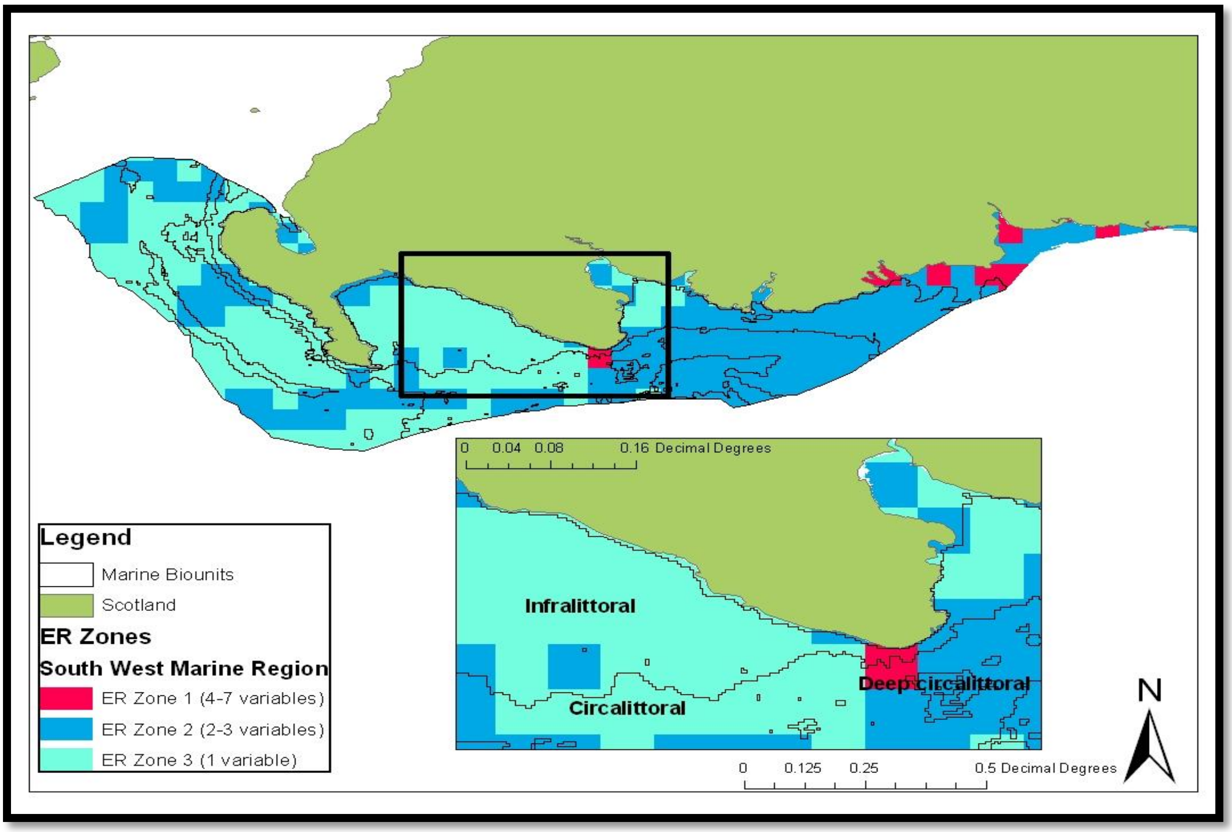


Figure A 2.8 - South West Marine Planning Area with Ecologically Rated Zones and Marine Biounits

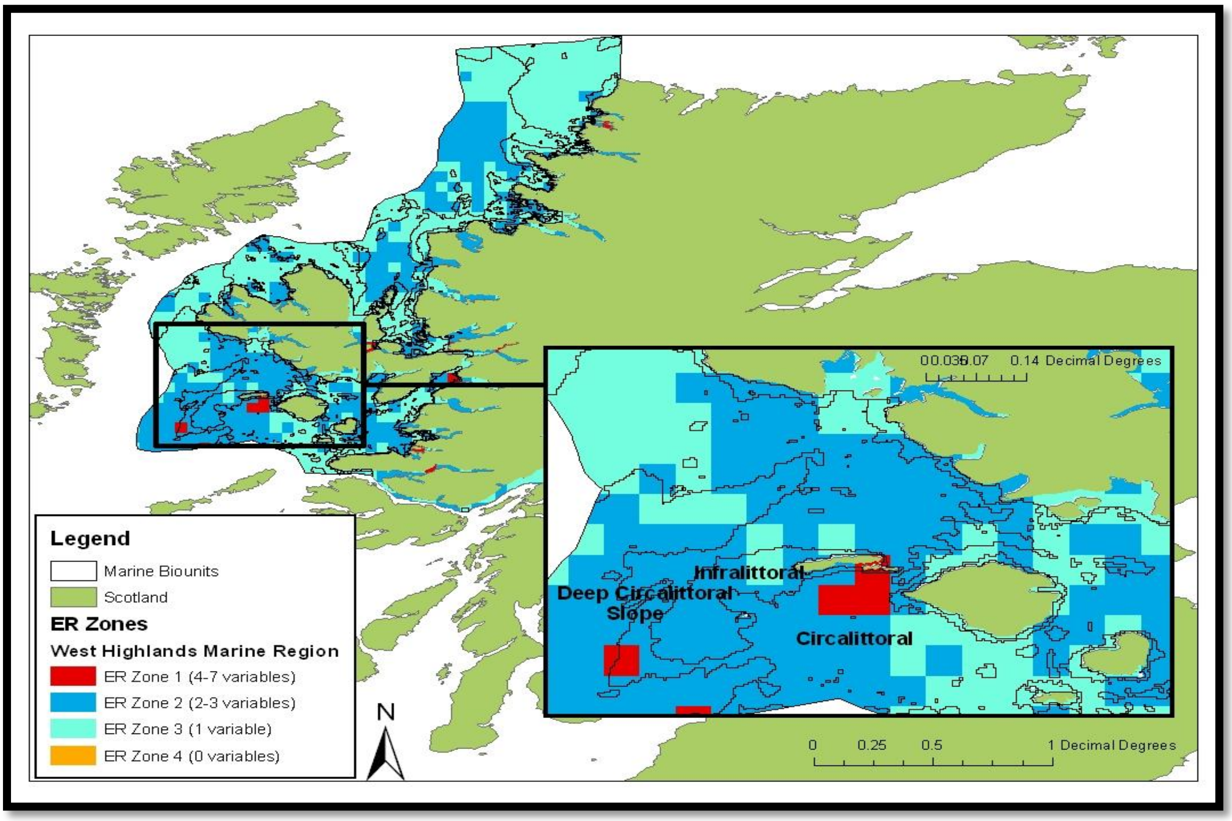


Figure A 19.9 - West Highland Marine Planning Area with Ecologically Rated Zones and Marine Biounits

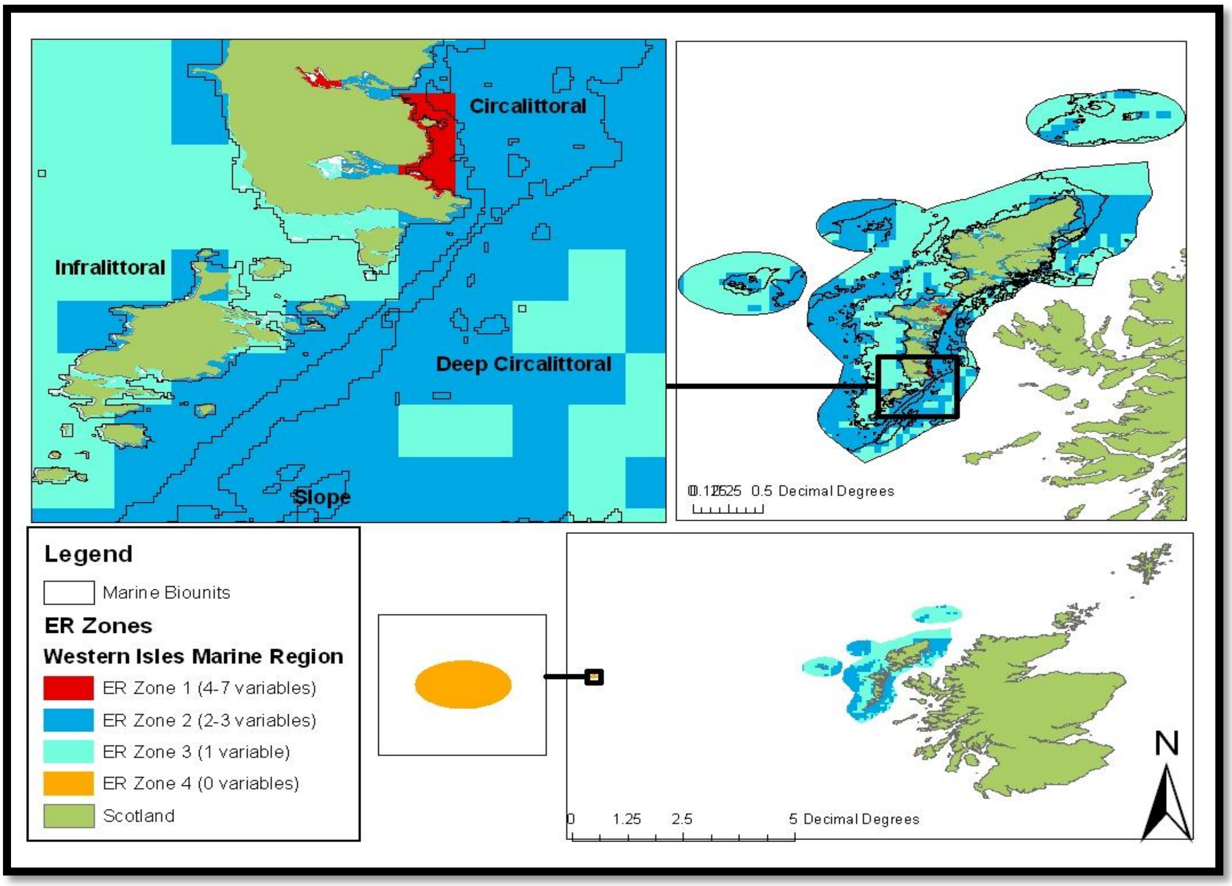


Figure A 2.10 - Western Isles Marine Planning Area with Ecologically Rated Zones and Marine Biounits

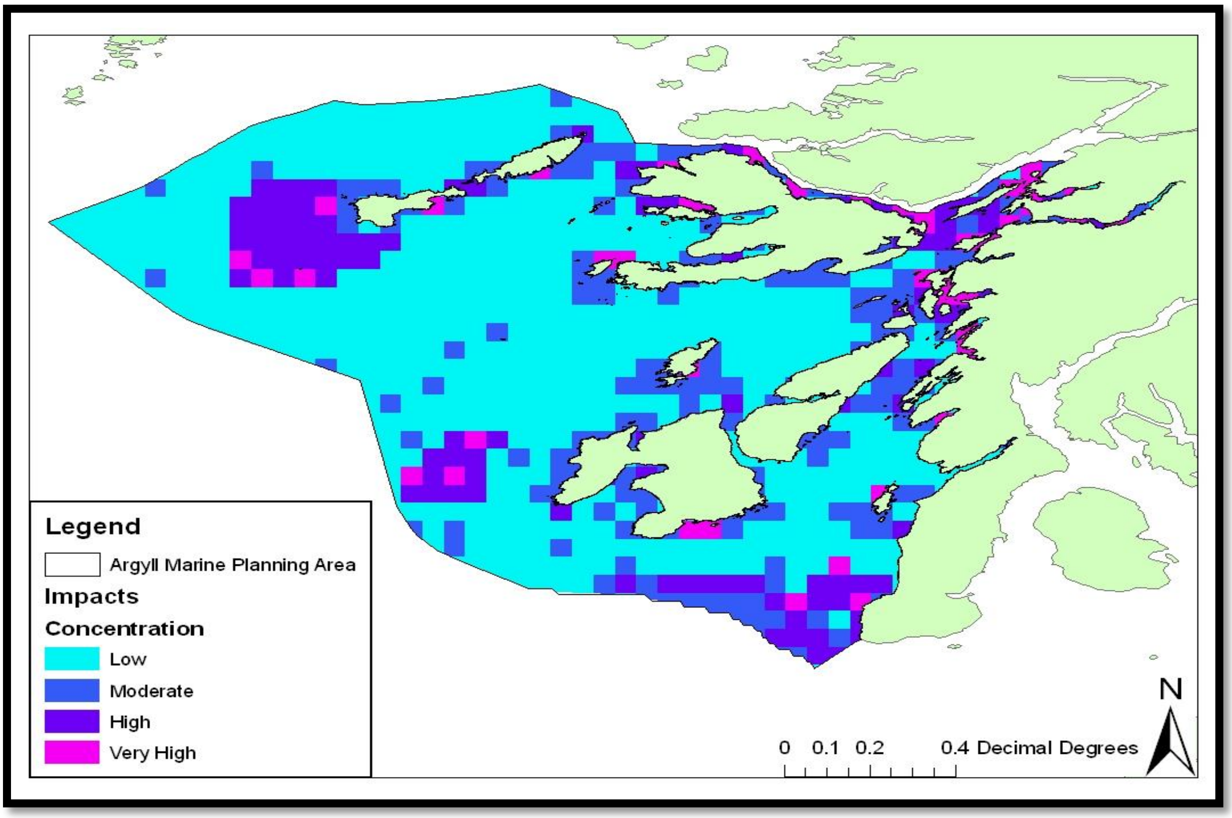


Figure A 2.11 - Argyll Marine Planning Area with Potential and Present Activities mapped.

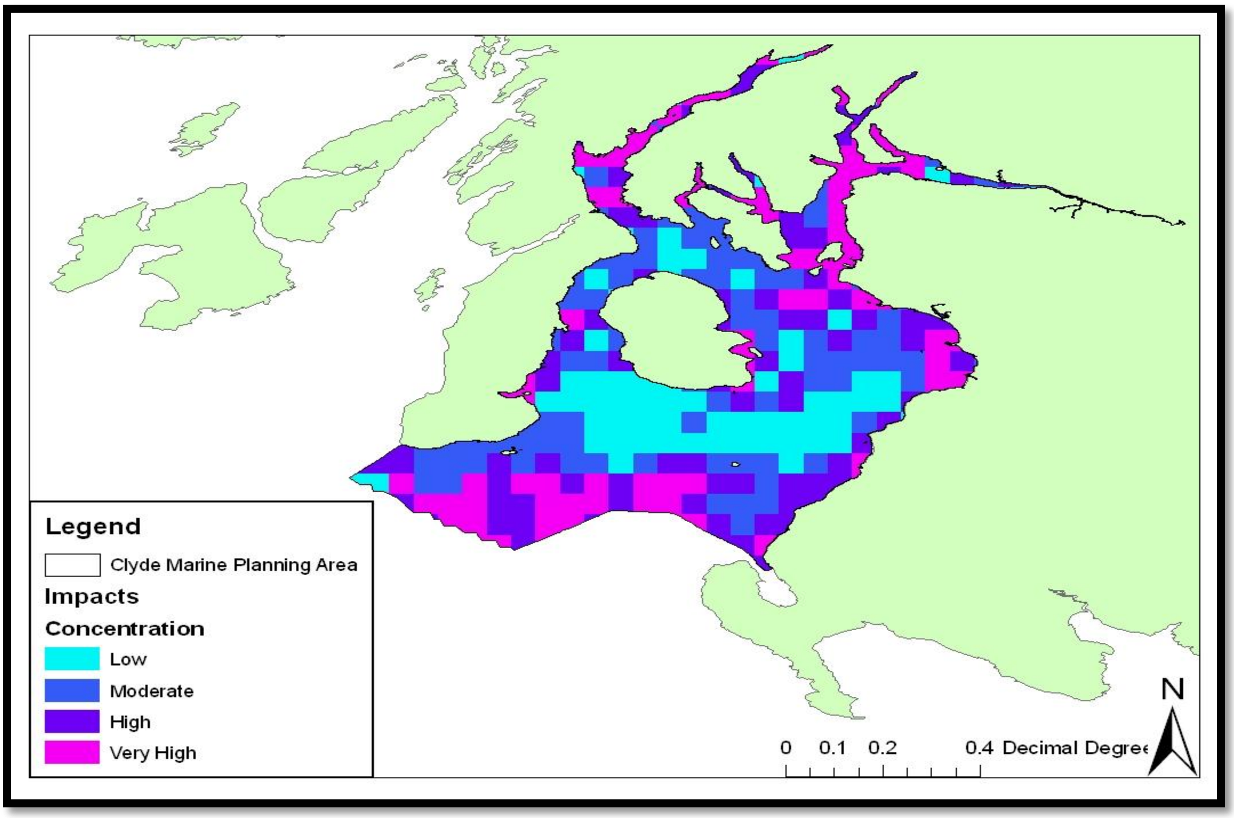


Figure A 2.12 - Clyde Marine Planning Area with Potential and Present Activities mapped.

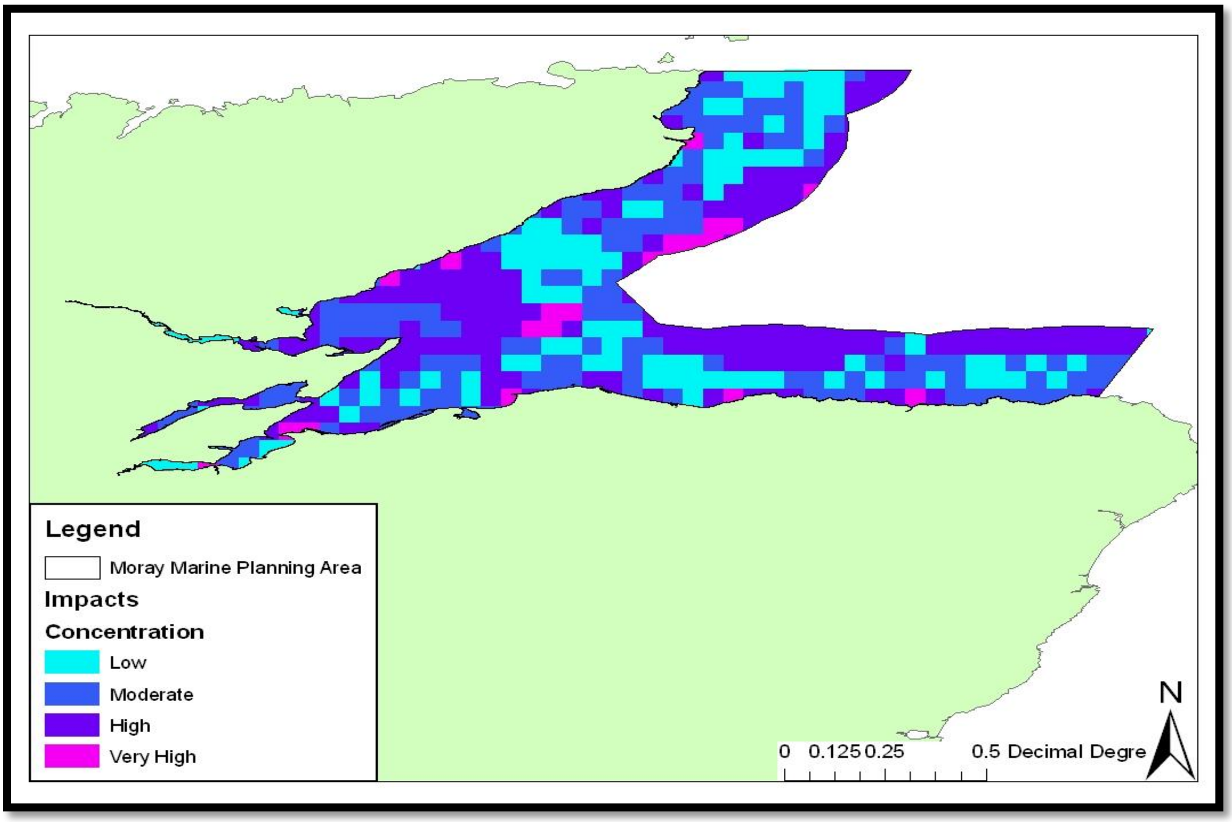


Figure A 2.13 - Moray Marine Planning Area with Potential and Present Activities mapped.

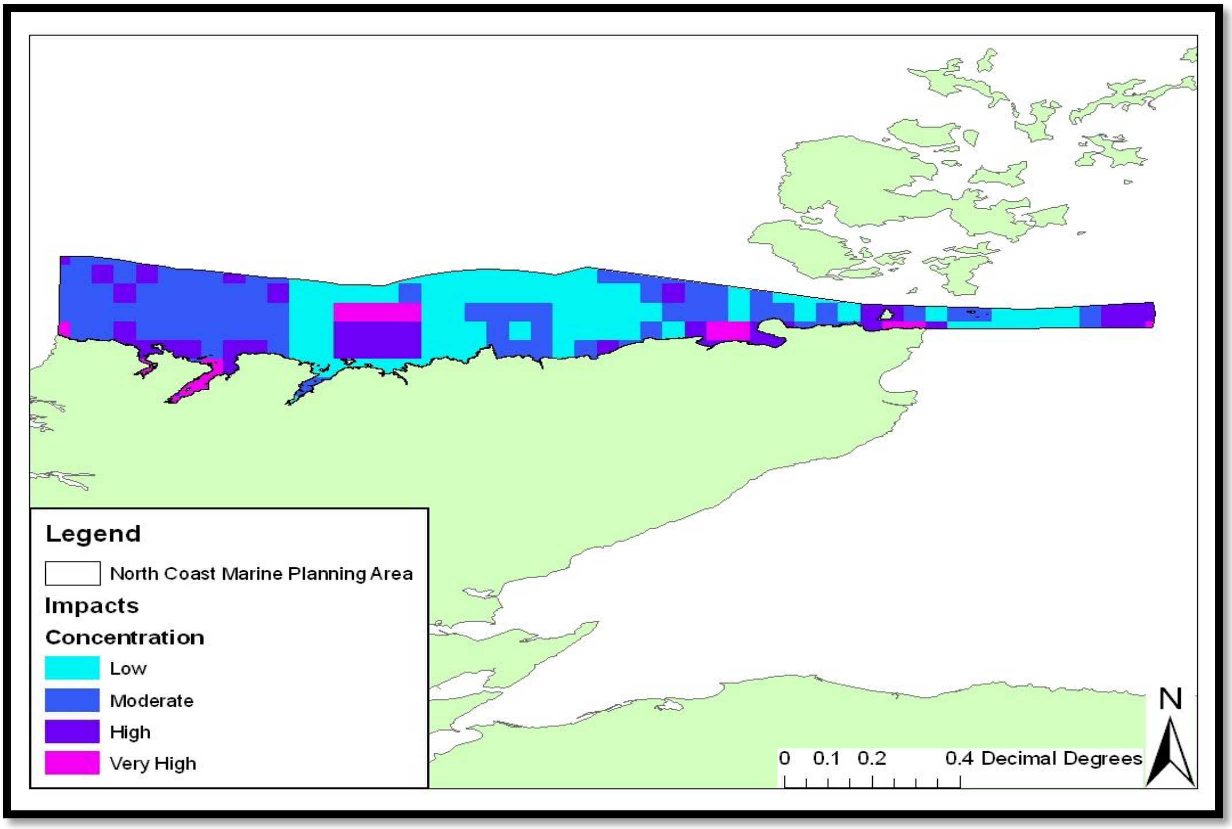


Figure A 2.14 - North Coast Marine Planning Area with Potential and Present Activities mapped.

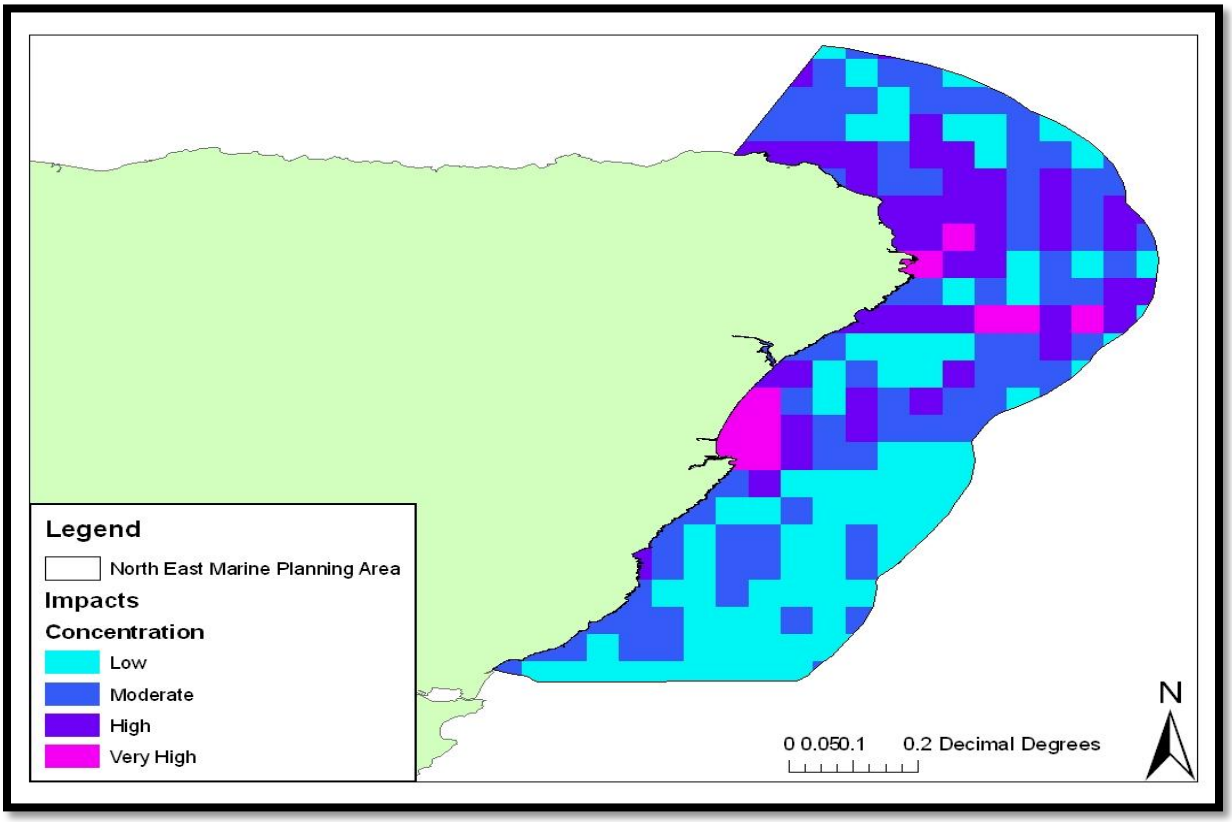


Figure A 2.15 - North East Marine Planning Area with Potential and Present Activities mapped.

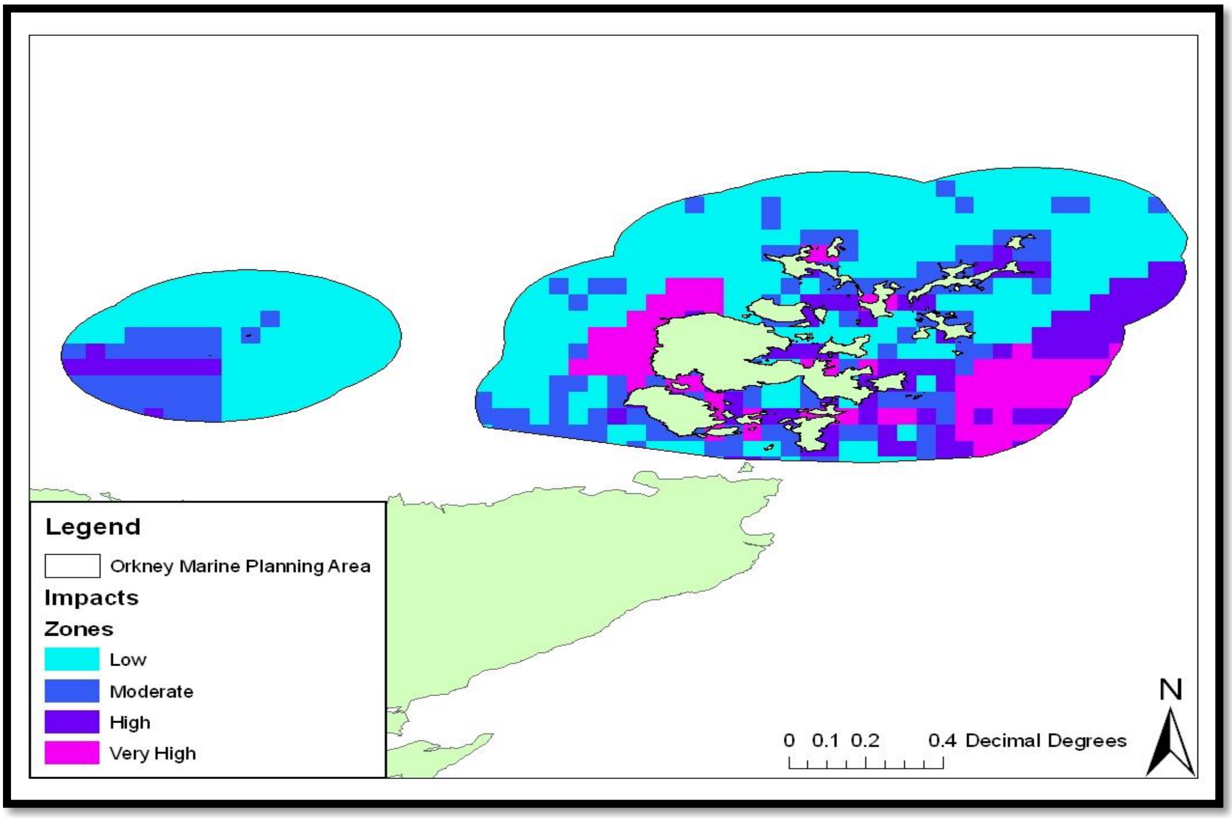


Figure A 2.16 - Orkney Marine Planning Area with Potential and Activities Impacts mapped.

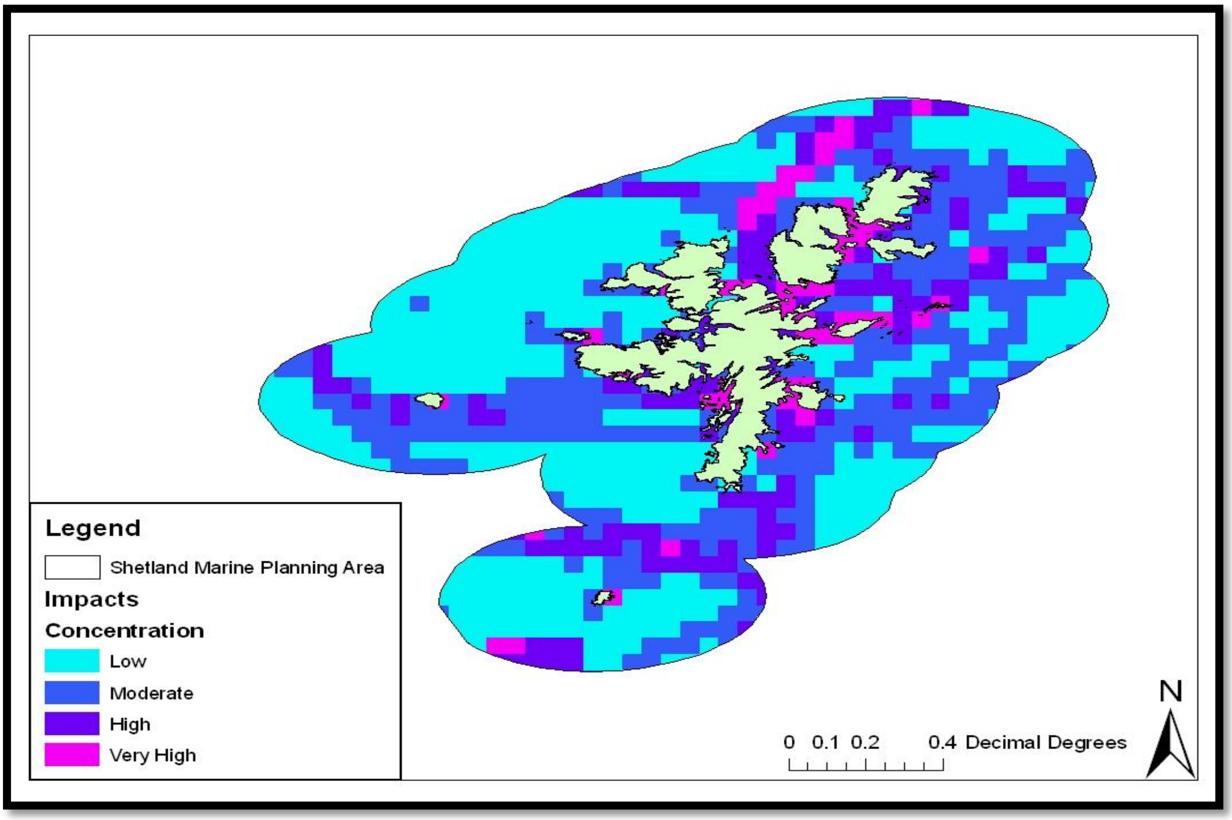


Figure A 2.17 - Shetland Marine Planning Area with Potential and Present Activities mapped.

