Project Final Report Form

Please complete this form including an Executive Summary and the Final project report and return by email to: research@sarf.org.uk
C/o FRM Ltd., Coillie Bhrochain, Bonskeid, Pitlochry, Perthshire PH16 5NP, Scotland
Tel./Fax: 01796 474473

Project Details

SARF Project ID Code: SARF 003

Project Title: Development of a GIS-based tool to assist planning of aquaculture developments

Project: Start date 1 March 2005
End date 28 February 2006

Name(s) and address(s) of contractor organisation(s): Institute of Aquaculture, University of Stirling, Stirling, FK9 4LA, UK

Contractor’s Project Manager: Dr Trevor Telfer

SARF Project Manager: Dr Mark James

Total SARF Project costs £19934
Total approved project expenditure £19934
Total actual project expenditure £19934

Total *approved staff input 6 months
Total *actual staff input
1 year fulltime research assistant + Professor + Senior Lecturer time, rather than 6 months research fellow as originally contracted

Is there any Intellectual Property arising from this project which is suitable for commercial exploitation (This question requires a YES/NO answer only. All other details of any Intellectual Property must be included under the Scientific Report or in an accompanying Annex).

.........YES NO

*Staff years of direct science effort

NOTES

SARF aims to place the results of its completed research projects in the public domain wherever possible. The form is designed to capture the information on the results and outputs of SARF-funded research in a format that is easily publishable through the SARF website. This form must be completed for all SARF projects. A supplementary Final Financial Report Form must be completed where a project is paid on a monthly basis or against quarterly invoices. No Final Financial Report Form is required where payments are made at agreed milestone points.

• This form is in Word format and the boxes may be expanded or reduced, as appropriate.

ACCESS TO INFORMATION

The information collected on this form will be stored electronically and may be sent to any SARF Board Members, or to individual researchers or organisations outwith SARF for the purposes of reviewing the project. SARF may also disclose the information to any outside organisation acting as an agent authorised by SARF to process final research reports on its behalf. SARF intends to publish this form on its website, unless there are cogent reasons not to do so, which may be justified as being in line with exemptions under the Environmental Information (Scotland) Regulations or the Freedom of Information (Scotland) Act 2000. SARF may be required to release information, including personal data and commercial information, on request under the Environmental Information Regulations or the Freedom of Information Act 2000. However, SARF will not permit any unwarranted breach of confidentiality or act in contravention of its obligations under the Data Protection Act 1998.

It is SARF’s intention to publish this form.

Please confirm your agreement for SARF to do so.................................................................YES NO
(a) When preparing this and related report forms, contractors should bear in mind that SARF intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow. SARF recognizes that in a small minority of cases there may be information, such as intellectual property or commercially confidential data, used in or generated by the research project, which should not be disclosed. In these cases, such information should be detailed in a separate annex (and clearly marked as "NOT TO BE PUBLISHED") so that the contents of the forms can be placed in the public domain. Where it is impossible to complete the Final Report without including references to any sensitive or confidential data, the information should be included and section (b) completed. NB: only in exceptional circumstances will SARF expect contractors to give a "No" answer. The principal reasons for withholding information should be in line with exemptions under the Environmental Information (Scotland) Regulations or the Freedom of Information (Scotland) Act 2000.

(b) If you have answered NO, please explain why the Final report should not be released into public domain

Scientific objectives
List the scientific objectives as set out in the contract. If necessary these can be expressed in abbreviated form. Indicate where amendments have been agreed with the SARF Project Manager, giving the date of amendment.

Develop a preliminary GIS-based tool encompassing a case study area, which can model the actual and/or future implications of fish farms on environmentally sensitive parameters, areas or places of conservation interest in the coastal area of Scotland. This will be achieved through detailed modelling based on a case study area (The Outer Hebridean Islands). This tool could be further developed for the whole of the Scottish coastline and has the potential for incorporation into WWW-based tools.

There are a number of objectives to fulfil the above:

1) Map sites through GIS which are environmentally sensitive and of conservation importance in relation to aquaculture location using existing databases and information available.

2) Implement modelling through GIS using existing dispersal models to investigate the impact of fish cages on these sensitive habitats.

3) Formulate "what-if" scenarios to look for alternative sites for existing and future fish farm developments.

4) Develop a final decision support tool for use by trained personnel at appropriate organizations, and in a format that could be developed into a web-based system in the future.

5) Training in the use of the initial tool developed through the project.

Milestones
List the milestones. It is the responsibility of the contractor to check fully that all milestones have been met and to provide a detailed explanation if this has not proved possible.

<table>
<thead>
<tr>
<th>Milestone Number</th>
<th>Title</th>
<th>Target Date</th>
<th>Milestone Met</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Data collection and database generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Development of specific decision modules</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Final GIS model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Model testing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Reporting and data dissemination</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If any milestones have not been met please give an explanation below.

The Milestones have been achieved though the target dates are not relevant as the staff effort was changed from the original contract. This meant that one person worked fulltime on this project rather than for a portion of their time as in the contract. This enabled the scope of work to be extended within the original budget, but original target dates are therefore not relevant. The full scope of the project was completed within one year of starting work.

**Declaration**
I declare that the information I have given in this form and in any associated documentation is correct to the best of my knowledge and belief.

<table>
<thead>
<tr>
<th>Name: Dr Trevor Telfer</th>
<th>Date: 16 May 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position held: Senior Lecturer</td>
<td></td>
</tr>
</tbody>
</table>
Introduction

- In March 2005 the Institute of Aquaculture, University of Stirling, commenced an R&D contract entitled “Development of a GIS-based tool to assist planning of aquaculture developments”. The project has been part funded by SARF, with additional resource input from the Institute of Aquaculture.

- The project undertook to develop a preliminary GIS-based tool encompassing a case study area, which can model the actual and/or future implications of fish farms on environmentally sensitive parameters, areas or places of conservation interest in the coastal area of Scotland. The intention is that the tool(s) could be further developed for the whole of the Scottish coastline.

- There were a number of interim objectives:
  - Map sites through GIS which are environmentally sensitive and of conservation importance in relation to aquaculture location using existing databases and available information.
  - Implement modelling through GIS using simple dispersal models to investigate the impact of fish cages on these sensitive habitats.
  - Formulate "what-if" scenarios to look for alternative sites for existing and future fish farm developments.
  - Rationalize the results from sensitivity mapping, environmental impacts modelling and "what-if" scenarios to develop a final decision support tool for use by trained personnel at appropriate organizations, and in a format that could be developed into a web-based system in the future.
  - Provide a training workshop on the use of the initial tools developed through the project.

- The Western Isles was selected as the case study area because the conditions for productive and successful fish cage aquaculture are favourable and this has led to a large and well established industry, within a discreet geographical area. In addition, the Islands are host to numerous internationally recognised protected habitats and species.

Approaches to model development

- A conceptual model was developed for Western Isles aquaculture in which three initial principal sub-models were selected:
  - **A cage suitability sub-model** was developed to address the importance of siting different types of cage technologies based on their physical design capabilities. This sub-model incorporated the previously identified important criteria of Currents, Bathymetry and Wave Climate. As a prerequisite for the cage suitability sub-model a **wave climate sub-model** was developed based on previous work at Institute of Aquaculture.
  - **A Biodiversity sub-model** was developed in order to identify ecologically sensitive habitats and both land and marine species of conservation concern.
  - **A Waste Dispersion sub-model** appropriate for large-scale multi-site analysis was developed in the form of a footprint model. Not all fish farm hydrological data was available and so only a small number of sites in the study area were modelled.

- The majority of the data used for these sub-models was sourced from internet sources and relevant governing agencies. Development of the spatial database was, as always, a lengthy process. Most data was supplied in varying formats and projections which needed conversion
before incorporation into the database. All data was geo-referenced to UTM-29n.

- To address aquaculture siting on a holistic level both the cage suitability and biodiversity sub-models were combined to create a final outcome of aquaculture site location using physical and biological criteria.

- These sub-models and overall final model address many current issues in aquaculture cage siting in an informative and coherent way. This approach is easily adaptable to the whole of the Scottish coastline, given the appropriate data, and with the ability to integrate additional data and model aspects as specifically relevant to individual study areas.

**Outcomes**

- The cage suitability model for the Western Isles modeled cages was designed for sheltered, semi exposed and exposed locations. The model results show that the most appropriate type of cage for the Western Isles is that designed for exposed regions. The model also assessed how well located current fish farm installations were. It was found that the majority of cages used were designed for semi-exposed regions and on the whole are sited appropriately.

- The biodiversity sub-model highlighted certain areas of high biodiversity, particularly Loch Roag, West Loch Tarbert, Loch resort, Loch Maddy and the Sound of Barra. Within the biodiversity sub-model constraint layers, (i.e. fishing and fish nursery areas) were also developed which demonstrated the capability of the sub-model to reflect current developments in legislation.

- The waste dispersion model showed how well relevant multi-site modelling and large scale modelling can be achieved within a GIS environment. The model gave deliberately conservative results and showed that solid waste dispersion has a relatively local impact extending, in most cases, up to 45m from the edge of the cage array. Although some aspects of this model are still being developed and assessed this is a solid basis on which to develop a multi-site model.

- The Overall model combines the Cage suitability sub-model and the Biodiversity sub-model to give an integrated outcome based on these aspects of site selection for decision makers. This enables policy decisions and “trade-offs” between parameters to be assessed. The end result achieved is a set of high level and holistic development tools.

**General conclusions**

- The great strength of this GIS-based model is that it uses ranking and weighting of variables which can allow regulators and environmental managers the flexibility to appropriately fine-tune the decision-making rules for different areas.

