



ECASA



Sixth Framework programme

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**Executive Summary**  
**Final Activity Report**  
**STREP**

**SIXTH FRAMEWORK PROGRAMME PRIORITY**  
 Integrating and Strengthening the European Research Area



Fin fish Cages, Cephalonia, Greece

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## Section 1

### 1.1 Context



The ECASA Project began in December 2004 and ran until November 2007. Proposing an ecosystem approach to the aim of achieving a sustainable aquaculture industry in Europe, the project identified three objectives which if addressed, could inform on effective Environmental Impact Assessment of aquaculture activities and aid in the selection of suitable sites for aquaculture.

The projects website may be accessed from <http://www.ecasa.org.uk> The public pages describe the objectives of the project, partners involved and there is a specific section developed as a resource area for stakeholders. All the issues of the project newsletter are available to download as pdf files from the project website, as are posters and presentations that have been used to disseminate the project.



The ECASA Project Team at the “Kick-Off” meeting held at the Scottish Association for Marine Science, Oban, Scotland in December 2004.



ECASA Partners at the second modelling workshop held at Napier University, Edinburgh, Scotland.

## 1.2 Project Execution

### 1.2.1 Summary Description of the Projects Objectives.

The ECASA project has addressed the following objectives:

To identify quantitative and qualitative indicators of the effects of aquaculture on the environment and vice-versa, and to assess their applicability.

To develop operational tools, including models, to establish and describe the relationship between environmental conditions and aquaculture activities over a range of ecosystems and aquaculture production systems.

To develop effective environmental impact assessment and site selection methods for coastal area management.

The first objective was achieved by considering the indicators of the interactions of aquaculture on the ecosystem, (work package 2) and also by considering the indicators of ecosystem changes influencing aquaculture, (work package 3). In all 55 indicators were identified and assessed during ECASA. Those indicators which passed through the selection process were then tested in the field during the summer of 2006 (work package 5).

The second objective was achieved through a rigorous process of model testing, development and validation, (work package 4). Some 20 models were identified as being applicable to the ECASA project objective and a standard procedure for assessing model reliability was developed. This objective pooled the outputs of work packages 2 and 3 and synthesized all the ECASA projects' activities into a virtual Toolbox.

The third objective was addressed through a pan-European field campaign in 2006. The indicators resulting from work packages 2 and 3 were tested in the field through work package 5, at a range of sites varying in environmental drivers, aquaculture practices and species farmed. The results from this field campaign were then used to test the efficacy of the indicators for a range of criteria, and validate, and/or develop the models arising from work package 4. Achieving this objective culminated in the development of a methodology for effective Environmental Impact Assessment and site selection for aquaculture activities in Europe, establishing the framework of the Toolbox.

By achieving these objectives ECASA provides support to the aquaculture industry on achieving sustainable practices. The innovative Toolbox, with its suite of environmental indicators and predictive models, will aid the assessment of marine sites for aquaculture activities and subsequently provide a consistent framework for the application of Environmental Impact Assessments, resulting in coherent and relevant Environmental Statements.

## 1.2.2 Project Objective 1.

*To identify quantitative and qualitative indicators of the effects of aquaculture on the environment and vice-versa, and to assess their applicability.*

This objective was divided between two work-packages; Work Package 2 identified and quantified the most relevant indicators of the interactions of aquaculture on ecosystems and Work Package 3 identified and quantified the main driving forces of ecosystem changes influencing aquaculture and developing appropriate environmental indicators.

### Work package 2.

Partners Involved: (1) SAMS, (2) University of Portsmouth, (3) Napier University, (4) National Institute of Biology, (5) IFM-GEOMAR, (7) University of Haifa, (8) University of Crete, (10) IMAR, (12) IFREMER, (13) AZTI, (14) DCF-UNIVE, (15) RBI, (16) UGOT.

### Work Performed.

The initial task undertaken by Work Package 2 was to develop an indicator classification system to ensure the maximum range of environmental impacts would have designated indicators. This classification grid listed indicators under four headings: physics, geochemistry, biology and socio-economics. Partners proposing indicators were then asked to complete an annotated sheet detailing the specific requirements for each indicator. In total 55 indicators were proposed for Work Package 2.

### Methodologies and approaches employed.

A method was proposed to collect the corresponding information, and a template of an annotated sheet was circulated and commented on by the participants, (see Appendix 1 for an example of an annotated indicator sheet). Partners were divided into subgroups according to the expertise available in the different institutes, with the aim of avoiding any overlap between different indicators and ensuring that the main aspects of the environmental impacts arising from aquaculture were covered. These subgroups and the indicators assessed by them are detailed in Table 1.1 For each sub-group, indicators were assessed according to criteria based on their efficiency, pertinence, and practical aspects. A classification was established to prioritize the use of the most efficient indicators (Table 1.2).

Table 1.1. Indicators assessed during Work Package 2.

| Sub Group                      | Indicators Assessed  |
|--------------------------------|--|
| <b>Sediment</b>                | Redox Eh in surficial sediment, Sulphate and ammonia gradient, Sediment carbon quality Index, Sediment oxygen consumption experiment, TOC in sediment, Sediment fluxes (trap), Total Organic Carbon in surface sediment, Ammonia-pore water, Sulphide/oxygen, Total Nitrogen in sediment, P-PO <sub>4</sub> in pore water, Heavy metals in sediment, Nitrifier bacterial population, Total phosphorus, Mono unsaturated fatty acid in benthos. |
| <b>Benthos</b>                 | Macrofauna: AMBI, Benthic trophic groups, Biomass Fractionation, Macrofauna-univariate, Macrofauna-ITI, Macrofauna-multivariate; Meiofauna diversity, Sediment test on meiofauna.  |
| <b>Water Quality</b>           | Minimum O <sub>2</sub> in bottom water, Secchi disk, Maximum production with respect to water quality in farm, Phytoplankton chlorophyll, Chlorophyll a, Winter nutrient concentration, Particulate organic Carbon (POC).  |
| <b>Coastal Zone Management</b> | Aquaculture production on shoreline, Validated distance, Water availability, Assets.   |
| <b>Genetic and Molecular</b>   | DNA-damage, Microsatellites DNA, mitochondrial DNA, EROD.  |
| <b>Socio-Economic</b>          | Attitudes, Conflicts, Consumer prices, Consumption share, Damage costs, Employment, Income, Multipliers, Output, Producer prices, Productivity, Profit, Protection costs, Regional dependency, Consumption products.   |

Table 1.2: Assessment of the pertinence of indicators according to the European marine aquaculture types. The scale goes from A, highly pertinent to E, not pertinent.

| Pertinence Quotation from A to |  | A                     | B           | C                     | D           | E                       |                  |
|--------------------------------|--|-----------------------|-------------|-----------------------|-------------|-------------------------|------------------|
| Environment                    |  | Offshore operations   |             | Coastal operations    |             |                         |                  |
| Tide                           |  | > 5 km and no shelter |             | Subtidal environments |             | Intertidal environments |                  |
| 07/01/2008                     | Techniques                               | Cages                 | Long-lines  | Cages                 | Long-lines  | Bottom culture          | Trestles culture |
| Species                        |  | fishes                | shellfishes | fishes                | shellfishes | shellfishes             | shellfishes      |
| Sediment                       | Redox Eh in surficial sediment           | A                     | B           | A                     | B           | B                       | B                |
| Sediment                       | sulfate and ammonia gradient             | A                     | C           | A                     | C           | C                       | C                |
| Sediment                       | Sediment carbon quality Index            | A                     | A           | A                     | A           | A                       | A                |
| Sediment                       | Sediment oxygen consumption experiment   | B                     | C           | B                     | C           | C                       | C                |
| Sediment                       | Toc in sediment                          | B                     | C           | B                     | C           | C                       | C                |
| Sediment                       | Sediment fluxes (trap)                   | A                     | A           | A                     | A           | A                       | A                |
| Sediment                       | Total Organic Carbon in surface sediment | A                     | C           | A                     | C           | C                       | C                |
| Sediment                       | ammonia-pore water                       | B                     | B           | B                     | B           | B                       | B                |
| Sediment                       | Sulphide/oxygen                          | A                     | B           | A                     | B           | B                       | B                |
| Sediment                       | Total Nitrogen in sediment               | B                     | B           | B                     | B           | B                       | B                |
| Sediment                       | P-PO4 in pore water                      | C                     | C           | C                     | C           | C                       | C                |
| Sediment                       | Heavy metals in sediment                 | B                     | D           | B                     | D           | D                       | D                |
| Sediment                       | Nitrifier bacterial population           | A                     | B           | A                     | B           | B                       | B                |
| Sediment                       | total phosphorus                         | B                     | B           | B                     | B           | B                       | B                |
| Sediment                       | Mono unsaturated fatty acid in benthos   | N/A                   | N/A         | N/A                   | N/A         | N/A                     | N/A              |
| Benthos                        | AMBI                                     | A                     | A           | A                     | A           | A                       | A                |
| Benthos                        | benthic trophic groups                   | B                     | C           | B                     | C           | C                       | C                |
| Benthos                        | Biomasse Fractionation                   | A                     | B           | A                     | B           | B                       | B                |
| Benthos                        | macrofauna presence                      | B                     | C           | B                     | C           | C                       | C                |
| Benthos                        | Macrofauna-univariate                    | B                     | B           | B                     | B           | B                       | B                |
| Benthos                        | Macrofauna-ITI                           | A                     | A           | A                     | A           | A                       | A                |
| Benthos                        | Macrofauna-multivariate                  | A                     | A           | A                     | A           | A                       | A                |
| Benthos                        | Meiofaunal diversity                     | A                     | A           | A                     | A           | A                       | A                |
| Benthos                        | Sediment test on meiofauna               | N/A                   | N/A         | N/A                   | N/A         | N/A                     | N/A              |
| water quality                  | Minimum O2 in bottom water               | A                     | B           | A                     | B           | D                       | C                |
| water quality                  | Secchi disk                              | C                     | C           | C                     | C           | E                       | E                |
| water quality                  | water quality in cages (O2, NH4+)        | A                     | C           | A                     | C           | C                       | C                |
| water quality                  | Growth                                   | A                     | D           | A                     | D           | D                       | D                |
| water quality                  | Chlorophyll a                            | C                     | A           | C                     | A           | A                       | A                |
| water quality                  | Winter nutrients concentration           | D                     | E           | D                     | E           | E                       | E                |
| water quality                  | Particulate organic Carbon (POC)         | B                     | A           | B                     | A           | A                       | A                |
| Coastal zone management        | Aquaculture production on shoreline      | A                     | A           | A                     | A           | A                       | A                |
| Coastal zone management        | validated distance                       | A                     | A           | A                     | A           | A                       | A                |
| Coastal zone management        | water availability                       | B                     | C           | B                     | C           | C                       | C                |
| Coastal zone management        | Assets                                   | A                     | C           | A                     | C           | C                       | C                |
| Genetics                       | DNA-damages                              | N/A                   | N/A         | N/A                   | N/A         | N/A                     | N/A              |
| Genetics                       | Microsatellites DNA                      | N/A                   | N/A         | N/A                   | N/A         | N/A                     | N/A              |
| Genetics                       | mitochondrial DNA                        | N/A                   | N/A         | N/A                   | N/A         | N/A                     | N/A              |
| Genetics                       | EROD                                     | N/A                   | N/A         | N/A                   | N/A         | N/A                     | N/A              |
| Socio-economics                | environmental damage costs               | A                     | C           | A                     | C           | C                       | C                |
| Socio-economics                | environmental protection costs           | A                     | C           | A                     | C           | C                       | C                |

Once this evaluation process was over, the second stage involved consulting with stakeholders and regulators on the final list of indicators. An important milestone was the international meeting which occurred in October 2007, when the ECASA, and the Toolbox, was presented to the stakeholders. Comments made by stakeholders have been included in the final list of indicators, and the associated annotated sheets. These documents have been incorporated into the ECASA Tool Box.