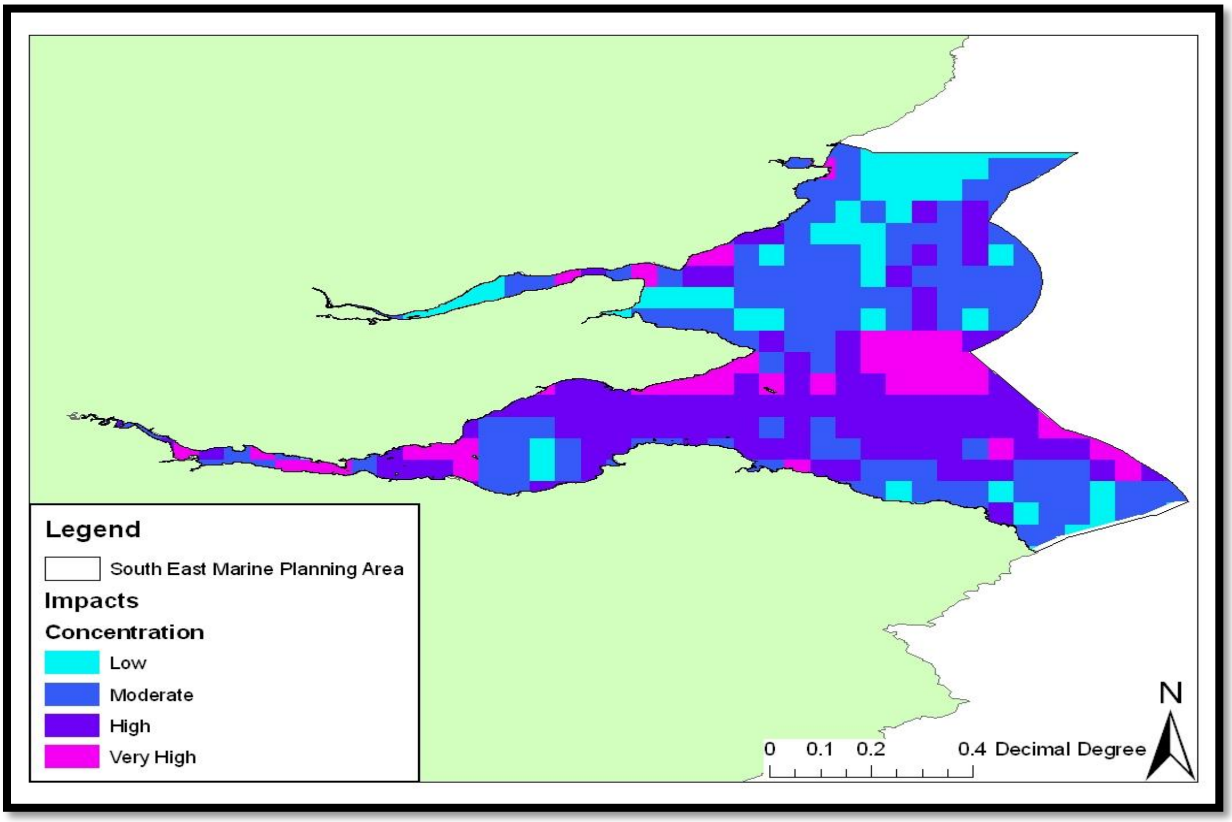


Figure A 2.18 - South East Marine Planning Area with Potential and Present Activities mapped.

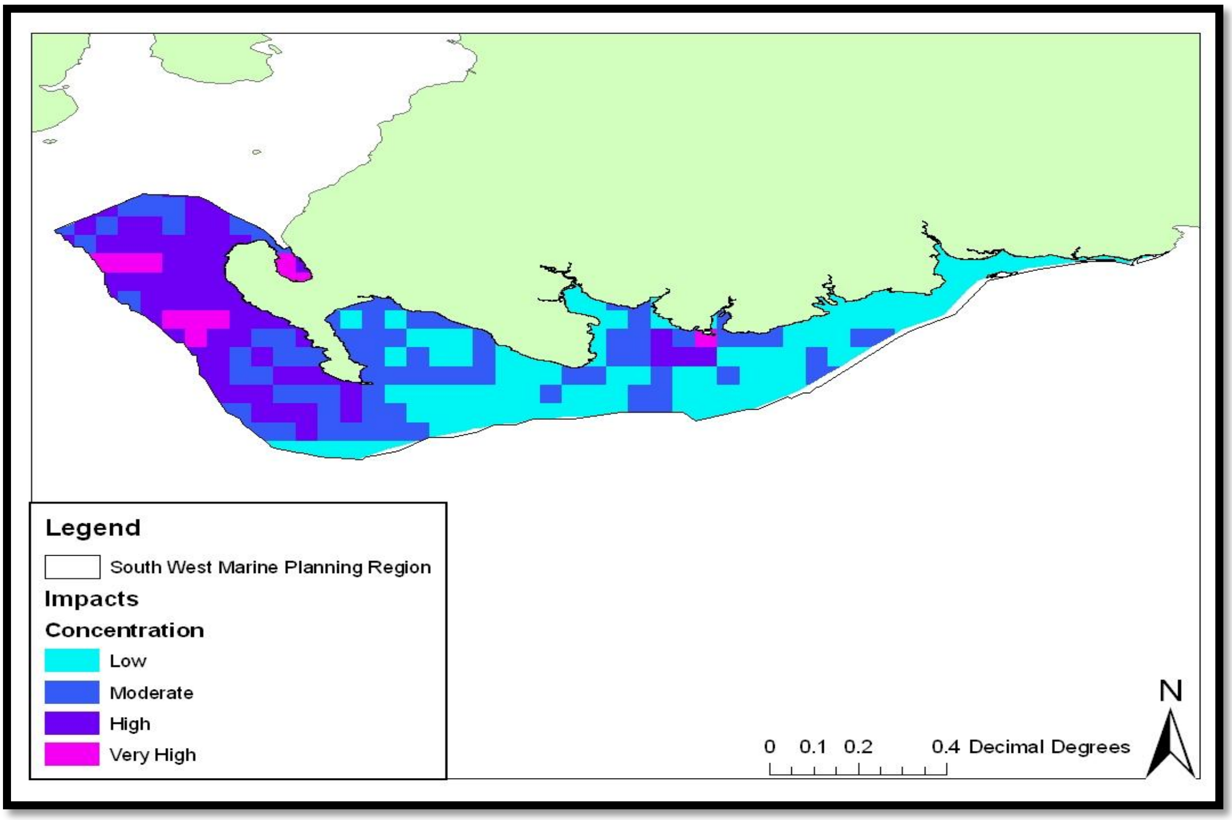


Figure A 2.19 - South West Marine Planning Area with Potential and Present Activities mapped.

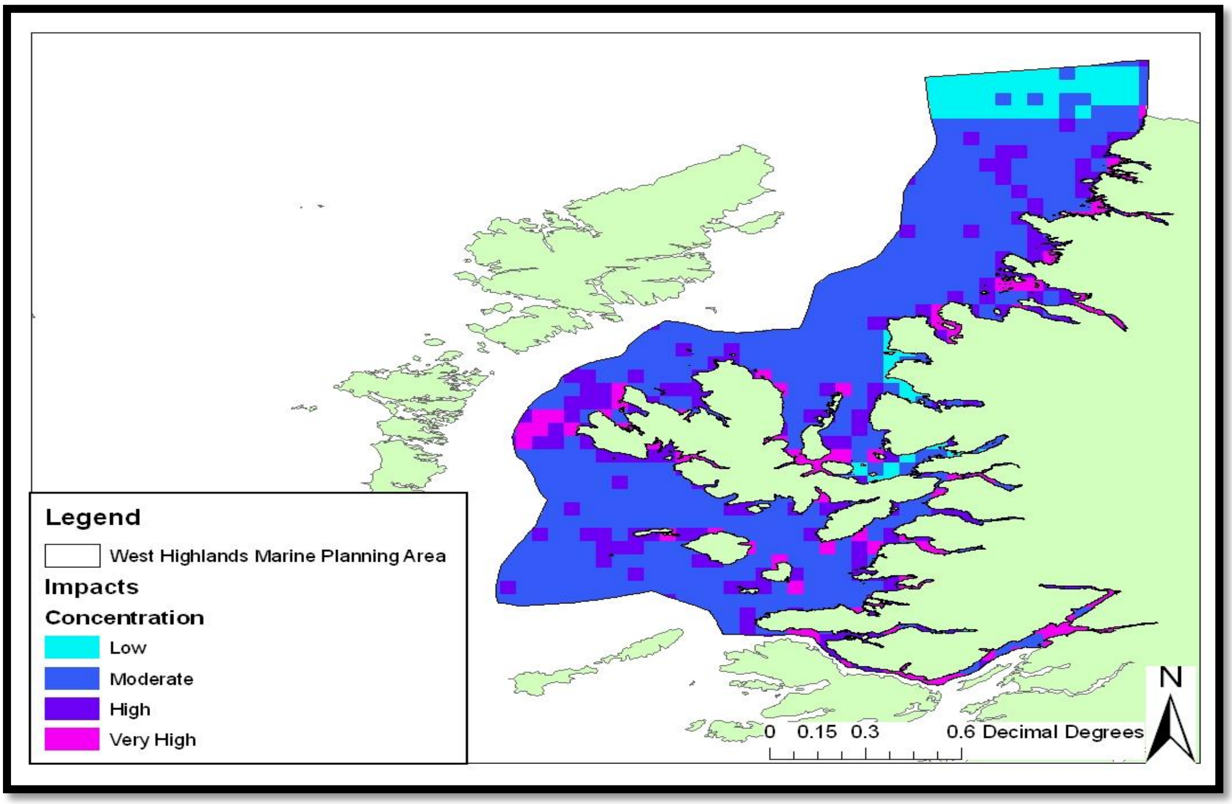


Figure A 2.20 West Highlands Marine Planning Area with Potential and Present Activities mapped.

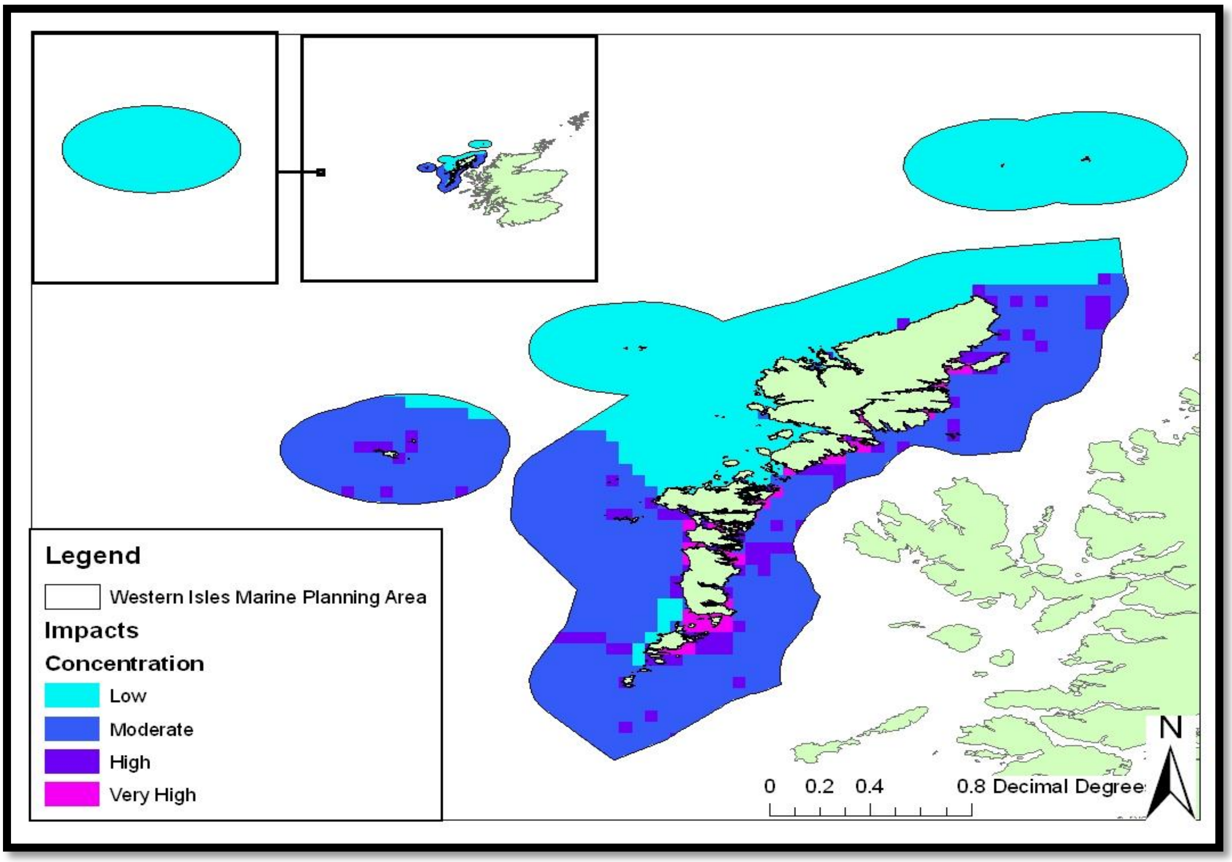


Figure A 2.21 - Western Isles Marine Planning Area with Potential and Present Activities mapped.

Table A 2.1 - The number of ‘Protected’ Planning Units (PUs) in the Argyll Marine Region and in each of the Ecologically Rated Zones

Argyll Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI	6	79	92		177
SPA	2	13	16		31
SAC	4	62	51		117
Ramsar	1	30			31
No-Take Zone	NA	NA	NA	NA	
					356

Table A 2.2 - The number of ‘Protected’ Planning Units (PUs) in the Clyde Marine Region and in each of the Ecologically Rated Zones

Clyde Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI	1	30	34		65
SPA		13	4		17
SAC		3	3		6
Ramsar		8	3		11
No-Take Zone		3			3
					102

Table A 2.310 - The number of ‘Protected’ Planning Units (PUs) in the Moray Marine Region and in each of the Ecologically Rated Zones

Moray Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI	14	109	3		126
SPA	14	85	1		100
SAC	14	153	9		176
Ramsar	14	48	1		63
No-Take Zone	NA	NA	NA	NA	
					465

Table A 2.4 - The number of ‘Protected’ Planning Units (PUs) in the North Coast Marine Region and in each of the Ecologically Rated Zones

North Coast Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI	1	23	33	1	58
SPA		17	22		39
SAC		7	13		20
Ramsar		3			3
No-Take Zone	NA	NA	NA	NA	
					120

Table A 2.5 - The number of 'Protected' Planning Units (PUs) in the North East Marine Region and in each of the Ecologically Rated Zones

North East Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI	2	26	3		31
SPA	2	16			18
SAC	2	12			14
Ramsar	2	3			2
No-Take Zone	NA	NA	NA	NA	
					68

Table A 2.6 - The number of 'Protected' Planning Units (PUs) in the Orkney Marine Region and in each of the Ecologically Rated Zones

Orkney Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI	1	36	20		57
SPA	1	48	33		82
SAC		23	14		37
Ramsar		12			12
No-Take Zone	NA	NA	NA	NA	
					188

Table A 2.7 - The number of 'Protected' Planning Units (PUs) in the Shetlands Marine Region and in each of the Ecologically Rated Zones

Shetland Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI		48	45		93
SPA		41	32		73
SAC		27	23		50
Ramsar		7			7
No-Take Zone	NA	NA	NA	NA	
					223

Table A 2.8 - The number of 'Protected' Planning Units (PUs) in the South East Marine Region and in each of the Ecologically Rated Zones

South East Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI	5	95	23		123
SPA	5	86	19		110
SAC		39	11		50
Ramsar	5	70	14		89
No-Take Zone	NA	NA	NA	NA	
					372

Table A 2.9 - The number of ‘Protected’ Planning Units (PUs) in the South West Marine Region and in each of the Ecologically Rated Zones

South West Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI	13	46	22		81
SPA	11	25			36
SAC	12	29	35		76
Ramsar	11	25			36
No-Take Zone	NA	NA	NA	NA	
					229

Table A 2.10 - The number of ‘Protected’ Planning Units (PUs) in the West Highlands Marine Region and in each of the Ecologically Rated Zones

West Highlands Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site	NA	NA	NA	NA	
SSSI	5	58	85		148
SPA	3	24	32		59
SAC	5	62	55	2	124
Ramsar	NA	NA	NA	NA	
No-Take Zone	NA	NA	NA	NA	
					331

Table A 2.11 - The number of ‘Protected’ Planning Units (PUs) in the Western Isles Marine Region and in each of the Ecologically Rated Zones

Western Isles Marine Region	ER Zone 1	ER Zone 2	ER Zone 3	ER Zone 4	Total No. Of Planning Units
World Heritage Site		11	7		18
SSSI	5	62	50	1	118
SPA		59	42		101
SAC	5	54	37		96
Ramsar	4	37			41
No-Take Zone	NA	NA	NA	NA	
					374

Appendix 3

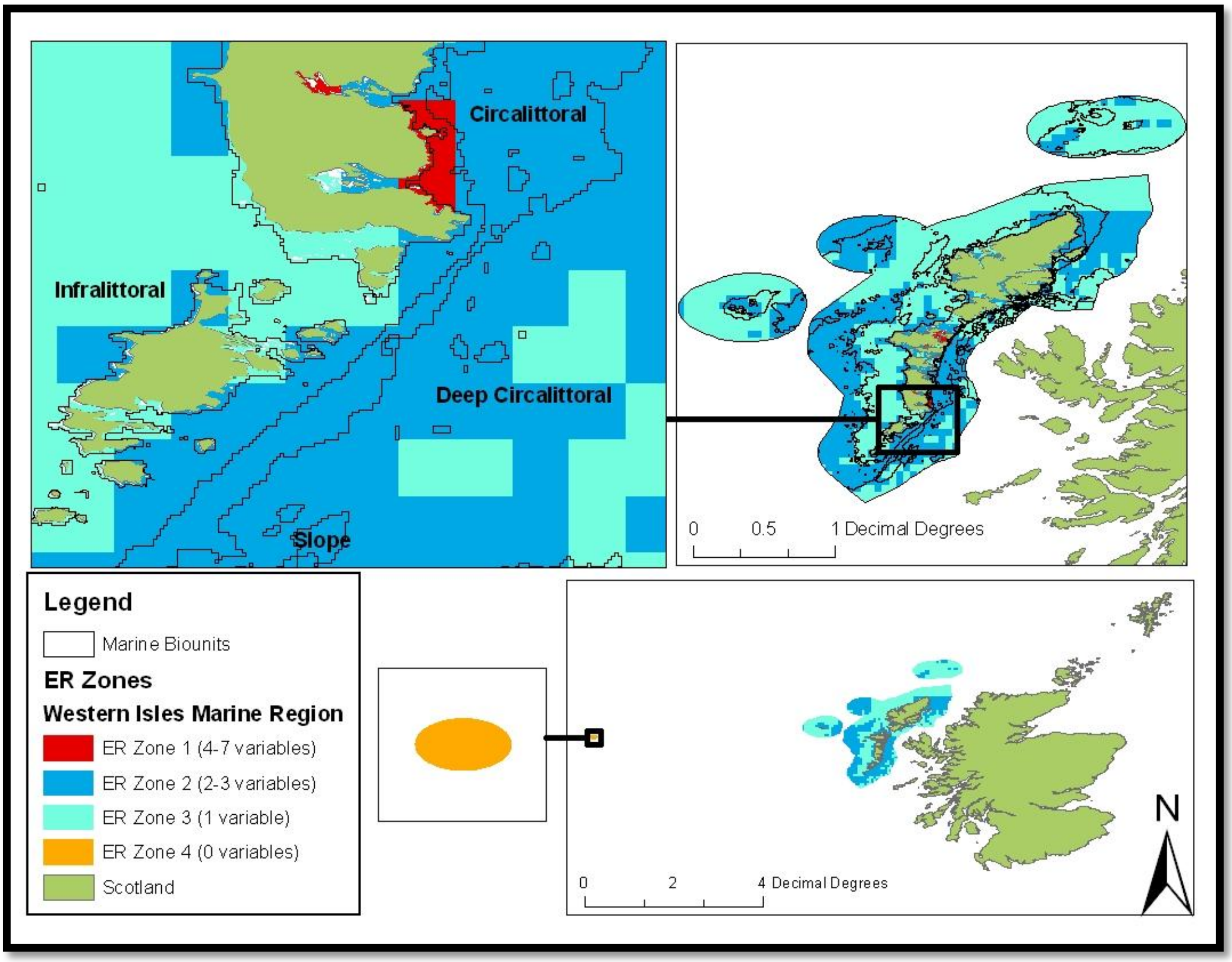
Aquaculture Site Selection: A GIS-based Approach to Marine Spatial Planning in Scotland.

By Lauren McWhinnie

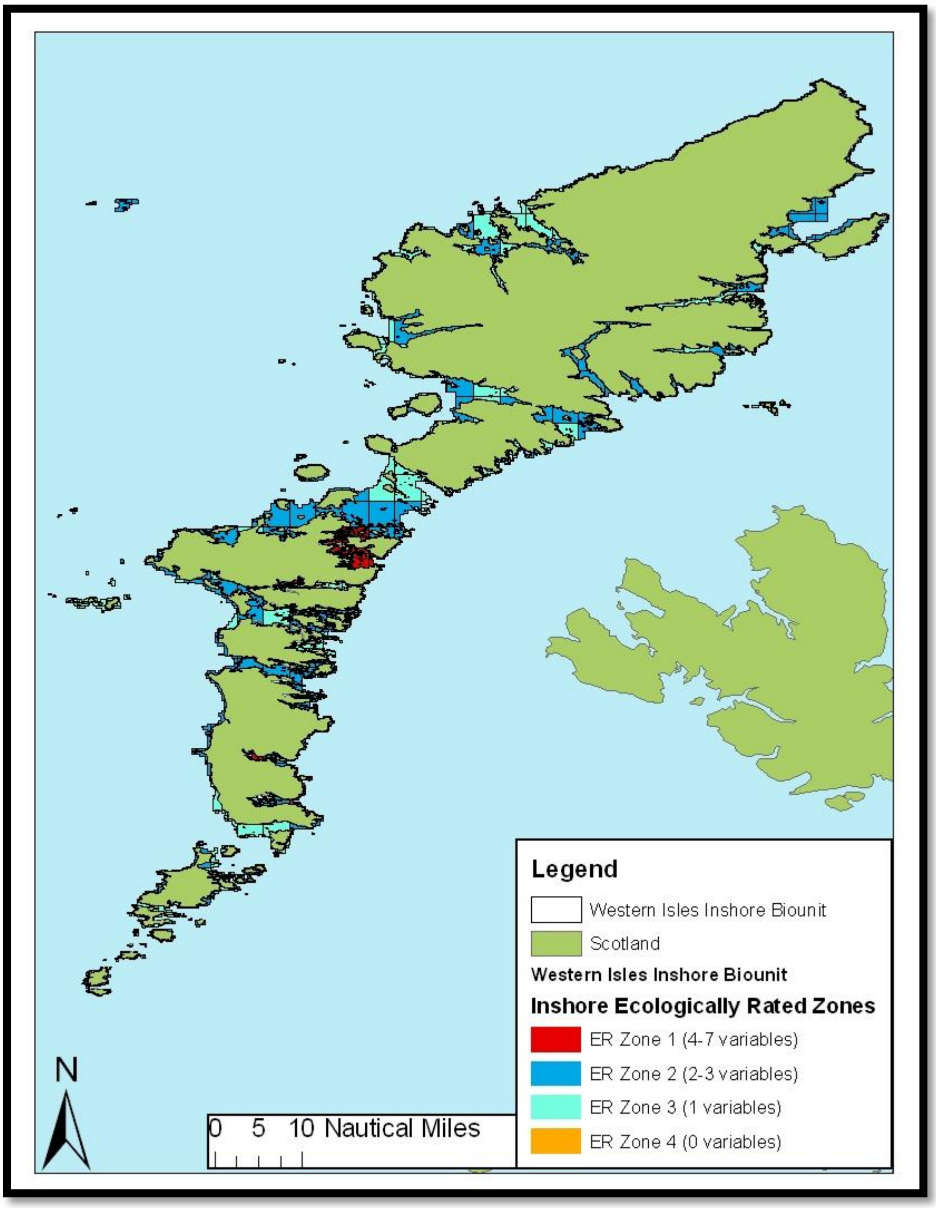
Heriot-Watt University

Quick Users Guide of the Marine Plan

Step 1: Map 4, page 29 (ER Zones in the Western Isles Marine Region). This map shows the Western Isles Marine Region Divided into 4 Biounits: Slope, Infralittoral, Deep Circalittoral and Circalittoral. Identify which Biounit you are in or concerned with.



Step 2: Refer to the relevant Biounit map, pages 30-34, which show the ER Zone boundaries at a local scale. Assess which of the ER Zones your development occurs in or is proposed to occur within.



Step 3: Familiarise yourself with the relevant goals, objectives and strategies that are guiding the development and use within the zone you are concerned with, pages 17-24.

Step 4: Ensure you are familiar with the statutory regulations that apply to your development or use (e.g. development plans, boating regulations, fish size). If in doubt, check with the relevant agencies that manage your type of development or use (e.g. SEPA).

Although every effort has been taken to ensure the accuracy of the information displayed, the authors make no representations, either expressed or implied, that the information displayed is accurate or fit for any purpose.

Foreword

The Western Isles Draft Marine Plan recognises that more information is required to assist the community and other organisations to make informed decisions concerning the marine environment in order to protect its natural and cultural heritage. Notwithstanding, we believe that this Marine Plan is a useful and important addition to the understanding of marine features and issues in this area and it will contribute to the spatial management of activities and features within this area.

Marine, coastal and estuarine planning in the future must be based on sustainable, integrated and ecological resources management that acknowledges:

- Land and marine catchments are interlinked by numerous ecological processes
- Ecosystems are complex and decisions made must consider the whole ecosystem not just individual resources

Resource use decisions must be:

- Underpinned by the precautionary principle and risk based assessments
- Reliant on the provision of robust information
- Based on the assumption that any potentially negative impacts caused by the decisions made are reversible

Information and relevant data must be continuously collected and updated in order to improve the validity of the planning decisions being made.

Contents

1.0 Executive Summary

The Western Isles Draft Marine Plan is an attempt to refine and test the application of the Marine Planning Framework for Scottish Waters and is envisaged as being one of eleven marine plans that would be produced for Scottish Waters.

The Marine Planning Framework has been developed using the principles of ecosystem based management, ecologically sustainable development and adaptive management. It is an approach to provide a framework for managing current and future activities within the capacity of the ecosystem whilst maintaining a healthy and productive marine environment for Scotland.

1.1 The Marine Planning Framework

The Marine Planning Framework was originally developed in partnership with local communities, councils and government agencies for South Australian waters by Day et al. (2008). It is a governmental approach to provide a framework to manage current and future activities while staying within the capacity of the ecosystem (Day et al., 2008) and therefore maintaining a healthy and productive marine environment for the region.

1.2 The Western Isles Region

The Western Isles is a chain of islands in the Atlantic Ocean that lie off the North West coast of Scotland. The Islands within this planning region are also known as the Outer Hebrides or officially called by their Gaelic name Na h – Eileanan Siar. The main islands form an archipelago of which the major Islands are Lewis and Harris, North Uist, Benbecula, South Uist and Barra. Lewis and Harris have a an area of some 2175km^2 making it the largest Island in Scotland; the Isle is unusual as it incorporates Lewis in the North and Harris in the South and both are frequently referred to as individual Islands despite being joined by a land border.

The larger Isles are deeply cut into by the sea in many areas such as Loch Ròg, Loch Seaforth and Loch nam Madadh. North and South Uist, Barra and Benbecula all have extensive sandy beaches associated with their coastlines.

Much of the Western Isles archipelago is highly protected habitat, including both the land and surrounding waters. There are 53 Sites of Special Scientific Interest (SSSIs) of which the largest is Loch an Duin in North Uist at 15,100 hectares and North Harris which is 12,700 hectares.

Nationally important populations of breeding wader birds are present in the Outer Hebrides including Common Redshank, Dunlin, Lapwing and Ringed Plover. The Islands also provide a habitat for other important species such as Hen Harrier, Golden Eagle and Otter. Offshore, Basking Sharks and a variety of cetacean species are regularly sighted and on the remote Islands seabird populations are of international significance. St. Kilda has a Northern Gannet population of around 60,000 pairs this comprises around 24% of the world population of this species. 49,000 breeding pairs of Leach's Petrel (90% of the European population), 136,000 pairs of Puffin (30% of the UK total) and 67,000 Northern Fulmar pairs (13% of the European population) are also all to be found on this small Island. Mingulay is also an important breeding ground for Razorbills with over 9,000 nesting pairs and around 6.3% of the European population. This area should also be noted for its cold water coral reefs, and an area just east of Mingulay is unique in that it is the only know location of extensive cold water coral reefs in the all of the UKs territorial waters.

The inhabited Western Islands have a population of around twenty six and a half thousand; the largest settlement is Stornoway on the Isle of Lewis, which has a population of just over eight thousand. There are also more than fifty uninhabited Islands that are greater than 40 hectares in size, these include the Barra Isles, Flannan Isles, Monach Isles, the Shiant Isles and the Islands of Loch Ròg. As with many main Island chains around Scotland, many of the more remote islands were abandoned during the 19th and 20th centuries. Even smaller isles and skerries and other island groups pepper the North Atlantic surrounding the main Islands. Some are not geologically part of the Outer Hebrides, but are administratively and in the majority of cases culturally for example St. Kilda. A similar distance away but to the North of Lewis are North Rona and Sula Sgeir, another two small and very remote Islands. The status of Rockall, which lies 228miles to the west of North Uist, was decreed by the Island of Rockall Act 1972 to also be a part of the Western Isles. This, however, remains a matter of international dispute.

Modern commercial activities centre on tourism, crafting, fishing and weaving, including the manufacturing of Harris Tweed. The Western Isles, including Stornoway, are defined by the Highlands and Islands Enterprise as an economically 'fragile area'; overall they are relatively reliant on primary industries and the public sector, with fishing and farming being particularly vulnerable to environmental impacts, changing market pressures and European legislation.

2.0 Performance Assessment System (PAS)

The Performance Assessment System (PAS) for the Western Isles Draft Marine Plan will evaluate the effectiveness of the Plan by reporting on the maintenance of ecosystem conditions in and around the Western Isles. The PAS identifies actions and responsibilities for agencies involved in management and monitoring of the marine environment. It would provide a reporting framework that could enable all agencies to contribute to a collaborative approach to deal with large-scale, long-term issues relating to the conservation and sustainable use of marine ecosystems and species.

3.0 Marine Planning Framework

This framework will be based on the principles of ecologically sustainable development; ecosystem-based management and adaptive management (see appendix 1, page 39 for guiding principle). The framework provides for:

- ➢ The development of eleven marine plans (see figure 1) covering the seven marine bio-zones in Scottish waters (see figure 3) and near-shore waters;
- ➢ Development and implementation of a Performance Assessment System (PAS) for each marine plan.