- All sub-models and models are written as macros which can be easily edited, modified and re-run to reflect changing opinion, regulation or legislation. The sub-models have been developed within a graphical environment that allows the construction and execution of multi-step models. The advantage of this method is that it allows batch processing (running many inputs through the same model to produce many outputs) and dynamic modelling (using the output of one iteration of a model as an input into the next iteration). Both these aspects of the Macro modeller are a strong tool in the implementation and process of modelling. In addition, these sub-models can be run as free-standing models or in combination with other sub-models developed now or in the future.

- These tools could be further developed for the whole of the Scottish coastline and have the potential to be made available via the Internet.

- The GIS models developed are discussed within the framework of an overall conceptual model for the development and management of aquaculture incorporating on-farm technology, ecosystem, society and policy components (Institute of Aquaculture, unpublished)
Project Report to SARF
As a guide this report should be no longer than 20 sides of A4. This report is to provide SARF with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow SARF to publish details of the outputs. This short report to SARF does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication.

The report to SARF should include:
- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and any action resulting from the research (e.g. IP, Knowledge Transfer).

References to published material
This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project (the box below will expand).

Most of the macro models, which have been applied to the final decision support tool for SARF, were developed by the GIS group at the Institute of Aquaculture prior to this project. The following references refer to these:


Development of a GIS-based tool to assist planning of aquaculture developments

A report to
The Scottish Aquaculture Research Forum

Donna C Hunter
Trevor C Telfer
Lindsay G Ross

Institute of Aquaculture
University of Stirling
April 2006

© University of Stirling, UK
## Contents

<table>
<thead>
<tr>
<th>Part</th>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive Summary</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><strong>PART 1</strong> GENERAL INTRODUCTION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Introduction</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>2 Aquaculture in the Western Isles</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td><strong>PART 2</strong> GIS SUB-MODELS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Cage suitability model for the physical environment</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>4 Biodiversity model</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>5 Simple waste dispersion model</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td><strong>PART 3</strong> OVERALL MODEL OUTCOMES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Overall aquaculture site suitability model</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>7 Future Developments</td>
<td></td>
<td>51</td>
</tr>
<tr>
<td>8 References</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>Appendix</td>
<td></td>
<td>56</td>
</tr>
</tbody>
</table>
Executive Summary

Introduction

- In March 2005 the Institute of Aquaculture, University of Stirling, commenced an R&D contract entitled “Development of a GIS-based tool to assist planning of aquaculture developments”. The project has been part funded by SARF, with additional resource input from the Institute of Aquaculture.

- The project undertook to develop a preliminary GIS-based tool encompassing a case study area, which can model the actual and/or future implications of fish farms on environmentally sensitive parameters, areas or places of conservation interest in the coastal area of Scotland. The intention is that the tool(s) could be further developed for the whole of the Scottish coastline.

- There were a number of interim objectives:
  - Map sites through GIS which are environmentally sensitive and of conservation importance in relation to aquaculture location using existing databases and available information.
  - Implement modelling through GIS using dispersal models to investigate the impact of fish cages on these sensitive habitats.
  - Formulate "what-if" scenarios to look for alternative sites for existing and future fish farm developments.
  - Rationalize the results from sensitivity mapping, environmental impacts modelling and "what-if" scenarios to develop a final decision support tool for use by trained personnel at appropriate organizations, and in a format that could be developed into a web-based system in the future.
  - Provide a training workshop on the use of the initial tools developed through the project.

- The Western Isles was selected as the case study area because the conditions for productive and successful fish cage aquaculture are favourable and this has led to a large and well established industry, within a discreet geographical area. In addition, the Islands are host to numerous internationally recognised protected habitats and species.

Approaches to model development

- A conceptual model was developed for Western Isles aquaculture in which three initial principal sub-models were selected:
  - A cage suitability sub-model was developed to address the importance of siting different types of cage technologies based on their physical design capabilities. This sub-model incorporated the previously identified important criteria of Currents, Bathymetry and Wave Climate. As a prerequisite for the cage suitability sub-model a wave climate sub-model was developed based on previous work at Institute of Aquaculture
  - A Biodiversity sub-model was developed in order to identify ecologically sensitive habitats and both land and marine species of conservation concern.
  - A Waste Dispersion sub-model appropriate for large-scale multi-site analysis was developed in the form of a footprint model. Not all fish farm hydrological data
was available and so only a small number of sites in the study area were modeled.

- The majority of the data used for these sub-models was sourced from internet sources and relevant governing agencies. Development of the spatial database was, as always, a lengthy process. Most data was supplied in varying formats and projections which needed conversion before incorporation into the database. All data was geo-referenced to UTM-29n.

- To address aquaculture siting on a holistic level both the cage suitability and biodiversity sub-models were combined to create a final outcome of aquaculture site location using physical and biological criteria.

- These sub-models and overall final model address many current issues in aquaculture cage siting in an informative and coherent way. This approach is easily adaptable to the whole of Scottish coastline, given the appropriate data, and with the ability to integrate additional data and model aspects as specifically relevant to individual study area.

**Outcomes**

- The cage suitability model for the Western Isles modeled cages designed for sheltered, semi exposed and exposed locations. The model results show that the most appropriate type of cage for the Western Isles is that designed for exposed regions. The model also assessed how well located current fish farm installations were. It was found that the majority of cages used were designed for semi-exposed regions and on the whole are sited appropriately.

- The biodiversity sub-model highlighted certain areas of high biodiversity, particularly Loch Roag, West Loch Tarbert, Loch resort, Loch Maddy and the Sound of Barra. Within the biodiversity sub-model constraint layers, i.e. fishing and fish nursery areas were also developed which demonstrated the capability of the sub-model to reflect current developments in legislation.

- The waste dispersion model showed how well relevant multi-site modelling and large scale modelling can be achieved within a GIS environment. The model gave deliberately conservative results and showed that solid waste dispersion has a relatively local impact extending, in most cases, up to 45m from the edge of the cage array. Although some aspects of this model are still being developed and assessed this is a solid basis on which to develop a multi-site model.

- The Overall model combines the Cage suitability sub-model and the Biodiversity sub-model to give an integrated outcome based on these aspects of site selection for decision makers. This enables policy decisions and “trade-offs” between parameters to be assessed. The end result achieved is a set of high level and holistic development tools.

**General conclusions**

- The great strength of this GIS-based model is that it uses ranking and weighting of variables which can allow regulators and environmental managers the flexibility to appropriately fine-tune the decision-making rules for different areas.

- All sub-models and models are written as macros which can be easily edited, modified and re-run to reflect changing opinion, regulation or legislation. The sub-models have been developed within a graphical environment that allows the construction and execution of multi-step models. The advantage of this method is that it allows batch processing (running many inputs through the same model to produce many outputs) and
dynamic modelling (using the output of one iteration of a model as an input into the next iteration). Both these aspects of the Macro modeller are a strong tool in the implementation and process of modelling. In addition, these sub-models can be run as free-standing models or in combination with other sub-models developed now or in the future.

• These tools could be further developed for the whole of the Scottish coastline and have the potential to be made available via the Internet.

• The GIS models developed is discussed within the framework of an overall conceptual model for the development and management of aquaculture incorporating on-farm technology, ecosystem, society and policy components (Institute of Aquaculture, unpublished)

• The existence of these free-standing tools means that it is currently possible to successfully meet the training objective of the project. However, the committee do not propose to take this training option further and it has been decided that it would be more beneficial to hold a wider meeting of all parties concerned in marine and coastal management and aquaculture to assess this area of work
PART 1 – GENERAL INTRODUCTION

1. Introduction

Intensive farming of fish and shellfish in Scotland is presently under review regarding its location and mode of environmental regulation. Impacts of aquaculture, including the introduction of nutrient and chemical waste into the environment, may have significant implications for the surrounding water and sedimentary environments, especially on localized species and habitats. Many of the coastal habitats around Scotland are designated as sensitive to environmental impact under the Natura 2000 programme. Furthermore, implementation of the Water Framework Directive requires the maintenance of high water quality standards taking full account of the effects of (fish farming) activities on chemical, biological and morphological features. Consequently, a structured approach to selection of sites for aquaculture development and the potential relocation of farm sites within sensitive areas is paramount. A tool, or tools, is required which will enable existing data on species and habitats of conservation and other importance (see SNH database) to model for site selection and aquaculture management factors, taking into account potential impacts on these environments. In addition development of such tools may prove useful to the future development of spatial tools to store and process environmental information as required under the forthcoming implementation of the EC Water Framework Directive (WFD).

This work is extremely important within Scottish aquaculture as present regulation and site selection for aquaculture sites, by statutory organisations, depends on the implementation of exclusion areas, areas of calculated sensitivity and estimation of general impacts to the surrounding environment through dispersal modelling. However, this approach while useful does not easily allow for locally sensitive issues and sites to be taken into account. A GIS-based system would use and build existing data and spatial models into a single site selection modelling system, covering such selection criteria as nutrients inputs; considerations from both the marine and terrestrial environments, such as proximity to tourism areas; other uses of the environment and transport infrastructure, and incorporate ecological information such as biotopes.

The management of coastal aquaculture in relation to areas of an environmentally sensitive nature or conservation interest is largely dependent on effective site selection (Gillibrand et al., 2002). A considerable amount of quantitative data and qualitative information is required for fish farm site selection procedures to be completed satisfactorily. As much of this data is spatial in nature, it can be integrated within spatial models using an approach based on Geographic Information Systems (GIS) (Ross et al., 1993). Further, the interaction between this information can be modelled through GIS to develop a decision support system (DSS) for coastal aquaculture (Aguilar-Manjarrez and Ross, 2000; Nath et al., 2000).