### **Work Package 3.**

Partners involved: (1) SAMS, (2) University of Portsmouth, (3) Napier University, (4) National Institute of Biology, (6) Akvaplan, (7) University of Haifa, (8) University of Crete, (10) IMAR, (12) IFREMER, (13) AZTI, (14) DCF-UNIVE, (15) RBI, (16) UGOT.

### **Work Performed.**

Work Package 3 addressed this task by carrying out an extensive bibliographic review as well as collaborative discussions to identify the forcing factors that affect the environment in aquaculture zones, their nature, strength and scale of impact. Data collected from various sources, such as the scientific literature, aquaculture industry and insurance companies, were used to assess these pressures and to address the issue of conflicts among the different uses of the coastal zone. Five types of forcing factors were identified and a set of indicators (17 in total) relating to the specific source of environmental pressure on aquaculture were proposed for consideration during aquaculture site-selection within the context of ICZM.

### **Methodologies and approaches employed.**

The extensive bibliographic review and productive discussions between partners indicated that the sources of pressure and their relative importance differ between geographic regions as well as between different types of aquaculture. It became apparent that anthropogenic forcing has a major influence on coasts and oceans, contributing greatly to ecosystem changes. From this, it was decided to follow the following methodology for ensuring the best and most comprehensive results. The initial stage was the development of a table which presented a general characterisation of the relationships between marine resource use (socioeconomic benefits) and indicators of environmental health (see Appendix 2). The table included environmental issues that are reported or expected to be significant for aquaculture (i.e. light conditions, turbidity, exotic species), and discriminate between shellfish and finfish production, as they have different environmental demands and occur in environments with different characteristics. Discussions were initiated between partners on the degree of severity of these interactions in different countries.

Based on this table illustrating the varying inter-relationships, the different human activities were ranked with regard to their degree of impact on each variable. This was further developed to show the interrelationship between different human activities and their potential impact on aquaculture. According to this table, all categories of human uses of the coastal zone are expected to have an effect on aquaculture. However, information derived from insurance companies and questionnaires distributed to farmers on farm losses, indicated that though anthropogenic forces are expected to have a significant impact on the aquaculture industry, the fact that they do not always coexist with aquaculture or they do not occur regularly, in reality, lowers the observed impact.

As a final step, the issue of incompatibilities between aquaculture and major uses of the coastal zone was revisited, and a final set of indicators associated with specific sources of pressure on aquaculture that need to be taken into account during site-selection is proposed.

**End results.**

Within the context of WP3, the socio-economic aspects of aquaculture development were investigated, and the objective of “identifying potential ways for measuring the additional cost caused by external environmental change” is explicitly addressed in an extensive report on the externalities caused by marine environmental disturbance (D11). Furthermore, a review on the methodologies for assessing the economic costs imposed on aquaculture by anthropogenic and natural environmental pressures is provided (D11), from which it becomes clear that the choice of method for measuring the economic cost caused by external environmental change will be determined not only by policy needs (notably the urgency with which information is needed) but also by whether the purpose is to examine the effects of environmental disturbance on a wider constituency of stakeholders than simply aquaculture producers. The outcome of this study is a selected set of indicators related to specific sources of environmental pressure on aquaculture (see Table 1.3), which should be considered for aquaculture site-selection within the context of ICZM.

Table 1.3. Indicators related to sources of environmental pressure on aquaculture.

| <b>Source of pressure</b> | <b>Potential indicators</b>   |
|---------------------------|---|
| Weather – Storms          | Frequency of storms<br>Wave-height (average and frequency of extreme values)<br>Fetch Openness  |
| Disease – Parasites       | Production by other farms using the same species at distance <2km<br>Water quality issues (See pollution below)   |
| Predator attacks          | Colonies of birds in the vicinity (<2km)<br>Colonies of seals in the vicinity (<1km)<br>Nesting beaches for sea turtles in the vicinity (<10km)<br>Frequency of observation of dolphins and tunas in the area |
| Pollution                 | Distance from land based sources of pollution<br>Distance from waste discharge points (2km)<br>Distance from harbours<br>Distance from rivers<br>Distance from major maritime routes                          |
| Other uses                | Distance from fishing grounds (1km)<br>Distance from tourist facilities (1km)<br>Distance from houses (1km)   |

### 1.2.3 Project Objective 2.

*To develop operational tools, including models, to establish and describe the relationship between environmental conditions and aquaculture activities over a range of ecosystems and aquaculture production systems.*

To achieve Objective 2 the applicability of the indicators proposed in Work Packages 2 and 3 were assessed and operational tools (e.g. models) were tested and developed to establish the functional relationship between the environment and aquaculture activities (Work Package 4).

Partner involved: (1) SAMS, (2) University of Portsmouth, (3) Napier University, (5) IFM-GEOMAR, (6) Akvaplan, (7) University of Haifa, (8) University of Crete, (9) PML, (10) IMAR, (12) IFREMER, (13) AZTI, (14) DCF-UNIVE, (15) RBI, (16) UGOT.

#### Work performed.

Work package 4 addressed this task by firstly establishing the theory for indicators and models in relation to ECASAs' objectives. This included the identification of the scale for which the models' parameterizations were appropriate and criteria of scientific robustness and practical utility for models. Partners were also asked to propose tests capable of falsifying their models. A template for model description, to be used in an inventory to take stock of existing models & capability, and identify gaps was developed, (see Appendix 3). This model descriptor included space for the description of a critical test of the relevant model. Intellectual property matters relating to models were also investigated.

In parallel to this the ECASA Toolbox also began to take shape. Various forms were considered and developed until the final version was decided on. The Toolbox is a set of hyperlinked web pages with the aim of providing a user-friendly document supplying information on environmental indicators, models and impact assessment procedures that may be used in assessing the environmental impacts of aquaculture.

#### Methodologies and approaches employed.

Work Package 4 has addressed this task in terms of a DPSIR perspective. According to this perspective, the wastes and by-products of fin-fish farming, or the depletion of phytoplankton by shellfish farms, constitute an (ecological) pressure on ecosystems, which may change in state as a result. Some of these changes are the environmental impact of mariculture, which should be managed so as to keep these impacts with acceptable limits. This is illustrated in Figure 2.1 below.

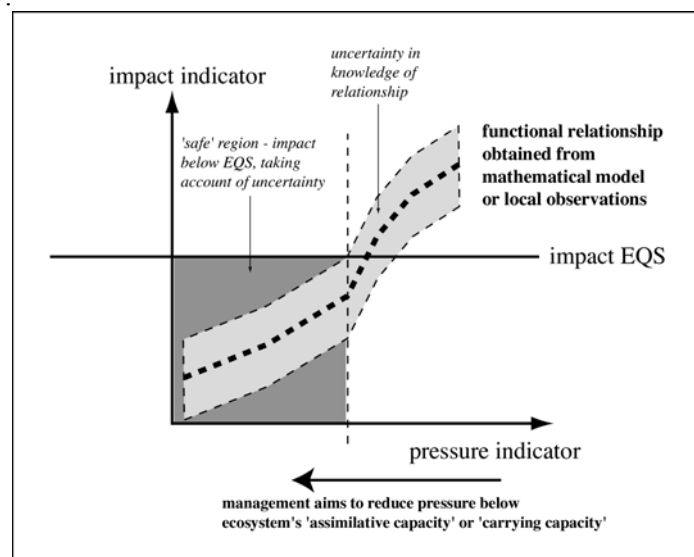


Figure 2.1. Pressure Impact Relationships

Figure 2.1 provides a generalized picture of pressure-impact relationships. It includes the idea of uncertainties in our knowledge of these relationships and of management in relation to assimilative capacity (for a polluting waste) or carrying capacity (where the environment provides a food source). ECASA also takes account of scale, where zone A scale is taken as local to a point source discharge, zone B scale, the scale of a water body in which water residence time is a few days, receiving one or more point source or diffuse inputs of waste, and zone C scale - that of the region, in which water residence times are measured in months and where the relevant maricultural concerns include the overall size of the industry. This approach has been developed further within ECASA, (see Figure 2.2)

In WP4, our method has been to explore indicators of pressures and state/impact, and relationships between pressure and state/impact indicators that can be used to manage aquaculture for sustainability. Figure 1.2 below sets out the theory diagrammatically for two cases. One case relates to assimilative waste, such as the nutrients or organic matter released by finfish farming, the second case relates to removal of a renewable resource, such as the planktonic micro-algae fed on by filter-feeding bivalves.

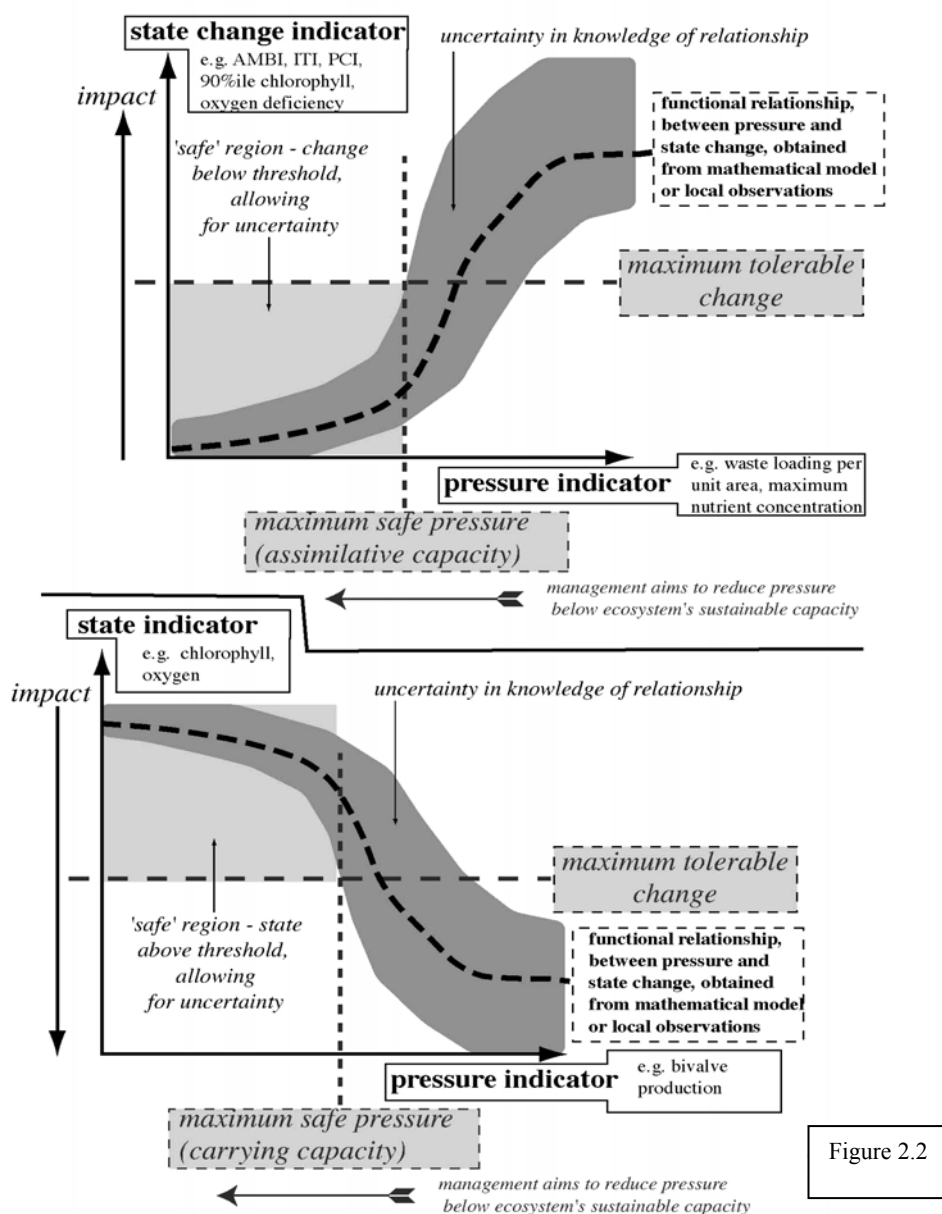


Figure 2.2

Figure 2.2. Illustrating the indicators of pressures and state/impact, and relationships between pressure and state/impact indicators that can be used to manage aquaculture for sustainability.