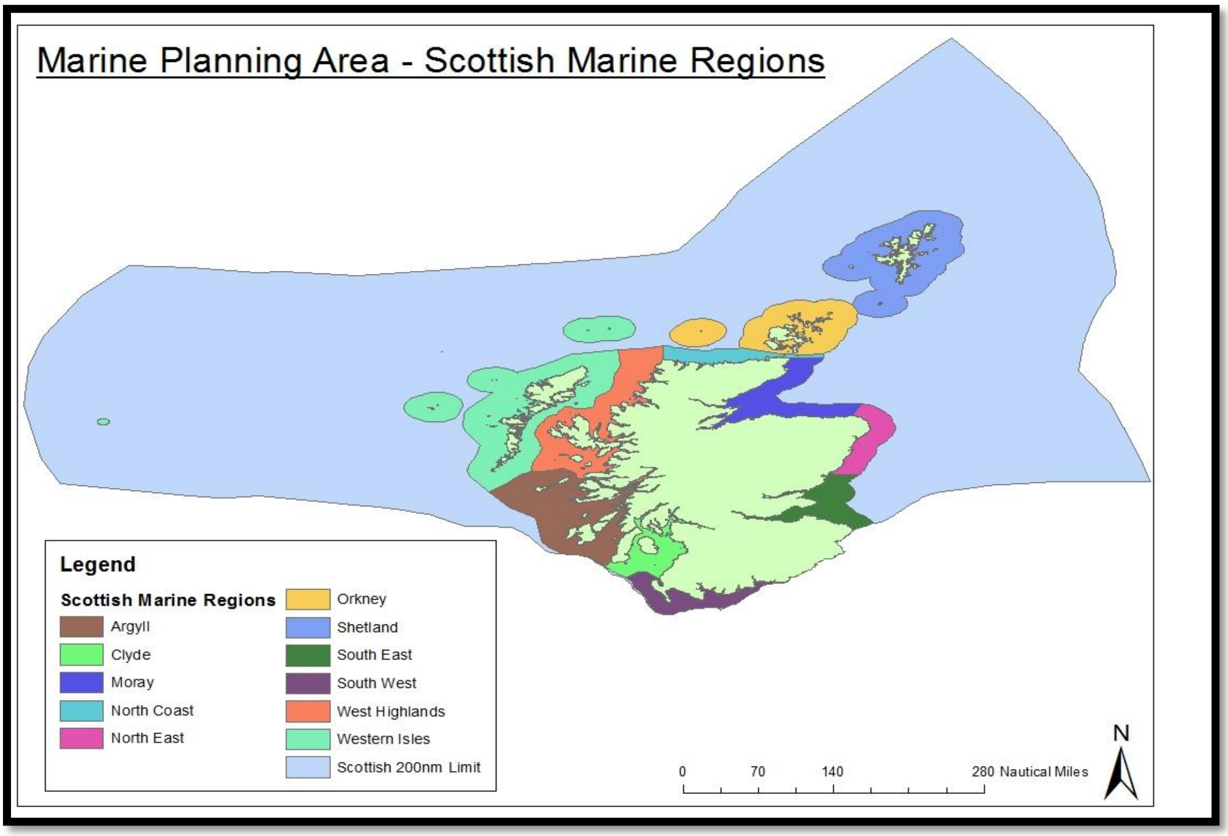


Figure 1.0 - Scottish Marine Plan Boundaries

4.0 Visions, Goals and Strategies for the Western Isles Marine Region

Vision Statement for the Western Isles Draft Marine Plan – *To ensure conservation and ecologically sustainable use within the Western Isles Marine Region, of the marine, coastal and estuarine environment by integration of marine and land use management through partnerships between community, industry and government.*

Goals

- Facilitate ecosystem based planning and management of the Western Isles Marine Region.
- Support a relationship between government, industry and the community in caring for the marine environment.
- Support integrated marine, estuarine and coastal planning and integrated catchment management mechanisms.
- Identify and protect indigenous and non-indigenous, natural and cultural marine heritage.

Strategies

- Develop an understanding and appreciation of the characteristics of the Western Isles Marine Region through assessing the current knowledge of its:
    - Planning and legislative framework
    - Surrounding settlement and facilities
    - Environmental values
    - Social, economic and cultural values
    - Current uses and potential impacts
    - Existing and required research
- Design a Marine Plan that delivers a planning framework for management across government, industry and recreational sectors that:
    - Integrates resource management on an ecosystem basis
    - Identifies values of the Western Isles Marine Region based on ecosystem based management, including environmental, economic, social and cultural values
    - Identifies ecologically rated zones to accommodate a range of activities
    - Identifies new information required
    - Is adaptive to changing conditions and improving knowledge
    - Adds value to existing management arrangements

The vision, goals and strategies have driven the development of this Draft Marine Plan.

5.0 Planning Area

The planning area for the Western Isles Draft Marine Plan includes all territorial waters seaward of the Mean High Water Spring tide out to 12 nautical miles (figure 2). The Western Isles region stretches from Coll and Tiree in the Inner Hebrides to Sule Stack and Sule Skerry off of Orkney, and includes all of the Outer Hebridean Islands that make up the Western Isles chain. These Islands are subject to ocean influences and are wet, windswept and generally treeless (except for sparse pockets of native shrubs and forestry plantations). The Islands themselves are all extremely varied in character from extensive moorlands and hills of Lewis and Harris, to the machair of the Uists and Barra and the seabird cliffs of the offshore Islands. The variety of habitats, influenced by climate, geology and agricultural activities support a large number of birds and a rich diversity of plants all of which combine to result in an outstanding natural heritage and landscape.

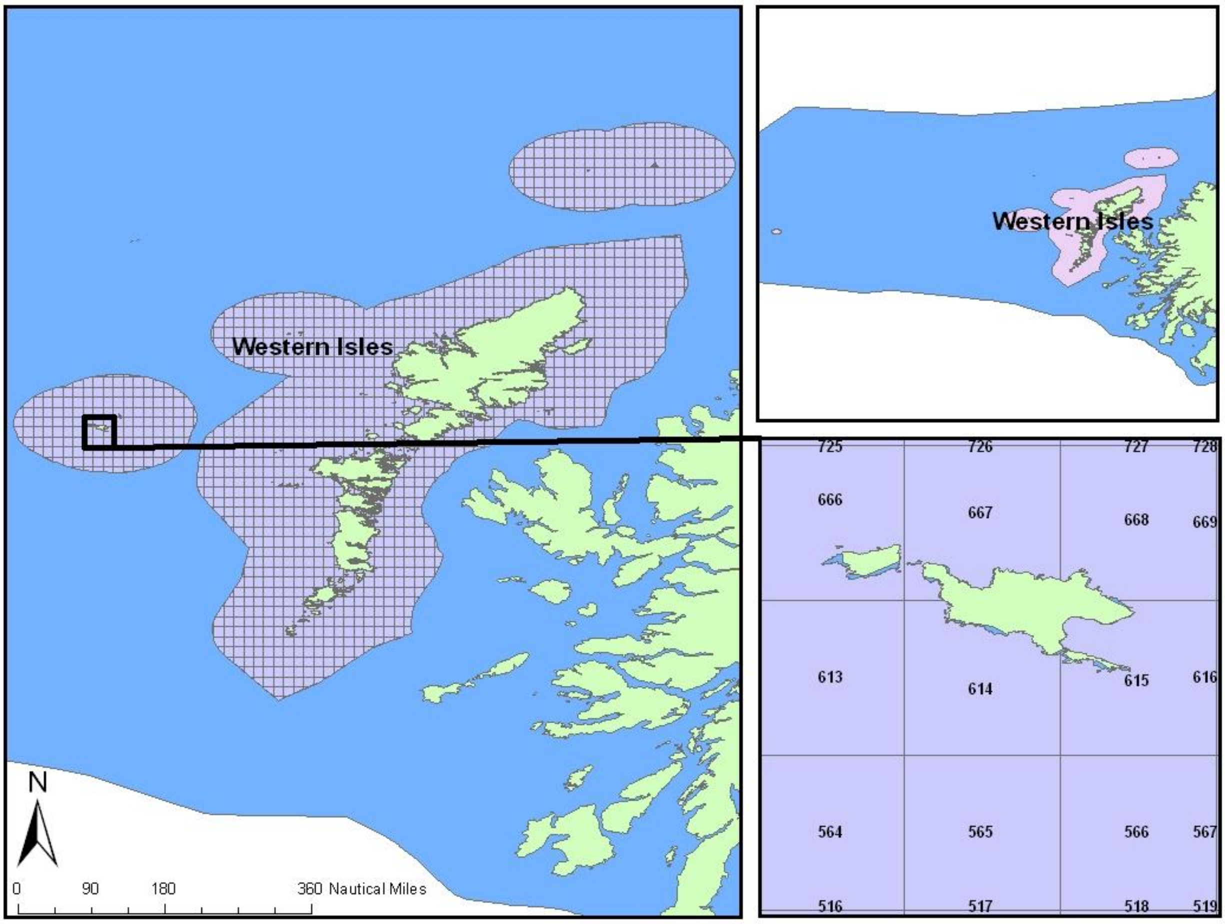


Figure 2.0 - Area covered by the Western Isles Draft Marine Plan

Throughout the Western Isles Region, the human population level and structure varies between Islands, but apart from Stornoway and its surrounding area, numbers are relatively low and in some cases are in decline. Most people are involved with either crafting or fishing and as such have strong links with the land and the sea. Many are dependent on aquaculture, estate work or tourism and a significant number of people are employed by the local authorities, agencies and other services providers.

Important wildlife and habitats of national and international conservation importance exist throughout these Islands and it is often difficult to find an area of land that does not host an internationally important species or habitat. The marine life of the Western Isles Region is thought to be more diverse than that found in their terrestrial habitats. Intertidal sand flats, non-tidal sand banks, sheltered rocky coasts, sealochs, saline lagoons, reefs and exposed rocky shores are all represented and many are of European importance and designated as marine Special Areas of Conservation (SACs).

Intertidal mudflats support communities of worms and molluscs whilst also providing important feeding areas for populations of breeding and wintering wading birds. Sea lochs are used extensively by aquaculturists who value their sheltered conditions, tidal currents and water quality. These same conditions are also favoured by marine creatures such as brittle stars, fan worms, anemones and sponges.

On St. Kilda and other more exposed Isles, places such as reefs, caves and vertical cliffs along their coastline are often colonized by different communities as the depth increases resulting in a distinct vertical zonation. In these areas kelp can continue down to greater depths than normal due to the exceptionally clear waters of the Atlantic Ocean. As the light fades this gives way to anemones and unusual corals such as Ross coral. The seas surrounding this area are rich in both demersal and pelagic fish, whilst crustaceans such as crabs and lobsters are also able to take shelter amongst the rocks. Seals are also often encountered resting in undersea chambers that are formed by huge boulders.

The Minch between the Western Isles and the West coast of Scotland supports a diverse range of habitats and fishing grounds. Smaller boats tend to fish for prawns on the more sheltered east coast during the winter months, returning in the summer months to the West coast of the Western Isles to places like Heisker (The Monach Isles) to fish for lobsters and fish.

Marine mammals are considered to be common in the Western Isles but have favoured localities at different times of the year. In august whales and dolphins come into the shallower waters to feed on squid and spawning fish. Additionally there are thought to be two resident schools of bottlenose dolphins in the sound of Barra and perhaps a group of Risso's dolphin in the Broadbay area near Stornoway. Common seals are abundant all year round in the sounds of Barra and Harris, giving birth on the rocky shores of Coll and Sgeirs in the summer. Most grey seal breeding colonies are formed on rocky exposed Islands like North Rona, Shillay, Coppay, Haskeir and Gasker; but the largest colony in the Western Isles, and the second largest in the world is found on the sandy beaches of the Monach Isles. Otters are also numerous along the coastline, as well as further inland.

6.0 Who will use this Marine Plan?

The Marine Plan is a planning and decision making tool to guide the development and use of the marine and coastal environment. It is intended for the following users:

- State and local government, management agencies, authorities, boards and other relevant planning and natural resource management bodies
- Industrial and commercial users and researchers
- Recreational users

Development and use within each zone will be guided by a series of goals, objectives and strategies. Adherence to these goals, objectives and strategies of each ecologically rated zone will apply equally to existing developments and use as it does to future developments and uses. For existing development and use, whether industrial, commercial or recreational, application of this Marine Plan will involve a review of current development and/or resource management plans that guide activities and practices. Future developments and uses would be guided at the planning phase by the relevant planning and/or management authority in accordance with the Marine Plan zoning arrangement.

6.1 Legislation

The Marine (Scotland) Act 2010 has introduced statutory marine planning for the first time in the Scottish marine area. This Act provides for a National Marine Plan and for the delegation of marine planning functions down to a regional scale. The Scottish Government's intentions are to delegate these functions to Marine Planning Partnerships that will be responsible for developing regional marine plans.

6.2 Planning and Management Authorities

The Marine (Scotland) Act 2010 provides powers for Ministers to create Scottish Marine Regions (SMRs) through secondary legislation and to delegate planning powers to the regional level. Development plans under this act could progressively incorporate zoning schemes and development related policies such as the one proposed here as they undergo plan amendments. Marine Plans such as this will also provide a sound basis for Regional marine Planning Partnerships to meet their responsibilities in developing Integrated Coastal Zone Management (ICZM) and take into account the National Marine Plan and specific directions from Ministers under sections 12-14 of the Marine (Scotland) Act 2010.

This draft marine plan recognizes that in some areas, particularly those that are adjacent to industrial areas, degradation of the marine environment will already often exceed the standards required to meet the zone objectives. It should be recognised that many areas are already regulated by several Acts that can be attributed to individual industries, such as MOD activities, and therefore this legislation will be unaffected by this new plan. In each of these cases however, regulatory agencies, industries and other users of the environment would be provided with objective targets to assist in identifying remedies for past and current impacts. These targets will then help plan for future development and use in a manner consistent with the zone objectives. Over time, these actions will then go on to facilitate the restoration of acceptable ecosystem conditions.

6.3 Commercial and Recreational Users of the Western Isles Marine Region

The majority of commercial and recreational uses of the marine environment are regulated and managed by a combination of local and government agencies. Regulations and management measures supported by these statues would be progressively modified to reflect Marine Plans. This Marine Plan will not seek to control the ongoing or day-to-day management of marine activities, but will strive to direct the integration of the various legislative instruments that regulate different activities. In this way it will facilitate the delivery of long term protection of the marine environment while still enabling a broad range of activities to occur in an ecologically sustainable manner.

7.0 Marine Bio-Zones and Bio-Units

Scotland can be divided into seven marine bio-zones according to depth: Circalittoral, Deep Circalittoral, Infralittoral, Lower Bathyal, Mid-Bathyal, Slope and Upper Bathyal (see figure 3) along with near-shore waters, that contain many smaller units that have been termed marine bio-units. Bio-zones and bio-units reflect the pattern of biodiversity at different scales/areas. This Draft Marine Plan is one of eleven that would be produced to cover the whole of the Scottish coastline.

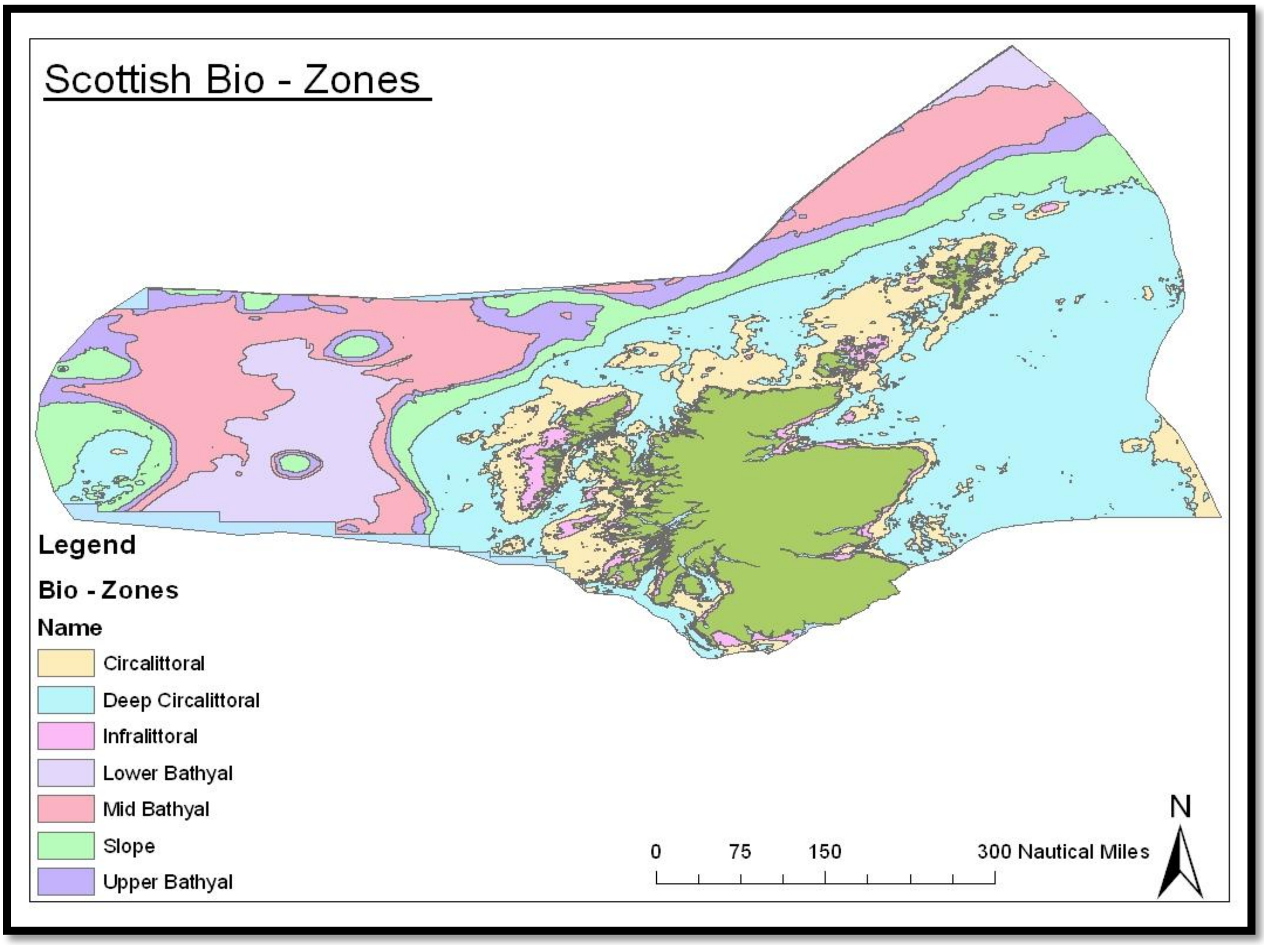


Figure 3.0 - Scottish Marine Bio-Zones

Planning and management guidance is delivered through a system of zones that have been derived through rating areas according to the contribution made by habitats and ecological processes to the biodiversity, ecological health and productivity of the whole marine planning area. The goals, objectives and strategies for each zone establish appropriate standards for development and use, ensuring the protection and maintenance of ecosystem functions and structures.

7.1 Benefits of Marine Plans

- They provide increased certainty for management of development and resource use
- They provide for long term protection of the marine environment
- They enable a broad range of activities to occur in an ecologically sustainable manner
- They allow for strategic integrated planning in the marine environment that spans across governmental agencies
- The addition of a Performance Assessment System provides an integrated monitoring and assessment system for the marine environment

8.0 Development and Use in the Western Isles

The majority of economic and urban development around the Western Isles Marine Region is located around the coast. These developments have impacted upon the many marine, coastal and estuarine habitats that are present and that are critical to the functioning of ecosystems within the Western Isles (see Map 1, page 26).

Industrial, rural and urban developments have been essential to ensuring economic and social growth of the more remote Western Isles Marine Region over the last few decades, and it is crucial that this growth continues in order to support communities inhabiting this region (see Map 2 page 27).

Impacts to the Western Isles marine ecosystems have come from many different sources. These range from water quality changes due to marine discharges from point and diffuse sources, to physical damage to benthic and other sensitive habitats by specific activities. Map 3 on page 28 provides a brief overview of the current concentration of activities that occur in the Western Isles Marine Region.

8.1 Cumulative Impacts

The majority of developments and uses, no matter how minimal, will have some degree of impact on the marine environment. When these individual impacts are combined they can result in a much larger cumulative impact. The marine planning process has identified that cumulative impacts from development and usage could be at risk of degrading areas that are critical to the health and productivity of the Western Isles. This in turn would have consequences for the sustainability of the industries and communities of the Western Isles.

Each activity such as drilling for oil, fishing, boating, aquaculture etc. should be considered in association with all other uses and their cumulative impacts on other environments. Land based activities can also have a substantial impact upon the marine environment. Terrestrial inputs from land based activities such as agriculture also have the potential to threaten water quality, biodiversity and other marine industries such as fishing or aquaculture. Therefore these terrestrial activities must also be taken into consideration when identifying cumulative impacts.

9.0 Ecologically Rated Zones

The development of a system of ecologically rated zones (ER Zones) (see table 1), based upon available knowledge and current understanding of the ecological variables found in the Western Isles Marine Planning area, will form the cornerstone of this Marine Plan. ER Zones reflect the importance of particular environments to the overall health of the Scottish marine, coastal and estuarine environment. In accordance with this, certain types and levels of development and use may be more suited to a particular Zone than others. The goals, objectives and strategies assigned for each zone will afford guidance in this area.

Table 1.0 - The Sequence of Ecologically Rated Zones

Zone Name	Description
ER Zone 1	Negligible impacts to habitats, negligible impacts to ecological processes
ER Zone 2	Minor impacts to habitats, minor impediment to ecological processes
ER Zone 3	Moderate impacts to habitats whilst safeguarding ecological processes
ER Zone 4	Research will determine allowable consequences to habitats

10.0 Ecologically Rated Zones – Definitions, Goals, Objectives and Strategies

10.1 Ecologically Rated Zone 1 (ER Zone 1)

Definition – zones classified as ER Zone1 will contain the highest diversity of marine habitats and species identified as suitable indicators of environmental capability. These include:

- Habitats and ecological processes critical to ecosystem function
- Unique ecological communities
- Species of conservational concern, including protected, threatened, rare and endemic species
- Habitats critical to the life cycle of species (e.g. breeding, nursery and feeding areas).

Arrangement s for managing development and use within ER Zone 1 will be primarily concerned with conservation and protection of the marine environment (species, habitats and ecological processes) as described under the Goal, Objective and Strategies laid out bellow.

Goal – development and use of the marine, coastal and estuarine environments is managed such that it will cause negligible impacts on the biodiversity, habitats and ecological processes important to the health and productivity of the ecosystem.

"Negligible impacts on habitats, negligible impediment to ecological processes"

Negligible – will not exceed minimal impacts to habitats or populations. It is unlikely to be measurable against any background variability. The interactions between habitats and ecosystems may be occurring but it is unlikely that there would be any change outside of natural variation. Any systems recovery will be measurable in days.

Objectives ER Zone 1 –

1. Ecologically sustainable development and use, both existing and in the future of the marine environment will not exceed negligible:
    a. Loss of biodiversity
    b. Impediment of ecological processes
    c. Impacts to habitat indicators e.g. intertidal mudflats
    d. Loading of sediments with heavy metals, persistent organic pollutants and other contaminants
    e. Change in water quality beyond the benchmark established by the Performance Assessment System for each Marine Plan
2. Environmental management of existing and future developments and use and the adoption of performance measures consistent with the Marine Plan objectives and development strategies to ensure compliance
3. Environmental impacts of past, existing and future development and use will be actively improved
4. Ecological processes underpinning economic, environmental, social and cultural values will be protected
5. Monitoring, evaluation and research will be publically available and aimed at increasing the understanding of the biodiversity, habitats and ecological processes of the marine environment and the cumulative impacts of development and use.

Strategies to Achieve Objectives of ER Zone 1 –

The following strategies should be applied by all management agencies with jurisdiction over the marine, coastal and estuarine environment, all operators of developments and all individuals that make use of these environments.

1. Adopt mechanisms to conserve and protect marine, coastal and estuarine:
    - Biodiversity
    - Habitats
    - Important spawning, breeding and nursery areas
    - Key feeding and resting areas
    - Endemic species
    - Species that are of a conservation concern
    - Ecological processes
2. Protect cultural and heritage values associated with the marine, coastal and estuarine environment
3. Adopt performance measures derived from the objectives (ER Zone 1) and manage existing and future economic, recreational, social and cultural

development and use to reduce and remove threats to achieving the objectives
4. Plan for future development and use that are consistent with the objectives (ER Zone 1) and with consideration of the cumulative impacts of development and use
5. Adopt mechanisms for the rehabilitation of degraded areas that may include relocation of existing uses that do not comply with the goals and objectives (ER Zone 1)
6. Respond to any changes in water quality where a trend away from an established benchmark is detected. Maintain water quality at the recommended benchmark given in the Marine Plan Performance Assessment System.
7. Contribute to both site specific and ecosystem level research and monitoring

10.2 Ecologically Rated Zone 2 (ER Zone 2)

Definition – zones classified as ER Zone2 contain a high diversity of marine habitats and species identified as suitable indicators of environmental capability.

Management of development and use within ER Zone 2 will be controlled and primarily concerned with protecting and maintaining the integrity of the marine environment (species, habitats and ecological processes) as described under the Goal, Objective and Strategies described below.

Goal – development and use is managed to ensure only minor impacts on the marine, coastal and estuarine biodiversity, habitats and ecological processes of the ecosystem.

"Minor impacts on habitats, minor impediment to ecological processes"

Minor – will not exceed lesser impacts to habitats or populations measurable against background variability. Recovery will be measured in months.

Objectives ER Zone 2–

1. Ecologically sustainable development and use, both existing and in the future of the marine environment will not exceed minor:
   a. Loss of biodiversity
   b. Impediment of ecological processes
   c. Impacts to habitat indicators e.g. intertidal mudflats
   d. Loading of sediments with heavy metals, persistent organic pollutants and other contaminants
   e. Change in water quality beyond the benchmark established by the Performance Assessment System for each Marine Plan
2. Environmental management of existing and future developments and use and the adoption of performance measures consistent with the Marine Plan objectives and development strategies to ensure compliance

3. Environmental impacts of past, existing and future development and use will be actively improved
4. Ecological processes underpinning economic, environmental, social and cultural values will be protected
5. Monitoring, evaluation and research will be publically available and aimed at increasing the understanding of the biodiversity, habitats and ecological processes of the marine environment and the cumulative impacts of development and use.

Strategies to Achieve Objectives of ER Zone 2 –

The following strategies should be applied by all management agencies with jurisdiction over the marine, coastal and estuarine environment, all operators of developments and all individuals that make use of these environments.

1. Adopt mechanisms to conserve and protect marine, coastal and estuarine:
    - Endemic species
    - Species that are of a conservational concern
    - Major spawning, breeding and nursery areas
    - Key feeding and resting areas
2. Adopt mechanisms to protect marine, coastal and estuarine:
    - Biodiversity
    - Habitats
    - Ecological processes
3. Protect cultural and heritage values associated with the marine, coastal and estuarine environment
4. Adopt performance measures derived from the objectives (ER Zone 2) and manage existing and future economic, recreational, social and cultural development and use to reduce and remove threats to achieving the objectives
5. Plan for future development and use that are consistent with the objectives (ER Zone 2) and with consideration of the cumulative impacts of development and use
6. Adopt mechanisms for the rehabilitation of degraded areas that may include relocation of existing uses that do not comply with the goals and objectives (ER Zone 2)
7. Respond to any changes in water quality where a trend away from an established benchmark is detected. Maintain water quality at the recommended benchmark given in the Marine Plan Performance Assessment System.
8. Contribute to both site specific and ecosystem level research and monitoring

10.3 Ecologically Rated Zone 3 (ER Zone 3)

Definition – zones classified as ER Zone 3 contain a moderate diversity of marine habitats and species identified as suitable indicators of environmental capability. Management of development and use will provide for ecologically sustainable development and use, underpinned by the precautionary principle, as described under the goal, objectives and strategies laid out below.

Goal – development and use of the marine, coastal and estuarine environments is managed to0 ensure that moderate environmental impacts to the biodiversity, habitats and ecological processes of ER Zone 3 do not jeopardize the health and productivity of the ecosystem.

"Moderate impacts on habitats whilst safeguarding ecological processes"

Moderate – will not exceed average impacts to habitats or populations. Measurable changes to ecosystem components without there being a major change in function (i.e. no loss of components). Recovery is measurable in years.

Objectives ER Zone 3 –

1. Ecologically sustainable development and use, both existing and in the future of the marine environment will not exceed moderate:
    a. Loss of biodiversity
    b. Impacts to soft-sediment habitat
    c. Loading of sediments with heavy metals, persistent organic pollutants and other contaminants
2. Degradation of habitats resulting from development or use will not compromise the ability of ecological processes to sustain ecosystems naturally
3. Development and use will maintain water quality in accordance with the benchmark established by the Performance Assessment System for each Marine Plan
4. Environmental management of existing and future developments and use will adopt performance measures consistent with the Marine Plan objectives and develop strategies to ensure compliance
5. Environmental impacts of past, existing and future development and use will be actively improved
6. Ecological processes underpinning economic, environmental, social and cultural values will be protected
7. Monitoring, evaluation and research will be publically available and aimed at increasing the understanding of the biodiversity, habitats and ecological processes of the marine environment and the cumulative impacts of development and use.

Strategies to Achieve Objectives of ER Zone 3 –

The following strategies should be applied by all management agencies with jurisdiction over the marine, coastal and estuarine environment, all operators of developments and all individuals that make use of these environments.

1. Adopt mechanisms to conserve and protect marine, coastal and estuarine:
    - Important spawning, breeding and nursery areas
    - Key feeding and resting areas
    - Endemic species
    - Species that are of a conservational concern
2. Adopt mechanisms to protect marine, coastal and estuarine:
    - Biodiversity
    - Habitats
    - Ecological processes
3. Protect cultural and heritage values associated with the marine, coastal and estuarine environment
4. Adopt performance measures derived from the objectives (ER Zone 3) and manage existing and future economic, recreational, social and cultural development and use to reduce and remove threats to achieving the objectives
5. Plan for future development and use that are consistent with the objectives (ER Zone 3) and with consideration of the cumulative impacts of development and use
6. Adopt mechanisms for the rehabilitation of degraded areas
7. Respond to any changes in water quality where a trend away from an established benchmark is detected. Maintain water quality at the recommended benchmark given in the Marine Plan Performance Assessment System.
8. Contribute to both site specific and ecosystem level research and monitoring

Key Habitat Standards

Where any key critical habitats are recognized to occur in ER Zone 3 the Marine Planning Framework requires that these habitats be managed by the goals and objectives of ER Zone 2. This may occur where habitat formation is limited or the partial habitat type was restricted. Furthermore, these areas may also be re-zoned as more information becomes available.

10.4 Ecologically Rated Zone 4 (ER Zone 4)

Definition – zones classified as ER Zone 4 include those marine habitats and species for which the available scientific data are inadequate to identify their importance to the maintenance of biodiversity, ecological health and productivity of the ecosystem.

Until appropriate research suggests otherwise, management agencies will adopt a precautionary stance, applying the environmental impact criteria of 'minor' to the management of development and use.

Research will ultimately enable the reclassification of this zone to ER Zone 1, ER Zone 2 or ER Zone 3.

Goal – development and use of the marine, coastal and estuarine environments is preceded by research to improve knowledge of the biodiversity, habitats and ecological processes of ER Zone 4.

"Research will determine allowable consequences to habitats"

Objectives ER Zone 4 (to be applied pending reclassification of an area following research)–

1. Future development and use will be reliant on a appropriate level of scientifically based knowledge
2. Until research suggests otherwise, ecologically sustainable development and use, (both existing and future) of the marine environment will not exceed minor:
    - Loss of biodiversity
    - Impediment of ecological processes
    - Impacts to critical habitats
    - Loading of sediments with heavy metals, persistent organic pollutants and other contaminants
    - Changes in water quality beyond the benchmark established by the Performance Assessment System for each Marine Plan
3. Environmental management of existing and future developments and use will adopt performance measures consistent with the Marine Plan objectives and develop strategies to ensure compliance
4. Environmental impacts of past, existing and future development and use will be actively improved through targeted rehabilitation, and passively, as natural regeneration becomes an outcome of improved development and use
5. Ecological processes underpinning economic, environmental, social and cultural values will be protected
6. Monitoring, evaluation and research will be publically available and aimed at increasing the understanding of the biodiversity, habitats and ecological processes of the marine environment and the cumulative impacts of development and use.
7. Improved understanding of the ecology of areas within ER Zone 4 will result in their reclassification to ER Zone 1, ER Zone 2 or ER Zone3, as appropriate

Strategies to Achieve Objectives of ER Zone 1 –

The following strategies should be applied by all management agencies with jurisdiction over the marine, coastal and estuarine environment, all operators of developments and all individuals that make use of these environments.

1. Ensure development or use is preceded by appropriate research to identify ecological risks and the vulnerability of the receiving environment
2. Protect cultural and heritage values associated with the marine, coastal and estuarine environment
3. Ensure that as new knowledge is gained, zoning and management of use is revised, according to the goals, objectives, and strategies for ER Zone1, ER Zone 2, or Zone 3, as appropriate
4. Review classification of zoning every two and a half years, incorporating the latest research

11.0 Performance Assessment System (PAS)

The performance Assessment System (PAS) for this Marine Plan will evaluate the effectiveness of the Plan by assessing and reporting on the maintenance of ecosystem conditions within the Western Isles Marine Area. Information generated will feed back into the PAS decision making process (see figure 4 over the page), providing the basis for adaptive management. The PAS sets in place an approach to monitoring of indicators elected to detect change, both natural and human induced, in the conditions of Scotlands, marine ecosystems. When applied to the ER Zone objectives, monitoring results will determine the adequacy of management measures in conserving and facilitating responsible resource use in the Western Isles.