GIS has been used successfully in the past for the development of aquaculture management systems under a variety of conditions; Mexico (Aguilar-Manjarrez and Ross, 1995), Bangladesh (Abdus Salam et al., 2000), Brazil (Beveridge et al., 2000) and Tenerife (Perez et al., 2005). Perez et al. successfully integrated water quality parameters (Perez et al., 2003a), the physical environment (Perez et al., 2003b), socio-economic measures, such as tourism and subjective information (e.g. visual impact) (Perez et al., 2003c). These systems have been instrumental within each of these countries in formulating aquaculture management policy and in directing much of the current and future research on site selection activities. Importantly, the Food and Agriculture Organisation (FAO) recognize the importance of GIS and are instrumental in promoting its use in aquaculture and fisheries management and planning (Graaf et al., 2003).
In the Scottish and UK context, GIS has been used extensively for storage and presentation of spatial information, in the forms of inspectable databases and maps for landscape characterization (SNH/CA, 2004) and land use monitoring. This system has also been used extensively for recording and relating aquatic environments in terms of biotope mapping and estimating their sensitivity to anthropogenic change, e.g. using data collected from the MarLIn project (MarLIn, 2004). Reports from the Fisheries Research Services (SEERAD) giving guidelines for locations of coastal aquaculture in Scotland (FRS, 2002) also give information on spatial distribution of nutrient enhancement of the environment from fish farms. The provision of a GIS system which could then be adapted for general use through the Internet, will allow more open environmental regulation by allowing both regulators and the industry (and potentially the public) to take part in the decision making process and judge whether the requested location of a fish farm is appropriate, or even to pre-select areas appropriate to different types of aquaculture or aquaculture systems.

The objective of this research is to develop a preliminary GIS-based tool for a case study area, which can model the actual and/or future impacts of fish farms, in relation to other physical and ecological factors on environmentally sensitive parameters, and areas or places of conservation interest in the coastal area of Scotland. This tool could be further developed for the whole of the Scottish coastline through specialized GIS programs and WWW tools. The initial objectives of this study were to:

1) Construct a spatial database appropriate for analysis and modelling of environmentally sensitive areas and areas of conservation importance in relation to aquaculture location using existing databases and available information.

2) Implement GIS-based modelling through using existing sub-modes on wave climate, waste dispersal, etc, to investigate the preferred location and subsequent impact of fish cages on these sensitive habitats.

3) Formulate "what-if" scenarios to look for alternative sites for existing and future fish farm developments.

4) Rationalize the results using sensitivity mapping, environmental impacts modelling and "what-if" scenarios to develop a final decision support tool or tools for use by trained personnel at appropriate organizations, and in a format that could be developed into a web-based system in the future.

5) Provide training in the use of the initial tool(s) developed through the project.

The interim objectives outlined above are interrelated and all form part of the overall objective, to produce a GIS-based decision support tool. The development of the tool will be dependent on completion of interim objectives 1) and 2). Testing of the model and its effectiveness in its implementation will be discovered through interim objective 3).

Three types or layers of models are used to give an overall suitability model for different aquaculture cage technologies. These are GIS layers based on:

- The physical environment
- Environmental biodiversity and sensitivity
- Aquaculture waste dispersion from cages

These sub-models are combined into an overall aquaculture suitability model as shown in Figure 1.1, which defines a grading of suitability for aquaculture throughout the Western Isles. The grading of suitability can be used as a decision support system for environmental managers and regulators for the effective siting and management of aquaculture systems. This type of model has the potential for expansion in both geographical terms and information terms, allowing more sub-models on other factors to be developed for other aspects of Scottish aquaculture.
The component sub-models in Fig. 1.1 originate from projects already developed at the Institute of Aquaculture, Stirling.

Figure 1.1: Flow chart to show interactions of primary data, sub-models and the final site selection model.

Data Sources:

The primary data were amassed from a variety of sources including the Internet, Public databases and from national agencies (Appendix 1). These were obtained under a variety of licenses appropriate to the research. In some cases there was considerable delay or non-provision of data from key sources, including government agencies. Some data were of poorer quality than claimed and had to be rejected.
2. Aquaculture in the Western Isles

Following the introduction of aquaculture to the Western Isles in the 1970’s, there has been rapid expansion. Currently there are eighty-seven active farm sites and numerous more consented areas. Aquaculture has brought many benefits to the fragile communities of the Western Isles both economical and social. While the environmental conditions are favourable for salmon farming with the vast majority of cage farms culturing this species a few also farm halibut and cod. Areas with the most favourable conditions for culture mainly occur in the large sea lochs and are utilized extensively (Figure 2.1). In the Western Isles farm size (biomass) varies greatly from low production less than 100t maximum allowable biomass (MAB) to larger operations with high production at nearly 2000t MAB, Figure 2.2 shows the biomass category consented by SEPA for each active site for the Western Isles. Cage aquaculture relies heavily on the coastal environment and resources and its growth the Western Isles has raised several issues of concern; particularly the potential for harmful impact from discharge of chemicals used for stock treatment and the effect of escaped farmed fish on the genetic diversity of wild stocks.

Figure 2.1: Location of all 87 currently active fish farms for the Western Isles; including detail of Loch Roag.
The industry has recognised and worked in co-operation with all relevant bodies to mitigate any possible impacts of its activities. As a result, there have been a series of initiatives involving the Scottish Executive and other key players to examine many of the issues that face the industry. This includes its interaction with the environment and its potential impact upon wild salmonid stocks.

Figure 2.2: Biomass classification of marine cage farms in the Outer Hebrides. 1 green 0-500t, 2 blue 500-1000t, 3 yellow 1000-1500t and 4 red 1500-2000t. For clarity, box A shows the farm sites displaced from the general map of the Western Isles in Box B.
The following three sub-models—cage suitability model, biodiversity model, and dispersion model—were all developed through GIS macro modelling. Macro models are free-standing tools with extreme flexibility allowing the user to access a wide range of possibilities to address different issues. Their greatest strength is the ease by which “what-if” scenarios can be built. Throughout this study choices have been made on the technologies, sensitive species, and areas of concern incorporated into the model. These choices can be altered in response to other needs, for example, the wave climate model lends itself to assessing the practicability of farming conditions and farm management issues. For example, assigning areas where it would be save or unsafe to carry out bath treatments for a high percentage of the time due to wave conditions. The proactive nature of the macro models allows almost any “what if” scenario to be addressed.

### 3. Cage Suitability Model

#### 3.1 Introduction

With the implementation of the EC Water Framework Directive requiring the maintenance of high water quality standards taking full account of the effects of activities on chemical, biological, and morphological features, fish farming has to adopt a much more structured approach to site location. Fish farming in the Western Isles has blossomed over the past ten years and shows no sign of slowing down. Judgments on fish cage site selection are often based on very little scientific background. The following Suitability Model for fish cage suitability is the nucleus of a structured GIS model for the process of location and guidance on future aquaculture development. Defining areas of suitability for fish farming is of great importance all cages have tolerance levels and are designed to cope with varying levels of weather conditions. Ensuring that cages are sited appropriately for the particular cage systems and designs is fundamental for long term operability while maintaining a high level of safety for operators.

#### 3.2 Important Factors for Suitability Mapping

Three major factors were used in identifying suitable areas based on predefined variables identified by Ross et al. (1993) and Perez et al. (2002) as being primary drivers behind fish cage siting, 1- wave climate, 2- water depth and 3- currents.

##### 3.2.1 Wave Climate

This factor is most important. The wave climate is the general condition of sea state at a particular location, the principal elements of which are the wave height, period parameters, and the wave direction. Recently, the importance of wave climate models was highlighted particularly for the Western Isles “Adequate specification and siting of salmon farm installations in respect of hydrological, in particular wave climate” (WIAA, 2005) as all marine and coastal activities must be able to contend with the state of the sea. The sea state of the Western Isles is sensitive to the North Atlantic Oscillation. This sensitivity can be seen
extending to the more sheltered Sea of the Hebrides. It is important to define the wave climate that the Western Isles experiences and harness that knowledge when creating a suitability map for the Western Isles. Using a model developed by Scott (2003) as a basis, bathymetry, wind speed and wind fetch data, were used to develop a model that simulated extreme / critical wave heights (Fig. 3.1).

Figure 3.1: Wave Climate model for the Western Isles

1 It should be remembered that the GIS model outputs are dynamic, multiscaled and designed to be seen on the computer screen, not fixed to a page. The visual results given in this report normally show the whole of the Western Isles, the same models give results on a very local scale which can be “zoomed in” upon on a computer screen.
3.2.2 Depth

Depth also requires detailed consideration for cage suitability as it has an influence on net size, anchorage system and anchoring method. Cages may be easily damaged in shallow water, whereas mooring systems needed for deeper waters may become limiting, giving a greater risk of losing stock.

3.2.3 Currents

This factor is extremely important as not only can it affect the productivity of a cage but it can also adversely affect the cage structure. Unfortunately sufficiently detailed data on currents and water movement over the Western Isles area could not be supplied commercially (ex Seazone Ltd). It was thus necessary to digitize the less detailed but still useful current data made available by NERC in UKDMAP. This current data are distinct from the more localised and highly detailed information used for the dispersion modelling.

3.2.4 Fish Farm Cages

Selection of the appropriate cage technology is dependent upon a number of factors including economics (capital and operating costs), biological factors (water exchange and quality, productivity), engineering (structural integrity and longevity) (Linfoot et al, 1990) and the locality in which the cage is to be placed. As the wave climate of the Western Isles is highly variable, there are several cage options which can be considered for use there, ranging from those designed for sheltered bays to cages designed for exposed offshore locations.