Following on from this the general objective of WP4 expands into those of

- identifying a small set of scale and culture-system relevant pressure indicators
- identifying an analogous set of scale and culture-system relevant impact indicators
- identifying a set of mathematical models that can be used diagnostically or prognostically to manage impact by controlling pressure.

An inventory of some 20 models has been assembled, based on the following general issues:

- theory for indicators and models in relation to ECASA objectives; this included the identification of the scale for which the model's parameterizations were appropriate;
- criteria of scientific robustness and practical utility for models; partners were asked to propose tests capable of falsifying their models.

- a template for model description, to be used in an inventory to take stock of existing models & capability, and identify gaps; the template included space for description of a critical test of the relevant model;
- intellectual property matters relating to models.

As the inventory was assembled, a need to distinguish between 'procedures' and models became evident. The key distinction is that models are scientific hypotheses that can be falsified (by testing against observations and previously specified criteria), whereas procedures are assessment schemes using indicators, models and pre-defined quality standards. Robustness and utility have different meanings for the two categories.

### **End results.**

The original specification for the deliverable for work package 4 was a "Toolpack". Initially described as a report on "the merits of the chosen indicator set including best methodologies for collection, analysis and interpretation, and on the recommended set of models, including criteria for choice of models depending on spatial scale and farm size, and guidance on the use of models to estimate site and water body assimilative capacity and sustainable production, and on the reliability of model predictions".

Following consultation with stakeholders, this has developed into a "virtual toolbox", a set of hyperlinked web pages at <http://www.ecasatoolbox.org.uk>, with the aim of providing a more user-friendly document.

The Toolbox consists of:

- a framework (a set of web pages) that allows several categories of users to link rapidly to web pages about relevant models and indicators;
- a set of web pages providing general guidance on the selection and use of the 'tools' investigated by ECASA - i.e., the indicators, models and environmental impact assessment procedure;
- individual web pages for each model investigated by ECASA, containing standard descriptions of the models, and, in some cases, standard reports of reliability tests, together with links to institutions from which models can be obtained or licensed;
- individual web pages for each indicator studied by ECASA;
- individual web pages for the main sites studied by ECASA, containing study reports in the form of 'Environmental Impact Assessments' for these sites, plus additional material relating to use and test of indicators and models at these sites.

Supplemental to the development of the Toolbox, reports on model development were presented at the second ECASA modelling workshop, held in Napier University, Edinburgh, 29-30 January 2007, where a standard procedure for assessing model reliability was developed, (see Appendix 4 for an example of model validation process). The Toolbox includes 7 reports on the use of this standard procedure, plus 4 reports about models that were (more appropriately) tested in other ways.

### 1.2.4 Project Objective 3.

*To develop effective environmental impact assessment and site selection methods for coastal area management.*

Work Package 5 will achieve Objective 3 through testing and validating the proposed indicators from Work Packages 2 and 3 for their relevance to EIA and effective site selection.

Partners involved: (1) SAMS, (2) University of Portsmouth, (3) Napier University, (4) NIB, (5) IFM-GEOMAR, (6) Akvaplan, (7) University of Haifa, (8) University of Crete, (9) PML, (10) IMAR, (11) ICRAM, (12) IFREMER, (13) AZTI, (14) DCF-UNIVE, (15) RBI, (16) UGOT.

#### Work performed.

To ensure a wide range of aquaculture practices operating within Europe were represented, a review of European aquaculture producers was performed. From this the criteria for the selection of study sites for fieldwork were established and a list of candidate sites prepared. A final list of sites, in ten European countries, are proposed for the ECASA field campaign representing an array of environmental conditions and cultivated species: as illustrated in Figure 3.1 below.



Figure 3.1. The geographic range of the ECASA study sites.

Both fin-fish and shellfish production systems are included, Fieldwork was carried out at each of the study sites, starting in April 2006 (Spain), and in most cases taking place throughout the summer months, when aquaculture was at peak capacity and production levels. In a few isolated cases, fieldwork extended into autumn 2006. Processing and analysis of most samples was completed by early 2007, though many partners required extra time to complete the quantitative and qualitative work with macro and meio-fauna. Partners who did not host study sites provided assistance to the others in the field and the laboratory, including analytical services, testing of indicators, model development and evaluation, etc. All of the relevant information for each study site, including the results of testing of various indicators and predictive models, was compiled into a comprehensive EIA-style Study Site Report.

#### **Methodologies and approaches employed.**

The following were the guiding criteria for selecting study sites. These criteria were formulated following discussion of suitable criteria at the project meetings. The site should:

- be representative of important forms of EU aquaculture: culture method (e.g. net pens, mussel long lines, rafts, bottom culture, trestle, pole), species (e.g. salmon, seabass/bream, tuna, cod, shi drum, mullets, mussels, oysters, clams), geographical features (e.g. exposed, protected, restricted exchange, WFD category and typology)
- have a good record of background data
- be accessible from the host partner's institute

In addition, the partner must have all necessary field equipment and lab gear and have good relations with the fish farmers to ensure access to the study site.

For each study site, a sampling plan was developed and benthic/water column sampling stations selected. A list of key variables to be measured at each site was identified. A book of protocols was collated, summarizing the methods to be employed in the field and in the laboratory. A comprehensive EIA-style study site report template was prepared and distributed among the partners to serve as a template for the final report that will be prepared for each study site and delivered to the stakeholders.

Detailed descriptions of all study sites were prepared including maps showing the locations of the farms and the layout of sampling stations relative to the farms. Historical environmental and oceanographic data for each study site were collected and provided an important role during the testing of indicators and models under consideration for inclusion in the ECASA Toolbox. Although every farm is unique, the selection of sampling stations was made on the basis of predominant current directions and velocities (which determine the distribution of particulate organic matter and nutrients around the farms) and a search for stations with high, low and “no” (reference) impact relative to the farm.

#### **End results.**

**Book of Protocols.** In order to ensure a high level of consistency in the fieldwork, and standardization of methodology across study sites (and among partners), a book of protocols, for sampling and measuring these variables was compiled, based on established and published methods. The Book of Protocols is available from the Toolbox.

**Study site reports.** These reports describe an aquaculture site, in relation to Environmental Impact Assessment and subsequent Environmental Statement. This culminated in the “ECASA Study Site Report” template. Each study site has a corresponding Study Site Report following this format. The unique aspect of the study site reports is that in addition to a detailed description of all aspects (ecological and socio-economic) of the aquaculture site and activity, there is an assessment of the predictive tools (indicators and models) that were tested

and could serve as part of the decision-support system to better enable stakeholders to make effective decisions with respect to site selection and sustainable management strategies.

### 1.3 Summary of ECASA results and possible use of tools

ECASA focused on indicators, models and the EIA process. Within the EIA process lies the concept of appropriate site selection. The key question asked in EIA relates to the appropriateness of the type and scale of human activity within the natural and social environment (the ecosystem) where it is proposed. Where the assessment is positive, this implies that the proposed activity is likely to be sustainable, as far as is foreseeable given the current and predicted state of that ecosystem. And vice versa. This then requires that appropriate tools are available to assess the baseline ecosystem state, to predict future changes that might be caused by the activity and to monitor changes from the baseline state in order to test whether such predictions were accurate and to ensure that the activity is complying with regulatory standards. With this set of tools the developer and the regulator have a means to understand, predict, monitor and regulate human activities to ensure economic, social and environmental sustainability, as far as is predictable given uncertainties in external economic, social and environmental drivers. Implicit in this process is the holistic consideration of all parts of the ecosystem: all of the environmental, social and economic impacts that are pertinent to the development. However, a risk-based approach should be used to ensure that the most sensitive aspects are considered in the greatest detail<sup>1</sup>.

ECASA has selected and assessed models and indicators that can be used by fish farmers and their regulators to contribute to the EIA process. Many of the indicators on pelagic and benthic ecology, as well as those relating to socio-economics, are well known and already currently used in many parts of the world. However, some are relatively new and have previously been little studied in relation to aquaculture. Similarly some, but not all, of the models tested have been developed specifically for aquaculture. Although some of these models are already used in aquaculture regulation (e.g. DEPOMOD and FjordEnv) several were previously not easily accessible to the aquaculture stakeholder community and are made available, together with supporting documentation and assessment, through the ECASA toolbox. For some applications, a choice of models is now available to the user while for others the user is led to a preferred option.

Although the EIA process is statutory in the EU, in several countries it is either omitted or there are concerns as to its quality. This is partly because there are no proscribed holistic “templates” for the production of Environmental Statements relating to aquaculture developments, and little guidance on the level and focus of the assessment. As mentioned above, the EIA process considers all likely interactions with the ecosystem (including societal elements) but should focus on these where risks of high impact are greatest.

While EIA pertains to new rather than existing developments, focusing on existing developments was the only practical option open to the project. A comprehensive template for an Environmental Statement was devised and completed for each study site. Although the distribution of resources was uneven between these sites, and thus the level of completion is variable between them, this exercise showed that producing

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<sup>1</sup> GESAMP (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP Joint Group of Experts on Scientific Aspects of Marine Environmental Protection) 2008. Assessment and communication of environmental risks in coastal aquaculture. Rome, FAO. *Reports and Studies GESAMP* No. 76: 198 pp.

a comprehensive analysis of the likely major interactions between aquaculture activities and the environment is quite feasible.

EIA is generally focused on the ecosystem close to the development. ECASA did not explicitly consider Strategic Environmental Assessment which assesses the environmental consequences of policies and plans. Large scale aquaculture development has not been rigorously assessed via the SEA methodology. However, several of the ecosystem modelling tools applied in ECASA have the potential to consider ecosystem level effects on wide spatial scales (e.g. dCSST, LESV, EcoWin, KK3D). Such models have great potential as regional assessment tools for strategic planning of aquaculture expansion.

The products of ECASA, models, indicators and guidelines, together with appropriate background information are presented in the project's key deliverable – the Toolbox. This is complete and will remain available on the internet for at least 2 years. However, no decision has been taken about its ultimate fate. If it proves popular (i.e. has a high hit rate) then it will remain available for longer. The decision as to whether to allow it to develop beyond the project has not yet been worked through.