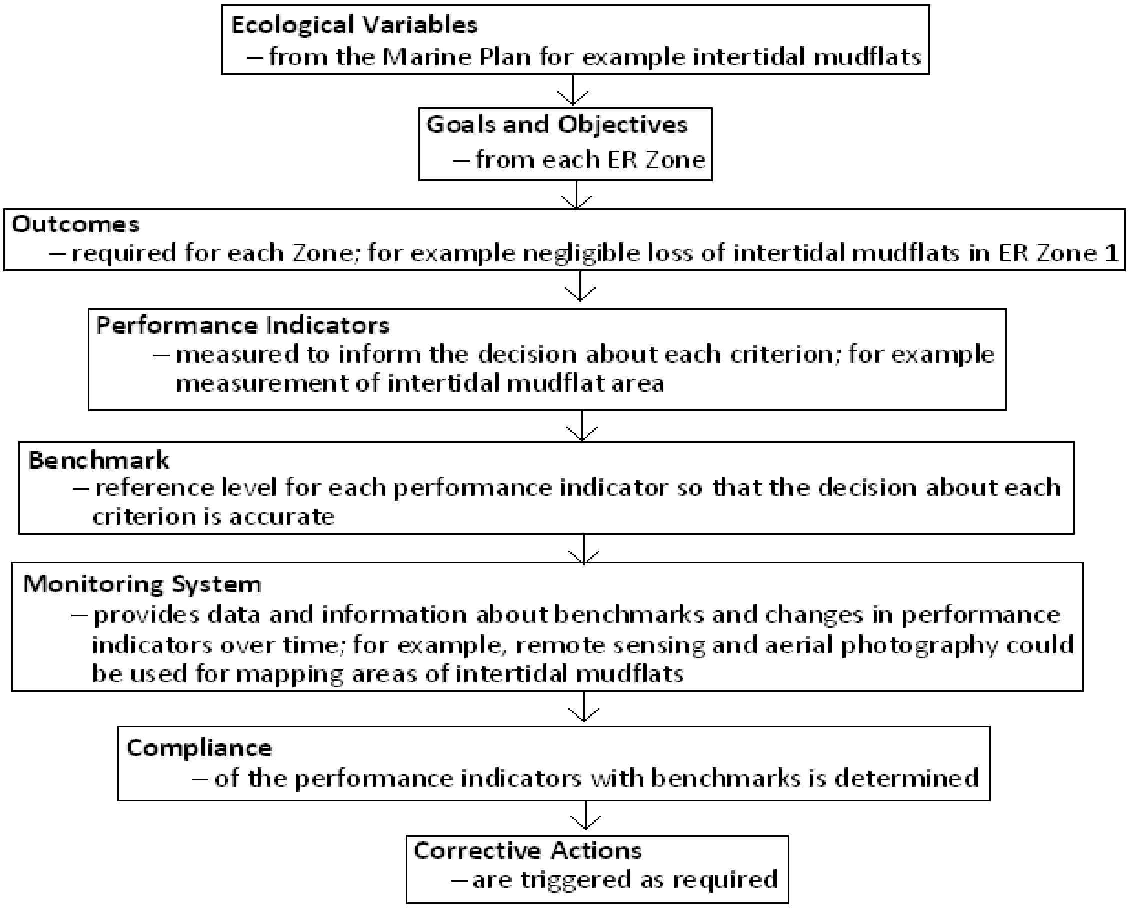
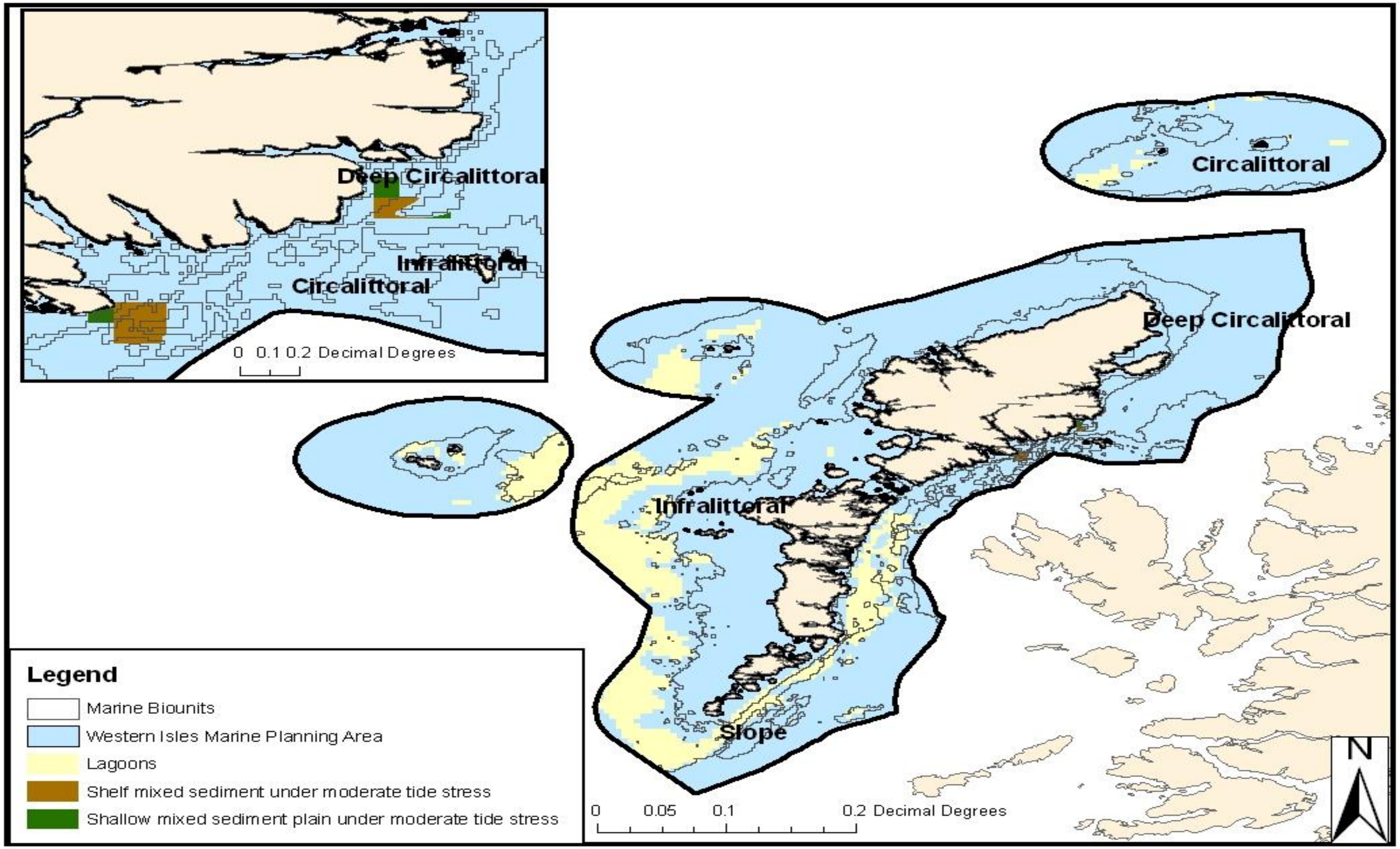


Figure 4.0 - Flow of decision making in the Western Isles Marine Plan Performance Assessment System, (adapted from Day et al., 2008).

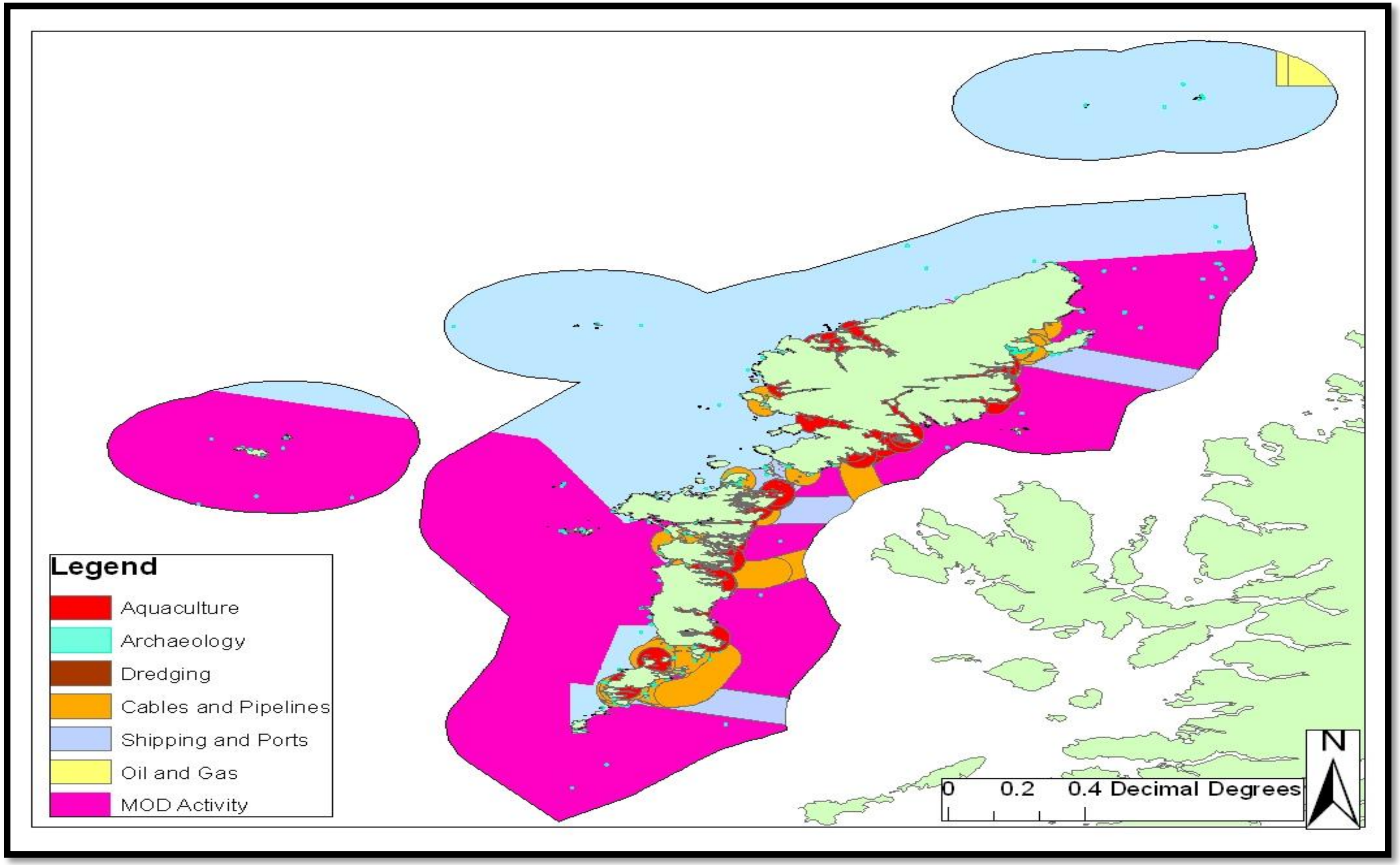
Performance Assessment Actions (first five year cycle of Western Isles Draft Marine Plan)

1. Preparation of a technical report of standard monitoring protocols for each performance indicator in the Western Isles Draft Marine Plan Performance Assessment System
2. Research and development benchmarks for each performance indicator in the Western Isles Draft Marine Plan Performance Assessment System
3. Development of an inter-agency technical design phase that focuses on a long term system of measurement and reporting for each performance indicator for the Western Isles Draft Marine Planning area.
4. Development of a sampling process that is cost effective and will detect level of change over both space and time that can acceptably conclude the achievement of the Marine Plan objectives for each performance indicator.
5. Development of benchmarks and standard monitoring protocol for measuring indicator within the Western Isles Draft Marine Plan area.
6. Monitor and reporting in the Western Isles Draft Marine Planning area using standard monitoring protocol at selected index sites that reflect a complete suite of environmental indicators.

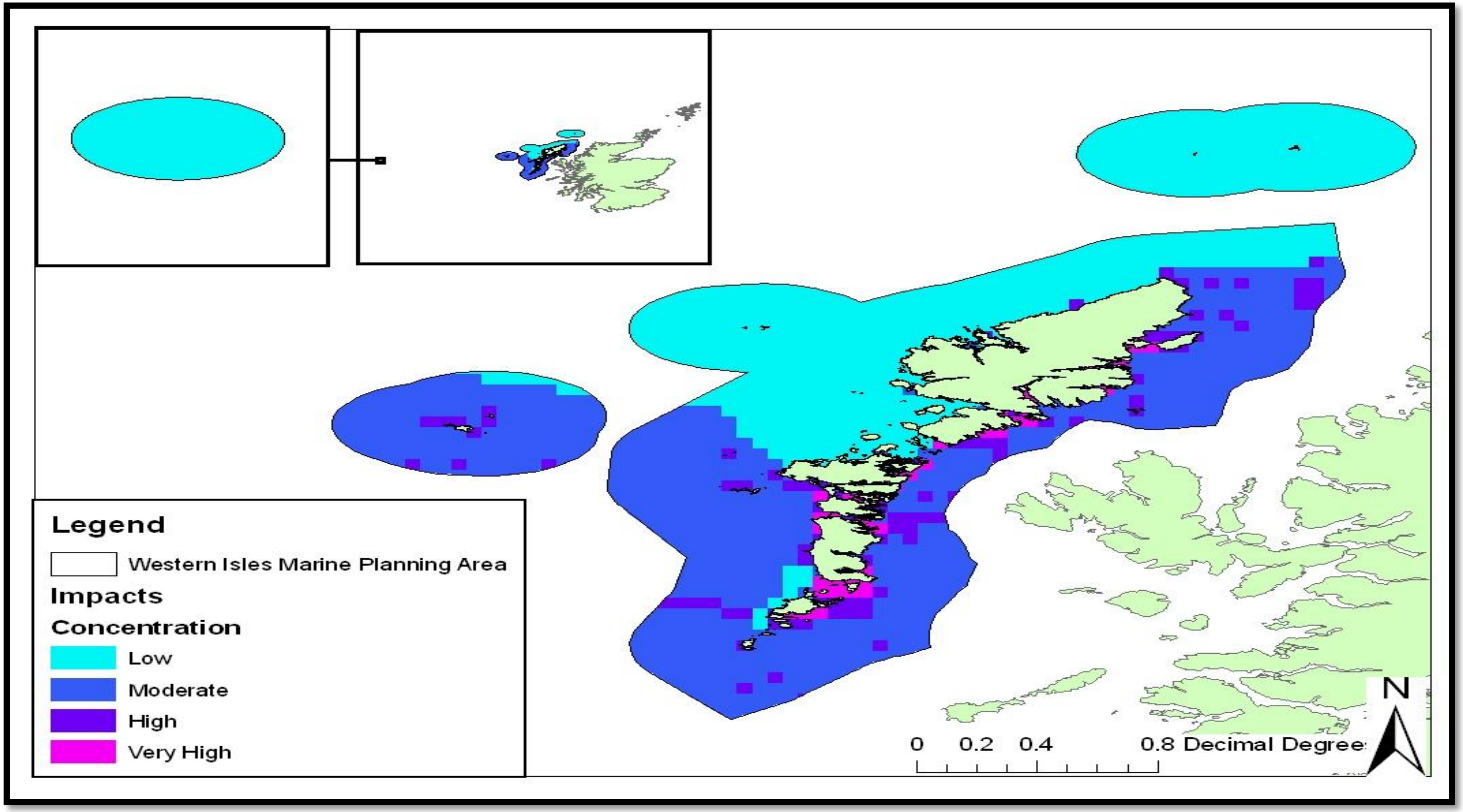
12.0 Maps



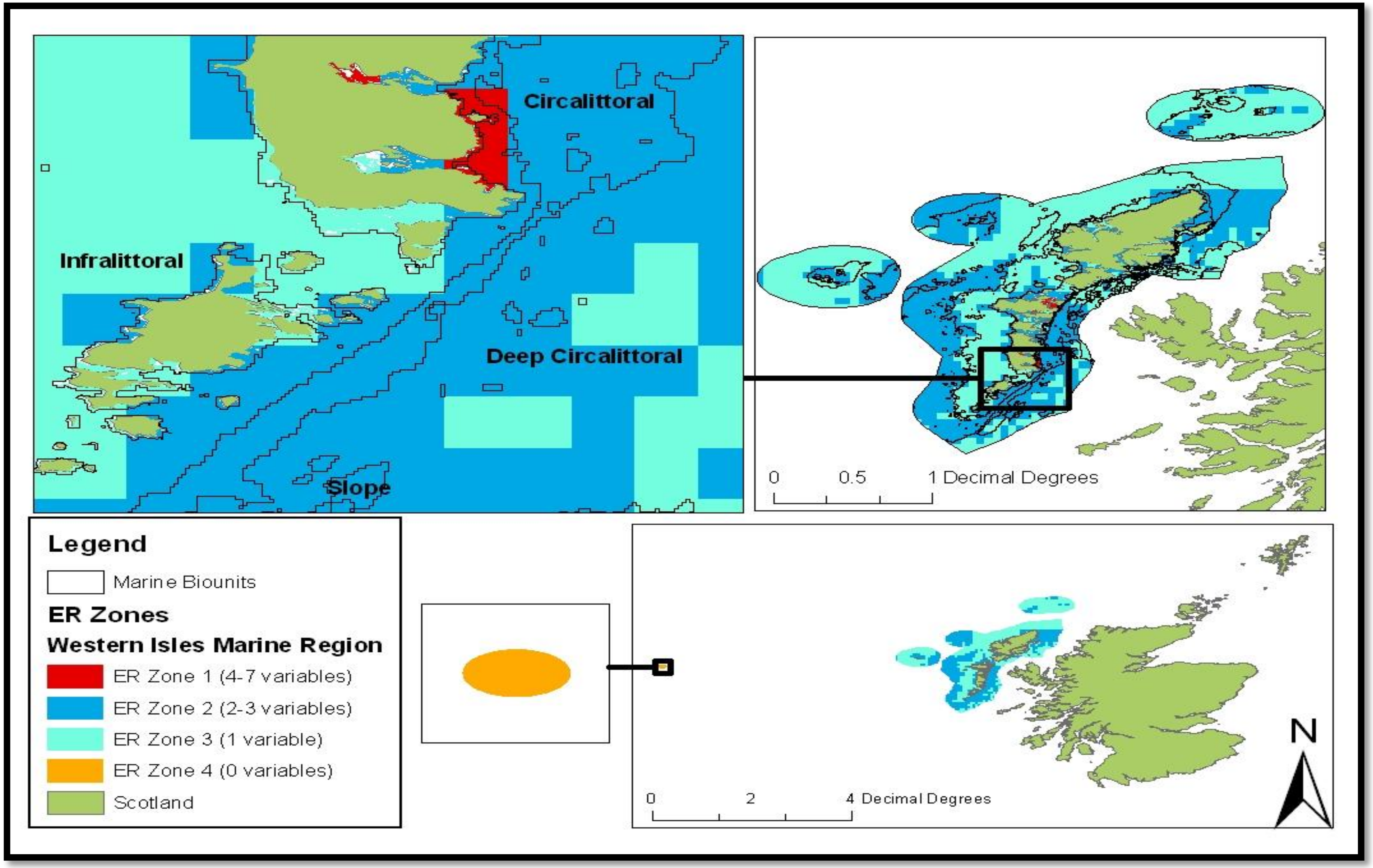
Map 1 – Western Isles Marine Planning Area Benthic Habitats of Importance



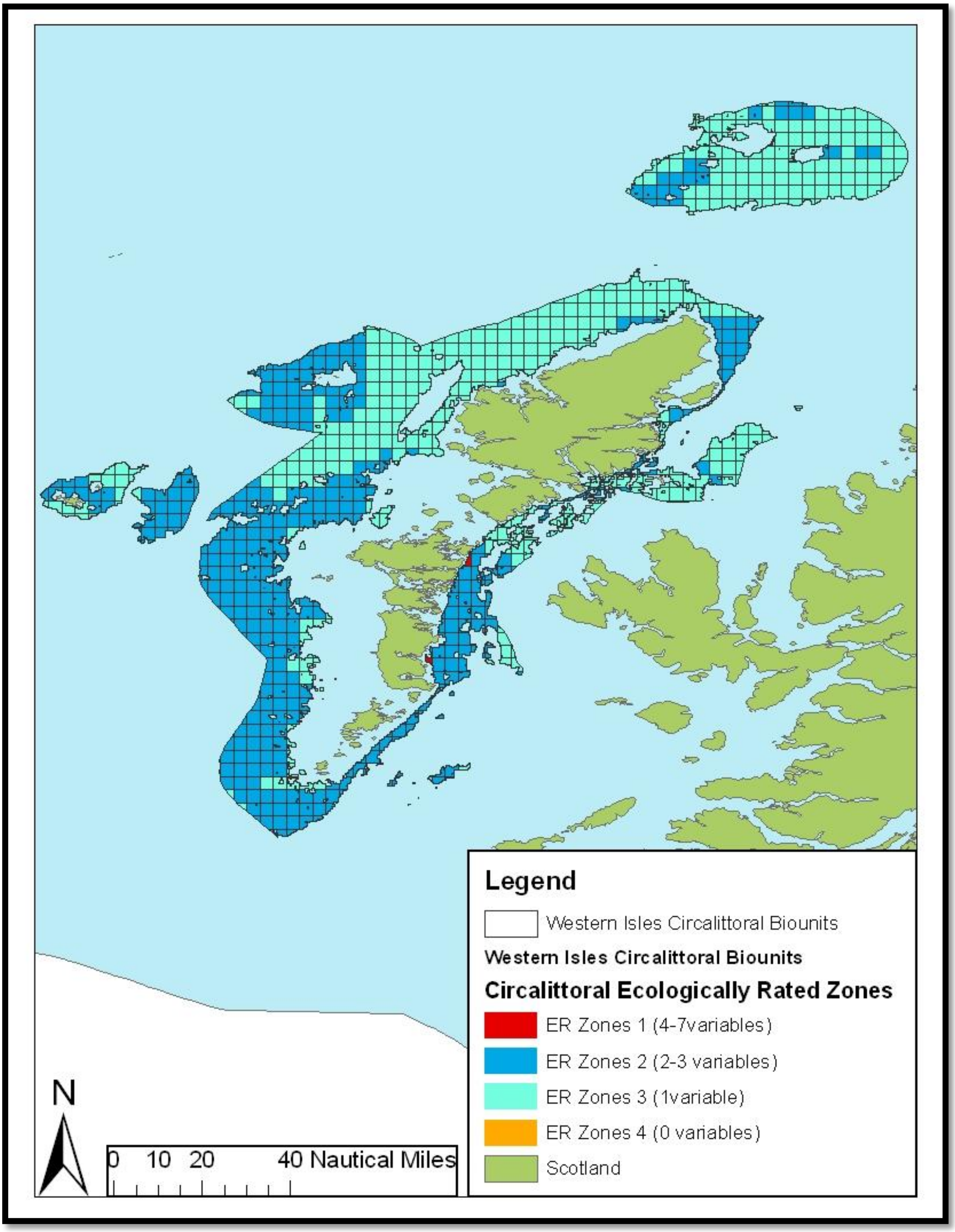
Map 2 – Western Isles Marine Planning Area Economic Uses



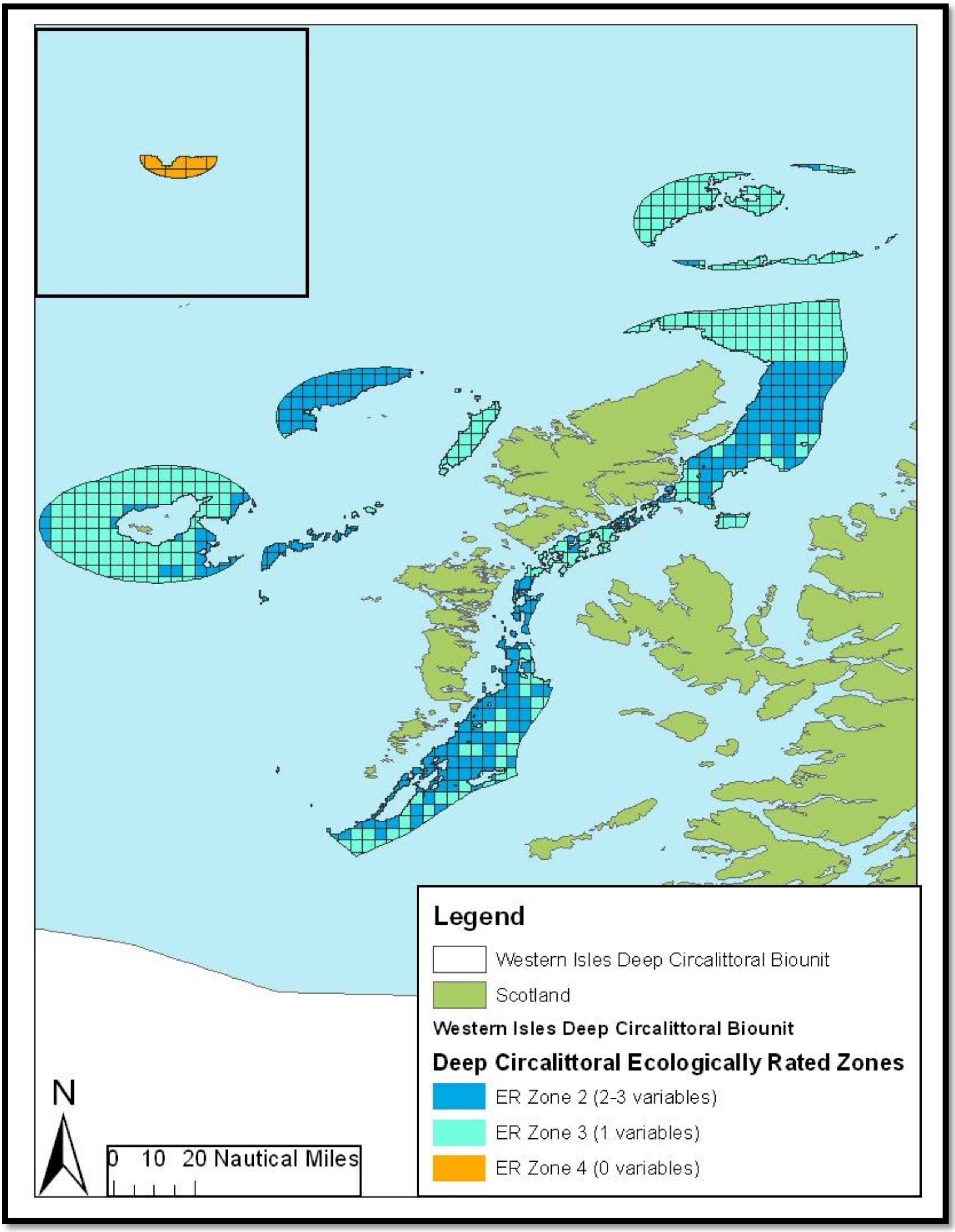
Map 3 –Relative Concentration of Potential and Present Impacts within the Western Isles Marine Planning Area



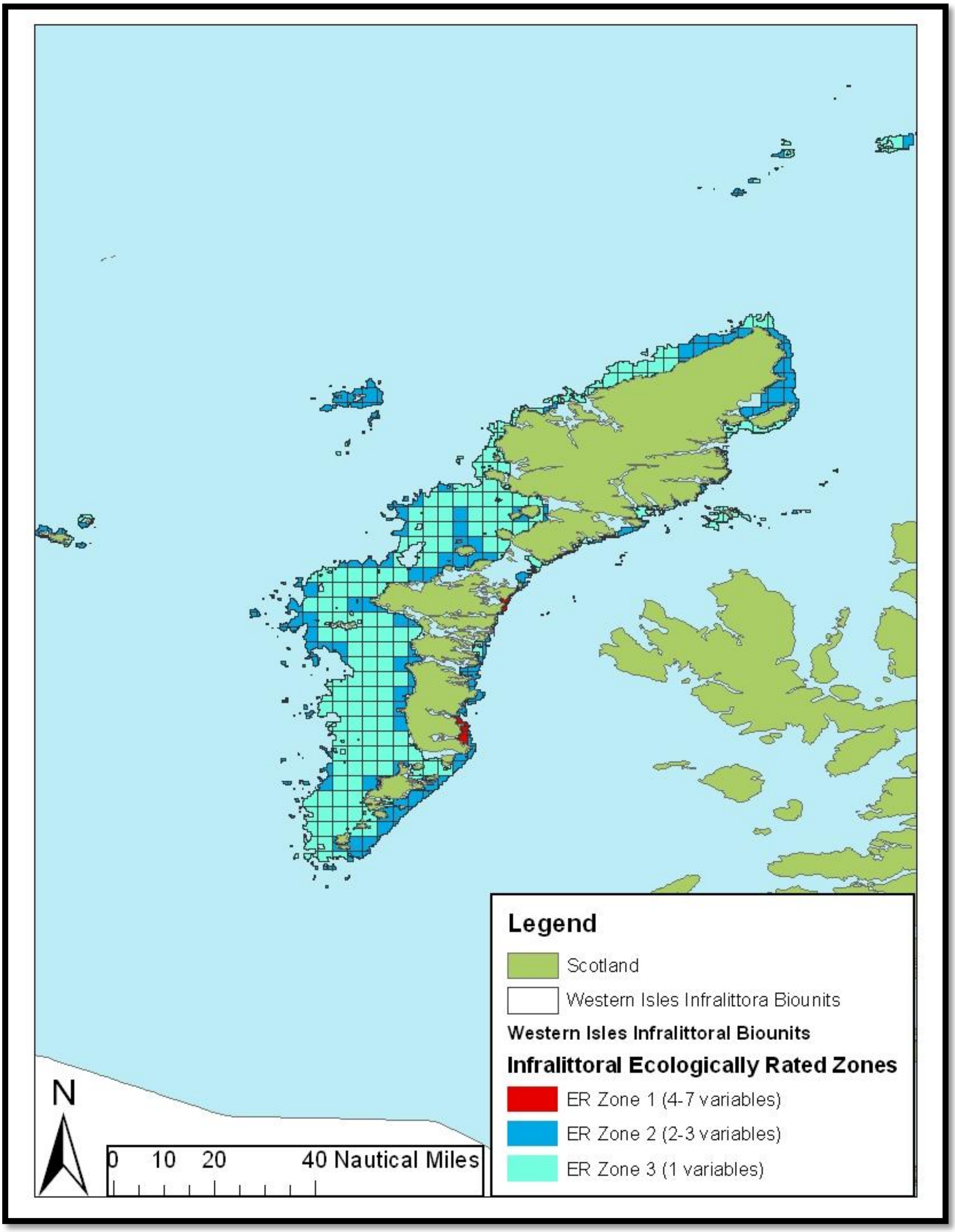
Map 4 – Western Isles Marine Planning Area Ecologically Rated Zones



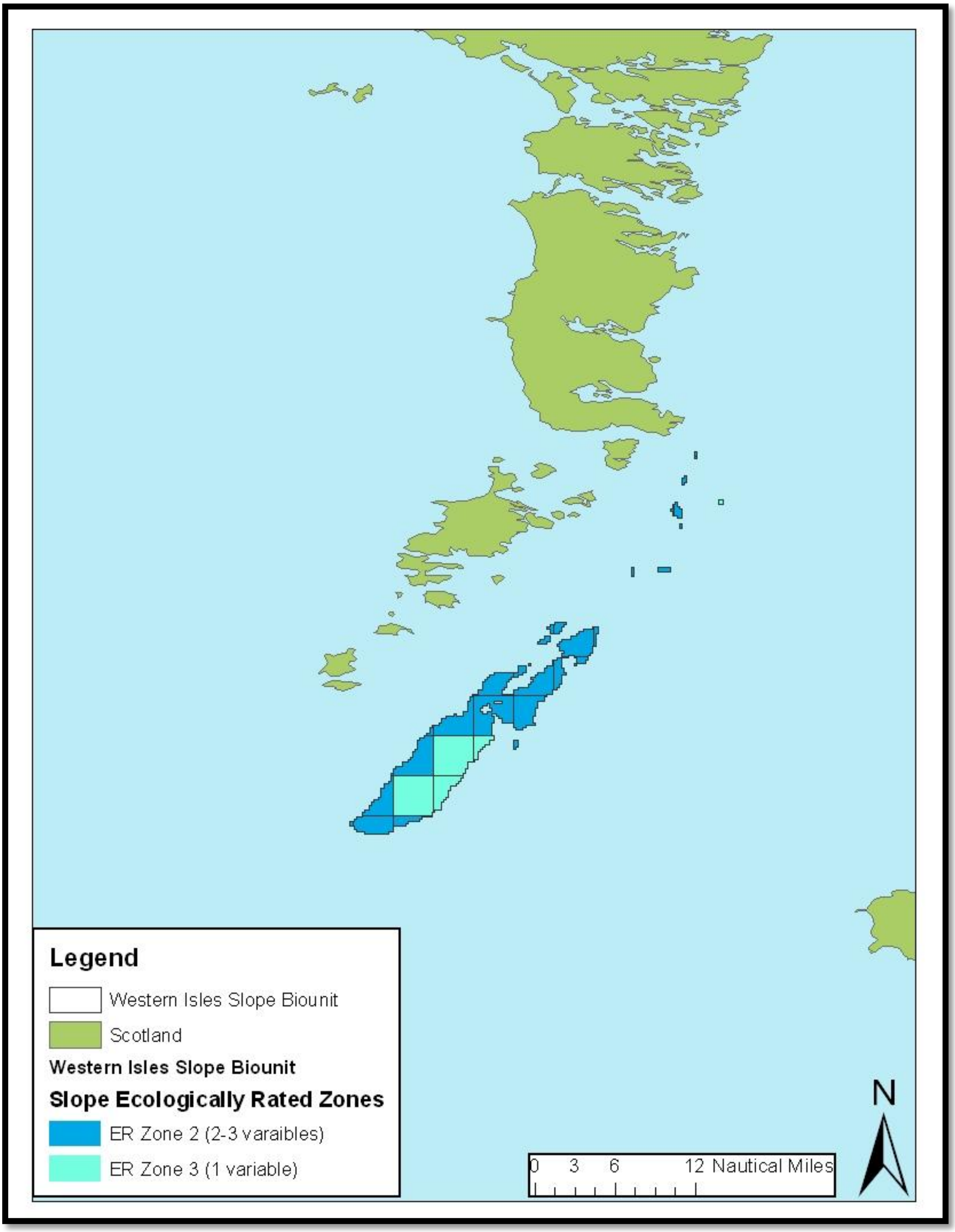
Map 5 – Western Isles Marine Planning Area Circalittoral Biounit