Kames Fish Farming Ltd (KFF) is a Scottish company that designs and manufactures a range of fish cages for different conditions. KFF have been supplying fish farming equipment and aquaculture systems and services to the fin fish and shellfish industry worldwide for over 25 years. KFF produce different type of cages to withstand different environmental conditions. Good guidelines are published by the manufacturer on environmental limits which their cages can withstand. Therefore examples of KFF cages were used as the basis of the suitability modelling to represent the different technologies available. From the range of cages manufactured by this company three were chosen; Large Modular Square cages (LMS) designed for sheltered locations currently used for salmon broodstock and salmon ongrowing in Scotland (shown in Figure 3.2); Circular 250 (C250) cages designed for ongrowing in fresh or saltwater in semi-exposed conditions, currently used in Scotland for trout, salmon and halibut farming (Figure 3.3); and Circular 315 cages (C315) for ongrowing in exposed and offshore conditions (Figure 3.4). The latter are not used in Scotland at present but there is potential to use this technology for the development of offshore sites in the future. Table 3.1 displays the manufacturers’ guidelines for the three cage systems chosen along with addition data.
Table 3.1: Manufacturers guidelines and product information (Kames Fish Farming Ltd)

<table>
<thead>
<tr>
<th>Cage type</th>
<th>Max wave Height (m)</th>
<th>Max current (Knots)</th>
<th>Cubic capacity (m³)</th>
<th>Locations Used</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMS</td>
<td>1.5</td>
<td>1.4</td>
<td>144 – 625</td>
<td>Greece, Scotland</td>
<td>Seabream, Sea bass, Salmon broodstock and salmon ongrowing</td>
</tr>
<tr>
<td>C250</td>
<td>3.5</td>
<td>1.6</td>
<td>700 – 800</td>
<td>Greece, Scotland</td>
<td>Bream, Bass, Trout, Salmon and Halibut</td>
</tr>
<tr>
<td>C315</td>
<td>6</td>
<td>1.8</td>
<td>3,000 – 17,000</td>
<td>Gran Canaria, Chile</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.2: Example layout of 12 x12 cages showing typical walkway dimensions and float position of KFF L M S cage. (after Kames Fish Farming Ltd)
Figure 3.3: Layout of KFF C 250 fish cages. (after Kames Fish Farming Ltd)

Figure 3.4: KFF C315 fish farm cage with cubic capacity of 3,000m³ to 17,000m³. (after Kames Fish Farming Ltd)
3.3 Results

3.3.1 LMS Cage Suitability Model

For the Large Modular Square suitability model (see Figure 3.5) ideal locations are restricted to inshore sea lochs to an area of approximately 69km$^2$. The most appropriate location for this type of cage is in Loch Seaforth, while Loch Leurbost, Loch Erisort and several small areas of Benbecula all show favourable conditions. As for Loch Roag, the physical climate restricts siting of this type of fish cage except within the innermost parts.

Figure 3.5: Cage Suitability Model for KFF Large Modular Square cages. 
Maximum suitability = 10.
3.3.2 C250 Cage Suitability Model

The Circular 250 fish cages are designed for semi exposed locations. It is calculated from the model that an approximately 257 km$^2$ of inshore waters offer favourable conditions for this type of cage in the Western Isles (Figure 3.6). Most of these areas can be seen in the sea lochs and some open coastal areas. Again Loch Seaforth, Loch Leurbost and Loch Erisort show favourable conditions, while West- and East Loch Tarbert and Loch Resort also show suitable locations. Loch Roag has a more extended suitable area compared to that for the LMS model. Lastly areas of North Uist and Benbecula also appear favourable.

![Figure 3.6: Cage Suitability Model for KFF Circular 250 cages. Maximum suitability = 10.](image)

Figure 3.6: Cage Suitability Model for KFF Circular 250 cages. Maximum suitability = 10.
3.3.3 C315 Cage Suitability Model

The circular 315 cage is designed for exposed regions and as such it shows the greatest area of favourable conditions of the three cages modelled at approximately 507 km$^2$ (Figure 3.7). Almost the entire coastline apart from Northern Lewis shows favourable conditions while most outer parts of sea lochs are extremely favourable. The depth of the nets designed for these cages (15 - 25 m) restricts their ability to be placed in shallow sea lochs.

Figure 3.7: Cage Suitability Model for Kames Circular 315 cages. 
Maximum suitability = 10.
Currently active cage fish farms are mostly based on semi-exposed designs and although most do not use KFF cages, there are many similarities between them and the cages used. Thus overlaying the locations of present aquaculture farms within the C250 cage suitability model shows that currently almost all farms are located within areas that are suitable for this cage type (Figure 3.8).

Figure 3.8: Current active fish farm locations (indicated as cyan dots) overlaid on the C250 cage suitability model. Maximum suitability = 10.
3.4 Discussion

A recent pilot study on site optimization for Loch Roag (WIAA, 2005) highlighted that “adequate specification and siting of salmon farm installations in respect of hydrological in particular wave climate” should be taken into account. The cage suitability model designed and implemented here for the Western Isles not only achieved this, in creating a wave climate model for the whole of the Western Isles, but also developed cage suitability models based on manufacturer’s guidelines. These physical suitability models indicate that the current locations of the active fish farms are on the whole appropriate. When considering present and future deployment of fish cages, such as those suggested in the Loch Roag site optimization plan, the positioning of the cages should be guided by these types of models. This will enable the correct technology to be used in the most appropriate environments thus ensuring long term site viability (less cost of repair), creating a safer working environment, and minimizing escaped farmed fish through storm damage.
4. **Biodiversity Model**

4.1 **Introduction**

The preservation, protection and improvement of environmental quality, including the conservation of natural habitats and of wild fauna and flora are an essential objective of general interest pursued by the European Community (Directive 92/43/EEC). With this as an aim for the Western Isles it was important to identify the ecologically sensitive habitats, both terrestrial and marine species, of conservation concern. The data obtained is developed into an integrated GIS sub-model to create a Biodiversity model for the Western Isles.

4.1.1 **Quantifying Biodiversity**

An internationally accepted framework for the description of biodiversity was defined by the 1992 Convention on Biological Diversity (Warwick & Clarke, 2001). This outlines three components of biodiversity, “within species diversity”, “between species diversity” and “of ecosystems diversity” (www.ceaa-acee.gc.ca).

“Within species” diversity is the difference between specimens of the same species. This is of importance for aquaculture and fisheries as these activities constantly use the same species of fish and yet require the best traits in these species. Genetic markers may be the only way of determining the different genetic traits in the same species and in a wider context of diversity this could be impractical. Nevertheless, the diversity of a species in a wider area could be useful for measuring diversity as, in theory, species with a wide genetic diversity are more adaptable to change and could exploit a greater range of habitats whereas a species with less genetic diversity could be more specific to a certain habitat. (www.ceaa-acee.gc.ca).

“Between species” diversity is the diversity of species in a sample of a certain area. This is the most widely used way of measuring biodiversity in an area and there may often be a lot of disparate data already present and available on species counts for a given area. A wide array of diversity measures can be used along with assessment of certain features of a particular species e.g. endangered species can be of use in quantifying biodiversity between species.

“Of ecosystem” diversity considers the features of an ecosystem, such as temperature, bathymetry or salinity. The diversity of ecosystems can be useful for conservation of biodiversity, as a very diverse ecosystem can hold a wide range of species. By identifying ecosystems of greater diversity, areas that are important for nature conservation can be highlighted. The issues surrounding measurement of ecosystem diversity are that it is difficult to practically measure all the variables of an ecosystem and that there are many different techniques used when sampling data, which can make it difficult to compare the biodiversity of different ecosystems (www.ceaa-acee.gc.ca).

From the many indices that are used to measure biodiversity, none are widely accepted as the rule. Most frequently, the decision is a practical one in which an index is chosen to meet the criteria and objectives of a particular study and which takes into consideration the availability of datasets. Primarily, it is necessary to consider factors of biodiversity and decide which of these are important for a given study; an index then can be chosen based on this. It is then necessary to ensure that the available data will fit the chosen index. Importantly, it is frequently necessary to use more than one index to describe the biodiversity of an area.
4.1.2 Marine Biodiversity indices

The marine environment holds a greater range of diversity than the terrestrial one and there are 14 animal phyla which are endemic to the marine environment (Warwick & Clarke, 2001). Consequently, measuring the biodiversity of the marine environment can be a more difficult task than measuring the diversity of the terrestrial environment.

Hiscock, (1997) outlined the factors, which need to be taken into account when considering measuring and conserving biodiversity in the marine environment. These can be summarised as follows:

- **Representativeness** - conserving biodiversity based on protecting representative examples from a range of habitats, using biotopes to classify representative areas.

- **Diversity** - the most commonly used method of measuring biodiversity, through the diversity between species in a certain area.

- **Risk of extinction** – the IUCN red list consists of categories from “critically endangered” to “vulnerable” which are a framework of the risk of extinction of different species, therefore highlighting the species that need to be protected (www.redlist.org).

- **Rarity** - the public perception of biodiversity is that conservation of rare species, habitats and communities, is an important part of biodiversity, yet it is hard to quantify in measurable terms. (www.redlist.org).

- **Sensitivity** – there are many factors that make a species sensitive (susceptible to pollution, unable to move away) this needs to be considered when a new activity takes place in an area, as sensitive species will be affected to a greater extent.

- **Dependency** – the dependency of a species, community on a certain location, this is more important if there are few alternative locations for the species, community.

- **Irreplaceability** – communities or species that if destroyed will not be capable of replacement. These need to be seriously considered for conservation.