#### **1.4 Synthesis of most suitable indicators for EIA and site selection**

Indicators of benthic impact have received the greatest attention in the past and represent the largest range of indicators examined in ECASA. Most of the benthic indicators rely on identification of all the animals in replicate sediment samples so there is little extra cost in evaluations of all of these. The most important factors explaining variability in biological indicators are those related to farm activity (production, years operating, distance to the cages) and the hydrographical characteristics of the area (current speed, water depth), interacting with sediment characteristics (grain size, redox, Total organic matter - TOM). However, sediment indicators alone explain relative little variability. Hence, the selected biological indicators usefully show the extent and degree of the impact of aquaculture, but also take into account the high percentage of unexplained variability, probably due to intra-site specific characteristics not studied in ECASA. ITI (Infaunal Trophic Index) and AMBI (AZTI Marine Biotic Index) seem to be good indicators of the benthic stress (in terms of the response to impact gradient). AMBI seems to be independent of sediment characteristics (grain size, etc.), whereas ITI is dependent on mud content, and both are related to factors directly linked with the activity (production) or dispersal factors (current speed, depth). Some biological indicators such as density, richness, or diversity, show sometimes contradictory results, with increasing or decreasing values, for the same impact in different locations.

Among the various univariate meiofaunal variables tested within the project, abundances of the “sensitive-to-disturbance” copepod nauplii and the highly criticized nematode/copepod ratio were found to change quite consistently with distance from aquaculture facilities. Furthermore, meiofauna community structure based on major metazoan taxa was useful in depicting changes along gradients of aquaculture impact.

The four water quality indicators evaluated at nine ECASA Study Sites: ammonium, reactive phosphorus, chlorophyll a and Secchi disk depth, did not provide conclusive evidence of the impact of finfish and shellfish farms and, in particular, about potential

adverse effects on the pelagic ecosystem. Focusing on single indicators, monitoring of ammonium and reactive phosphorus provides evidence (on average) of nutrient enrichment near the farms. However, deviations of Chlorophyll a and Secchi Disk from the reference values observed at those sites were not correlated with those of the nutrients.

A priority set of pressures on aquaculture that need to be taken into account during site-selection within the context of ICZM include weather (storms), disease/parasites, predation and pollution. Weather condition variations and especially the occurrence of storm events were indicated as a significant source of damage for the aquaculture industry, which could lead to enormous economical losses. Therefore, assessment of exposure is of extreme importance during site selection of both individual farms and aquaculture zones. Although farmers themselves reduce the issue by avoiding very exposed sites, storm damage was identified as the most important source of financial losses by all sources of information. On the other hand, exposure is an important prerequisite for both adequate and high quality water as well as for removal of wastes. In this context, there is a need for optimisation of the site selection with regard to weather conditions and hydrography, in the context of available and affordable engineering. Indicators for this aspect are suggested to be the: frequency of storms, wave-height (average and frequency of extreme values) and fetch.

Disease and parasites are together the second most important issue for aquaculture welfare, identified as a source of damage to aquaculture that in many cases stems from aquaculture practices themselves. Aquaculture welfare is strongly dependent on the management of individual farms (e.g. stocking density, health management, and use of prophylactic measures) and partly due to environmental issues, such as the quality of the ambient water and proximity to other farms. Suggested indicators of aquaculture welfare are: production by other farms using the same species at distance <2km and water quality issues (see below, pollution)

Predators also cause losses to fish farms at unpredictable rates. Some anti-predator tools (scarers, nets, etc.) are used for birds but the efficiency of anti-predator devices is less well documented for turtles, seals, dolphins and tuna, which have been shown to cause damages to both farmed fish and nets. The fact that many predators have statutory protection implies that aquaculture must avoid areas where such species frequently occur and where derogations are not available. Suggested indicators for this aspect are: colonies of birds in the vicinity (<2km), colonies of seals in the vicinity (<1km), nesting beaches for sea turtles in the vicinity (<10km) and frequency of observation of dolphins and tuna in the area.

Pollution was not identified as a major source of losses but was by far considered the most significant risk for aquaculture, as it is known from the literature that in cases of pollution incidents (particularly oil spills, in Scotland, Spain and Greece) the result was total destruction of the farmed capital. Both land based sources of pollution and maritime operations may contribute to problems as well as to other less well identified issues that may have negative effects on aquaculture, such as the introduction of nuisance alien species through ballast water. Suggested indicators for this aspect are: distance from land based sources of pollution - distance from waste discharge points, distance from harbours, distance from rivers (having significant human impacts); and distance from major maritime routes

Although not well documented in the scientific literature there are also issues that could directly or indirectly affect aquaculture by inducing socio-economic conflicts with other resource users, particularly tourism and fishing. Potential indicators for this aspect are suggested to be the distances of aquaculture facilities from: fishing grounds, tourist facilities, and houses.

The assessment of the desirability of investment projects in aquaculture as in any other industry should be based on a clear framework for the valuation of both the private and social costs and benefits involved. A way to achieve this is through economic analysis. Financial analysis deals with the input costs and the market value of production of a private investor, for whom the main objective is likely to be the maximisation of profits. On the other hand, the accounting system of economic analysis is much broader and encompasses elements that may be ignored by the private investor but which can imply significant costs to society. The need for economic analysis stems from the fact that projects intended to yield benefits in the form of the provision of goods and services may negatively affect society as a whole. This may be the case with the environmental impacts of aquaculture or other production activities. When these impacts are not compensated we are in the presence of a market failure, defined in economics as an externality. In ECASA we present examples of the calculation of Net Present Value (NPV) as an indicator of whether the development is worthwhile in the long term, a measure of economic sustainability.

## **1.5 Synthesis and critical analysis of the results achieved including gaps in research**

The ECASA toolbox contains an ordered collection of tools (models, indicators, guidelines and examples of EIA documentation) of use to a wide range of stakeholders and is the main result of ECASA. In addition to this public output, analysis of the results is currently being written up as manuscripts for submission to international peer-reviewed journals. Without wishing to pre-judge the conclusions of these ongoing efforts a few general conclusions of the results can be derived.

### **1.5.1 Indicators**

#### **1.5.1.1. Macrobenthos**

Benthic macrofaunal indicators are the best researched and most developed of the indicators and are relevant to a wide range of culture types. Although 2 of these indicators (AMBI and ITI) performed very well in terms of producing clear trends in relation to distance from the farm it would be unwise to discard simpler indicators such as diversity indicators, and indeed the univariate indicators such as numbers of species, as these are useful and relatively easy to understand and compute or measure. These simple indicators rely on identification of all the animals present in a sample to lowest practical taxonomic level, and because the species list that is the product of this identification is the basis for the more complex indicators, there is no additional cost in their use. Other studies have shown that valuable information can be obtained when analysing sample to higher taxonomic levels (i.e. lower taxonomic resolution, e.g. to family level) but this then precludes the use of ITI and AMBI and other indicators that require species level identification. There are concerns about the high

costs and the availability of sufficient taxonomic expertise to identify large numbers of samples to species level. The response to these concerns is threefold. i. Assessing the changes to the macrobenthic assemblage around aquaculture operations is the most useful and direct measure of impact available. ii. Although the costs are high compared to some other indicators, they are very small compared with the turnover of the vast majority of aquaculture operations. iii. The lack of trained taxonomists is of particular concern in some countries. The experience in others is that when the market is driven by a regulators demand, it develops the capacity to supply these services relatively quickly and competition between analysts helps reduce prices.

### **1.5.1.2 Meiobenthos**

Meiobenthic indicators are not widely used at present in aquaculture. However, in principle the meiobenthos represent a useful group for assessing impacts from fish farms. Owing to their short life cycle they might be expected to respond rapidly to changes in organic loading from farms. In ECASA the nematode/copepod ratio was found to change quite consistently with distance from the farm as did community structure. Meiobenthos are however very sensitive to sampling method, requiring an undisturbed sediment surface and therefore collection by diver or hydraulically damped corer. Thus meiobenthic indicators are not a practical option at every fish farm site.

### **1.5.1.3 Sediment, production and environmental indicators**

As macrobenthos is laborious, time-consuming and expensive to identify quantitatively, and in some areas there is a shortage of skill capacity, the identification of a simple, universal sediment indicator of biogeochemical status that could be used as a proxy has been much researched. While some regulators have implemented schemes that are principally based on sediment indicators (notably in New Brunswick, Canada) most continue to require macrobenthic as well as geochemical indicators to be determined for monitoring purposes.

In ECASA we grouped data from 58 stations into biological parameters (e.g. density, richness), location variables (e.g. current velocity, depth, distance to the cage, latitude), sediment variables (e.g. grain size, redox potential, TOM), and farm activity (years of functioning and production). The most important factors explaining variability in biological indicators were those related to the activity of the farms (production, years operating, distance from the station to the cages) and the hydrographical characteristics of the area (current speed, water depth); these factors together explained 29.1% of the variability for all locations. These factors supplemented with the sediment characteristics (grain size, redox, TOM), explained 20.8% of the variability; whereas sediment alone explained 4.8% of the total variability. Hence, the selected biological indicators represent well the extent of the impact of aquaculture, although it is important to consider the high percentage of unexplained variability (45.3%), which is probably due to intra-site specific characteristics not studied in ECASA.

### **1.5.1.4. Water quality indicators**

The four water quality indicators evaluated at nine ECASA Study Sites: ammonium, reactive phosphorus, chlorophyll a and Secchi disk depth, did not provide conclusive evidence of the impact of finfish and shellfish farms and, in particular, about potential adverse effects on the pelagic ecosystem. Focusing on single indicators, monitoring of

ammonium and reactive phosphorus provides evidence (on average) of nutrient enrichment near the farms. However, deviations of Chlorophyll a and Secchi Disk from the reference values observed at those sites were not correlated with those of the nutrients. Several previous studies have failed to find clear links between local primary production and water column nutrient concentrations. In many cases this is because the timescale of biological response is greater than the residence time of the receiving water body. This therefore leads on to wider scale considerations and cumulative effect assessment and this is best considered by models. However, models require validation data and we do not therefore suggest that collecting data on water column indicators has no value but rather that the objectives in collecting such data need to be clear.

From the fish/shellfish health perspective, water column oxygen concentration is clearly a key indicator but as this is already well understood, and routinely measured at many culture sites, ECASA did not focus on this indicator from the animal health perspective.

### **1.5.1.5 Socioeconomic indicators**

Sustainability indicators are part of the governance framework for aquaculture, and most commentators now accept that the socio-economic as well as the environmental dimensions of sustainability should be included. These indicators need to measure not only the operating performance of commercial fish farms – which at its simplest could be summarized using financial ratios - but the wider impacts of aquaculture on society at large. Indeed, it is precisely these impacts which, within the DPSIR framework, can be expected to invoke an institutional response intended to alter the way in which aquaculture is regulated and managed.

The socio-economic indicators proposed in ECASA are classified in terms of four major governance objectives – supply availability, livelihood security, economic efficiency and social acceptability. It is important to emphasise that, like all indicators, they are often only meaningful when used comparatively. The basis of comparison may typically be either (i) *normative* – i.e. the performance of aquaculture is compared with some standard or norm considered acceptable (e.g. income per capita, environmental damage costs), or (ii) *empirical* – i.e. the industry's performance is tracked over time or compared with that of another country (e.g. trends in employment, productivity, prices, etc.).

### **1.5.2 Models**

In most countries where aquaculture is expanding, both industry and regulator are turning to increasingly sophisticated modelling techniques to answer questions related to sustainability for both business and planning purposes. ECASA considered 16 models (or model suites). These had a wide range of applications in terms of scale of interest (local to regional, individual based to ecosystem level), culture types (from fish cages to intertidal bottom culture), species (from tuna to mussels) and purpose (carrying capacity to benthic impact). The ECASA toolbox contains a great deal of information on these models, their utility and their reliability and, to the best of our knowledge, represents a unique resource of such tools for aquaculture assessment and planning. No two models had precisely the same objective so head-to-head comparisons were not possible. On the whole, the models tested achieved their

purpose and the bounds of their reliability have been more clearly defined as a consequence of testing. Most importantly their limitations and constraints should be more transparent to the stakeholder community. They were utilised for a variety of purposes at the ECASA study sites and examples of their utility can be seen in the context of real commercial ventures.