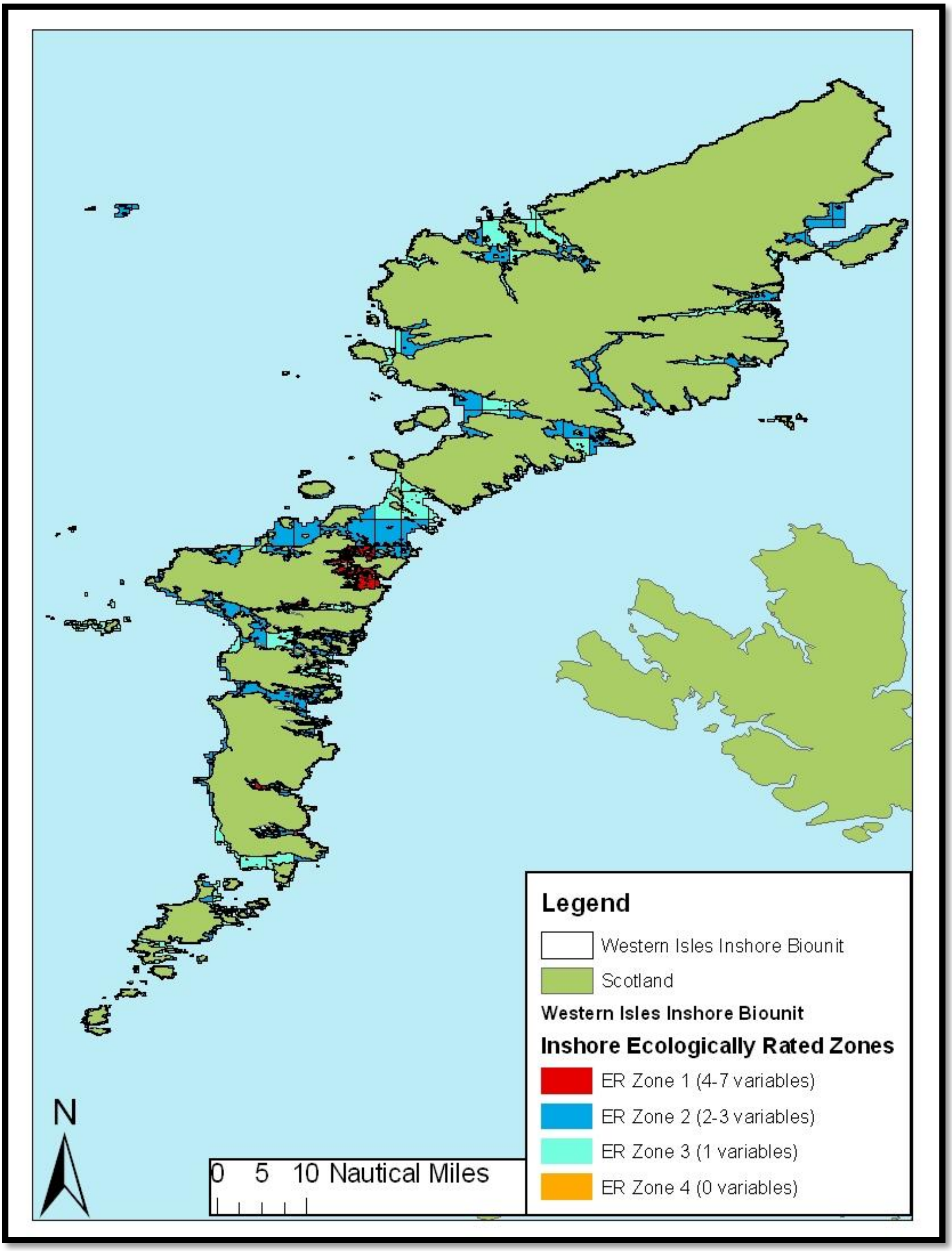
Map 6 – Western Isles Marine Planning Area Deep Circalittoral Biounit



Map 7 – Western Isles Marine Planning Area Infralittoral Biounit



Map 8 – Western Isles Marine Planning Area Slope Biounit



Map 9 – Western Isles Marine Planning Area Near-shore Waters

13.0 Glossary

Biodiversity – the variability amongst living organisms from all sources including marine, terrestrial and other aquatic ecosystems and the ecological complexes they are part of. This includes diversity within species, between species and of ecosystems.

Bio-Region – an area defined by a combination of biological and geographic data, rather than by geopolitical considerations. Generally a system of related interconnected ecosystems.

Bio-Unit – biophysical units (microscale, hundreds of km^2), which identify functional ecosystem-based management units (for example rocky shores, reef systems etc.) defined primarily on the basis of coastal physiography, topography and major marine physical habitats or seascape features and habitat distributions.

Breeding Area – a site used by one or more species mainly for the purpose of breeding or giving birth.

Conserve – to preserve or set aside areas of the natural environment from potential degradation arising from human use.

Conservation – action or actions resulting in the preservation of the natural environment

Critical – refers to biodiversity, habitats and ecological processes without which the functioning capacity or integrity of systems would be lost.

Cumulative – created by successive additions (for example of impacts)

Degradation – a state of reduced environmental quality

Ecological Processes – dynamic biological and physical processes, for example natural cycles, sediment movements, nutrient cycling and migratory species movement

Ecologically Sustainable Development – using, conserving and enhancing the communities' resources so that ecological processes, on which life depends, are maintained and the total quality of life both now and in the future can be increased.

Ecosystem – a dynamic complex of plants, animals and microorganism communities and their non-living environmental interacting as a functional unit

Ecosystem Based Management – the planning and management of multiple economic, social and cultural values and uses is integrated across sectors and is managed within ecological constraints.

Endemic – a species that is unique to or confined within a specific location

Estuarine – semi- enclosed waterbody at the downstream end of a freshwater system that is subject to marine, freshwater and terrestrial influences and experiences periodic fluctuations and gradients in salinity

Goal – the desired overarching long-term outcome

Habitat – a characteristic biological assemblage and/or physical structure

Intertidal – the zone of coast between the mean high water level and mean low water level

Nursery Area – habitats providing shelter and food to marine fauna during the vulnerable or juvenile stages of its life cycle

Objective – components of a goal that, if met, would ensure that the goal is achieved; clear statement of what management is to achieve

Productivity – the rate at which radiant energy is used by producers to form organic substances as food for consumers

Spawning Communities – habitats critical to the spawning stages of the reproductive cycle of marine organisms, spawning areas are often geographically distinct from nursery areas

Species of Conservation Concern – a collective term encompassing all species protected under any Scottish, UK or European legislation, agreement or treatise

Strategy – a plan of action intended to accomplish specific goals and objectives

Subtidal – benthic zone from the low tide line to the seaward edge of the continental slope

Use – economic, recreational, social or cultural activities in the marine, coastal and estuarine environment that may not be directly associated with development and as such may not be subject to regulation via the development assessment process. Many uses, such as commercial and recreational fishing are managed by either European or local government authorities.

14.0 Appendix

Core objectives and guiding principles for ecologically sustainable development:

Goal

- Development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends

Objectives

- To enhance individual and community well-being and welfare by following a path of economic development that safeguards the welfare of future generations
- To provide equity within and between generations
- To protect biological diversity and maintain essential ecological process

Guiding Principles

- Any decision making processes should integrate both long and short term economic, environmental, social and equity considerations
- Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation
- The global dimension of environmental impacts of actions and policies should be recognised and considered
- Decisions and actions should provide for broad community involvement on issues which affect them.

These guiding principles and core objectives must be considered as a package. No objectives or principles should predominate over the others. A balanced approach is required that takes into account all these objectives and principles in order to pursue the goal of Ecologically Sustainable Development.

Principles of Ecosystem-based Management

Adaptive and Precautionary Management – Management acknowledges that because scientific and other information is often incomplete and as such, actions with poorly understood or consequences that are difficult to reverse should be avoided. Adaptive management regards management as a learning process that incorporates the experience from previous actions and improved knowledge of the system and enables managers to adapt to changing levels of uncertainty and to allow progressive improvement.

Data Collection – Management collects information beyond that required to management of individual sectors. It includes an inventory of biodiversity assets, baseline assessments of ecosystem functions, measurements of the interactions of sectors and improved management and use of existing data.

Ecosystem Boundaries – Management acts within ecological boundaries and across administrative, political and jurisdictional boundaries.

Interactions between Ecological Levels – Management ensures that connections between and across all levels (species, populations, habitats and regions) are taken into account in resolving issues – focussing on any one level is inappropriate.

Maintenance of Ecosystem Integrity – Management focuses include the maintenance of ecological integrity. It has the stewardship of total national biological diversity (genes, species, communities and habitats) and the ecological processes that maintain that diversity.

Management of Human Activities – Management recognises that human activities are fundamental influences on many marine ecological patterns and processes and in turn are affected by them. Although human activities are the focus of most management actions, they are recognised as being embedded in marine ecosystem functioning.

Monitoring of Management – Management uses measurable performance indicators to assess the success or failure of its actions. Monitoring provides feedback that is critical to evaluating and refining management approaches.

Values – Management recognises, accepts and incorporates biodiversity values into all resource allocation processes that could affect the ocean ecosystems, even when scientific and technical knowledge may be insufficient for a full definition of values. However, management recognises that human values will play a dominant role in decision making on marine resources and ocean use.

Appendix 4

Table A 4.0 - Data utilised for the Prototype Zoning Scheme within Scottish waters.

Layer	Group	Title	Source	Data Included & Comments
Scottish Marine Regions		SMRs	Marine Scotland Science (MSS)	11 Scottish Marine Regions
Priority Marine Features	Environmental Habitats	PMFs	JNCC	Carbonate Mounds, Intertidal Mud Flats, Oceanic Ridges and Seamounts, are all PMF habitats that were used.
UKSea Map 2010 Seabed Landscapes	Environmental Habitats	Seabed Habitats	JNCC	5 rarest (according to area) seabed and coastal marine landscapes were selected.
Beaches with Environmental Awards	Environmental Habitats	Beaches	MSS	Beaches include those designated with the following awards: Blue Flag, Clean Safe Seas, Combined Coastal Award and Seaside Awards.
Priority Marine Features	Environmental Uniqueness	PMFs	JNCC	Coral Gardens and Deep Sea Sponges, Intertidal Mytilus, Littoral Chalk Communities, *Lophelia* Reefs, *Maerl* Beds, *Modiolus*, *Sabellaria* Reefs, Sea Pen Communities and *Zostera* Beds were all used.
RAMSAR Sites	Environmental Uniqueness	RAMSARS	SNH	Identified wetlands of international importance specifically as waterfowl habitats.
Spawning and Nursery Areas of important fisheries	Environmental Uniqueness	Spawning and Nursery Areas	CEFAS	High intensity Spawning and Nursery grounds. Nursery grounds are those areas with a high relative abundance of juveniles. More important spawning areas have a higher concentration of eggs and/or larvae.
Seabird Nesting Sites	Environmental Uniqueness	Nesting Sites	JNCC	Nesting sites and counts for: Black Guillemot, Fulmar, Gannet, Kittiwake, Little Tern and Puffin
Cetacean Hotspots	Environmental Uniqueness	Encounter Rate	MSS/JNCC	Taken from the Atlas of Cetacean Distribution in North West European Waters. Showing areas with a higher than average encounter rate.
Seal haul out sites	Environmental Uniqueness	Seal haul out sites	MSS	Common and Grey
No – Take-Zone	Environmental Uniqueness	No-take-zone	MSS	Lamlash Bay on the Isle of Arran
Offshore and Coastal SACs, SPA, SSSI, World Heritage Sites	Environmental Uniqueness	Offshore/ SACs, SPAs, SSSI, World Heritage Sites	JNCC/SNH	Newly designated offshore SACs and coastal SACs (Special Areas of Conservation), SPAs (Special Areas of Protection), SSSIs (Sites of Special Scientific Interest) and St Kilda World Heritage Site.
Archaeology	Activities	Archaeology Sites & Wrecks	RCAHMS/Historic Scotland	Designated Shipwrecks and Marine Archaeological Sites
Aquaculture	Activities	Lease Sites	The Crown Estate/SEPA	Finfish and Shellfish (Active) Sites
CO_2 Storage	Activities	Storage Sites	DECC	Hydrocarbon Fields and Saline Aquifers
Dredging and Disposal	Activities	Regulated Areas	MSS/EDINA	Dredged areas under license and Dumping grounds
Military Activities	Activities	Restricted Areas	EDINA/Marine Scotland Science	Firing Danger Areas, Submarine Areas and Practice Areas
Oil and Gas	Activities	Licensed Areas	DECC/EDINA	Significant Discoveries and Oil and Gas Seabed Wells information was buffered at 0.005 decimal degrees. Fallowing Blocks, Hydrocarbon Fields and Oil and Gas areas under license.
Ports, Harbours and Shipping	Activities	Transportation Areas	Maritime and Coastguard Agency, Department of Transport, RYA, via EDINA and MSS	Harbour Jurisdictions, Shipping and Ferry Routes, Small Craft Facilities, IMO Traffic Scheme, Deep Water Route and Caution Areas
Renewables	Activities	Lease Sites	The Crown Estate	Wind Farm Lease Sites, Tidal Lease Sites, Wave Lease Sites and Scottish Energy Awards
Sea Fisheries	Activities	Fishing Activity	MSS	High Intensity Fishing grounds of Pelagic and Demersal Stocks Finfish and Shellfish Species
Submarine Pipelines and Cables	Activities	Spatial Extent	UK Deal via EDINA	Cables (Coaxial, Fibre optic and telegraph) and Pipelines

Table A 4.1 – Percentage Cover of the different zoning applications in the Offshore SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1	11	28.98	4.03
2		34.3	6.3
3A	82.48	27.25	74.47
3B	3.87	8.87	11.95
4	2.65	0.6	3.25

Table A 4.2 – Percentage Cover of the different zoning applications in the Shetland SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1		0.42	
2		40.57	
3A	36.58	38.78	32.49
3B	49.06		41.93
4	14.36	20.23	25.58

Table A 4.3 – Percentage Cover of the different zoning applications in the Moray SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1		2.03	
2		19.14	
3A	41	23.65	21.85
3B	14.64	10.14	17.34
4	44.36	45.05	60.81

Table A 4.4 – Percentage Cover of the different zoning applications in the North East SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1			
2		30.3	
3A	30.3	22.94	16.02
3B	54.98	3.03	38.96
4	13.85	42.86	44.16

Table A 4.5 – Percentage Cover of the different zoning applications in the South East SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1		0.9	
2		13.17	
3A		6.89	
3B	64.07	20.06	37.13
4	35.93	58.98	62.87

Table A 4.6 – Percentage Cover of the different zoning applications in the Clyde SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1	0.32	0.32	
2			
3A	38.83	34.95	14.56
3B	40.13		18.45
4	98.06	64.72	66.99

Table A 4.7 – Percentage Cover of the different zoning applications in the Orkney SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1		2.27	
2		46.88	
3A	70.54	23.37	59.49
3B	13.88	2.41	9.92
4	15.58	25.07	30.59

Table A 4.8 - Percentage Cover of the different zoning applications in the North Coast SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1	0.43	6.49	0.43
2		25.54	
3A	63.2	29.44	48.92
3B	6.06	6.06	8.66
4	30.74	32.47	41.99

Table A 4.9 – Percentage Cover of the different zoning applications in the South West SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1		3.82	
2		9.72	
3A	47.92	35.76	28.82
3B	18.75	5.9	16.67
4	33.33	44.79	54.51

Table A 4.10 – Percentage Cover of the different zoning applications in the Argyll SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1		0.35	
2		0.12	
3A	52.72	68.44	41.16
3B	23.24	5.43	23.82
4	24.05	25.66	35.03

Table A 4.11 – Percentage Cover of the different zoning applications in the Western Isles SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1		32.77	
2		7.3	
3A	58.69	49.32	54.43
3B	29.28	0.06	26.63
4	12.02	10.54	18.94

Table A 4.12 – Percentage Cover of the different zoning applications in the West Highlands SMR

Zone	% Cover Environmental	% Cover Activities	% Cover Prototype
1		2.12	
2			
3A	39.03	68.28	33.14
3B	38.09	0.35	26.53
4	22.88	29.25	40.33

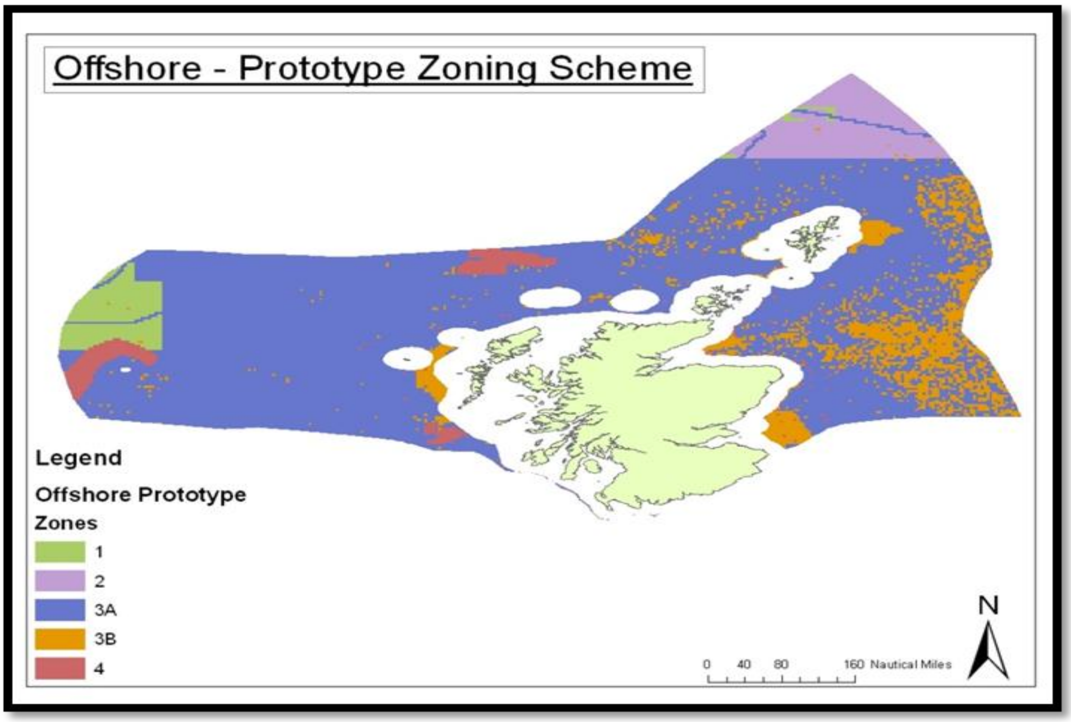


Figure A 4.0 – Application of the Prototype Zoning Scheme to the Offshore SMR.

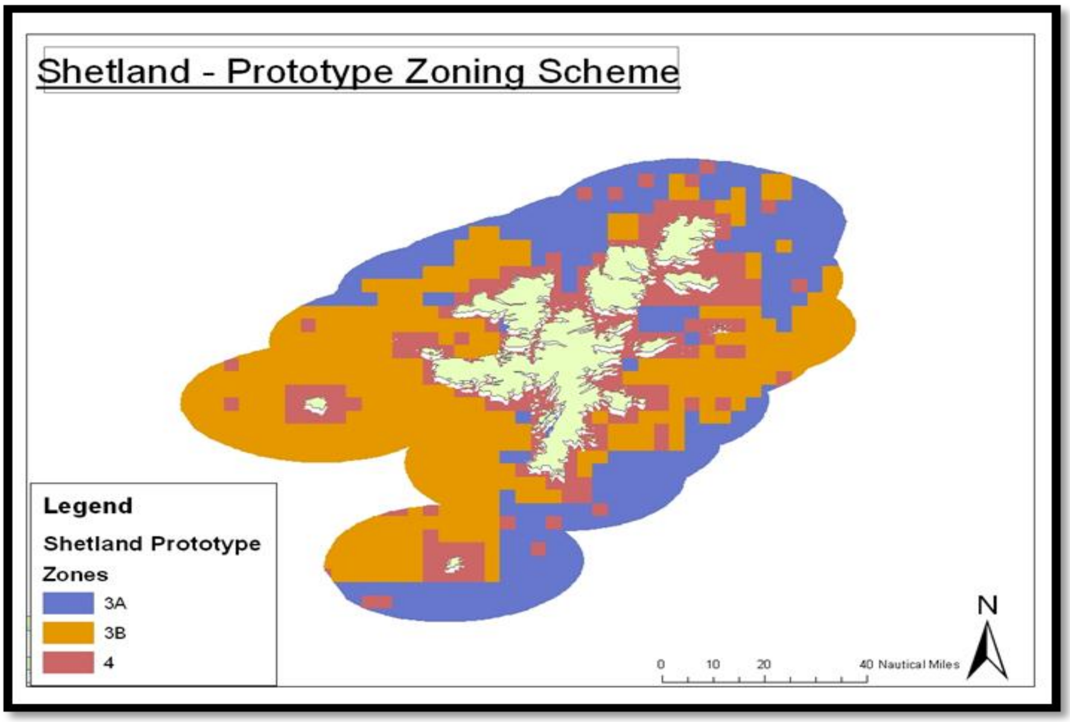


Figure A 4.1 - Application of the Prototype Zoning Scheme to the Shetland SMR.

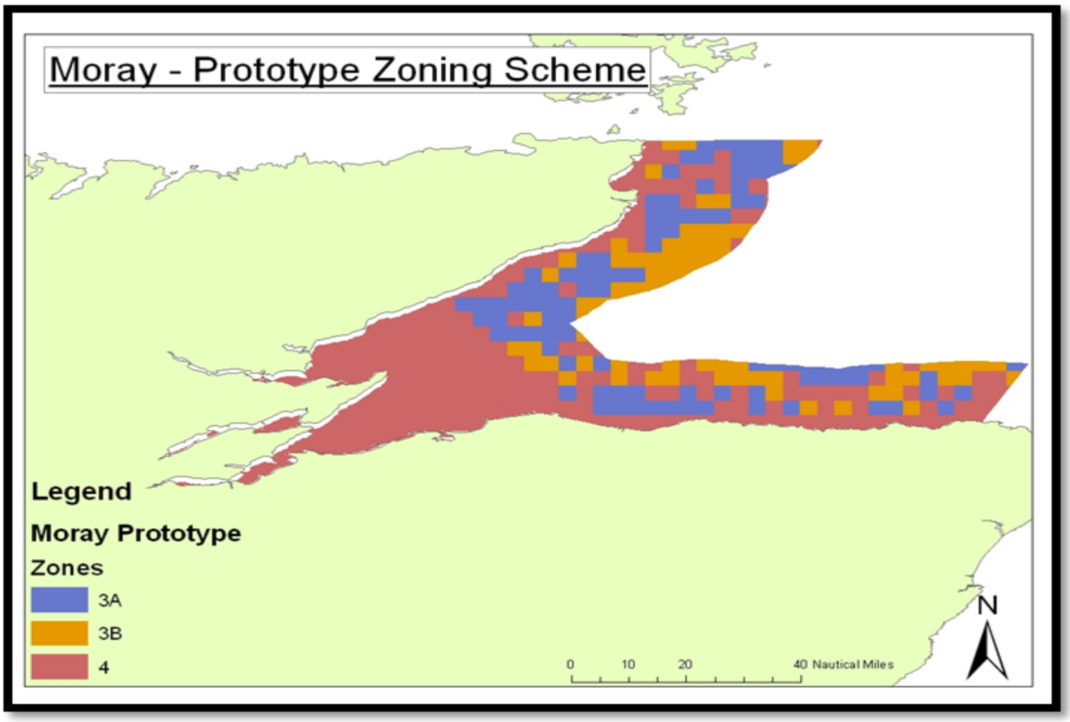


Figure A 4.2 - Application of the Prototype Zoning Scheme to the Moray SMR.

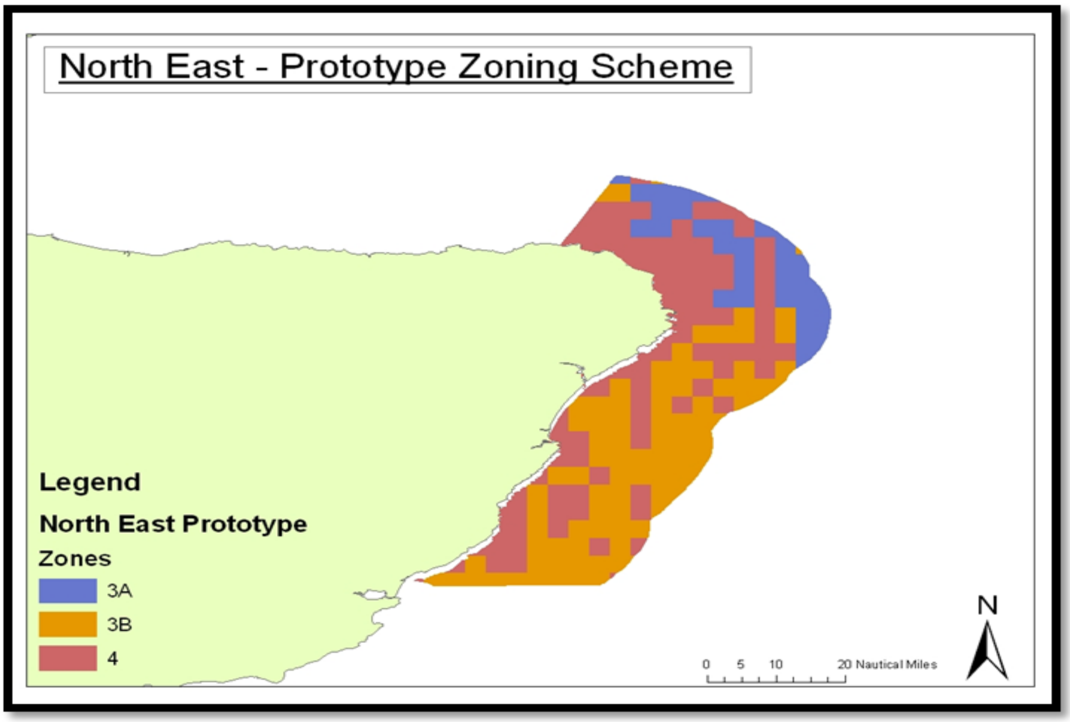


Figure A 4.3 - Application of the Prototype Zoning Scheme to the North East SMR.

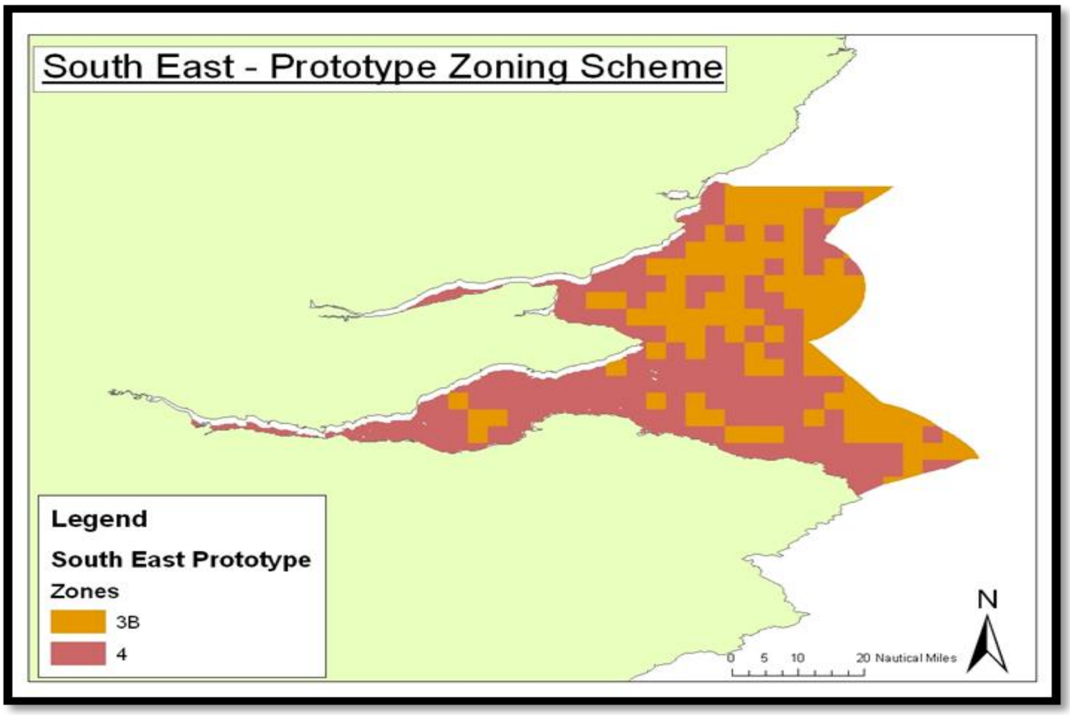


Figure A 4.4 - Application of the Prototype Zoning Scheme to the South East SMR.

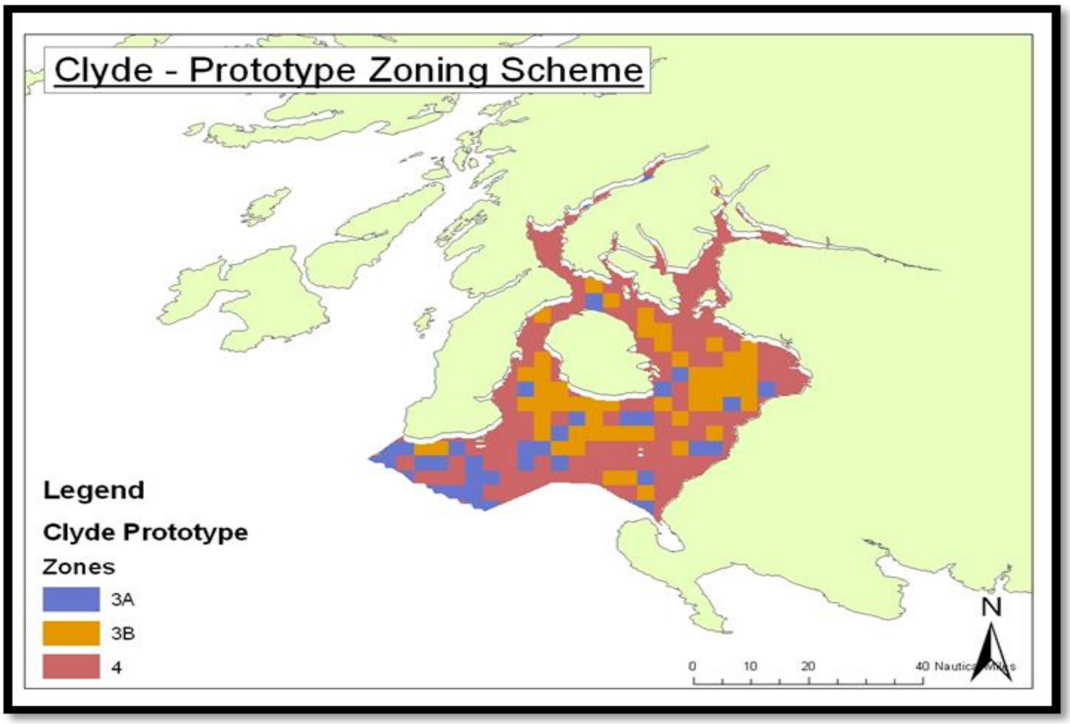


Figure A 4.5 - Application of the Prototype Zoning Scheme to the Clyde SMR.