- **Naturalness** – conservation is considered important in areas that are natural and have no man-made features i.e. pollution, non-native species. This is less of a problem in the marine environment as most of it is natural.

- **Extent** – sites with greater diversity or more biotopes in the smallest area will be considered for conservation, as the management of an area for conservation has to be viable.

4.1.3 Indices used

For reasons of data availability and practicality, not all biodiversity indices could be considered in this study. Those that were used are summarized below:

**Endangered species**

Endangered species are an important characteristic of biodiversity, as extinction of a certain species will effect the composition of overall biodiversity. The IUCN red book is a list of endangered species specified via a set of threshold parameters such as; distributional range, population size, population history as well as risk of extinction. However imperfect knowledge of the marine realm infers this data may be incomplete (Akcakaya et al, 2000,
Species which may be sensitive to aquaculture

Due to the range of different aspects of aquaculture one important feature of biodiversity to include is species which could be sensitive to aquaculture. Some species are more likely to be damaged by aquaculture than others. Marine Life Information Network has set up a database illustrating the species predominantly at risk from aquaculture practices. The database is constructed on the perception that a specific activity will impact on the environmental factors surrounding it, by defining species which are affected by these changes in the environment they have a list of species which are sensitive to that specific activity (www.marlin.ac.uk). The list of species which could be sensitive to aquaculture according to the Marlin database was utilized to illustrate the distribution of these species over the study area.

Diversity Indices

The project combined the use of seabed sediment biotopes and diversity indices for the area of the Outer Hebrides. Sediment biotopes were created from available benthic data on the communities present for each sediment type, assuming that sediment type or particle size is key in determining the community found (Eleftheriou & Basford, 1989). Many authors, through a variety of indices have suggested the measurement of diversity via a quantitative technique. Two indices were selected for the purpose of the study; these are the Shannon-Weiner index (all so referred to as the Shannon index) and the Simpson’s Index.

Type I heterogeneity measures are mainly sensitive to changes in rare species in the community sample, an example of a type I index is the Shannon-Weiner function (Peet, 1974). Measures the uncertainty of what species will be picked next at random from a sample i.e. a greater diversity in a sample gives more uncertainty of the next species. There is scepticism over the worth of this measure especially when relating it to the marine environment yet it is still the most widely used index for measuring diversity and produces practical quantitative results (Gray, 2000 and Krebs, 1989).

Type II heterogeneity measures are more sensitive to the changes in the more abundant species; the Simpson’s index is an example of a type II index (Peet, 1974). It calculates the probability that two species picked from random in a sample will belong to the same species. The usefulness of this measure is reduced due to its ignorance of rare species within the community (Mangurran, 1988; Krebs, 1989).

The purpose of this part of the study was to create a spatial database representing biodiversity for the area of the Outer Hebrides to help determine placement of aquaculture sites in relation to biodiversity.

4.2 Methods

4.2.1 Sources of data

Table 4.1 shows the sources and type of data used for the biodiversity models. It was important to identify expert data and information regarding species which could be affected or be in conflict with aquaculture. The Marlin database met this requirement and additional information on species conservation status was sourced from the IUCN Red List of threatened species. While actual species presence was supplied through the National Biodiversity Network Gateway, suitable data on species was difficult to locate as many agencies held data but in an incompatible format. Within the short time period allotted it was not feasible to develop these data sets, although this would need to be addressed in future studies.
Table 4.1: List of data sources used for the biodiversity models.

<table>
<thead>
<tr>
<th>Data</th>
<th>Format</th>
<th>Source</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species present in 10Km squares of the ordnance survey grid.</td>
<td>Excel files (72 files in total for the study area).</td>
<td>National Biodiversity Network Gateway <a href="http://www.searchnbn.net">www.searchnbn.net</a></td>
<td>The area of the Outer Hebrides (NA, NB, NF, NG, NL).</td>
</tr>
<tr>
<td>Designated Protected Areas (Ramsar, SPA, SAC, SSSI, NSA)</td>
<td>GIS Polygon Vector layer.</td>
<td>Scottish Natural Heritage</td>
<td>The whole of Scotland.</td>
</tr>
<tr>
<td>List of species sensitive to aquaculture</td>
<td>Copied into Excel files.</td>
<td>Marine Life Information Network <a href="http://www.marlin.ac.uk">www.marlin.ac.uk</a></td>
<td>No specific area.</td>
</tr>
<tr>
<td>Vector layer of the coast of the Outer Hebrides</td>
<td>GIS Line Vector layer. Created at Stirling University</td>
<td>Edina Digimap</td>
<td>The area of the Outer Hebrides.</td>
</tr>
<tr>
<td>Map of sediment distribution</td>
<td>Paper print out</td>
<td></td>
<td>Around the coast of Great Britain</td>
</tr>
</tbody>
</table>

4.2.2 Organization of data

The Outer Hebridean Isles can be divided into 100 km² squares through the Ordnance Survey grid; the squares which cover this area are NA, NB, NF, NG, and NL. Each of these squares are then divided into 100 squares of 10km². 72 of these squares were utilized for the present project. The national biodiversity network (NBN) gateway [www.searchnbn.net](http://www.searchnbn.net) contains lists of species present in each of these 10 km squares. This information was utilized to create layers of species richness, endangered species and species which are sensitive to aquaculture. Initial development of these 10km squares highlighted the coarse nature of the data and the restrictions this would place on the interpretation of results. Using the extensive tools available within IDRISI this coarse data was enhanced and improved through surface interpolation. Interpolating a surface takes sample data points to create a full surface. The 10km squares were broken down by taking centre points and the four diagonals for each square. The point vector file created was then processed through the IDRISI modules TIN and TINSURF which creates a surface. TIN takes the vector point file and produces a triangulated irregular network. The TIN model is developed further in the module TINSURF to create a full raster surface.

The IUCN [www.iucnredlist.org](http://www.iucnredlist.org) contains data for all the endangered species in the world, this can be divided into separate countries, the list for endangered species in the United Kingdom was copied into an excel file. The list of endangered species was then checked against each of the species lists received from the NBN gateway to distinguish if any of the
endangered species were present in these 10 km squares. An EXCEL function was used to carry out this process.

4.2.3 Vector layer construction

The individual species vector layers were initially created in lat/long format as vector polygon files using the lat/long coordinates of each corner point of the 10 km squares.

4.2.4 Protected areas

The Western Isles is renowned for its variety of unique habitats and vast array of species. Numerous legislative protected areas recognize these facts. These range from international level such as Ramsar sites, SACs and SPAs to UK level NSA and SSSIs. Scottish Natural Heritage supplied vector layers in a plane reference system which was converted into the UTM 29n reference system.

4.2.5 Fish spawning and nursery grounds

Fish spawning and nursery grounds have been identified as a conservation priority area in many studies (Roberts et al., 2005). Identifying areas where life stage transitions take place are critical to a species population dynamics. Habitats or sites that are critical for several key species may attract a higher priority and this point is particularly relevant to the Western Isles where numerous commercially valuable species have spawning and nursery areas. For the Western Isles establishing where vulnerable life stages occur can identify areas requiring greater protection and this strategically placed protection can benefit the species concerned by improving habitat quality and feeding opportunities, as well as greater survival of offspring and protection at aggregation sites (Apostolaki et al. 2002; Roberts and Sargeant 2002; Norse et al., 2005).

CEFAS supplied data on thirteen commercially important fish for the whole of the UK. A map of important spawning and nursery areas was created by overlaying each species individual layer. This gives priority areas of where more than one species uses the habitat at vulnerable stages.

4.2.6 Endangered species

There are ten species present in the study area which are on the IUCN’s red list of endangered species. A vector polygon layer was created for each of these species illustrating their individual distribution for the Outer Hebrides. The module RECLASS was used to rank each layer on a scale of one to five depending upon the level to which each species is endangered. Table 4.3 illustrates a list of these classifications.

<table>
<thead>
<tr>
<th>Vector layers created</th>
<th>Classification</th>
<th>Layer Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>A sturio</td>
<td>Critically endangered</td>
<td>5</td>
</tr>
<tr>
<td>M margaritifera</td>
<td>Endangered</td>
<td>4</td>
</tr>
<tr>
<td>C maximus</td>
<td>Vulnerable</td>
<td>3</td>
</tr>
<tr>
<td>G morhua</td>
<td>Vulnerable</td>
<td>3</td>
</tr>
<tr>
<td>M aeglefinus</td>
<td>Vulnerable</td>
<td>3</td>
</tr>
<tr>
<td>V angustior</td>
<td>Lower risk /conservation dependant</td>
<td>2</td>
</tr>
<tr>
<td>E esculentus</td>
<td>Lower risk / near threatened</td>
<td>1</td>
</tr>
<tr>
<td>L lutra</td>
<td>Lower risk / near threatened</td>
<td>1</td>
</tr>
<tr>
<td>M arion</td>
<td>Lower risk / near threatened</td>
<td>1</td>
</tr>
<tr>
<td>R clavata</td>
<td>Lower risk / near threatened</td>
<td>1</td>
</tr>
</tbody>
</table>
4.2.7 Species which are sensitive to aquaculture

There are thirteen species present in the study area which are sensitive to aquaculture (MarLIN, 2004). Each species was individually located as a vector layer. The layer was then classified using the module RECLASS depending on how sensitive to aquaculture each species are, the layer ranks are shown in Table 4.4. These species are used without modification from the data available. This maintains objectivity. Local knowledge and expertise may contradict the published information and could be incorporated into later versions of the models.