#### **1.5.4 EIA**

It became apparent during the initial stages of ECASA that in many of the Member States the EIA process as outlined in the Directive was not commonly carried out for aquaculture developments. Thus several partners had no experience of this process. We decided that an additional objective for our field studies (i.e. in addition to testing and evaluating models and indicators) would be that additional data would be collected to attempt the completion of post-development Environmental Statements (ES) (as opposed to conventional Environmental Statements that gather information on environmental and social costs and benefits to inform the planning process). To this end a template was produced that in addition to allowing reporting of assessment of ECASA indicators and models also collected the background information that is necessary for an ES on the basis of a template used previously by the co-ordinator and found to be satisfactory. All study site reports (see the toolbox) follow this format, although for some sites a reduced format was accepted owing to resource constraints. In all cases the basic information necessary for a holistic assessment of the impacts of the site were collected and can be used as guides for future EIAs. It is likely to be highly beneficial (pro-competitive) if a common framework of EIA process and ES reporting can be implemented across the member states and it is hoped that ECASA results will contribute to this. There are however some important points that perhaps are not emphasised in the individual reports:

i Although all aspects of the environment and ecosystem need to be addressed the relative weighting must be decided using a risk-based approach. Thus issues that have potential to have a high impact must receive more detailed consideration. If this approach is not taken then ESs can become very long (and dull), being padded out with unnecessary information on un-contentious issues while perhaps glossing over the main issues for that site.

ii The ES must consider social aspects, both costs and benefits. While a full economic valuation of costs and benefits may be problematic owing to the complexity of both social and natural systems, the ES must clearly state the major social issues alongside the major environmental concerns in order that planning authorities and the public can reach balanced or at least transparent decisions.

iii Although the Directive is focused on developments at particular sites individually, the ES must place the proposed development in the context of other use of the marine environment and consider cumulative effects of both aquaculture and other sources of environmental disturbance.

### 1.5.3 Social acceptability of aquaculture

There is evidence from public attitude studies conducted in the Mediterranean and Scotland that the social acceptability of aquaculture is linked to its perceived environmental impact. It is precisely this issue of social acceptability that was addressed within the ECASA project. The question asked is: What do people want from aquaculture? To answer this, Project Partners at the University of Portsmouth developed a survey-based approach which aimed to elicit public and stakeholder attitudes towards the environmental performance of aquaculture. Salmon farming in Scotland was used as a case study, though on the basis of the results we are confident that the methodology can be adapted to other areas and situations (e.g. sea bass or sea bream in the Mediterranean) where the social acceptability of aquaculture is an issue. The public attitude survey covered five Scottish coastal areas where salmon farming is already developed and may possibly develop further in the future. These were: Highland, Argyll and Bute, Orkney, Shetland, and the Western Isles. Questionnaires were sent in the Autumn of 2006 to a random sample of householders on the Electoral Registers for Scotland, generating a total of 745 usable responses. The survey of stakeholders commenced in Spring 2007, and consisted in total of 39 key representatives of the following interest groups: regulators (5), industry (3), environmental organisations (6), wild fish interests (6), economic development agencies (6), independent experts (10), and consumer organisations (3).

The results indicate that public attitudes towards the future of the salmon farming industry are a function of the weights people attach to the beneficial effects of industry expansion (i.e. job creation, increased supplies, etc.) as against the perceived negative effects associated with environmental degradation. Specifically, those who favoured an expansion of salmon farming generally accorded the lowest priority to minimising environmental damage and correspondingly more weight to economic objectives. Conversely, those who wanted to see a downsizing of the industry put more weight on environmental issues. These results from the general public provide a benchmark against which to compare the findings of the stakeholder survey, which exposed marked differences between the interest groups in the relative importance attached to the various socio-economic and environmental performance indicators. There is a debate to be had over the implications of these differences, but at the very least it implies that stakeholder influence over aquaculture policy needs to be judged in terms of how far the preferences of particular interest groups are congruent with those of the public at large.

The survey of the general public also found significant regional variations in attitudes towards salmon farming, with a higher proportion of respondents in the Western Isles favouring an expansion of the industry than in any of the other coastal areas covered by the survey. Part of the explanation for this difference may lie with the varying economic profiles of these five regions, and it is noteworthy that the Western Isles is an area where unemployment rates have historically been above those for the rest of Scotland and also that here the jobs density is below that of the other regions surveyed. In the Western Isles, more so than elsewhere, we might therefore expect that attitudes to any industry which creates jobs and sustains livelihoods would be positive. Support for this argument was provided by a statistical analysis of the survey data showing that neighbourhood characteristics (specifically, area deprivation) appear to have a significant influence on public preferences towards aquaculture development. If that is the case, then it suggests that the way people evaluate the

trade-off between the socio-economic and environmental effects of aquaculture cannot be separated from the local and regional context in which such choices are made.

## 1.6 List of publications

### Papers

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## **1.7 The impact of the project on the aquaculture industry.**

The failure of the traditional sectoral approach to sustainably manage the environment and natural resources in the face of increasing human pressures and impacts was first formally acknowledged at the Earth Summit held in Rio de Janeiro in 1992. This led to a paradigm shift in environmental management with the focus on implementing a holistic 'Ecosystem Approach' involving social, economic and environmental sectors with the aim of achieving sustainable development. Aquaculture within the European Union is a growth industry, utilising freshwater and marine environments to produce shell-fish and fin-fish for human consumption. This industry is vitally important for the stability of the rural communities, in which it is based, providing employment where there are few other job opportunities. To ensure the durability of this industry and secure its long term employment the strategy for continued development must combine farming technologies, socio-economics, natural resource use and governance, via a systematic integrated assessment process of both its positive and negative impacts so that sustainability can be achieved. It is to this aim that ECASA has been focused.

ECASA has aimed to develop theory as well as tools for a sustainable aquaculture industry. A sustainable finfish or shellfish farm is one that will continue to return an income to its owner, proportionate to capital and labour. A sustainable site is one that will continue to provide the ecosystem goods and services on which the farm depends, and those which other people use. Inherent in achieving this sustainable development is the selection of suitable sites for aquaculture activities and ensuring the actual environmental impacts of the farm are effectively assessed.

The range of aquaculture practices and species cultured that occur in Europe were comprehensively studied during ECASA. The results of the field testing of the various tools selected during the first part of the project is incorporated in the final output of the Project. This innovative product is a virtual Toolbox, aimed specifically at farmers and regulators in the aquaculture industry. The Toolbox is freely available on the internet to any interested party to investigate. It gives information on the regulatory requirements in Europe regarding aquaculture, the process of Environmental Impact Assessment and the indicators, models and protocols used in implementation.

The Toolbox provides a novel approach to selecting suitable sites for aquaculture and maintaining those sites already in use for sustainable production. Site selection for aquaculture has often proved inadequate on a range of scales, both with respect to the receiving ecosystem and with respect to ecosystem services to cultured species. Similarly, there are problems regarding effective Environmental Impact Assessments, and the resultant accompanying Environmental Statements. After consultation with stakeholders across Europe the Toolbox has been tailored to provide a selection of environmental tools and protocols that may be implemented when selecting sites for aquaculture or assessing those already in operation. The impact of this novel product cannot be predicted.

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## Section 2.

### 2.1 Publishable results of the final plan for using and disseminating the knowledge.

#### Partner 12 IFREMER.

- Result description

The main result of the WP2, on which IFREMER is a major contributor, consists in a list of indicators describing the impact of aquaculture on ecosystems, together with annotated sheets explaining the meaning of every proposed indicators, its validity, and its use for different ecosystem compartments, species, type of aquaculture and rearing environments. These indicators address the different aspects of environmental and socio-economics impacts of the marine aquaculture (Fish and shellfish). They are aiming at providing the full coverage of how the consequences of aquaculture may affect the functioning and the structure of host ecosystems. They differ from the classical indicators of sustainable development, by the fact that they are focusing on a unique activity, and its relationships with all aspects of an ecosystem

- Potential users.

These results might be used by all scientists, environmentalists, stakeholders and R&D departments.

- Stage of development

Annotated sheets can be still improved, and indicators added before the final selection, during the course of the ECASA contract. The documents presented shall be considered as drafts until the final process of ECASA is ended (proposal of indicators and models, field-tests of these tools, and the final selection of tools kits (indicators and models) to be used in EIA and site selection for aquaculture)

- Collaboration sought or offered

Indicators related to aquaculture are currently produced through many process, within several agencies (UNEP, FAO, GESAMP, ICES). Also, other European contracts aim at the production of indicators (CONSENSUS). Information is exchanged, with the different coordinators and workpackage leaders of these groups, to gain the benefit of these different approaches. This exchange should be intensified before the end of the ECASA contract.

- Collaborator details

Potential partner for exchanging information on indicators related to aquaculture are other European contracts, international agencies, national institutes and stakeholders representatives having an interest in the ecosystem approach of sustainable aquaculture, which are not partners within the ECASA community.

Apart from ECASA, the main community which produces indicators for the marine aquaculture is the one based on the CONSENSUS contract. While the aims are not identical to those of ECASA, several groups of stakeholders are participating to this contract.

Among the international agencies are the Environmental European Agency which publishes indicators on the assessment of environmental performance of European marine fisheries and aquaculture (technical report n° 87), the ICES, the FAO (various GESAMP reports), the OECD and regional agencies (OSPAR commission, HELCOM commission, Blue Plan for the Mediterranean sea).

National institutes may produce indicators for their own purpose or for filling the needs expressed at higher levels. The corresponding data are difficult to gather and to compare, since they may be obtained with divergent aims.

- Intellectual property

Rights are protected according to the ECASA agreements.

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### **Partner 15 Rudjer Boskovic Institute.**

Marko Jusup, Sunčana Geček and Tarzan Legović, Impact of aquacultures on the marine ecosystem: modelling benthic carbon loading over variable depth.  
Ecological Modelling (in review)

#### **Abstract:**

In order to be used within EIA study, we have developed a 3-dimensional particle-tracking model for prediction of benthic carbon loading (BCL) caused by fish farms. The model is based on stochastic differential equations for particle transport consistent with the well-known semi-empirical advection/diffusion equation. It requires only easily obtainable input data in the form of measured current record and a specification of local bathymetry. The model accounts for advection by long-term residual and tidal currents, turbulent diffusion, realistic bathymetry and variations in daily (monthly, yearly) emissions from fish farms.

Here we concentrate on the changes in sedimentation pattern caused by various bathymetric shapes. Examination of idealized cases reveals where and why we can expect the worst impact on benthic communities. For future reference, these results will be included into guidelines for fish farming.

Keywords: fish farms, benthic carbon loading, model, variable depth

Jasminka Klanjšček and Tarzan Legović, Is anchovy (*Engraulis encrasicolus*, L.) overfished in the Adriatic Sea? Ecological Modelling (in review)

Abstract:

Based on Santojanni et al. (2003) stock size estimates for the period from 1975 to 1996, we constructed a model to investigate population dynamics of anchovies. Using numeric simulations we calculate the maximum sustainable catch (MSC) as well as the optimum level of spawning stock to maintain the MSC. By comparing computed levels with Santojanni et al. estimates, we find that the anchovy population is below the optimum level i.e. overfished since 1982. We find evidence of overfishing in 1982, 1985, 1986 and 1988. We claim that the large catch in 1985 was more responsible for the collapse of anchovy fisheries in 1987 than low recruitment levels. We investigate possible ways of fishing using the two stage model by considering three fishing scenarios: the whole stock is fished with equal effort, only mature individuals are fished, mature and immature individuals are fished with unequal effort. We show that the best strategy is to fish only the spawning stock.