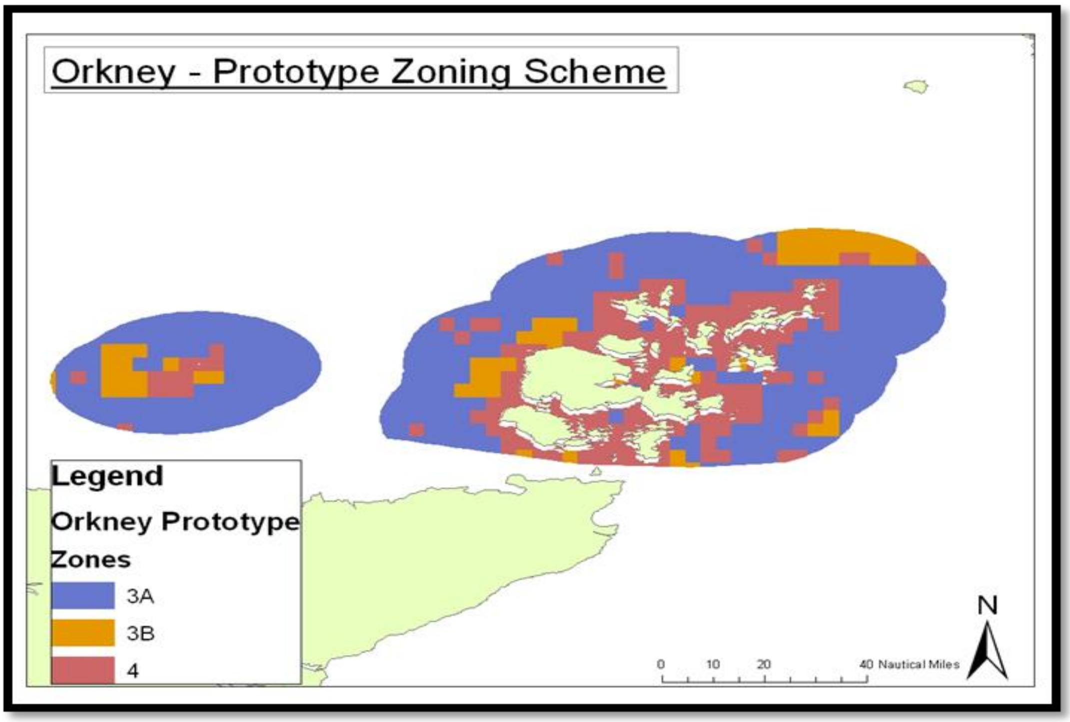


Figure A 4.6 - Application of the Prototype Zoning Scheme to the Orkney SMR.

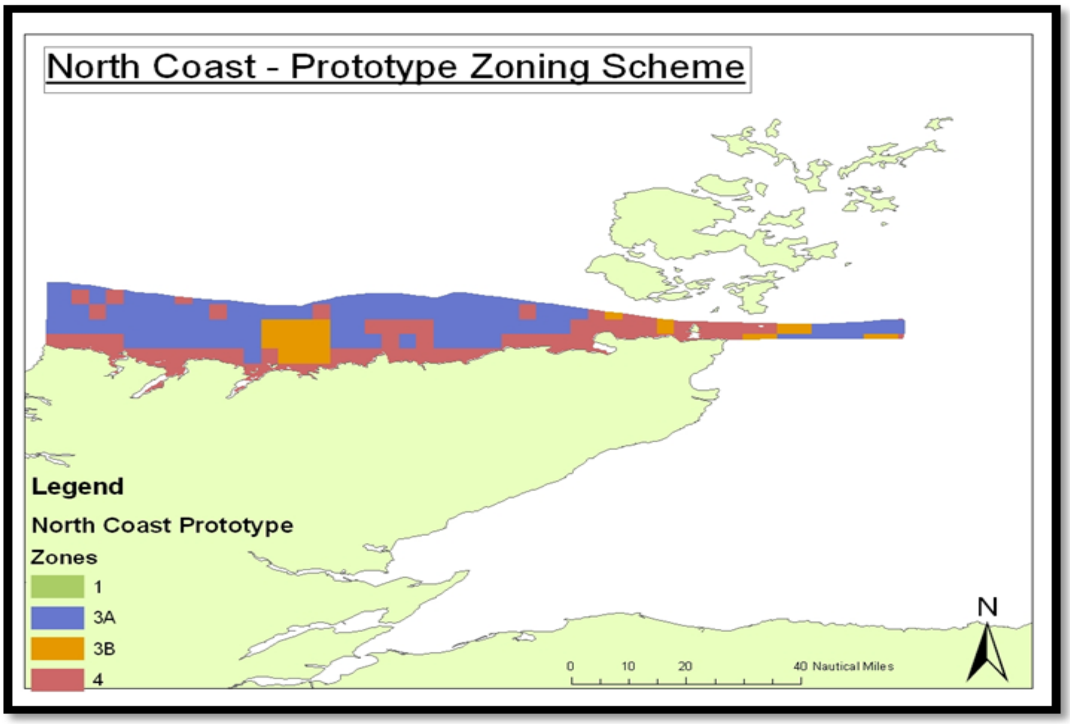


Figure A 4.7 - Application of the Prototype Zoning Scheme to the North Coast SMR.

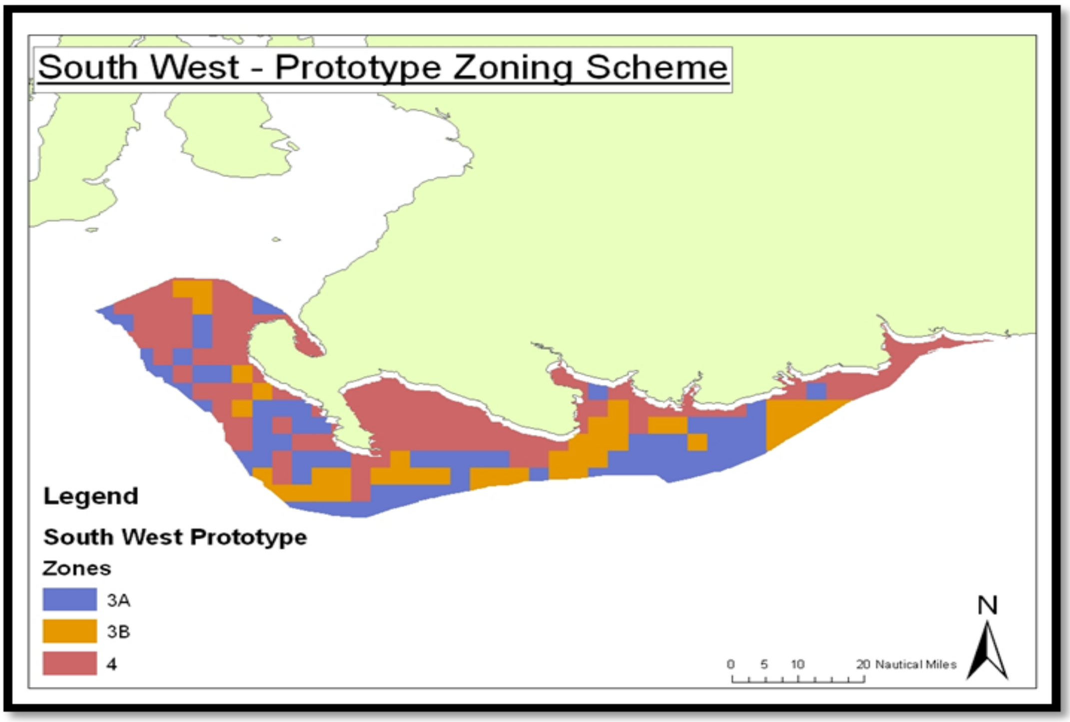


Figure A 4.8 - Application of the Prototype Zoning Scheme to the South West SMR.

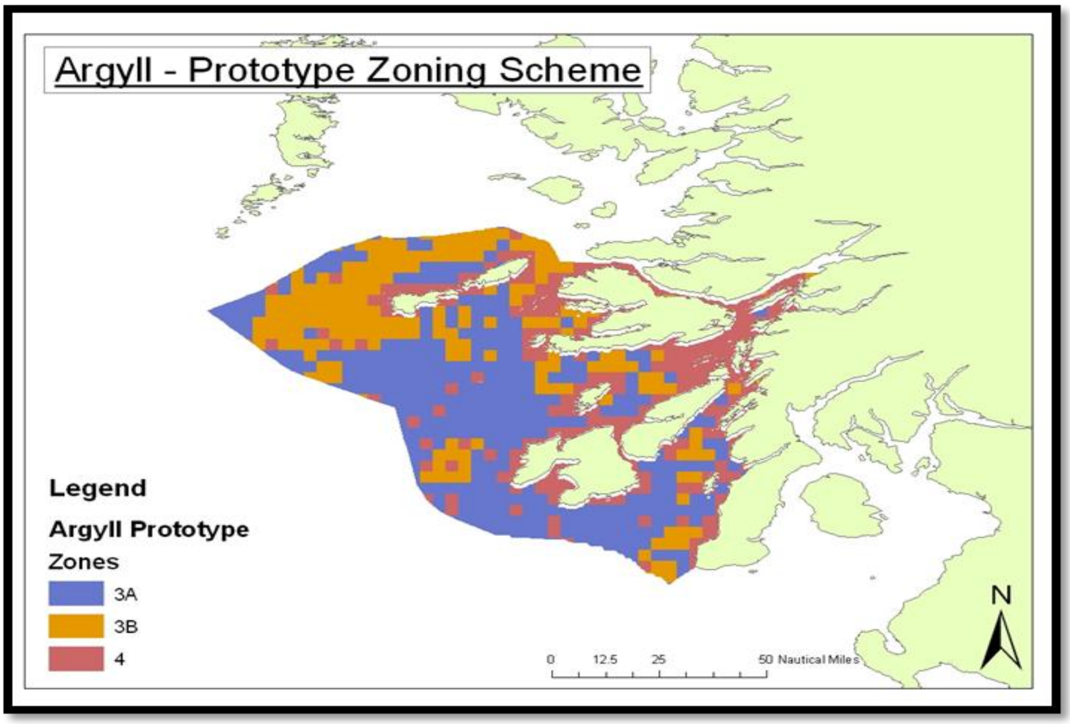


Figure A 4.9 - Application of the Prototype Zoning Scheme to the Argyll SMR.

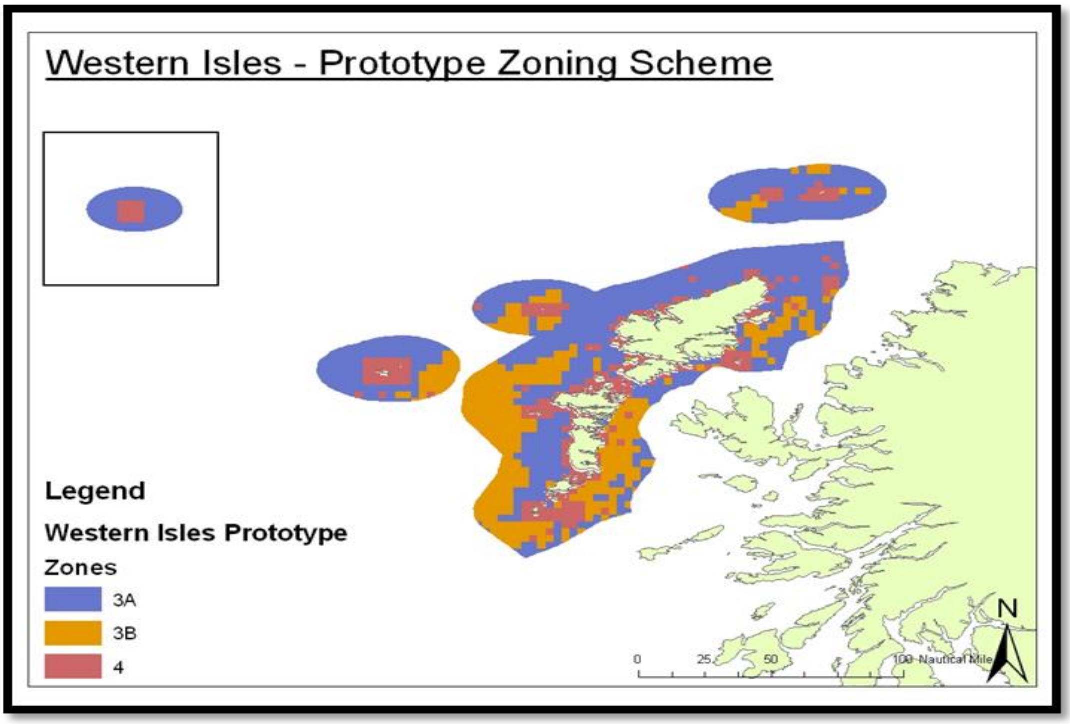


Figure A 4.10 - Application of the Prototype Zoning Scheme to the Western Isles SMR.

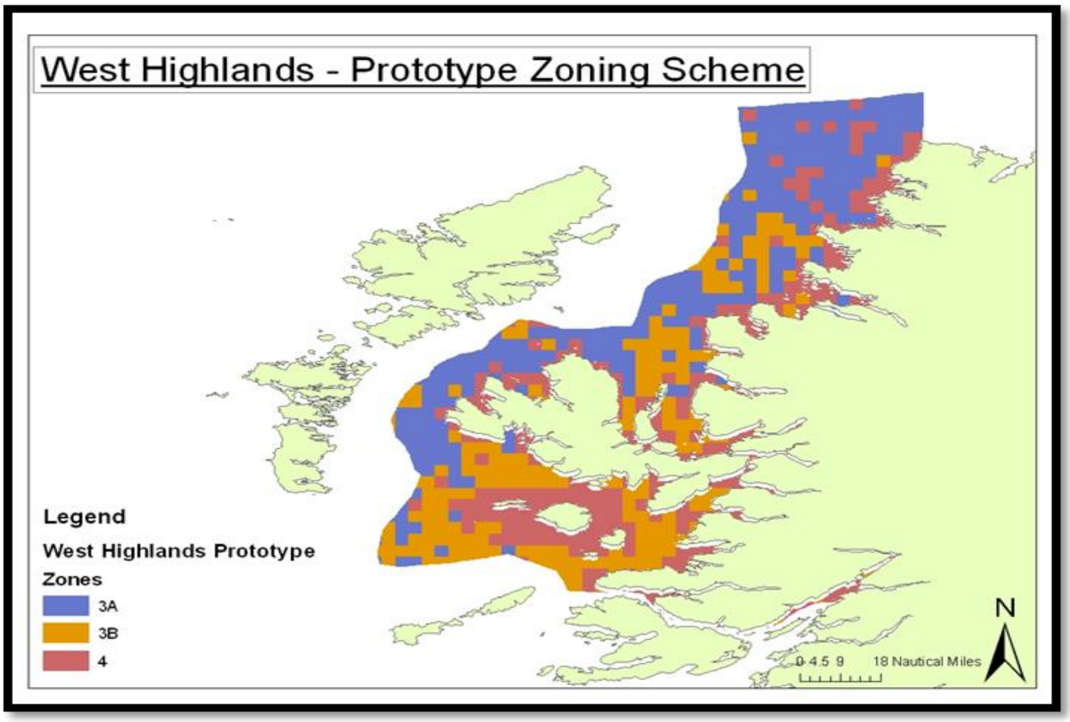


Figure A 4.11 - Application of the Prototype Zoning Scheme to the West Highlands SMR.

Appendix 5

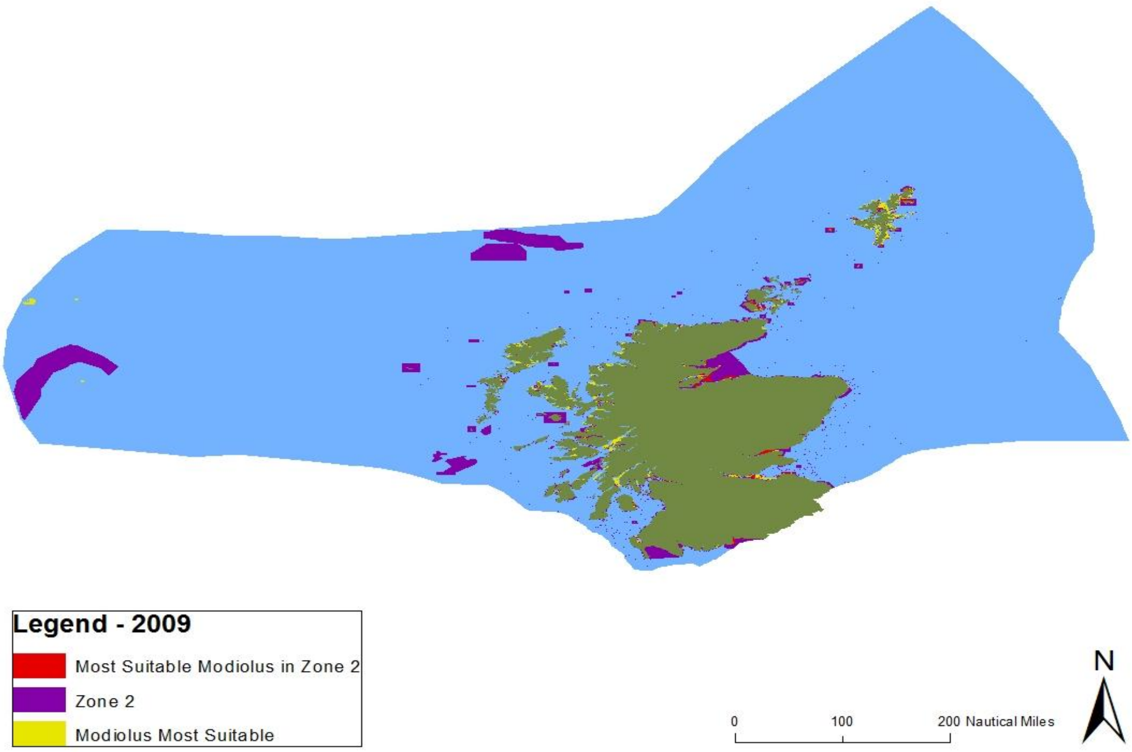


Figure A 5.0 - Identification of the 'Most Suitable' habitats for *Modiolus modiolus* within Zone 2 (Conservation Priority Zone) in 2009

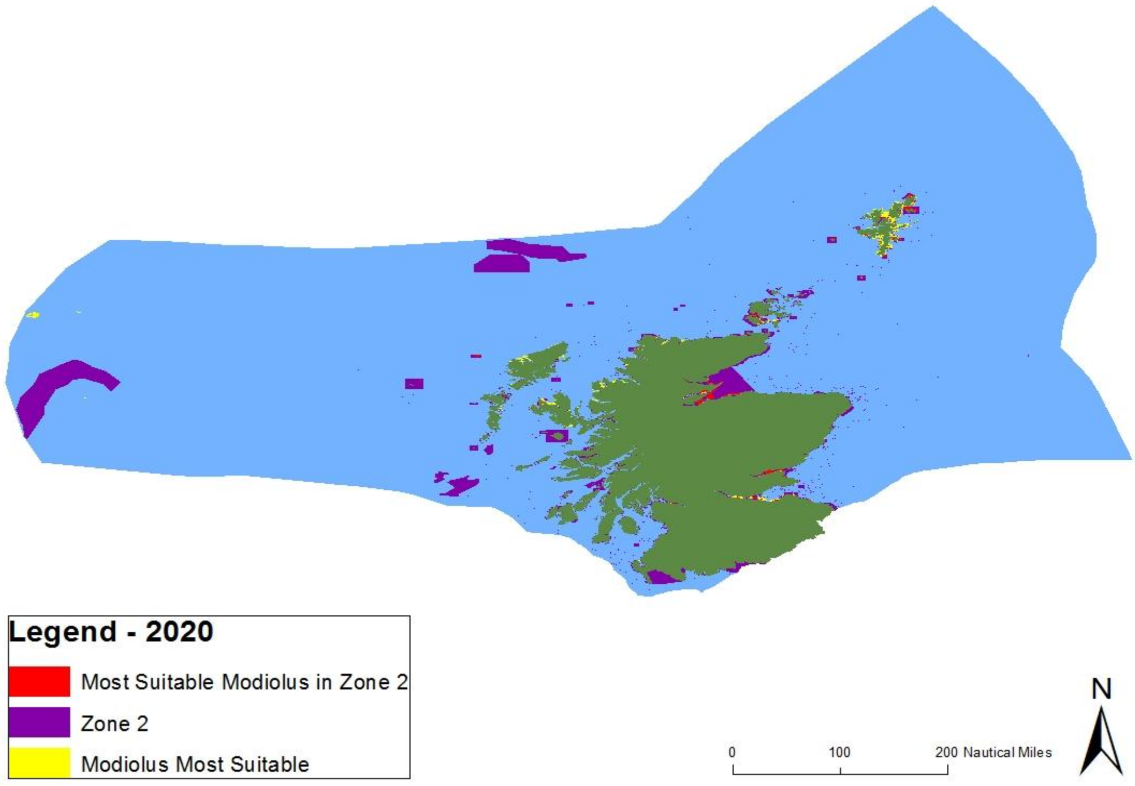


Figure A 5.1 - Identification of the 'Most Suitable' habitats for *Modiolus modiolus* within Zone 2 (Conservation Priority Zone) in 2020

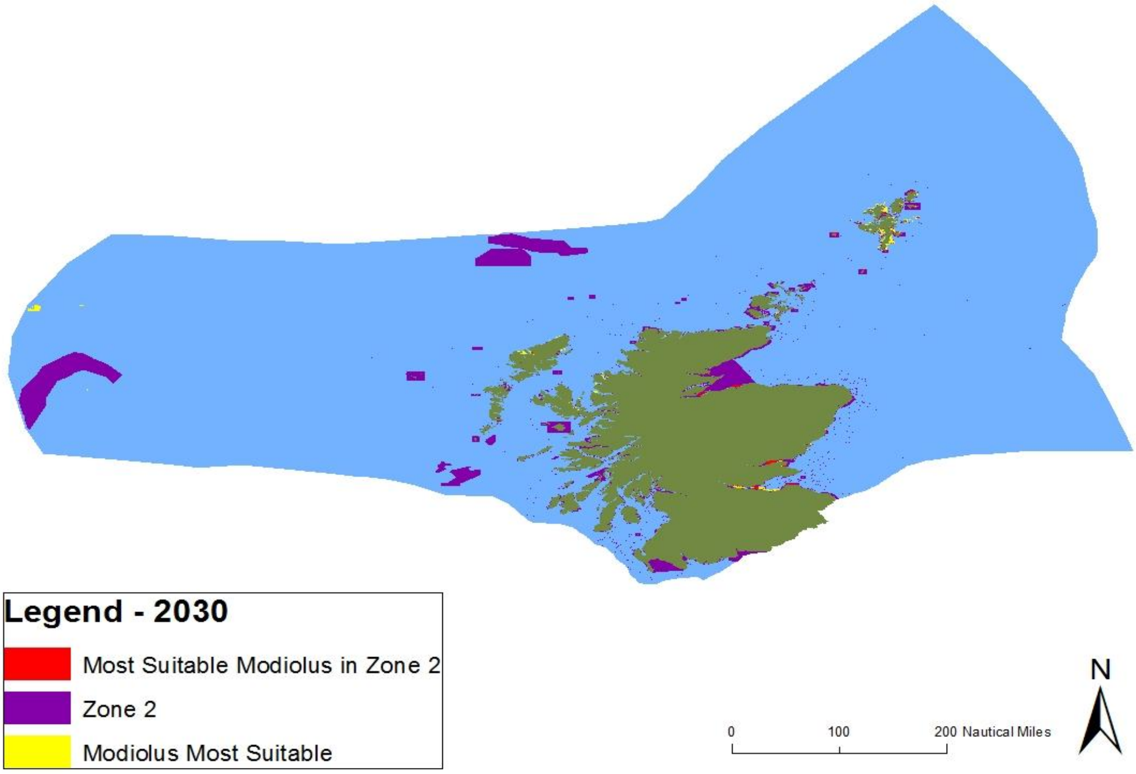


Figure A 5.2 - Identification of the 'Most Suitable' habitats for *Modiolus modiolus* within Zone 2 (Conservation Priority Zone) in 2030

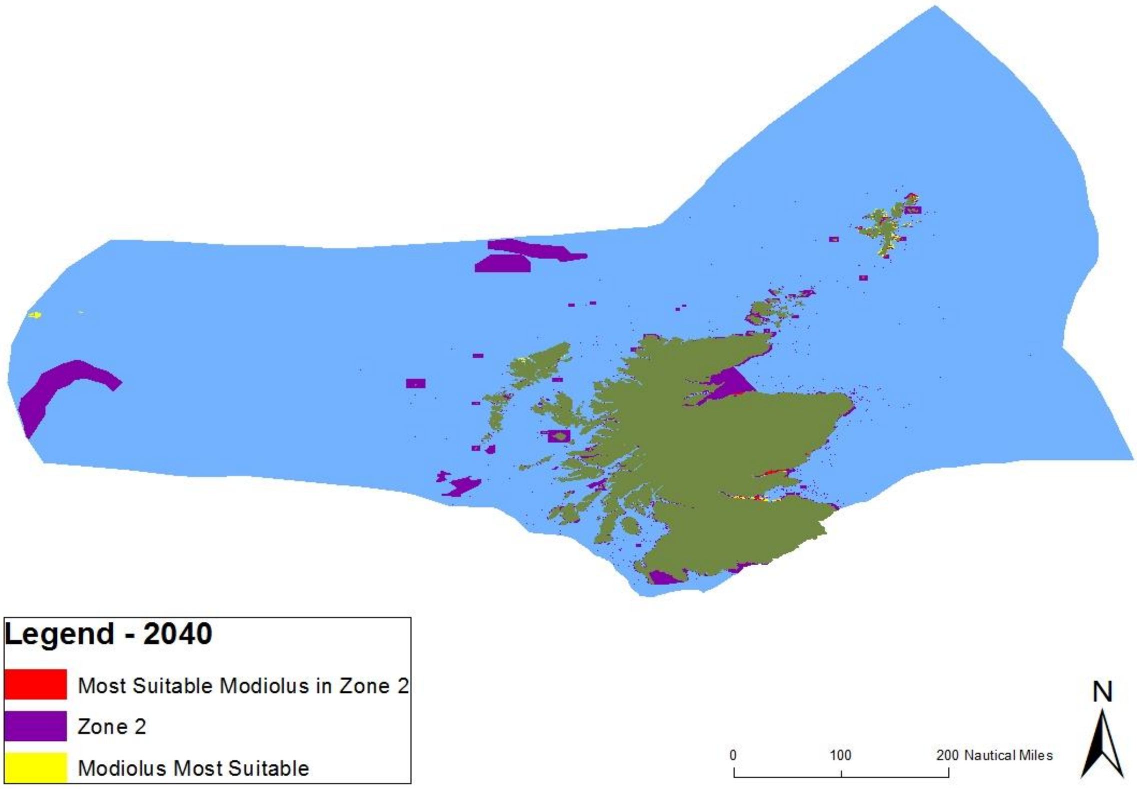


Figure A 5.3 - Identification of the 'Most Suitable' habitats for *Modiolus modiolus* within Zone 2 (Conservation Priority Zone) in 2040

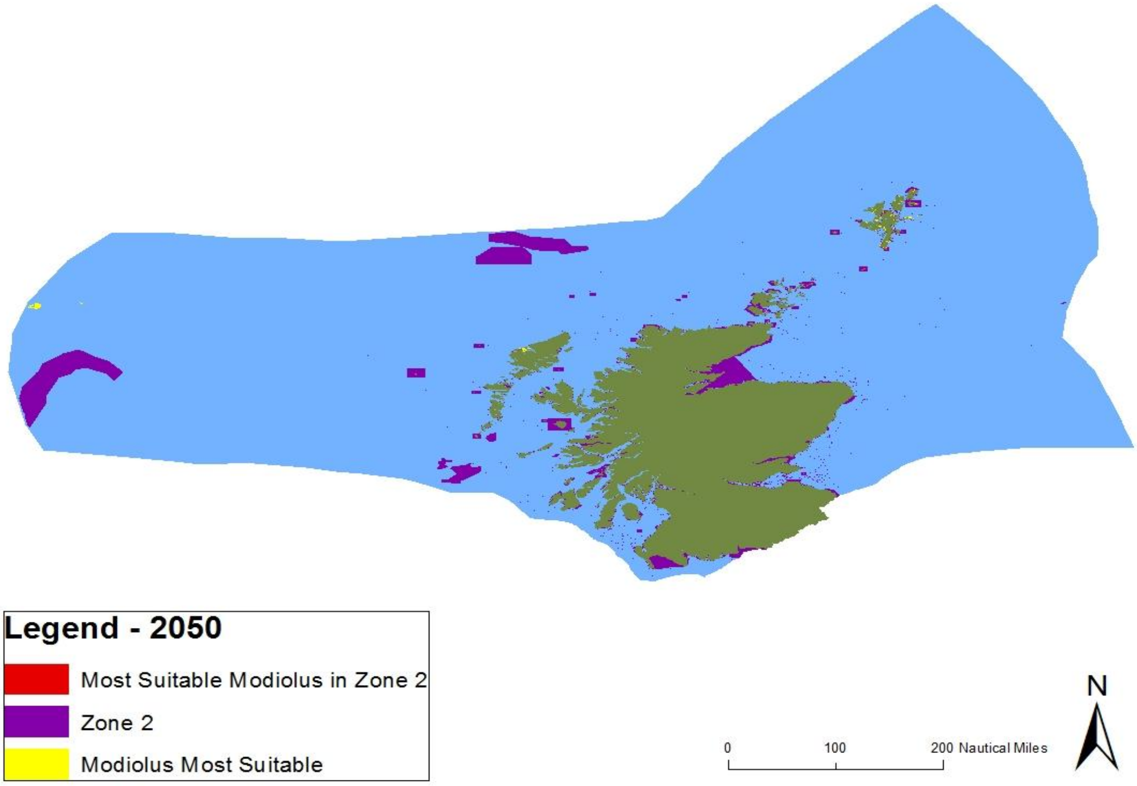


Figure A 5.4 -Identification of the 'Most Suitable' habitats for *Modiolus modiolus* within Zone 2 (Conservation Priority Zone) in 2050

Table A 5.0 - Area of PMFs within each of the Multiple-Use Zones alongside % Cover

	Area Coverage (km^2)							% of Most Suitable Features in each Zone					
Coral Gardens													
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1A**	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	24485	391	129	25016	10		50031	49	1		50	0.02	
2020	34916	400	131	35456	10		70913	49	1		50	0.01	
2030	50970	406	131	51518	12		103037	49			50	0.01	
2040	67627	408	137	68177	12		136361	50			50	0.01	
2050	76244	434	137	76820	12		153647	50			50	0.01	
***Lophelia pertusa* Reefs**													
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1A**	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	23270	5784	4893	34002	111		68060	34	8	7	50	0.16	
2020	22054	6663	4835	33527	79		67158	33	10	7	50	0.12	
2030	23018	7442	4745	35167	77		70449	33	11	7	50	0.11	
2040	23126	6581	4900	34565	74		69246	33	10	7	50	0.11	
2050	22926	6213	5033	34124	67		68363	34	9	7	50	0.10	
Maerl Beds													
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1A**	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	2416	111	729	3288	5	0.03	6594.03	37	2	11	50	0.76	
2020	1031	169	853	2064	10		4127	25	4	21	50	0.24	
2030	507	135	568	1226	15	0.07	2451.07	21	6	23	50	0.61	
2040	160	97	260	517			1034	15	9	25	50		
2050	57	25	53	136		0.07	271.07	21	9	20	50		0.03
***Modiolus modiolus* Horse Mussel Beds**													
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1A**	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	1389	142	762	2293		0.1	4586.1	30	3	17	50		
2020	753	122	586	1460		0.1	2921.1	26	4	20	50		
2030	431	92	280	803		0.1	1606.1	27	6	17	50		0.01
2040	314	60	212	587		0.1	1606.1	27	5	18	50		0.01
2050	170	20	36	226		0.1	452.1	38	4	8	50		0.02
Intertidal *Mytilus edulis* beds on mixed and sandy sediments													
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1A**	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	724	69	592	1386			2771	26	2	21	50		
2020	766	77	623	1467			2933	26	3	21	50		
2030	767	77	622	1467			2933	26	3	21	50		
2040	766	77	623	1468			2934	26	3	21	50		
2050	769	77	629	1477			2952	26	3	21	50		
Sea-pen and burying Mega-fauna Communities													
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1A**	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	1173	15771	1806	30423	1071	0.1	60844.1	19	26	3	50	1.76	
2020	7971	13949	990	23723	811	0.1	47444.1	17	29	2	50	1.71	
2030	7086	14680	383	22978	828	0.1	45955.1	15	32	1	50	1.8	
2040	5989	14859	261	21917	807		43833	14	34	1	50	1.84	
2050	6065	15961	190	23296	1079		46591	13	34		50	2.32	
Deep Sea Sponge Aggregations													
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1A**	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	18956	2978	4114	25918	10		51976	36	6	8	50	0.02	
2020	21560	4888	4399	30746	28		61621	35	8	7	50	0.05	
2030	25295	7313	4376	36894	43		73921	34	10	6	50	0.06	
2040	26982	4530	4534	35952	36		72034	37	6	6	50	0.05	
2050	27589	1615	4730	33824	19		67777	41	2	7	50	0.03	
***Zostera* Beds**													
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1A**	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	711	9	149	869			1738	41	1	9	50		
2020	249	33	146	428			856	29	4	17	50		
2030	212	17	98	337			673	32	3	15	50	1.34	
2040	105	39	168	312			624	17	6	27	50		
2050	38	13	38	89			178	21	7	21	50		