Table 4.4: Classifications of species sensitive to aquaculture which are present in the study area

<table>
<thead>
<tr>
<th>Vector layers created</th>
<th>Classification</th>
<th>Layer Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>P calcareum</td>
<td>Very High</td>
<td>5</td>
</tr>
<tr>
<td>T gouldi</td>
<td>Very High</td>
<td>5</td>
</tr>
<tr>
<td>L coralloides</td>
<td>Very High</td>
<td>5</td>
</tr>
<tr>
<td>Z marina</td>
<td>Very High</td>
<td>5</td>
</tr>
<tr>
<td>L glaciale</td>
<td>Very High</td>
<td>5</td>
</tr>
<tr>
<td>O edulis</td>
<td>Very High</td>
<td>5</td>
</tr>
<tr>
<td>M modiolus</td>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>A nodosum</td>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>C glaucum</td>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>F quadrangularis</td>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>L incrustans</td>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>N mixta</td>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>N lapillus</td>
<td>High</td>
<td>4</td>
</tr>
</tbody>
</table>

4.2.8 Diversity indices

Vector layers were created using the Simpson’s Index and the Shannon-Weiner Index to calculate the diversity of the benthic fauna. Table 4.5 shows the result for both the Simpson’s and the Shannon-Weiner index for each sediment type. The data was then reclassified to convert the sediment type in the biotope vector layer to its calculated diversity measure for both the Simpson’s and the Shannon-Weiner indices. This created two more vector layers, the Simpson’s measure for the benthic fauna of the Outer Hebrides and the Shannon-Weiner measure for the benthic fauna of the Outer Hebrides.

Table 4 5: Simpson’s and Shannon-Weiner diversity indices for the four different sediment types used for the project.

<table>
<thead>
<tr>
<th>Sediment type</th>
<th>Simpsons</th>
<th>Shannon-Weiner</th>
</tr>
</thead>
<tbody>
<tr>
<td>4- Very Fine</td>
<td>0.84</td>
<td>3.41</td>
</tr>
<tr>
<td>3- Fine</td>
<td>0.89</td>
<td>3.55</td>
</tr>
<tr>
<td>2- Medium</td>
<td>0.92</td>
<td>4.13</td>
</tr>
<tr>
<td>1- Coarse</td>
<td>0.88</td>
<td>3.35</td>
</tr>
</tbody>
</table>

This clearly is a generalisation which will be improved in as more data becomes available, especially community level data for seabed habitats around the Western Isles, from which diversity scores may be calculated.
4.2.9 Raster layers

Raster layers were produced from the vector layer data. A blank raster layer was first formed using the spatial parameters for the study area. The POLYRAS module was then used to convert the polygon vector layer into the raster layers. Consequently for each of the vector layers created a raster layer was generated which had the appropriate study area and in UTM 29n format.

4.2.10 Models

The layers for both the endangered species and species sensitive to aquaculture were used in sub-models. From these five separate raster layers were produced, each representing different aspects of biodiversity;

- Protected Areas SAC, SPA, SSSI, Ramsar, NSA
- Commercially important fish spawning and nursery areas
- Distribution of endangered species
- Distribution of species sensitive to aquaculture
- Shannon-Weiner index for benthic fauna

These data were used to create a main model using multi-criteria evaluation (Figure 4.1). Two of the source layers were also reclassified and subsequently used as simple constraints (see below).

*Figure 4.1: Creation of Biodiversity model for the Western Isles using the five predefined diversity indices.*
4.3 Results

4.3.1 Fish spawning and Nursery Areas

The fish spawning and nursery areas layer (Figure 4.2) clearly shows the North Minch to be very important as spawning and nursery grounds. In addition, Loch Seaforth, Loch Erisort and Loch Leurport are priority conservation areas for commercially important species.

Figure 4.2: Areas which support vulnerable life stages for thirteen commercially important fish species. Maximum vulnerability = 18.
4.3.2 Protected Areas

Figure 4.3 illustrates the overlay of all five protected site layers. As no distinction is made between each protection type they are each given the same value 1. Thus, areas with more than one type of protective legislation order show with a higher number. For example North Harris is affected by four layers whereas Loch Maddy and the coast of South Uist have up to five layers within their areas.

Figure 4.3: Designated protected Areas
4.3.3 Endangered Species

Fig 4.4 shows the model of endangered species present within the study area. Ten endangered species were located at different points throughout the study area. The areas around south of Lewis and Harris have the highest numbers of endangered species, while the Butt of Lewis is the only area recorded as containing a species which is critically endangered (*Acipenser sturio*). The areas with lowest numbers of endangered species are mainly around Uist, Barra and the east and west of north of Lewis.

*Figure 4.4: Distribution of species present on the IUCN redlist of endangered species for the area of the Outer Hebrides. Maximum endangerment = 9.*
4.3.4 Species Sensitive to Aquaculture

The distribution of thirteen different species found within the study area which are thought to be sensitive to aquaculture is represented in Fig 4.5. In contrast to the distribution of endangered species, the areas with highest numbers of sensitive species are North and South Uist and Loch Roag. These are the areas where the highest species richness occurs, suggesting a correlation between both factors. The areas of lowest number of sensitive species are south of Barra and some sites along the coast of Lewis.

Figure 4.5: Distribution of species sensitive to aquaculture according to the MarLIN database for the area of the Outer Hebrides. Maximum sensitivity = 38.
4.3.5 Diversity Indices

The Shannon-Weiner and the Simpson’s index measurements based on the sediment data are shown in Figures 4.6 and 4.7 respectively. Higher values indicate increasing diversity for both models. The Shannon-Weiner index shows a greater variation in diversity between sediments than the Simpson’s index.

*Figure 4.6: Distribution of benthic diversity according to the Shannon-Weiner index of diversity x10, for the area of the Outer Hebrides.*
Figure 4.7: Distribution of benthic diversity according to the Simpson’s index of diversity x100, for the area of the Outer Hebrides.

Three main areas which have a greater benthic diversity are highlighted from these layers. In the east and west of Lewis and Eriskay, the sediment present in these areas is medium. The areas with least diversity are different for the two indices. The Shannon-Weiner Index highlights the Butt of Lewis and the southern tip of Barra, where the sediment type is very coarse and mobile, as having lower infaunal diversity. The Simpsons index illustrates that very fine sediments have the lowest infaunal diversity; these areas are present in many sea lochs of Lewis, predominantly on the east coast.
4.3.6 Biodiversity Modelling

Multi-criteria evaluations (MCE) were carried out to create a model of biodiversity in the Outer Hebrides. Figure 4.8 shows the result from the MCE.

*Figure 4.8: Overall Biodiversity model for the Western Isles. Maximum diversity = 20.*

All biodiversity indices were given the same weighting in the MCE. As can be seen from this map areas with highest biodiversity can be found in numerous parts of the Western Isles from Loch Roag on the West of Lewis, while over on the east of Lewis Loch Leurbost, Loch
Erisort and Loch Seaforth exhibit high biodiversity. High biodiversity can also be found at West Loch Tarbert, Loch resort, Loch Maddy and the sound of Barra.

4.3.7 Biodiversity Constraint Sub-models

Use of data layer as constraints within MCE allows exclusion of areas in which no development can be allowed. Such areas are usually policy-based and may include anything from shipping lanes to environmentally sensitive areas. Figs 4.9a,b, show examples of areas which may be used as constraints in a spatial model. The modelling is flexible in terms of future policy guidelines. For example, at present there are no defined policies or guidelines referring to biodiversity. If this situation were to change which it most certainly will, these changes could easily be incorporated into the model. For example, as SNH and the other bodies concerned highlight the need for marine parks in the future.

![Figure 4.9: Boolean constraint layers. Black areas highlight high priority conservation areas in relation to – A) spawning and nursery areas of commercially important fisheries species, B) species sensitive to aquaculture](image)

An example of the value of these constraints within the models is the importance of commercial fisheries within the Western Isle. By mapping and constraining these areas no aquaculture would be assumed to occur in these locations. Equally, constraints on fish farming near maerl beds are modelled as these as particularly sensitive to aquaculture. The results of this type of modelling can be seen further in Section 6.
5. Simple Waste Dispersion Model

5.1 Introduction

The Western Isles has what are believed to be extremely favourable conditions for aquaculture which has lead to a rapid and increasing level of aquaculture activity. However with this successful production questions have been raised about the environmental concerns and the possible negative ecological impacts. There is a greater need to allocate aquaculture to suitable locations which do not cause conflict with native species or conservation areas and lastly to avoid, minimise and manage undesirable effects on the surrounding environment.

This section will concentrate on incorporating a simple particulate waste dispersion model into the GIS model. Environmental managers have pointed out the necessity of minimizing environmental impacts if productivity is to be sustainable (Scottish Exec, 1999). There are a variety of wastes released into the environment from fish farm sites, with a significant fraction being particulate organic waste in the form of uneaten feed and faeces (Beveridge, 2005). An important consequence of the distribution of this waste is a footprint of waste organic matter from each cage site. Although different opinions have been expressed about both the magnitude and type of aquaculture effects, consensus exists that the gradient of diminishing impact varies from location to location, and that in the worst case scenario, the sediment environment under cages can become anoxic (Iwama. 1991; Karakassis et al, 1999). While such impacts are extreme, they are also highly localised and are less likely to be significant at regional scales than any more subtle effects that extend hundreds of meters out from farm sites. Distribution models for organic waste from aquaculture can be used to predict possible impacts on the environment, helping environmental regulators to make informed decisions when licensing new marine fish farm developments and granting consent to discharge waste.