Keywords: two stage model, optimum fishery, anchovy, stock estimates

Tarzan Legović, Adriatic Sea: Impact of demersal fishery and evidence of the Volterra principle to the extreme. Ecological Modelling (in review)

Abstract:

Published comparison of data from two sets of cruises in the Adriatic Sea, Hvar, 1948-1949 and MEDITS 1996-1998 have shown a significant decrease of total and commercial demersal fish stocks during fifty years of fishery. Furthermore, it has been shown previously that the stock of [Chondrichthyes](#) has decreased while the stock of Osteichthyes has increased relative to [Chondrichthyes](#) and, for several species, the increase is in absolute values too. Using simple logistic population growth under proportional harvesting it is shown which reported categories have been overfished. It is also shown that observed changes in [Chondrichthyes](#) and Osteichthyes are in agreement with the Volterra principle down to the extinction of predators. Furthermore, using Gause competition model under increasing fishery it is shown that an initially dominant competitor may become a marginal competitor, in agreement with observations.

Keywords: overfishing, prey-predator models, competition model.

## **Partner 10 Institute of marine Research, (IMAR).**

EcoWin 2000 (E2K) – Ecological modelling platform (Ferreira, 1995)

The EcoWin2000 (E2K) modelling platform makes use of an object-oriented programming (OOP) approach to implement ecological models for aquatic systems and it is applicable at the ecosystem scale. The basic underlying structure is that of a spatial (1D, 2D and 3D) framework of boxes, within each of which the relevant biogeochemistry and population dynamics are resolved. E2K contains about one hundred objects, corresponding to hierarchies for simulating e.g. hydrodynamics, air temperature, oyster growth, seeding and harvesting processes, etc.

The usage of object-oriented methods to simulate processes in ecological systems simplifies model development due to the flexibility associated with the modularity and inheritance properties of the objects themselves and provides a much greater conceptual approximation between natural ecosystems and interacting objects relative to structured programming.

The EcoWin 2000 ecological modelling platform was used to implement a research model simulating the major biogeochemical processes of pelagic and benthic for eutrophication and carrying capacity assessment in the Ria Formosa (ECASA study site). Water and pelagic state variables were redistributed within the Ria Formosa and exchanged with the ocean using the flows calculated with an hydrodynamic model (MOHID), and appropriate forcing was imposed at land and ocean boundaries for salinity, nutrients and phytoplankton (Nobre et al, 2005). In order to assess the carrying capacity of the system some variables were developed / improved, such as the benthic variables and the seeding/harvesting features.

#### FARM – Farm Aquaculture Resource Management

The intended scope of the FARM model is for shellfish farms (without the use of artificial food) in coastal and estuarine waters. The model runs as a web-based client-server application with a very simple interface, hiding the complex internal processing which includes transport equations, shellfish individual growth for several species, population dynamics and dissolved oxygen balance.

The FARM model is designed in order to determine the appropriate shellfish density for optimal carrying capacity (the greatest sustainable yield of market sized animals within a given time period) in a given farm (Ferreira et al, 2007). The general setting of the model assumes that water is flowing from left to right and transports suspended matter (chl a and POM) that is filtered and eaten by the farmed shellfish.

The FARM model allows to calculate the yield of the farm based on:

- a) food supply
- b) farm size
- c) environmental parameters

and it integrates the ASSETS model, being able to assess farm related eutrophication effects (including mitigation).

The development of the FARM model began in 2006 with the objective of preparing a model which took into account the transport of water properties across a shellfish farm (suspended or bottom culture) and which simulated growth as a function of availability of drivers such as chlorophyll a and organic detritus. The model incorporates population dynamics, allowing farmers to examine the production of the marketable cohort, and applies a simplified version of the well-tested ASSETS (NOAA/IMAR) eutrophication assessment model in order to evaluate the changes to water quality associated with shellfish production. The individual shellfish models were developed, calibrated and validated by PML, and further field trials of FARM are currently underway in Scotland, Ireland and China.

#### ASSETS – Integrated approach for Eutrophication assessment

ASSETS is a screening model that can be used as an integrated approach for eutrophication assessment. This model provides an overall classification of the eutrophication status of the system into five classes: High (best), Good, Moderate, Poor and Bad (worst), by aggregating the results of three diagnostic indices (Bricker et al, 2003):

1- Overall Human Influence (OHI), an index of pressure using simple mass balance model based on land nutrient loading and system susceptibility;

2- Overall Eutrophication Conditions (OEC), a symptom based evaluation of state calculated by aggregating primary and secondary eutrophication symptoms (using a combination matrix). The symptoms are evaluated using a logical decision process (Bricker et al, 2003) applied to the variables chlorophyll a and macroalgae for the Primary Symptoms Method (PSM) and dissolved oxygen, submerged aquatic vegetation (SAV) loss and nuisance and toxic algal blooms for the Secondary Symptom Method (SSM).

3 – Definition of Future Outlook (DFO), an indicator of how conditions in the system will change in the future (eg prediction of conditions) based on expected changes in management and land use within the watershed combined with an assessment of the susceptibility of the system and is graded to five classes (from best to worst): Improve High, Improve Low, No evolution, Worsen Low and Worsen High. A component to evaluate what the management response should be based on present condition and susceptibility is in development.

(<http://www.eutro.org/documents/Slides%20ASLO2005%20SS72%20Response.pdf>)

In the case of the Ria Formosa (an ECASA system) model, the outputs of a detailed dynamic model were used to drive the ASSETS screening model, which resulted in an eutrophication status classification of Good.

#### WISE Approach

The Wild species Integration for Shellfish Ecoaquaculture (WISE) is an ecosystem modelling approach aimed at improving shellfish aquaculture management by explicitly considering natural benthic biodiversity (Sequeira et al, in press). This methodology uses a combination of benthic field survey data, sediment and bathymetric mapping, physiological models and dynamic ecosystem modelling. The WISE approach helps to understand the baseline food requirements for maintaining natural benthic biodiversity of suspension-feeding organisms, thus informing managers on potential upper thresholds for shellfish aquaculture. It was tested in four coastal systems in Europe and China, including bays, estuaries and sea lochs with widely differing aquaculture activities. In Loch Creran, an ECASA study site, the density of wild individuals was estimated to be 175 ind m<sup>-2</sup> (total: 2.6 X 10<sup>9</sup>) and total clearance rates by wild populations were calculated as 40% d<sup>-1</sup> in Loch Creran (93 – 99 x 10<sup>6</sup> m<sup>3</sup> d<sup>-1</sup>), meaning that 56 % of total primary production in Loch Creran is consumed annually by wild organisms. Integration of the WISE approach within broader ecological modelling (such as EcoWin2000 illustrates some of the trade-offs between commercial aquaculture and the conservation of biodiversity, showing that rates of and capacities for shellfish culture are reduced when both wild and cultured suspension-feeding species are considered in relation to the available seston. When food resources are partitioned between wild and cultivated species,

there is a decrease in individual length and weight, resulting in a lower aquaculture production (e.g. for Pacific oyster in Loch Creran, a reduction of 34 % was predicted).

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## Partner 16. University of Goteborg.

1) Development of the screening model FjordEnv. The FjordEnv model can be used by e.g. regulators to calculate environmental effects of fish farming and municipal and industrial wastewater on fjords and other inshore areas. It can also be used to calculate environmental effects of dredging and building road-banks in sea straits and changing runoff.

The article "The vertical transport of POM regulated by fjord topography" written by Erlandsson C.P. and accepted by *Journal of Geophysical Research – Biogeosciences*, was produced during the project. The results will be used to further develop the model FjordEnv (Stigebrandt, 2001). A conceptual/analytical model for vertical transport of POM, Fc, was developed covering the combination of the three possible sources of POM/nutrients to an enclosed area; the coastal water, local supply, and nutrient rich local deepwater. The mathematical formulation of the conceptual model includes several factors describing to which degree various physical mechanisms in the fjord are influencing Fc. The new sub model can thus be used to categorise areas with respect to sensitivity to local and large scale eutrophication, which is an important step towards better management and more sustainable exploitation of the coastal zone.

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2) Development of the screening model FjordEnv. The FjordEnv model can be used by e.g. regulators to calculate environmental effects of fish farming and municipal and industrial wastewater on fjords and other inshore areas. It can also be used to calculate environmental effects of dredging and building road-banks in sea straits and changing runoff.

The article "The vertical transport of POM regulated by fjord topography" written by Erlandsson C.P. and Stigebrandt A., 2006) and printed in Journal of Marine Systems 60: 19-29, was produced during the project. The results will be used to further develop the model FjordEnv (Stigebrandt, 2001). Changed local supply of nutrients in coastal waters can lead to changed content of phytoplankton. This influences the visibility, and thereby the water quality in the surface layers, which can be observed by e.g. the Secchi disk. Secchi depth is used as an environmental indicator in the FjordEnv model. However, the translation of Secchi depth observations to plankton content is complicated by the existence of light attenuating matter entering with runoff from land. To increase the utility of Secchi depth measurements to assess local eutrophication in coastal waters, a formula for calculating the Secchi depth in areas influenced by freshwater was developed. The study includes data analysis of Secchi depth, chlorophyll content, wind speed, and freshwater height estimated from salinity at two stations in the Gullmar Fjord in Sweden.