Table A 5.1 - Relative % Coverage of PMF within the Multiple-Use Zoning Scheme

%cover MS in zone (Weighted per zone within Scottish Sea area)						
Coral Gardens						
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	50	0.7		100		
2020	51	0.5		100		
2030	51	0.4		100		
2040	51	0.3		100		
2050	51	0.2		100		
***Lophelia pertusa* Reefs**						
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	35	7.5	0.5	100		
2020	34	8.7	0.5	100		
2030	34	9.3	0.4	100		
2040	34	8.3	0.5	100		
2050	34	8	0.5	100		
Maerl Beds						
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	36	1.4	0.7	96		
2020	25	3.5	1.3	96		
2030	20	4.6	1.5	96		
2040	15	7.8	1.6	95		
2050	20	7.6	1.2	94		
***Modiolus modiolus* Horse Mussel Beds**						
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	30	2.6	1	95		
2020	17	2.4	0.9	65		
2030	26	4.8	1.1	96		
2040	26	4.3	1.1	96		
2050	37	3.7	0.5	95		
Intertidal *Mytilus edulis* beds on mixed and sandy sediments						
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	26	2.1	1.4	97		
2020	26	2.2	1.4	97		
2030	26	2.2	1.4	97		
2040	26	2.2	1.4	97		
2050	26	2.2	1.4	97		
Sea-pen and burying Mega-fauna Communities						
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	20	22.7	0.2	100		
2020	17	25.7	0.1	100		
2030	6	28	0.1	100		
2040	14	29.7		100		
2050	13	30		100		
Deep Sea Sponge Aggregations						
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	38	5	0.5	100		
2020	36	7	0.5	100		
2030	35	8.7	0.4	100		
2040	38	5.5	0.4	100		
2050	42	2.1	0.5	100		
***Zostera* Beds**						
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	40	0.4	0.5	95		
2020	28	3	1	93		
2030	31	2.1	0.9	95		
2040	16	5.2	1.7	94		
2050	20	5.9	1.3	9.2		

Table A 5.2 - Areas of PMFs within each of the Prototype Zones alongside % Cover

	Area Coverage (km^2)						% of Most Suitable Features in each Zone				
***Lophelia pertusa* Reefs**											
	Zone 1	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009				27732	6269	34001				82	18
2020				27408	6119	33527				82	18
2030				29092	6075	35167				83	17
2040				28343	6221	34564				82	18
2050				27742	6381	34123				81	19
Coral Gardens											
	Zone 1	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009				24863	152	25015				99	1
2020				35301	155	35456				100	
2030				51362	155	51517				100	
2040				68014	162	68176				100	
2050				76657	163	76820				100	
Maerl Beds											
	Zone 1	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	1	1	21	587	2797	3407			1	17	82
2020	1	1	8	258	1873	2141				12	87
2030	1		4	104	1161	1270				8	91
2040			1	4	538	543				1	99
2050				23	119	142				16	84
***Modiolus modiolus* Horse Mussel Beds**											
	Zone 1	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	1	1	13	316	2060	2391			1	13	86
2020			8	137	1362	1507			1	9	90
2030		1	2	128	706	837				15	85
2040			1	110	501	612				18	82
2050			1	94	143	238				40	60
Intertidal *Mytilus edulis* beds on mixed and sandy sediments											
	Zone 1	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009			8	130	1288	1426			1	9	90
2020			6	195	1323	1524				13	87
2030	1		4	104	1161	1270				8	91
2040			8	137	1363	1508			1	9	90
2050			8	137	1372	1517			1	9	90
Sea-pen and burying Mega-fauna Communities											
	Zone 1	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	1		15	24174	6305	30495				79	21
2020			5	20104	3642	23751				85	15
2030			3	20524	2461	22988				89	11
2040			1	19930	1993	21924				91	9
2050			1	21662	1636	23299				93	7
Deep Sea Sponge Aggregations											
	Zone 1	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009				20677	5241	25918				79	21
2020				25209	5537	30746				85	15
2030				31417	5482	36899				89	11
2040				30314	5641	35955				91	9
2050				27979	5844	33823				93	7
***Zostera* Beds**											
	Zone 1	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**	**Total**	**Zone 1**	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009	1		9	123	776	909			1	14	85
2020			4	55	401	460			1	12	87
2030			2	36	315	353			1	10	89
2040				7	323	330				2	98
2050			1	2	93	96			1	2	97

Table A 5.3 - % Relative Coverage of PMFs within the Prototype Zoning Scheme

%cover MS in zone (Weighted per zone within Scottish Sea area)					
Coral Gardens					
	Zone 1	**Zone 2**	**Zone 3A**	**Zone 3B**	**Zone 4**
2009				33	
2020				37	
2030				42	
2040				45	
2050				45	
***Lophelia pertusa* Reefs**					
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**
2009				27	2
2020				30	2
2030				35	2
2040				37	2
2050				37	2
Maerl Beds					
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**
2009				6	10
2020				4	10
2030				3	11
2040					12
2050				7	10
***Modiolus modiolus* Horse Mussel Beds**					
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**
2009				4	10
2020				2	7
2030				6	10
2040				8	10
2050				18	7
Intertidal *Mytilus edulis* beds on mixed and sandy sediments					
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**
2009				3	11
2020				5	10
2030				4	11
2040				4	11
2050				4	11
Sea-pen and burying Mega-fauna Communities					
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**
2009				27	2
2020				31	2
2030				38	1
2040				41	1
2050				42	1
Deep Sea Sponge Aggregations					
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**
2009				27	2
2020				30	2
2030				36	2
2040				38	2
2050				37	2
***Zostera* Beds**					
	Zone 1A	**Zone 1B**	**Zone 2**	**Zone 3A**	**Zone 3B**
2009			1	5	10
2020				4	10
2030				4	10
2040				1	11
2050				1	11

Appendix 6

Table A 6.0 - Suitability scores for each criterion in the Socio-Infrastructure Sub-Model

	1	2	3	4	5	6	7	8
Conflicting Activities	High	High	Med	Med	Low	Low	Low	Low
Beaches (km)	0-1	1-2	2-4	4-6	6-8	8-10	10-15	15-95
Towns and Transport Links (km)	0-1	1-2	2-3	3-4	4-5	5-6	6-8	8-74
Small Craft Facilities (km)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-76
Ports (km)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-94
Pollution (km)	0-0.5	0.5-1	1-2	2-3	3-4	4-5	5-6	6-63
Heritage (km)	0-0.2	0.2-0.5	0.5-0.75	0.75-1	1-1.25	1.25-1.5	1.5-2	2-54
Aquaculture (km)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-77

Table A 6.1 - Suitability scores for each criterion in the Biophysical Sub-Model

	1	2	3	4	5	6	7	8
Current (ms¹)	(0-4) (40-59)	(4-5) (38-40)	(5-6) (36-38)	(6-7) (34-36)	(7-8) (32-34)	(8-9) (31-32)	(9-10) (30-31)	(10-30)
Water Depth (m)	(512--10) (-2391--80)	(-10--20) (-80--75)	(-20--25) (-75--80)	(-25--30) (-70--75)	(-30--35) (-65--70)	(-35--40) (-60--65)	(-40--45) (-55--60)	(-45--55)
Chlorophyl (mg/m²)	11-11.4	0-3	3-6	6-7	7-8	8-9	10-11	9-10
Sediment (grain size)	Fine	Fine/ Deep	Mixed/ Upper	Mixed	Mixed / Deep	Course/ Upper	Course/ Deeper	Rock/ Deep
Temperature (°C)					0-7	7-8	(8-9)(10-11)	9-10
Wave Height (m)	0-0.5	0.5-1	1-1.2	1.2-1.4	1.4-1.6	1.6-1.8	1.8-2	2-2.2

Table A 6.2 - A pairwise comparison matrix for assessing relative importance of Social-Infrastructure factors for finfish aquaculture in Scotland (numbers show the rating of the row factors relative to the column factors)

Social - Infrastructure	Distance from Beaches	Distance from Sewage/ Pollution Sites	Distance from Aquaculture	Distance to Transport Links	Natural/ Social Heritage Sites and Towns	Conflicting Activities	Distance from Small Craft Facilities	Distance from Ports and Harbours	Weight
Distance from Beaches	1	1/9	1/7	1/3	3	1/7	1/3	1/5	0.02
Distance from Sewage/Pollution Sites	9	1	5	7	9	3	5	3	0.3
Distance from Aquaculture	7	1/5	1	7	9	1/5	3	5	0.15
Distance to Transport Links	3	1/7	1/7	1	3	1/9	1/3	1/5	0.03
Natural/Social Heritage Sites and Towns	1/3	1/9	1/9	1/3	1	1/9	1/3	1/5	0.01
Conflicting Activities	7	1/3	5	9	9	1	7	7	0.25
Distance from Small Craft Facilities	3	1/5	1/3	3	3	1/7	1	1/5	0.14
Distance from Ports and Harbours	5	1/3	1/5	5	5	1/7	5	1	0.1
Consistency Ratio (C.R.): 0.07									

Table A 6.3 - A pairwise comparison matrix for assessing relative importance of Biophysical factors for finfish aquaculture in Scotland (numbers show the rating of the row factors relative to the column factors)

Biophysical	**Water Depth**	**Current Velocity**	**Chlorophyll a**	**Temp**	**Sediment Type**	**Max Wave Height**	**Weight**
Water Depth	1	3	7	5	3	1/5	0.21
Current Velocity	9	1	5	7	9	3	0.17
Chlorophyll a	7	1/5	1	7	9	1/5	0.03
Temperature	3	1/7	1/7	1	3	1/9	0.05
Sediment Type	1/3	1/9	1/9	1/3	1	1/9	0.09
Max Wave Height	7	1/3	5	9	9	1	0.45
Consistency Ratio (C.R.): 0.039							

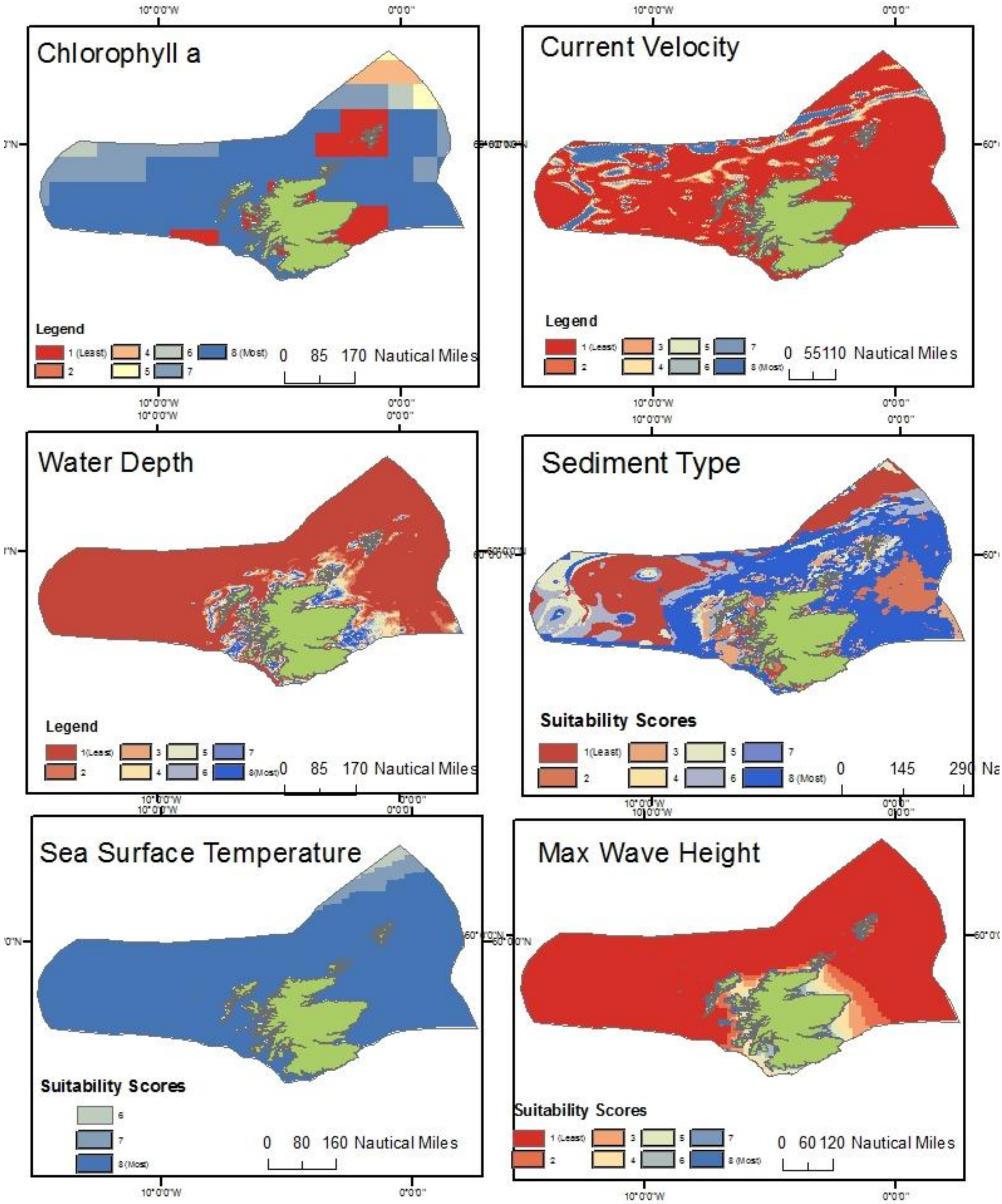


Figure A 6.0 – Maps showing the individual layers used in the Biophysical Sub-Model after data standardisation.

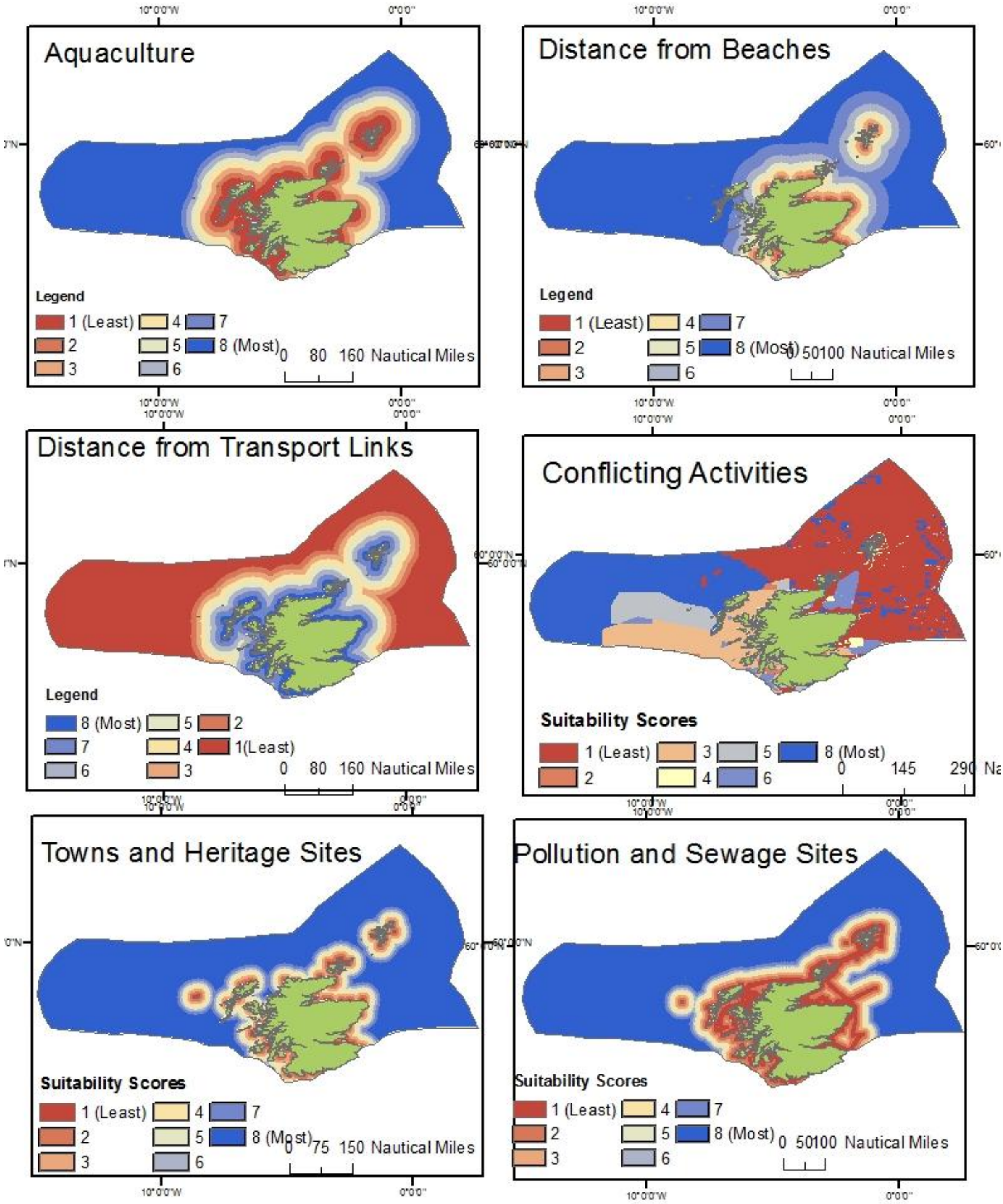


Figure A 6.1 – Maps showing the individual layers used in the Biophysical Sub-Model after data standardisation.

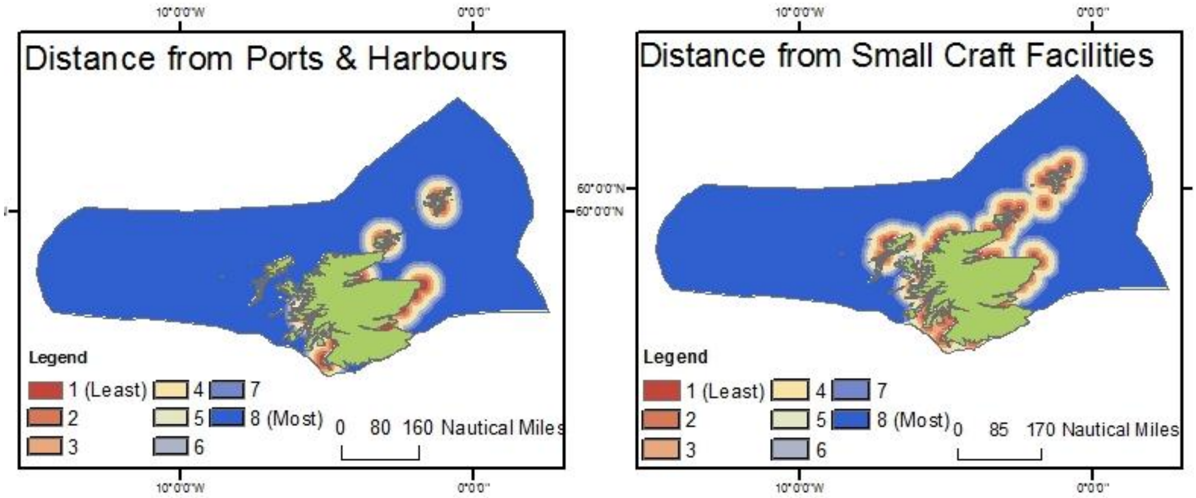


Figure A 6.2 – Maps showing the individual layers used in the Biophysical Sub-Model after data standardisation.

Table A 6.4 – A Pairwise Comparison Matrix for assessing relative importance of final site selection models for finfish aquaculture site selection in Scotland (numbers show the rating of the row factors relative to the column factor).

Factor requirement for assessment of finfish culture site selection	**Biophysical**	**Social-Infrastructure**	**Weight**
Model 1 (Biophysical<Social-Infrastructure)			
Socio-Infrastructure	1	3/2	0.6
Biophysical	2/3	1	0.4
Consistency Ratio (C.R.):0.00			
Model 2 (Social-Infrastructure>Biophysical)			
Socio-Infrastructure	1	2/3	0.4
Biophysical	3/2	1	0.6
Consistency Ratio (C.R.):0.00			

Appendix 7

Table A 7.0 Suitability scores for each criterion in the Socio-Infrastructure Sub-Model

	1	2	3	4	5	6	7	8
Aquaculture (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	7.68
Beaches & Heritage Sites (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	5.45
Protected Marine Areas (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	3.04
Important Fishing Grounds (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	3.12
Small Craft Facilities (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	7.6
Towns and Transport Links (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.8	7.4

Table A 7.1 Suitability scores for each criterion in the Biophysical Sub-Model

	1	2	3	4	5	6	7	8
Chlorophyll a ($mg\ m^3$)	11.4	4	5	6	7	8	9	10
Current Velocity (cm/sec)	0-4 40-59	4-5 38-40	5-6 36-38	6-7 34-36	7-8 32-34	8-9 31-32	9-10 30-31	10-30
Sediment (Grain Size)	Fine	Fine/ Deep	Mixed/ Upper	Mixed	Mixed/ Deep	Rock/ Deep	Course/ Upper	Course/ Deep
Temperature (°C)			8.44	8.6	8.8	9.0	9.5	11.56
Turbidity (mg/L)	8.79	4.954	4.9	4.845	4.778	4.698	4.6	4.47
Water Depth (m)	0-(-5) (-100)-(-2661)	(-90)-(-100)	(-80)-(-90)	(-75)-(-80)	(-65)-(-75)	(-60)-(-65)	(-55)-(-60)	(-5)-(-55)

Table A 7.2 A pair-wise comparison matrix for assessing relative importance of Social-Infrastructure factors for shellfish aquaculture in Scotland (numbers show the rating of the row factors relative to the column factors)

Social -Infrastructure	Distance from Aquaculture	Distance from Beaches and Heritage Sites	Designated Protected Areas	Important Fishing Grounds	Distance from Small Craft Facilities	Distance from Towns and Transport Links	Weight
Distance from Aquaculture	1	9	3	3	9	7	0.41
Distance from Beaches and Heritage Sites	1/9	1	1/7	1/3	3	3	0.07
Designated Protected Areas	1/3	7	1	5	9	7	0.30
Important Fishing Grounds	1/3	3	1/5	1	7	5	0.15
Distance from Small Craft Facilities	1/9	1/3	1/9	1/7	1	1/3	0.03
Distance from Towns and Transport Links	1/7	1/3	1/7	1/5	3	1	0.05
Consistency Ratio (C.R.): 0.07							

Table A 7.3 A pairwise comparison matrix for assessing relative importance of Biophysical factors for shellfish aquaculture in Scotland (numbers show the rating of the row factors relative to the column factors)

Biophysical	Chlorophyll a	Current Velocity	Sediment Type	Temperature	Turbidity	Water Depth	Weight
Chlorophyll a	1	3	7	5	3	1/5	0.21
Current Velocity	9	1	5	7	9	3	0.17
Sediment Type	7	1/5	1	7	9	1/5	0.03
Temperature	3	1/7	1/7	1	3	1/9	0.05
Turbidity	1/3	1/9	1/9	1/3	1	1/9	0.09
Water Depth	7	1/3	5	9	9	1	0.45
Consistency Ratio (C.R.): 0.1							

Table A 7.4 – A Pairwise Comparison Matrix for assessing relative importance of final site selection models for shellfish aquaculture site selection in Scotland (numbers show the rating of the row factors relative to the column factor).

Factor requirement for assessment of finfish culture site selection	**Biophysical**	**Social-Infrastructure**	**Weight**
Model 1 (Biophysical<Social-Infrastructure)			
Socio-Infrastructure	1	3/2	0.6
Biophysical	2/3	1	0.4
Consistency Ratio (C.R.):0.00			
Model 2 (Social-Infrastructure>Biophysical)			
Socio-Infrastructure	1	2/3	0.4
Biophysical	3/2	1	0.6
Consistency Ratio (C.R.):0.00			

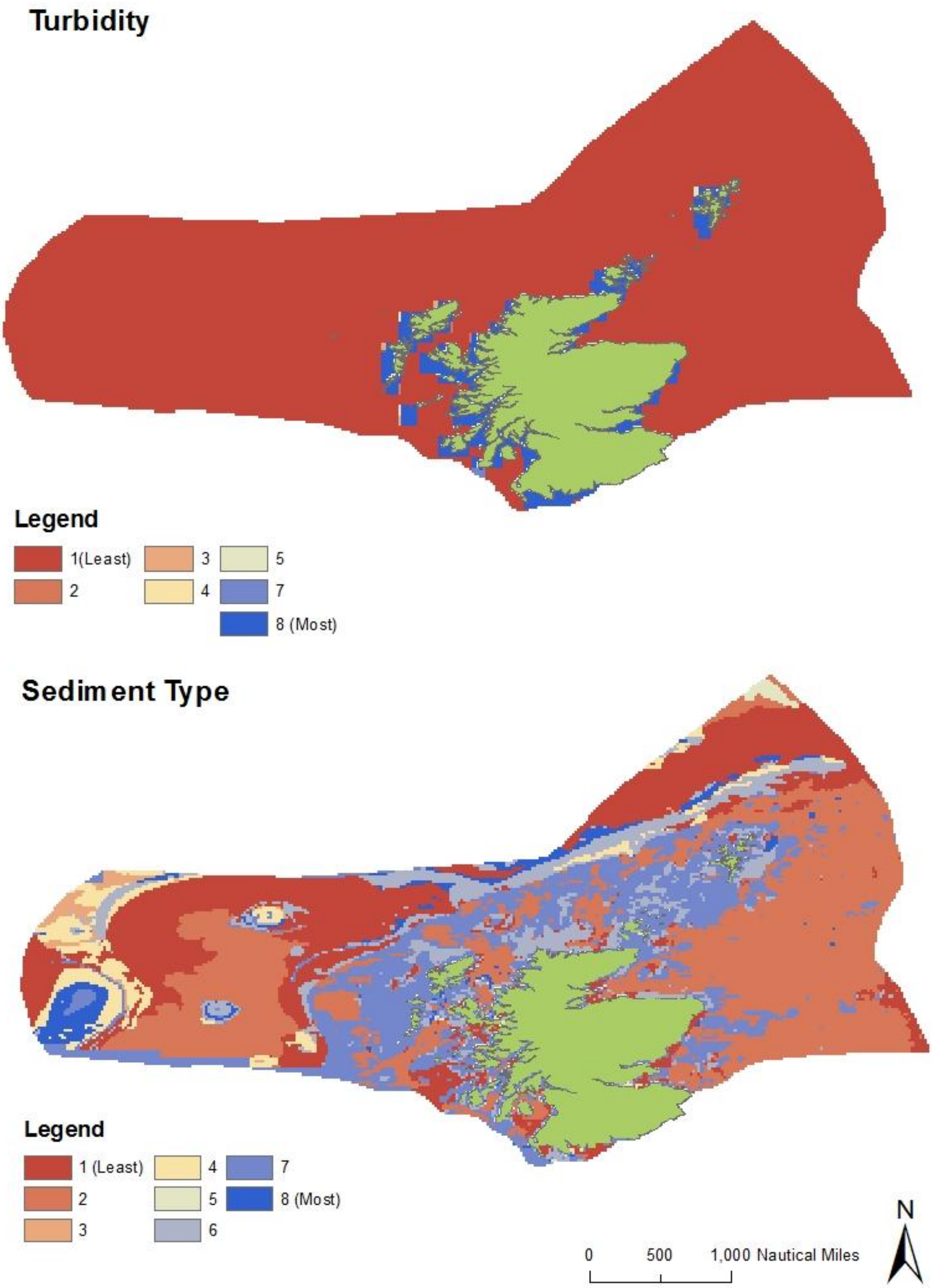


Figure A 7.0 – Maps showing the individual Turbidity and Sediment layers used in the Biophysical Sub-Model after data standardisation.

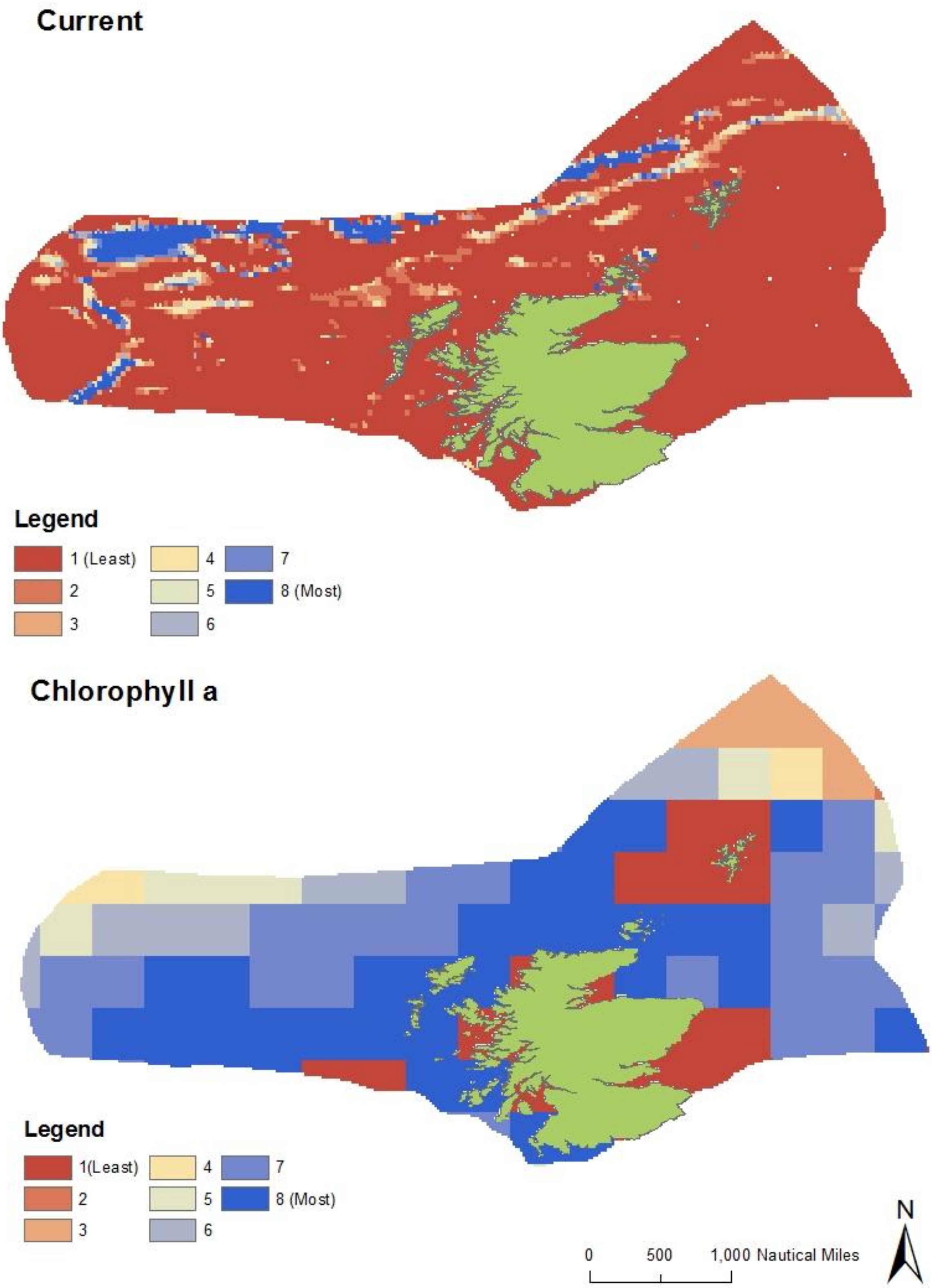


Figure A 7.1 – Maps showing the individual current and chlorophyll layers used in the Biophysical Sub-Model after data standardisation.