Models of dispersion of fish farm waste have been under development at the Institute of Aquaculture since the early 1990s. The model for dispersion of particulate wastes has developed through a series of stages, from complex spreadsheet models of particulate waste dispersion (Telfer, 1995), through a simple adaptation of the spreadsheet models’ structure for use with GIS (Perez et al, 2002) to a fully integrated GIS dispersion model (Corner et al, 2006) for incorporation into coastal zone models. In addition, there are a variety of other quantitative models developed e.g. DEPOMOD, AWATS, MOM and MEROMOD. All of these models give a spatial output and can be incorporated into GIS layers. The present study though uses a non-quantitative footprint model as it is the zone of potential impact rather than the amount of impact which is considered most important at this stage. Although a non-quantitative waste footprint has been incorporated a quantitative model such as that developed by Corner et al, (2006) could potentially be used. This was outwith the scope and time frame of this particular study. Future developments in this direction are currently being undertaken at Institute of Aquaculture.

The aim here was to estimate the spread of the waste materials (feed and faeces) through a simple spreadsheet-based “footprint” model developed for multiple sites as part of this project. The model calculates the absolute distribution of the wastes with no quantification. Under real conditions there would be very minimal waste at the edge of the footprint with higher build up beneath the cages. This was used as an absolute worse case. The output from the footprint model was a vector file from which the area of waste dispersion for the Western Isles fish farms can be plotted in IDRISI.
5.2 Waste Dispersion Model development

Water current flow data for 25 of the 87 active fish farms were modelled. The “waste-footprint” model incorporates data for settling velocities (using Chen et al, 1999) and current meter data (date, time, current speed, direction and depth of deployment). This format follows standard SEPA hydrographic data requirements. Figure 5.1 shows the layout, input areas highlighted in yellow and the graphical results.

The results from the “waste footprint” model were incorporated into IDRISI via an MS Access™ database, one for the faeces and one for the food. The food and faeces data are then rasterized, geo-referenced and overlaid to create an overall footprint raster file. All farms modelled are then overlaid to create a single raster file for the whole of the Western Isles. The final step involves converting the final waste footprint multi-site raster file to a vector file and this creates the final footprint model.

5.3 Results

The 25 farms which were modelled all fell within the area from Loch Maddy, in North Uist, to Loch Roag and Loch Ererisort, Isle of Lewis (see Figure 5.2). It is interesting that most of the farms fall within areas that have been considered extremely vulnerable to environmental impacts from aquaculture. The modelled footprints of waste distribution are given in Figure 5.3 to 5.7.

![Figure 5.1: Basic “waste footprint” model for waste dispersion](image-url)
Figure 5.2: Areas highlighted in red represent the areas where active fish farm sites waste dispersion was modelled.
From these illustrations, it is apparent that solid-waste footprints do not have a wide ranging area of impact for Western Isles fish farms. The extent to which each footprint impacts its surrounding environment is clearly dependent on its local hydrodynamic climate which is extremely varied.

Loch Roag (Figure 5.4) has five farms modelled which have very individual footprints. The water flow data indicates a complex hydrological climate coupled to a varied coastline. The Farms with the greatest footprint area are C and E showing a dispersion of up to 80 m from the cages, while farms A, B and D extended 40 m in varying directions from the cages depending on the localised conditions.
A different pattern emerges at Loch Leurbost, Loch Erisort and Loch Odhairn (see Figure 5.5). The hydrological climate here shows a more circular tidal ellipse where three of the more exposed farms (Farms C, E and G) have a relatively circular footprint pattern expanding 40 m from the cages. Three smaller footprints from the Farms B, D and F were also circular in pattern and extend approximately twenty metres. Of note is Farm A, where the sheltered conditions and low tidal currents give a circular footprint of only 10 m.
The area containing fish farms with the largest footprints is located in the Sound of Harris near Stromay and Hermetray (Figure 5.6), which has a high flushing rate. Fish farm B, in Figure 5.6, had the largest waste footprint (up to 120 m from the edge of the cages) out of the twenty five farms modelled, while the two farms on either side (A and C) disperse to approx. 60 m from the cage edge. In this same Figure the farms D and E, located in Loch Maddy, had a smaller footprints extending to a maximum of approx. 40 m from the cages.
In the coastal area around Loch Seaforth and East Loch Tarbert (Figure 5.7) the fish farm footprint patterns extend no further than 40 m from the cages. Interestingly, the actual shapes of the footprints are more dependent on water flow in relation to the coastline shape.
5.4 Practical Applications of the Basic Waste Footprint Model

To show the current potential of this multi-site waste dispersion model it was overlaid onto the biodiversity model (the biodiversity model is presented in Section 4). This shows the relationship between the dispersion of cage waste and the faunal biodiversity. For example, the five farms in Loch Roag (Figure 5.8) have waste footprints which overlay areas of high biodiversity. As most of the biodiversity is recent, this suggests that there is probably no large scale impact on biodiversity within this area.
Figure 5.8: Loch Roag, Waste Footprint model overlaid on the Biodiversity model.

Figure 5.9 illustrates that the fish farms within the Sound of Harris have larger dispersion footprints but are distributing waste into an area of lower biodiversity.

This type of modelling assesses the current disposition of fish farms and their footprint models. However, it can also be applied predictively to any potential site. SEPA require baseline data to be gathered before granting licenses and this data has been used as factors in the model. Thus by simply running the basic footprint model on the baseline data a basic picture of the area of likely affect can be generated.
5.5 Discussion

For the twenty five farms modelled the average distance that a farm's footprint will extend is about 44 metres beyond the edge of the cages. Of the twenty five farms modelled, some of which are situated quite close to each other, no overlaps of footprints occur. Further cage farms can be added to this sub-model as more data becomes available.

This type of large scale model at a multi-site level has not been developed previously. The capabilities of IDRISI GIS software easily allow this type of modelling and exhibit an innovative and proactive way to model multi-site solid waste dispersion for aquaculture. This model, though in its infancy, shows great potential as it highlights the current flaws of individual farm site modelling. Future developments of this model will incorporate additional aspects based on requirements set out by SEPA. The model will be developed further to maximise its potential and improvements and additional aspects are already being explored.
PART 3 – OVERALL MODEL OUTCOMES

6. Overall aquaculture site suitability model

6.1 Introduction

Although aquaculture is extremely important to the economy of the Western Isles it has to coexist with a variety of unusual or sensitive habitats and rare species. In addition, aquaculture production must be achieved within certain limits defined by the physical environment and also meet a range of legislative requirements. In order for these factors to be used in a single decision support system, the overall model must take into account both physical and biological characteristics for optimally locating aquaculture sites, by combining the individual layer models described in the previous sections.

6.2 Methods

The sub-model outcomes can be combined into a final suitability model. This is achieved by reclassifying the biodiversity layers so that the highest numbers are re-ranked to become the lowest numbers and lowest biodiversity areas in the model become the highest ranked areas 8-9. This standardizes the low numbers (in this case high biodiversity/sensitivity) as more unsuitable for aquaculture. See Figure 6.1.

![Biodiversity Model re-ranked to highlight areas high in biodiversity with 0-1 and areas with low biodiversity as 7-8.](image)

The overall models of suitability for the different type of cage systems for aquaculture will identify an area which is ideal for aquaculture based on the physical and biological environment. However, aquaculture may also be carried out in less ideal areas (lower
suitability scores) although there will be a greater risk of technology failure and greater potential for impact on environmentally sensitive areas and biodiversity. Nevertheless, these risks can be weighed against benefits by environmental managers and regulators, and can become conditions of lease (i.e. codes of practice to prevent escaped fish, employment of waste containment techniques).

6.3 Results

6.3.1 LMS overall site suitability model

The overall suitability for aquaculture using LMS type cages, shown in Figure 6.2, indicate that there are only 4 km² of ideal conditions, confined to Loch Seafirth, West Loch Tarbert, small section of inner of West and East Loch Roag and small sections located around North Uist and Benbecula.

Figure 6.2: Aquaculture site suitability model based on physical and biological characteristics for C250 cages
6.3.2 C250 overall site suitability model

The overall suitability model for aquaculture using the C250 type cages, given in Figure 6.3, indicates that ideal conditions occur in an area of 35 km². Much of this area is in the sea lochs and some coastal areas. Again Loch Seaforth, Loch Leurbost and Loch Erisort show favourable conditions. While West and East Loch Tarbert also Loch Resort also has suitable locations.

Figure 6.3: Aquaculture site suitability model based on physical and biological characteristics for C250 cages
6.3.3 C315 overall site suitability model

Ideal conditions for the C315 cages, designed to be situated in exposed regions, extended to 118 km², (Fig. 6.4. Almost all the inshore coastal areas apart from Northern Lewis are favourable while most outer areas of sea lochs are extremely favourable. It was clear from the overall models that this type of cage system is most suitable for fish farming in the Western Isles by exploiting the more exposed areas and thus avoiding areas of greatest biodiversity and environmental sensitivity. On the basis of this the constraints were incorporated into the overall suitability model for this cage type (see Section 4.3.7 and 6.3.4).

Figure 6.4: Aquaculture site suitability model based on physical and biological characteristics for C315 cages
6.3.4 C315 Site Suitability Model with Constraints.

As described in Section 5.3 current legislation governing aquaculture and its relationship with biodiversity is not well defined. However, this may not always be the case especially with mounting pressure to create marine protected zones or parks. This may completely exclude aquaculture from certain protected or sensitive areas. The following models are based on C315 cage suitability for physical properties (wave climate) constrained by areas containing to fishery nursery areas Figure 6.5 and sensitive species Figure 6.6.