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## **2.2 Appendices.**

**2.2.1 Appendix 1. An example of an annotated indicator sheet.**

| <b>Name</b>  | AMBI  |                          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
|--|---|--------------------------|----------------------------|--------------------------|--------------|-------------|-------------|--------------|--------------------|-------------|--------------|----------------------|-----------------|--------------|-------------|--------------|-------------------|------------|--------------|
| <b>DPSIR class</b>                                 | Impact  |                          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| <b>ECASA subgroups</b>                             | Benthos   |                          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| <b>ECASA code</b>                                  | AMBI  |                          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| <b>Proposed by participant</b>                     | 13 – AZTI, Spain  |                          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| <b>Definition, computation,</b>                    | <p>AMBI = ((0 x %GI) + (1.5 x %GII) + (3 x %GIII) + (4.5 x %GIV) + (6 x %GV))/100</p> <p>The result is a number in a range of 0-6 (7 for azoic sediments) that can be simplified into five classes from undisturbed communities to extremely disturbed communities (<i>sensu</i> Grall and Glémarec (1997)), or from High to Bad Status (<i>sensu</i> European Water Framework Directive (WFD), in the assessment of the Ecological Status).</p> <p>There is a freeware tool at <a href="http://www.azti.es">www.azti.es</a> to calculate the AMBI automatically and visualize graphically the results</p>  |                          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| <b>Data required</b>                               | Input data are densities of macrobenthic species from soft-bottom samples (if possible, per replicate).   |                          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| <b>Summary, scientific meaning, implementation</b> | <p>The AMBI, as defined by Borja <i>et al.</i> (2000, 2003a), is a biotic index which provides a ‘pollution classification’ of a particular site, representing the benthic community ‘health’ (<i>sensu</i> Grall and Glémarec, 1997). The AMBI is based upon previous ecological models, such as those of Glémarec and Hily (1981) and Hily (1984). The theoretical basis is that of the ecological adaptative strategies of the <i>r</i>, <i>k</i> and T (McArthur and Wilson, 1967; Pianka, 1970; and Gray, 1979) and the ecological succession in stressed environments (Bellan, 1967; Pearson and Rosenberg, 1978; and Salen-Picard, 1983).</p> <p>Taking into account the final objective of the proposal, several thresholds in the scale of the AMBI were established; those were based upon the distribution of the abundance of each species, to one of five ecological groups (sensitive to pollution, indifferent, tolerant, and second and first-order opportunistic species) (see Figure 2, in Borja <i>et al.</i>, 2000). These thresholds are coincident with the ‘benthic community health’ proposed by Grall and Glémarec (1997) (see Table 1, in Borja <i>et al.</i>, 2000), whose sources can be found in Reish (1959), Bellan (1967) and Pearson and Rosenberg (1976).</p> <p>The thresholds are also closely related with the definitions of the WFD, for detecting disturbed and undisturbed locations (see Borja <i>et al.</i> (2003a), Muxika <i>et al.</i> (2003), Salas <i>et al.</i> (2004), Muxika <i>et al.</i> (2005), Muniz <i>et al.</i> (in press) for different case-studies; and Borja <i>et al.</i> (2003b,c), for equivalences with the WFD).</p> |                          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| <b>Range of validity</b>                           | <table border="1"> <thead> <tr> <th>AMBI</th> <th>Disturbance Classification</th> <th>EcoQ (<i>sensu</i> WFD)</th> </tr> </thead> <tbody> <tr> <td>0.0&lt;AMBI≤1.2</td> <td>Undisturbed</td> <td>High Status</td> </tr> <tr> <td>1.2&lt;AMBI≤3.3</td> <td>Slightly Disturbed</td> <td>Good Status</td> </tr> <tr> <td>3.3&lt;AMBI≤4.3</td> <td rowspan="2">Moderately Disturbed</td> <td>Moderate Status</td> </tr> <tr> <td>4.3&lt;AMBI≤5.0</td> <td>Poor Status</td> </tr> <tr> <td>5.0&lt;AMBI≤5.5</td> <td rowspan="2">Heavily Disturbed</td> <td rowspan="2">Bad Status</td> </tr> <tr> <td>5.5&lt;AMBI≤6.0</td> </tr> </tbody> </table>   | AMBI                     | Disturbance Classification | EcoQ ( <i>sensu</i> WFD) | 0.0<AMBI≤1.2 | Undisturbed | High Status | 1.2<AMBI≤3.3 | Slightly Disturbed | Good Status | 3.3<AMBI≤4.3 | Moderately Disturbed | Moderate Status | 4.3<AMBI≤5.0 | Poor Status | 5.0<AMBI≤5.5 | Heavily Disturbed | Bad Status | 5.5<AMBI≤6.0 |
| AMBI   | Disturbance Classification  | EcoQ ( <i>sensu</i> WFD) |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| 0.0<AMBI≤1.2                                       | Undisturbed   | High Status              |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| 1.2<AMBI≤3.3                                       | Slightly Disturbed  | Good Status              |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| 3.3<AMBI≤4.3                                       | Moderately Disturbed  | Moderate Status          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| 4.3<AMBI≤5.0                                       |   | Poor Status              |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| 5.0<AMBI≤5.5                                       | Heavily Disturbed   | Bad Status               |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |
| 5.5<AMBI≤6.0                                       |   |                          |                            |                          |              |             |             |              |                    |             |              |                      |                 |              |             |              |                   |            |              |

|   |  |
|---|--|
| Species concerned (fishes/molluscs)       | All Species  |
| Related type of aquaculture               | All types  |
| Relevant environments for this indicator  | All types of coastal and estuarine environments, including coastal lagoons.  |
| Geographic scale                          | Local to regional  |
| Direct relevance to objectives            | – A (The AMBI is being used successfully in EIA, but it has also been proposed as one of the tools for the application of the WFD).  |
| Clarity in design.                        | – A (There are many references on its use and, recently, we have submitted a guideline to Marine Pollution Bulletin).  |
| Realistic collection or development costs | – B (It is very practical and it is based upon general ecological models, but benthos identification is always expensive in terms of the identification of species needed for the application. However, this is not a problem of the indicator, but a general problem in monitoring studies).  |
| High quality and reliability              | – A (We expected good results from aquaculture impact. We have previous information (see Muxika <i>et al.</i> , 2005) and, taking into account that most of the cage impact comes from organic matter enrichment, we expect a good reliability)  |
| Appropriate spatial and temporal scale    | – A (The AMBI shows good reliability with spatial and temporal gradients (Borja <i>et al.</i> , 2000, 2003 and Muxika <i>et al.</i> , 2003, 2005). On the other hand, when there is not impact, the AMBI remains very stable, although there are strong changes in the population structure and abundance, due to seasonal variability). |
| Obvious significance                      | – A (It is very easy to understand by the stakeholders, as the output is a number in a range from 0 to 7 and the gradients can be illustrated in a Surfer type figure with different colours).   |
| advantages                                |  |
| disadvantages                             |  |

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## State of validation

Related to aquaculture, we have checked it only with Greek data (Muxika *et al.*, 2005), but it has been tested under many other different impact sources (see references).

## recommendations

2.2.2 Appendix 2 Work Package 3 methodology.

TABLE 2. IMPACT ON SOCIO/ECONOMIC BENEFITS IN THE COASTAL ZONE

| VARIABLES                         | SEAFOOD | Finfish | Shellfish | Aquaculture | WASTE DISPOSAL | Municipal | Industrial | Agroforestry | TOURISM | MARITIME OPERATIONS | FISHING PRACTICES | OIL/GAS EXTRACTION/ PRODUCTION | MINERAL EXTRACTION | CRITICAL HABITATS | Coral Reef Ecosystems | Estuaries | Wetlands including Mangroves | Submerged Macrophyte Communities | Other Spawning and Nursing Areas | COASTAL AREA DEVELOPMENT | COASTAL AGRICULTURE | HYDROLOGICAL CYCLE ALTERATIONS | RECREATION WATER |
|-----------------------------------|---------|---------|-----------|-------------|----------------|-----------|------------|--------------|---------|---------------------|-------------------|--------------------------------|--------------------|-------------------|-----------------------|-----------|------------------------------|----------------------------------|----------------------------------|--------------------------|---------------------|--------------------------------|------------------|
| Algal toxins                      | ↑1      | ↑1      | ↑1        | ↑1          |                |           |            |              | ↑1      |                     |                   |                                |                    |                   | ←3                    |           |                              |                                  |                                  |                          |                     |                                | ↑2               |
| Artificial Radionuclides          |         |         |           |             |                |           | ←1         |              |         | ←3                  |                   |                                |                    |                   |                       |           |                              |                                  |                                  |                          |                     |                                |                  |
| Dissolved Oxygen                  | ↑1      | ↑1      | ↑1        | ↑1          |                | ←1        | ←1         | ←2           | ↑3      | ←3                  |                   | ←3                             |                    |                   |                       | ↑1        | ↑3                           | ↑3                               | ↑2                               | ←2                       | ←3                  | ←3                             |                  |
| Herbicides/ Pesticides/Biocides   | ↑2      | ↑2      | ↑2        | ↑2          |                | ←2        | ←3         | ←1           | ←2      | ←3                  |                   |                                |                    |                   | ↑2                    | ↓2        | ↑2                           | ↑2                               | ↑2                               |                          | ←1                  |                                |                  |
| Human Pathogens                   | ↑1      | ↑1      | ↑1        | ↑1          |                | ↑1        |            |              | ↓1      | ←3                  |                   |                                |                    |                   |                       |           |                              |                                  |                                  |                          |                     |                                | ↑1               |
| Litter/Plastics                   | ↑3      |         |           | ←3          |                | ←1        | ←1         | ←3           | ↓1      | ↓2                  | ←3                |                                |                    |                   |                       |           |                              |                                  |                                  |                          | ←3                  |                                | ↑2               |
| Metals and Organo Metals          | ↑1      | ↑2      |           | ↑3          |                | ←2        | ←1         | ←2           |         | ←3                  |                   |                                | ←1                 |                   |                       | ↑2        |                              |                                  |                                  | ←2                       | ←2                  |                                |                  |
| Nutrients                         |         |         |           | ↓3          |                | ←1        | ←3         | ←1           | ↓3      | ←3                  |                   |                                |                    |                   | ↑2                    | ↓2        |                              | ↓2                               |                                  | ↑3                       | ↑1                  | ↑1                             |                  |
| PAHs                              | ↑3      | ↑2      |           | ↑3          |                | ←2        | ←2         | ←3           |         | ←3                  |                   | ←1                             |                    |                   |                       | ↑2        |                              |                                  |                                  | ←3                       | ←3                  |                                |                  |
| Petroleum Hydrocarbon/Oil         | ↑3      | ↑1      |           | ↑3          |                | ←1        | ←2         | ←3           | ↑1      | ↓2                  |                   | ←1                             |                    |                   | ↑3                    | ↑2        | ↑1                           | ↑3                               | ↑1                               |                          |                     |                                | ↑2               |
| Phytoplankton abundance/diversity | ↑1      | ↑1      |           |             |                | ←2        | ←3         | ←1           | ↓3      |                     |                   |                                |                    |                   | ↑3                    |           | ↑3                           | ↑3                               |                                  | ↑3                       | ↑1                  | ↑1                             |                  |
| Pharmaceuticals                   |         |         |           | ←2          |                | ←3        | ←2         | ←3           |         |                     |                   |                                |                    |                   |                       |           |                              |                                  |                                  |                          |                     |                                |                  |
| Suspended Particulate Matter      |         | ↑3      |           | ↓3          |                | ←1        | ←2         | ←1           | ↓2      | ←1                  | ←3                | ←3                             | ←2                 |                   | ↑1                    | ↓2        |                              | ↑3                               | ↑3                               | ←2                       | ←2                  | ←1                             | ↑3               |
| Synthetic Organics/POPs           | ↑3      | ↑2      |           | ↑3          |                | ←3        | ←1         | ←2           |         | ←3                  |                   |                                |                    |                   | ↑3                    | ↓2        | ↑3                           |                                  |                                  | ←3                       | ←3                  |                                |                  |