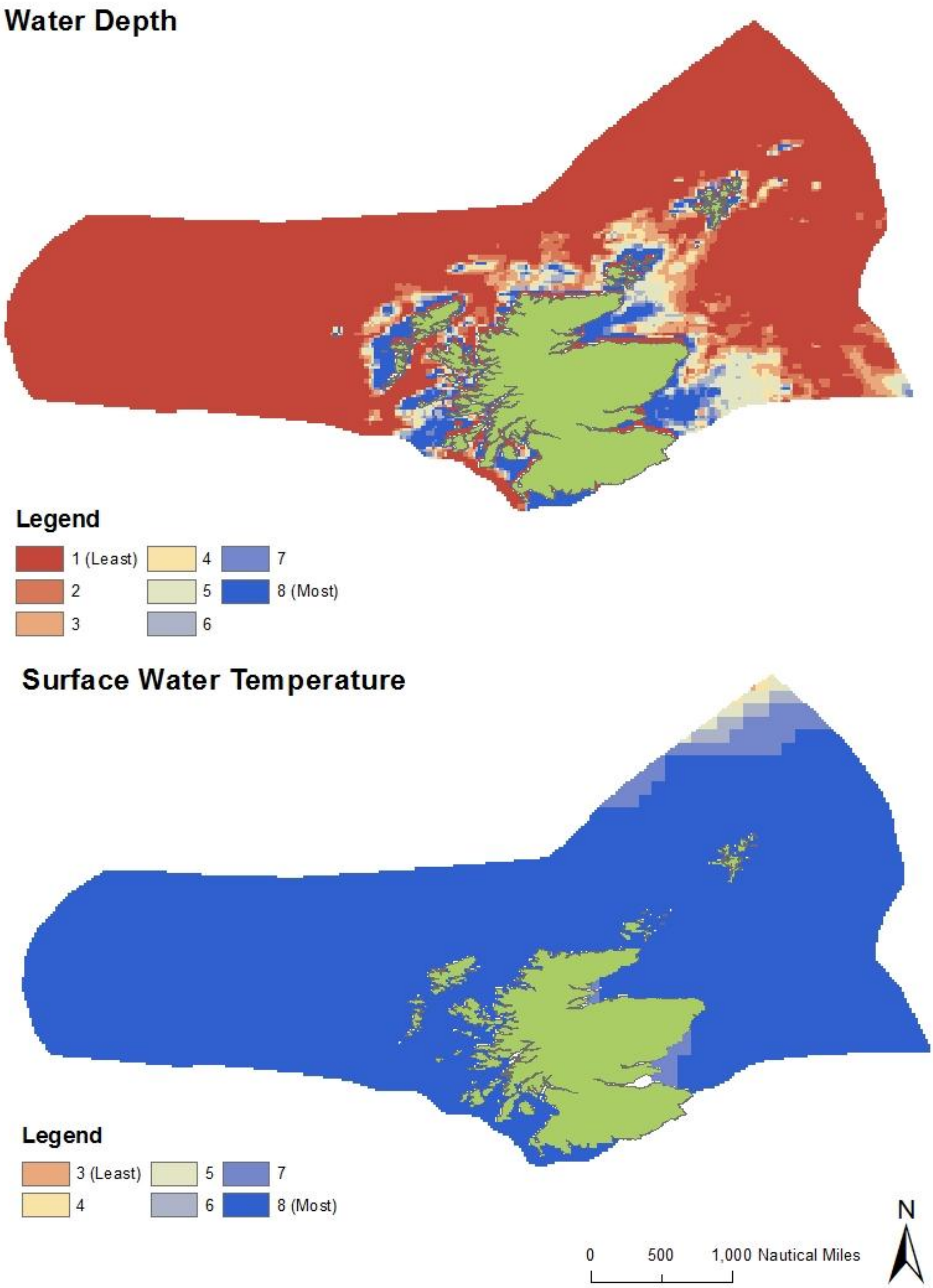


Figure A 7.2 – Maps showing the individual water depth and temperature layers used in the Biophysical Sub-Model after data standardisation.

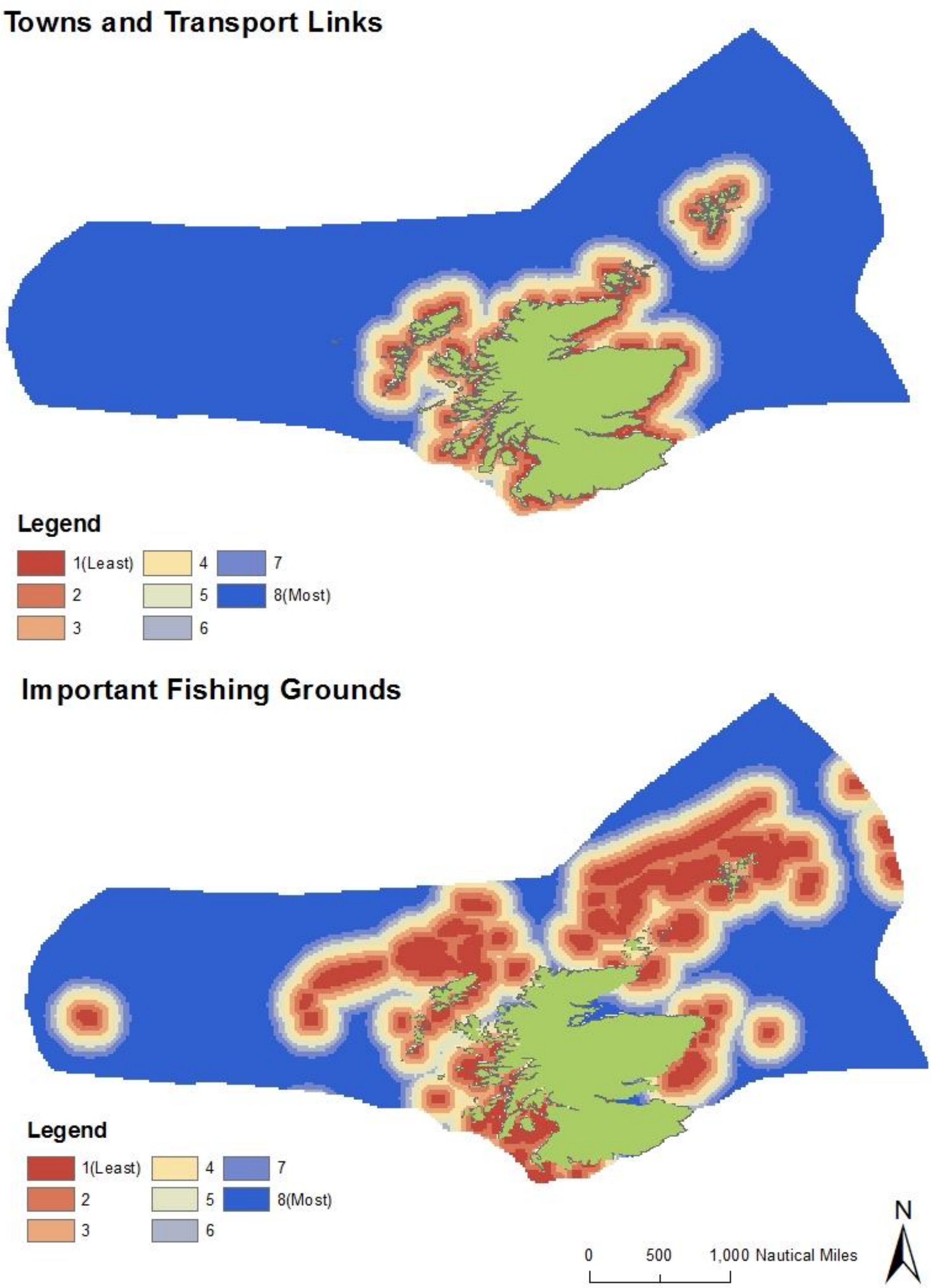


Figure A 7.3 – Maps showing the individual Towns and Transport and Important Fishing Grounds layers used in the Social-Infrastructure Sub-Model after data standardisation.

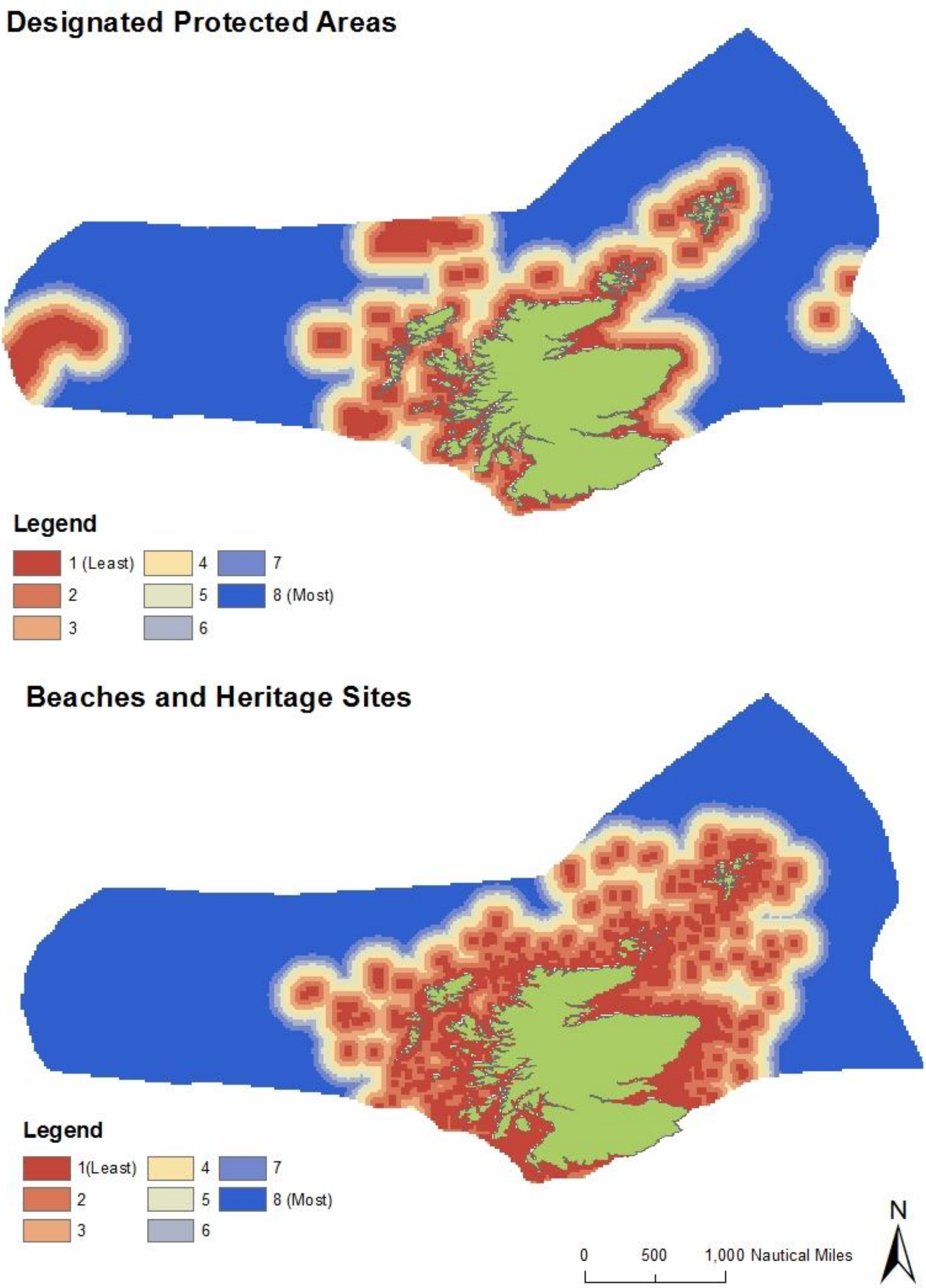
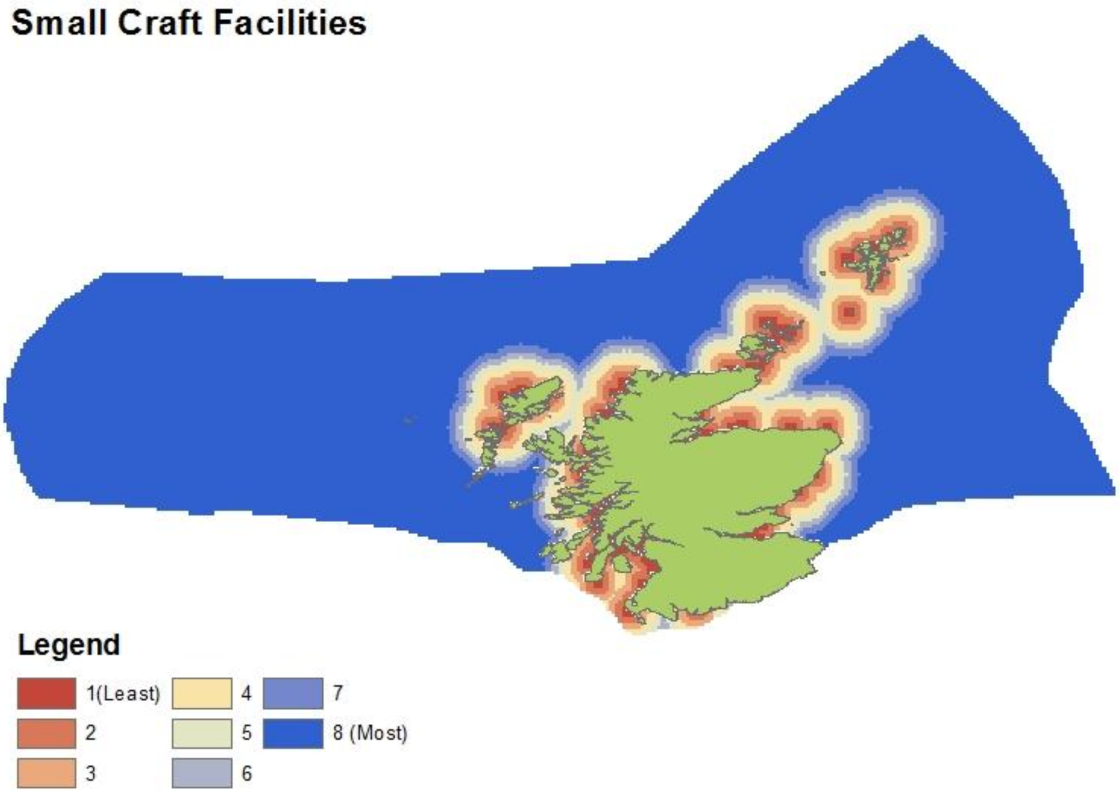


Figure A 7.4 – Maps showing the individual Designated Protected Areas and Beaches and Heritage layers used in the Social-Infrastructure Sub-Model after data standardisation.



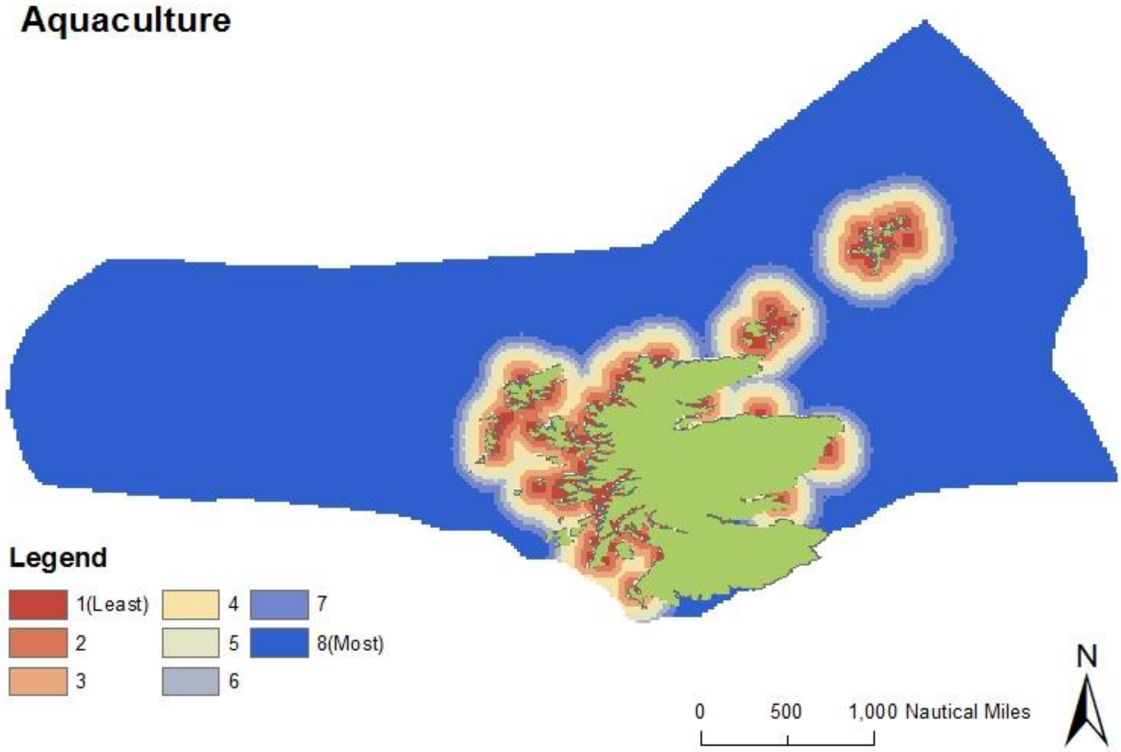
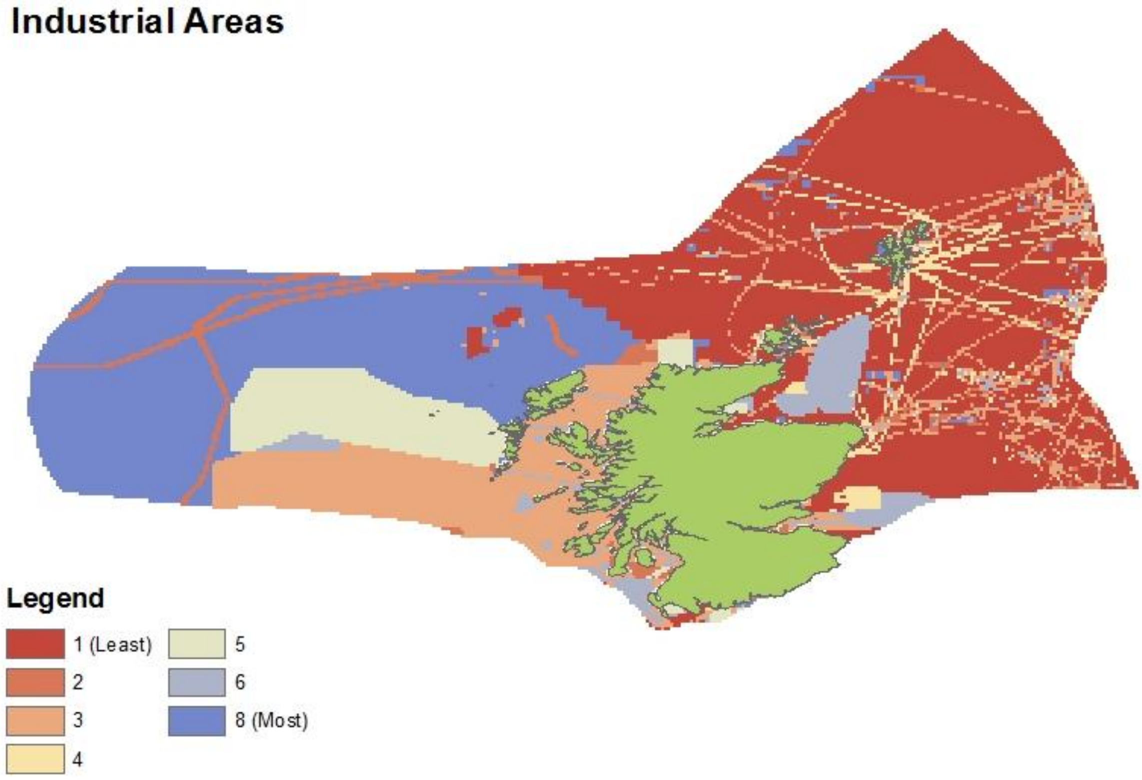


Figure A 7.5 – Maps showing the individual Small Craft and Aquaculture layers used in the Social-Infrastructure Sub-Model after data standardisation.



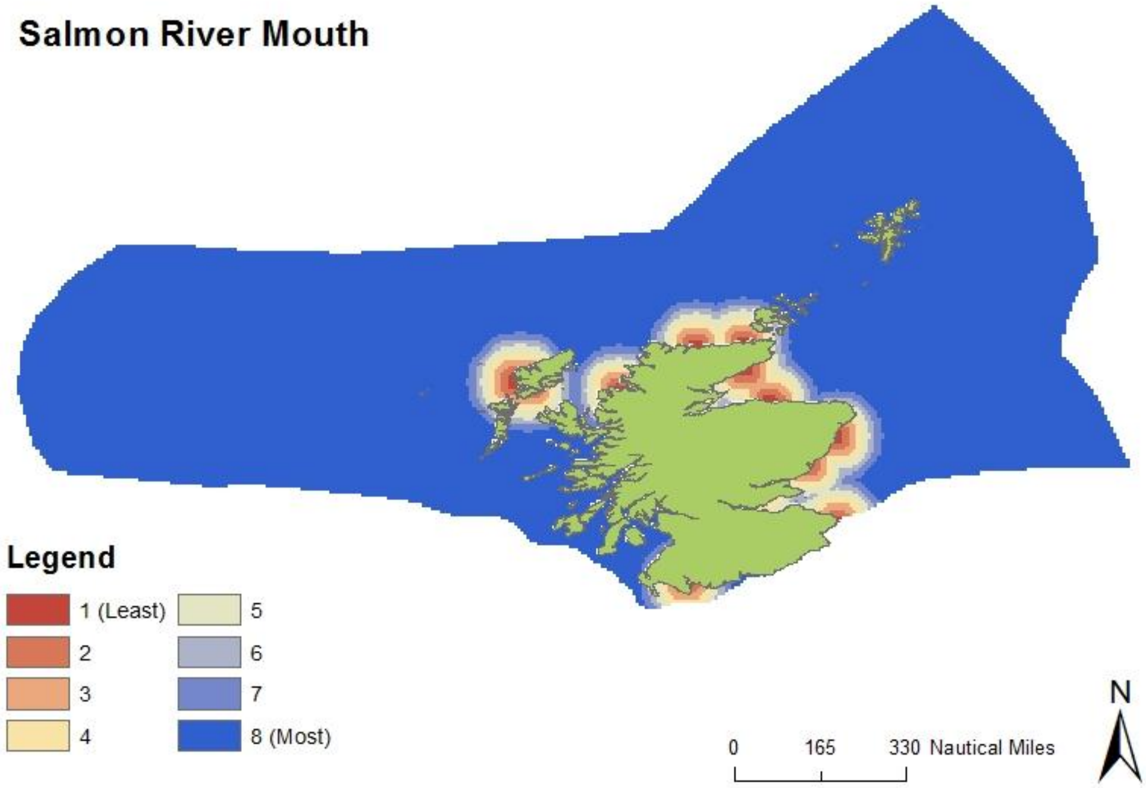


Figure A 7.6 – Maps showing the areas with concentrated industrial activities and mouths of salmon rivers layers used in the revised running of the shellfish model after data standardisation.

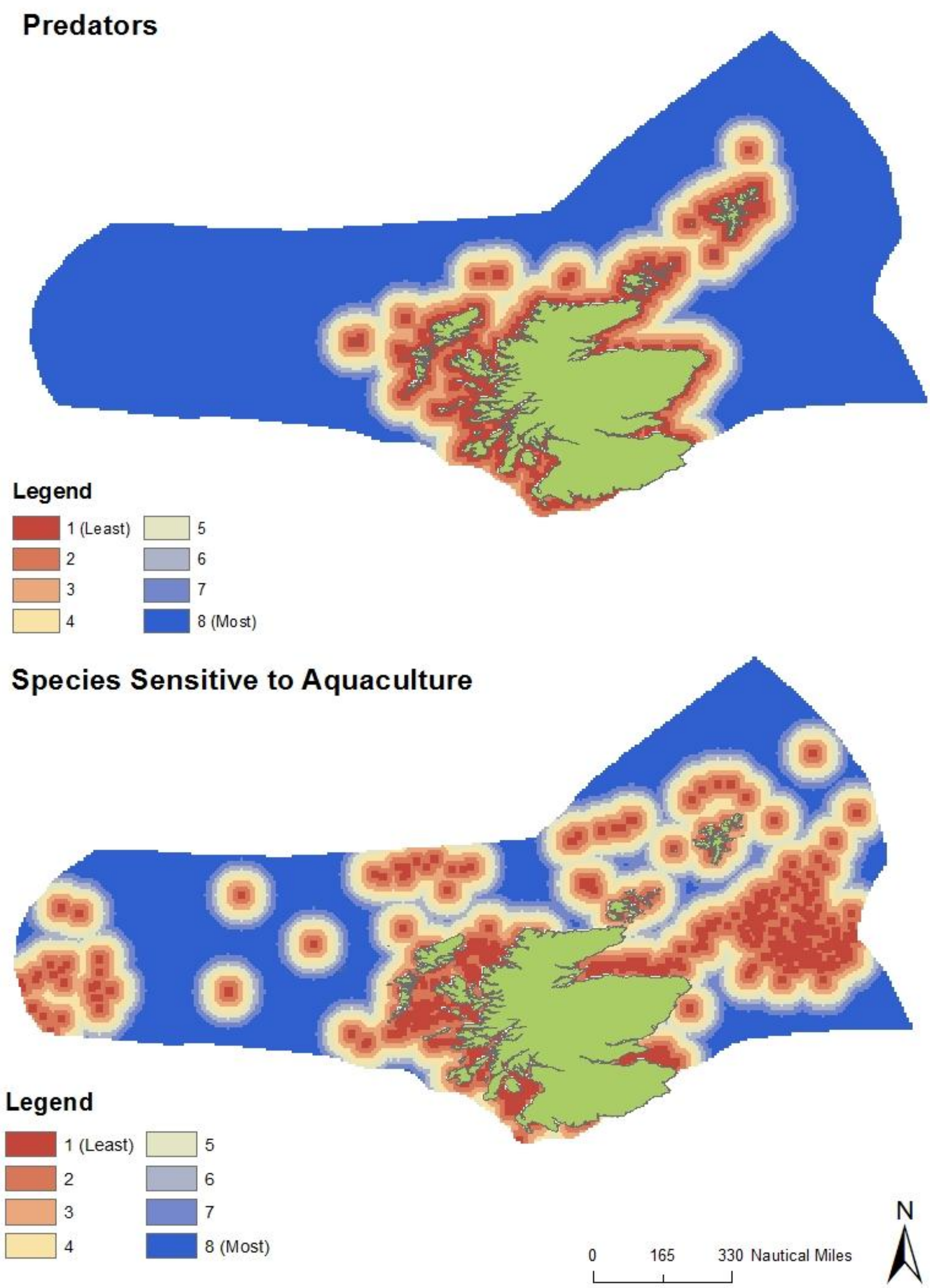


Figure A 7.7 – Maps showing the predator hotspots and species sensitive to aquaculture layers used in the revised running of the shellfish model after data standardisation.

Table A 7.5 Suitability scores for each criterion in the Revised Shellfish Sub-Model

	1	2	3	4	5	6	7	8
Aquaculture (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	7.68
Beaches & Heritage Sites (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	5.45
Protected Marine Areas (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	3.04
Important Fishing Grounds (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	3.12
Small Craft Facilities (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	7.6
Towns and Transport Links (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.8	7.4
Concentration of Industrial Activities (km)	<6	<5	<4	<3	<2	<1		No Legislated Activities
Chlorophyll a (mg m^3)	11.4	4	5	6	7	8	9	10
Current Velocity (cm/sec)	0-4 40-59	4-5 38-40	5-6 36-38	6-7 34-36	7-8 32-34	8-9 31-32	9-10 30-31	10-30
Sediment (Grain Size)	Fine	Fine/ Deep	Mixed/ Upper	Mixed	Mixed/ Deep	Rock/ Deep	Course/ Upper	Course/ Deep
Temperature (°C)			8.44	8.6	8.8	9.0	9.5	11.56
Turbidity (mg/L)	8.79	4.954	4.9	4.845	4.778	4.698	4.6	4.47
Water Depth (m)	0-(-5) (-100)-(-2661)	(-90)-(-100)	(-80)-(-90)	(-75)-(-80)	(-65)-(-75)	(-60)-(-65)	(-55)-(-60)	(-5)-(-55)
Predator (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	8.69
Species Sensitive to Aquaculture (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	5.09
Salmon River Mouth (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	9.74

Table A 7.6 A pair-wise comparison matrix for assessing relative importance of Physical factors for revised shellfish aquaculture site selection model in Scotland (numbers show the rating of the row factors relative to the column factors)

Physical	Chlorophyll a	Current Velocity	Sediment Type	Temperature	Turbidity	Water Depth	Weight
Chlorophyll a	1	1/7	5	1/5	1/3	1/7	0.06
Current Velocity	7	1	9	1/3	3	1/3	0.19
Sediment Type	1/5	1/9	1	1/9	1/7	1/9	0. 02
Temperature	5	3	9	1	5	3	0.38
Turbidity	3	1/3	7	1/5	1	1/3	0.10
Water Depth	7	3	9	1/3	3	1	0.25
Consistency Ratio (C.R.): 0.1							

Table A 7.7 A pair-wise comparison matrix for assessing relative importance of Biological factors for revised shellfish aquaculture site selection model in Scotland (numbers show the rating of the row factors relative to the column factors)

Biological	Predators	Species Sensitive to Aquaculture	Designated Protected Areas	Important Fishing Grounds	Salmon River Mouth	Weight
Predators	1	1/9	1/7	3	1/5	0.06
Species Sensitive to Aquaculture	9	1	5	9	7	0.56
Designated Protected Areas	7	1/5	1	7	3	0. 23
Important Fishing Grounds	1/3	1/9	1/7	1	1/3	0.04
Salmon River Mouth	5	1/7	1/3	3	1	0.12
Consistency Ratio (C.R.): 0.1						

Table A 7.8 A pair-wise comparison matrix for assessing relative importance of Social-Infrastructure factors for revised shellfish aquaculture site selection model in Scotland (numbers show the rating of the row factors relative to the column factors)

Social-Infrastructure	Aquaculture	Beaches and Heritage Sites	Industrial Areas	Small Craft Facilities	Towns and Transport Links	Weight
Aquaculture	1	5	1/9	5	3	0.18
Beaches and Heritage Sites	1/5	1	1/9	1/3	1/5	0.03
Industrial Areas	9	9	1	9	9	0. 62
Small Craft Facilities	1/5	3	1/9	1	1/3	0.06
Towns and Transport Links	1/3	5	1/9	3	1	0.11
Consistency Ratio (C.R.): 0.1						

Table A 7.9 – A Pairwise Comparison Matrix for assessing relative importance of revised site selection models for shellfish aquaculture site selection in Scotland (numbers show the rating of the row factors relative to the column factor).

Factor requirement for assessment of shellfish culture site selection	Physical	Socio-Infrastructure	Biological	Weight
Model 1 (Physical>Social-Infrastructure>Biological)				
Physical	1	7	3	0.62
Social-Infrastructure	1/7	1	1/7	0.31
Biological	1/3	7	1	0.07
Consistency Ratio (C.R.):0.00				
Model 2 (Social-Infrastructure>Biological>Physical)				
Social-Infrastructure	1	7	3	0.62
Biological	1/7	1	1/7	0.31
Physical	1/3	7	1	0.07
Consistency Ratio (C.R.):0.00				
Model 3 (Biological> Physical>Social-Infrastructure)				
Biological	1	7	3	0.62
Physical	1/7	1	1/7	0.31
Socio-Infrastructure	1/3	7	1	0.07
Consistency Ratio (C.R.):0.00				

Appendix 8

Table A 8.0 Data Layers used in the Suitability Analysis, illustrating the data range allocated to each suitability score

	1	2	3	4	5	6	7	8
Conflicting Activities	High	High	Med	Med	Low	Low	Low	Low
Beaches (km)	0-1	1-2	2-4	4-6	6-8	8-10	10-15	15-95
Towns/ Transport Links (km)	0-1	1-2	2-3	3-4	4-5	5-6	6-8	8-74
Small Craft Facilities (km)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-76
Ports (km)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-94
Pollution (km)	0-0.5	0.5-1	1-2	2-3	3-4	4-5	5-6	6-63
Heritage (km)	0-0.2	0.2-0.5	0.5-0.75	0.75-1	1-1.25	1.25-1.5	1.5-2	2-54
Aquaculture (km)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-77
Protected Marine Areas (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	3.04
Fishing Grounds (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	3.12
Predators (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	8.69
Species Sensitive to Aqua (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	5.09
Nursery/Fishing Grounds (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	5.51
Salmon River Mouths (km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	9.74
Current (ms^1)	(0-4)(40-59)	(4-5)(38-40)	(5-6)(36-38)	(6-7)(34-36)	(7-8)(32-34)	(8-9)(31-32)	(9-10)(30-31)	(10-30)
Water Depth (m)	(512--10) (-2391--80)	(-10--20) (-80--75)	(-20--25) (-75--80)	(-25--30) (-70--75)	(-30--35) (-65--70)	(-35--40) (-60--65)	(-40--45) (-55--60)	(-45--55)
Chlorophyl (mg/m^2)	11-11.4	0-3	3-6	6-7	7-8	8-9	10-11	9-10
Sediment (grain size)	Fine	Fine/Deep	Mixed/Upper	Mixed	Mixed/Deep	Coarse/Upper	Coarse/Deeper	Rock/Deep
Temperature (°C)					0-7	7-8	(8-9) (10-11)	9-10
Wave Height (m)	0-0.5	0.5-1	1-1.2	1.2-1.4	1.4-1.6	1.6-1.8	1.8-2	2-2.2