*Figure 6.5: C315 cage suitability model with constraints for spawning/nursery areas*
Figure 6.6: C315 cage suitability model with constraints for species sensitive to Aquaculture
6.4 Discussion

The final model of site suitability can be used for site selection of marine cage aquaculture based on the ability of the aquaculture technology to endure environmental conditions and take into account biological criteria such as biodiversity, sensitive environments and species, and fishery nurseries. The models give scores of suitability for the different cage technologies, and using these scores environmental managers and regulators are able to make decisions about siting of cage culture, or look for potential other locations within a similar locality or management area. This process is in marked contrast to the current EIA process of site selection. It allows a proactive approach to ranking areas and developing options of sites instead of simple "yes or no" scenarios as occurs with the current EIA process. This type of decision support tool is not a fixed engine for regulation but is very ideally suited for the exploratory, pre-development stages.

Clearly, the models and sub-models developed give results on the basis of the information entered within the databases, and where gaps in these data occur, use of the model by aquaculture developers, regulators, interested groups or policy makers will require assumptions to be made. These assumptions will be dependent on the particular use of the models. The final model is a "decision support system". This is exactly as it says, and it gives modelled information on the basis of a considerable amount of data which is used in a logical structure to support the decisions of the end user. It does not replace the need for end-user expertise in making the final decision, and should never be thought of as doing so. This is a common misconception when using any form of model or modelling software.

Models, including those developed here are also subject to change through new information becoming available, revised requirements of the end-user or revised regulatory parameters. The GIS decision support system developed within this project can be easily adapted to take account of current (and future) legislation and guidelines or to follow emerging environmental regulation policies. In addition more sub-models may be added, to give a wider range of perspectives or a more refined outcome, as more data becomes available. This approach will benefit both government and the aquaculture industry as it can be used to maximize production in suitable areas, without impacting on environmentally sensitive areas. This is discussed more fully in Section 7.

The GIS sub-models and models developed are free-standing. However, it is important to note that these tools are not fixed and that the internal rules can easily be changed within the underlying macros. This means that what-if scenarios can be explored rapidly and with relative ease. The final models can be used by the non- GIS expert for both decision making and updating of data and other rules within the models. With further development, through implementation of the necessary software and server support, this would even be possible through the internet. However, actual model development with any GIS system is highly specialized and development of additional sub-models, additional layers and extension of geographical ranges should be done by an expert.
7. Future Development

GIS modelling is a complex, multi-step process involving data collection and processing, development of mathematical and logical models, verification of these models and consultation with expert advisors and end users usually at a number of stages (Fig 7.1). Although further work is still necessary, this project has dealt with a number of these stages to the point where useful and verifiable output can be generated.

The project outlined in this report develops a preliminary decision support tool, or tools, for marine fish cage farming in the Western isles. The tool is complete in that it can take into account interactions between the physical environment for cage suitability, waste dispersion and biodiversity implications of site selections for different cage technologies used for marine cage culture. Whereas the overall tool developed, together with its component models and sub-models, can be used as self standing models, these are under continual development and can be extended through:

1. Expansion of geographical range i.e. model for the west coast of Scotland.
2. Increasing the range of variables in the underlying spatial databases. This would increase the scope of the existing models and give potential for the addition of layers within the overall tool.
3. Increasing the quality and resolution of data where necessary.
4. Presenting the outcomes of the models/tool in an easily accessible form, i.e. web-based outputs.

Fig. 7.1. Conceptual model of stages in GIS project development. (from Ross, 2005, World Fish Center).
Clearly scaling of the model to encompass the whole of the west coast of Scotland, or at least those areas being used or having potential for marine cage culture, could simply be a case of increasing the database information or could incorporate further information, providing this is spatial data in an appropriate format (raster or vector). This would include all of SEPA’s regulatory data which can be focused on a geographic location (existing or potential fish farm site) or output from dispersion modelling. For example, the output from DEPOMOD is spatial and is imported into SURFER™ (Golden Software Inc) for plotting; this same information could be imported directly into a GIS. A quantitative dispersion model, entirely within GIS, has already been developed for particulate dispersion from fish cage culture (see Corner et al., 2006). Equally, modelled levels of carrying capacity (SEERAD, 2004) could be incorporated within the GIS tool and used to estimate how outputs from new fish farms can be deducted as a part of the site selection process. Better still, a carrying capacity based on nutrient inputs from catchments and adjacent water bodies (including natural and anthropogenic inputs) can be calculated and modelled using the inbuilt ecological modelling functions of GIS software such as IDRISI Kilimanjaro or IDRISI Andes.

In addition to using standard georeferenced data sources, data entry into GIS databases can also be in a variety of standard formats data such as MS Excel™ (.xls) and MS Access™ (.mdb), or simple ASCII text files (.txt). The only modelling requirement is that the data be in spatial format or be linked to a particular spatial location, which can be related to a standard spatial system (e.g. WGS84 longitude/latitude, UTM, OSGB36 etc).

Each of the models and modules developed within this project can be used as stand alone models or as part of the overall tool. Together, these also form a part of an overall aquaculture management system, which can be established at a range of scales and to cover any area, from a sealoch/fjord to Europe-wide. A conceptual model for such a system, which incorporates all aspects involved with aquaculture management, is given in Figure 7.2. The parts of this conceptual model developed through the present SARF 003 project are indicated.

The overall model developed for SARF003 research project used a variety of data; some was obtained from public sources, some from sources under educational license, and some under commercial license (see Appendix 1 for itemized list). If these GIS models are developed further for commercial application, beyond the scope of a research project, then some of the data obtained under license will require re-licensing. This should be the responsibility of those organizations using or exploiting the final model for commercial purposes, especially as the data would need periodic updating. The cost of this would clearly be incorporated into the commercial cost of running the model, and not as part of the overall model development.
Figure 7.2 Conceptual model of an integrative GIS-based decision support tool for effective implementation of aquaculture development. The sections of this model developed as part of the SARF003 project are outlined by the crosshatched area.
8. References

Cited journals and articles:


**Web Sources:**


## Appendix 1

### Table A1: Sources of Data for Layers in the database

<table>
<thead>
<tr>
<th>Database Layer</th>
<th>Description</th>
<th>Supplier/Creator</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td>Vector</td>
<td>Edina Digimap</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Forest</td>
<td>Vector</td>
<td>Edina Digimap</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Towns</td>
<td>Vector</td>
<td>Edina Digimap</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Rivers</td>
<td>Vector</td>
<td>Edina Digimap</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Land Farm sites</td>
<td>Vector</td>
<td>Edina Digimap</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Freshwater bodies</td>
<td>Vector</td>
<td>Edina Digimap</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Western Isle Coastline</td>
<td>Vector</td>
<td>Edina Digimap</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Aquaculture Current sites</td>
<td>Vector</td>
<td>Edina Digimap</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Bathymetry</td>
<td>Vector</td>
<td>BGS Digbath250</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Seabed</td>
<td>Vector</td>
<td>BGS</td>
<td>Academic Licence</td>
</tr>
<tr>
<td>Well</td>
<td>Vector data set of offshore well positions and descriptive attributes</td>
<td>UKDEAL</td>
<td>Free information about UK offshore oil and gas</td>
</tr>
<tr>
<td>3d seis</td>
<td>Vector data of seismic descriptive attributes for surveys</td>
<td>UKDEAL</td>
<td>Free information about UK offshore oil and gas</td>
</tr>
<tr>
<td>Hcfield</td>
<td>Vector data of offshore UK hydrocarbon fields</td>
<td>UKDEAL</td>
<td>Free information about UK offshore oil and gas</td>
</tr>
<tr>
<td>Licegoe</td>
<td>Vector</td>
<td>UKDEAL</td>
<td>Free information about UK offshore oil and gas</td>
</tr>
<tr>
<td>Licegoew</td>
<td>Vector</td>
<td>UKDEAL</td>
<td>Free information about UK offshore oil and gas</td>
</tr>
<tr>
<td>Database Layer</td>
<td>Description</td>
<td>Supplier/Creator</td>
<td>Availability</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Pipeline</td>
<td>Vector data on positions and descriptive attributes of current pipeline</td>
<td>UKDEAL</td>
<td>Free information about UK offshore oil and gas</td>
</tr>
<tr>
<td>Surface</td>
<td>Vector data of surface attributes such as platforms, FPSO’s, buoys etc.</td>
<td>UKDEAL</td>
<td>Free information about UK offshore oil and gas</td>
</tr>
<tr>
<td>Land use</td>
<td>Vector</td>
<td>Scottish National Heritage</td>
<td>Public</td>
</tr>
<tr>
<td>Satellite images</td>
<td>GeoTIFF</td>
<td>Global Land Cover Facility/ GoogleEarth</td>
<td>Public</td>
</tr>
<tr>
<td>Protected Areas</td>
<td>Ramsar, SSSI, SAC,SPA, NSA</td>
<td>Scottish National Heritage</td>
<td>Public</td>
</tr>
<tr>
<td>Currents</td>
<td>Data from tidal diamonds supplied from Maptech</td>
<td>MapTech, chart numbers BA14, BA07</td>
<td>Commercial Licence</td>
</tr>
<tr>
<td>Species Information</td>
<td>Data on species for each 10km² for the Western Isles completely on land and up to 30km coastal.</td>
<td>National Biodiversity Network</td>
<td>Public</td>
</tr>
<tr>
<td>Shipping Lanes</td>
<td>Data for all shipping routes for this company to the from the Western Isles</td>
<td>Caledonian Macbrayne</td>
<td>Public</td>
</tr>
<tr>
<td>Fish Farm data</td>
<td>Data collected by SEPA on recorded/allowed biomass, chemical usage and waste information for all Western Isles Sites.</td>
<td>Scottish Environment Protection Agency</td>
<td></td>
</tr>
<tr>
<td>Fish Spawning and Nursery Areas</td>
<td>Data on thirteen commercially important fish species.</td>
<td>Centre for Environment, Fisheries and Aquaculture Science</td>
<td>Public</td>
</tr>
</tbody>
</table>