### 2.2.3 Appendix 3. An example of a model descriptor.

| 1   | Name of model                           | Reporter/Institute (email address)  |
|-----|---|---|
| 1.a | <b>DEPOMOD</b>                          | Chris Cromey<br>Scottish Association for Marine Science (SAMS), Oban, Argyll. PA34 4AD. UK.<br>email: <a href="mailto:chjc@sams.ac.uk">chjc@sams.ac.uk</a><br>Tel. +44 1631 559 266 |
| 1.b | date this form was completed or updated | 11 <sup>th</sup> September 2007   |

| 2   | Short DESCRIPTION of model  |  |
|-----|---|--|
| 2.a | <i>Main state variables:</i>  | Particulates (total solids, carbon, tracer or other particulate component) and Infaunal Trophic Index (ITI)  |
| 2.b | <i>Scale to which applicable:</i>   | local to discharge, scale A  |
| 2.c | <i>General description.</i><br><br><i>NB: if the model is complicated, or has easily distinguishable components (such as a physical and a biological sub-models) that can be, or have been, used separately, it may be easier to complete one form for each of the main components.</i> | <p>A particle tracking model used for predicting flux of particulate waste material (with resuspension) and associated benthic impact of fish farms. Simulated particles sink and are displaced by currents and random-walk eddy dispersion. Shear in the water column can be represented by layers in the model. Resuspension is a function of near-bed currents. Net depositional flux is predicted in <math>\text{g m}^{-2} \text{yr}^{-1}</math> on a 2-D grid beneath a cage. Benthic community impact is predicted by an empirical relationship between depositional flux and the ITI. Sediment content (<math>\text{g kg}^{-1}</math>) of a particulate component, such as a medicine, can also be predicted. DEPOMOD is a major component of the AutoDEPOMOD modelling software.</p> |
| 2.d | <i>Key semi-universal parameters and example values (which should apply at least regionally or for at least one type of water body); summarize any restrictions or reservations about these parameters</i>  | <p>Locally-relevant horizontal and vertical dispersion coefficients.</p> <p>Water content and digestibility of the food to be used at the stage of the growing cycle to be modelled, feed wastage estimations; food and faecal settling velocity data (default and recommended values available for salmon)</p> <p>Resuspension model predictions from default parameters should be verified by checking predicted with observed benthic impact.</p>   |
| 2.e | <i>Main forcing data needed - initial values of state variables; boundary conditions; inputs; imposed environmental conditions; generalized loss terms. State whether single values or time-series needed.</i>  | <p>A current velocity timeseries is needed for an area close to the fish farm site, together with some knowledge of the vertical structure of the water column;</p> <p>Bathymetry, either from a site survey or from an Admiralty chart of the area, and number and dimensions (length, width and depth) of cages and the proposed/existing positions of these cages.</p>  |

|     |                                     |   |
|-----|-------------------------------------|---|
| 2.f | <i>Restrictions to use of model</i> | <p>Feed input data (kg food d<sup>-1</sup> for the whole farm) and mean fish size for the intended scenarios</p> <p>Model found to work well for soft sediment and low to moderately dispersive sites. Model requires further testing in dispersive, hard sediments areas.</p> <p>Plus see note in 2d above relating to re-suspensive sites</p> |
|-----|-------------------------------------|---|

| <b>3</b> Possibly relevant INDICATORS and example EcoQOs |                 |
|--|-----------------|
| 3.a  | <i>Driver</i>   |
| 3.b  | <i>Pressure</i> |
| 3.c  | <i>State</i>    |
| 3.d  | <i>Impact</i>   |
| 3.e  | <i>Response</i> |

| <b>4</b> STATUS of model <i>NB: refers to scientific theory and equation set; distinguish from implementation</i> |   |
|---|---|
| 4.a   | <p><i>Origin(ator) of model concept and initial formulation:</i></p> <p>A. Edwards (SMBA) for fish farms; UK 'Comprehensive Studies Task Team' (CSTT, 1994) for urban waste water discharges</p>  |
| 4.b   | <p><i>Present status of model, including scientific basis of claimed robustness and key matters still needing study:</i></p> <p>To validate near-field, sea surface to sea bed particle tracking algorithms, a 24 hour sediment trap study was undertaken at the two sites. For the dispersive site, model predictions of flux (g m<sup>-2</sup> d<sup>-1</sup>) generally agreed well with field data and an accuracy of ±20% was achieved. At the depositional site, an improved accuracy of ±13% was achieved.</p> <p>The resuspension model was validated in a study with UV fluorescent particles with similar settling characteristics to salmonid faeces and food. Tracer was introduced to the seabed and sediment samples taken on days 0, 3, 10, 17 and 30 to measure the horizontal and vertical distribution of tracer in sediments. The bulk of the deployed tracer initially deposited in an area 25 m radius from the release point and was observed to steadily decrease to zero over a period of 30 days. The validated model generally gave good predictions of total mass budgets (±7% of total tracer released) particularly where tracer concentrations were high near the release point.</p> <p>Correlations between predicted solids accumulation (g m<sup>-2</sup> yr<sup>-1</sup>) and observed Infaunal Trophic Index (ITI) and total abundance have been established using data from several fish farm sites. Envelopes of Acceptable Precision (EAP) have also been established. These allow predictions of</p> |

|     |  |
|-----|--|
|     | <p>indices to be obtained where the width of the EAP reflects natural variability of the benthic data measured for duplicate samples.</p> <p><i>Key matters needing study:</i> The model is primarily validated for soft sediments and depositional to dispersive sites, and has not been extensively tested in offshore or very dispersive sites, coarse/hard sediments (e.g. bedrock, sand), sites with underwater cliffs, shallow sites dominated by wind-wave resuspension. Flocculation or disaggregation behaviour of particles are not included. Current in the grid is horizontally homogenous, therefore accuracy decreases at increasing distance from farm in areas of complex topography/bathymetry. See below for references.</p> |
| 4.c | <p><i>Present use:</i></p> <p>Regulation of sea lice treatment chemical discharges from Scottish fish farms; regulation of maximum biomass for new applications. See: SEPA (2005a). User can validate their own local version of the model by measuring benthic impact indicators for their local environment and then establishing a relationship between predicted flux and benthic impact.</p>  |
| 4.d | <p><i>Potential use and development in ECASA :</i></p> <p>Estimating benthic impact of organic waste and medicines from farming of Salmon (primarily), cod and mussels in North Atlantic + other macro tidal and fjordic areas.</p> <p>Development of model to establish correlations between predictions (e.g. solids flux) and any indicators short listed in WP2. Coupling to hydrodynamic models of larger areas for determination of scale B effects. Development of model to establish relationships between solids flux and readily measurable biochemical indicators such as sediment free sulphide and sediment oxygen consumption.</p>   |

| <b>5 IMPLEMENTATION of model</b> |  |
|----------------------------------|--|
| 5.a                              | <p><i>State of implementation :</i></p> <p><i>(This refers to realization of model theory in numerical algorithms, spreadsheets, computer programs, etc. to provide solutions of the model equations when supplied with appropriate forcing data.</i></p> <p>Algorithms programmed in Borland Delphi 7 running under Windows 98 or later. Compiled, executable code is the usual form distributed.</p> |
| 5.b                              | <p><i>State of documentation</i></p> <p><i>(which describes how to use an implementation as well as giving model theory)</i></p> <p>Electronic user manual complete with software. Detailed documentation for use of the model in regulation of Scottish farms is given by SEPA (2005b).</p> <p>Training workshops in model use are available either in person or online (contact the author).</p>     |
| 5.c                              | <p><i>Intellectual property concerns – if none stated here, model and implementation will</i></p> <p>Model algorithms, source and executable code for implementation are property of SEPA and SAMS. Software is sold under license to external bodies and source code is</p>   |

|   |   |
|---|---|
| <i>be deemed to freely available on request</i> | not distributed with license. Software in form of executable code available to ECASA partners for non-commercial use. |
|---|---|

| <b>6.</b> | <b>TESTING of model</b>  |   |
|-----------|--|---|
| 6.a       | <i>Summary of conditions and measurements needed:</i><br><br><i>Refer back to 2.e if necessary. Highlight observations needed for model testing.</i> | Observations needed for model testing: hydrography, bathymetry, cage layouts, detailed husbandry data as in 2.e. Some or all of the following in order of preference are required for validation: benthic macrofaunal univariate indices distributions; solids flux (from sediment traps); some other tracer which can be used as signature for fish farm wastes = biochemical variables (e.g. free sediment sulphide measurements, sediment oxygen consumption) along organic gradient |
| 6.b       | <i>Criteria for model rejection</i>  | Model predictions have an EAP (Envelope of Acceptable Precision) which was established during validation and reflects variability of observations and predictions. Expect 88 % of data to fit in the EAP and this can be tested for a transect of sampling stations (e.g. 0, 25, 50 and possibly 75 m). Model rejected if less than 88 % of observations are not contained within the model EAP for comparative studies.  |

| <b>7</b> | <b>OTHER models</b>   |   |
|----------|---|---|
| 7.a      | <i>Used explicitly or implicitly with this model</i>  | None, but the model could make use of output from a hydrodynamic model. |
| 7.b      | <i>Similar models (which might serve roughly the same purpose in relation to mariculture)</i> | TRIMODENA (Partner AZTI); KK3D (Partner RBI)                            |

| <b>8.</b> | <b>REFERENCES cited</b>   |   |
|-----------|---|---|
|           |   | <i>show in bold the most important paper describing the model</i> |
|           | Cromey, C.J., Black, K.D., Edwards, A. & Jack I.A. (1998). Modelling the Deposition and Biological Effects of Organic Carbon from Marine Sewage Discharges. <i>Estuarine Coastal and Shelf Science</i> , 47, 295-308.   |   |
|           | <b>Cromey, C.J., Nickell, T.D. &amp; Black, K.D. (2002). DEPOMOD - modelling the deposition and biological effects of waste solids from marine cage farms. <i>Aquaculture</i>, 214, 211-239.</b>  |   |
|           | Cromey, C.J., Nickell, T.D., Black, K.D., Provost, P.G., Griffiths, C.R. (2002). Validation of a fish farm waste resuspension model by use of a particulate tracer discharged from a point source in a coastal environment. <i>Estuaries</i> , 25, 916-929.                                   |   |
|           | Cromey, C.J. and Black, K.D. (2005). Modelling the impacts of finfish aquaculture. In: B.T.Hargrave (ed.) <i>Environmental effects of marine finfish aquaculture. The Handbook of Environmental Chemistry (volume 5, part M): Water Pollution</i> , 129-155, Springer Verlag, ISSN 1433-6863. |   |
|           | Cromey, C.J. and Black, K.D. (2005). Modelling the impacts of finfish aquaculture. In: B.T.Hargrave (ed.) <i>Environmental effects of marine finfish aquaculture. The Handbook of Environmental Chemistry (volume 5, part M): Water Pollution</i> , 129-155, Springer Verlag, ISSN 1433-6863. |   |
|           | SEPA (2005a). <i>Aquaculture: modelling</i> . Scottish Environmental Protection Agency. Web page(s), URL: <a href="http://www.sepa.org.uk/aquaculture/modelling">http://www.sepa.org.uk/aquaculture/modelling</a> (seen 11 September 2007).   |   |
|           | SEPA (2005b). <i>Regulation and Monitoring of Marine Cage Fish Farming in Scotland: Annex H : Methods</i>   |   |

for Modelling In-feed Anti-parasitics and Benthic effects. Issue No: 2.3 Issue date: 18 May 2005.  
Available at: [http://www.sepa.org.uk/pdf/guidance/fish\\_farm\\_manual/annex/H.pdf](http://www.sepa.org.uk/pdf/guidance/fish_farm_manual/annex/H.pdf) (seen 11  
September 2007)

## 2.2.4 Appendix 4. An example of model validation.

### ECASA WP 4 Application of the DEB model to the sites of Baie des Veys (Normandy, France) and Loch Creran (Scotland)

Aline Gangnery, Cédric Bacher, Stéphane Pouvreau

#### Introduction

The DEB (Dynamic Energy Budget) model describes the energy flows through an organism and also changes in the environment with varying food densities and temperature. The model allows to simulate individual growth rate and reproduction. The background of the DEB theory can be found in Kooijman (2000). This theory was recently applied to several bivalve species (van der Veer et al., 2006) and particularly, a parameterisation was specifically developed for the Pacific oyster, *Crassostrea gigas* (Pouvreau et al., 2006). The DEB model was proposed as a modelling tool within the ECASA project to assess *i*) the impact of bivalves on their environment (*e.g.* estimation of ingestion fluxes) and *ii*) the response of bivalves to modifications of their environment (*e.g.* modification of the individual growth rate). In this work, we applied the model to two study sites of the ECASA project: the Baie des Veys (France) and Loch Creran (Scotland). Both sites support the cultivation of *C. gigas*. Goodness of fit of the model was evaluated according to the procedure defined within the ECASA project (Portilla and Tett, 2007). This note aims to make a synthesis of results obtained through this application.

#### Material and methods

Two datasets were available for the two sites.

Individual growth of oysters was followed in the Baie des Veys between March 2002 and August 2003. Flesh dry mass and shell length were measured at each sampling date and the oyster population was sampled 16 times during the survey. Water temperature and concentration in chlorophyll *a* were also followed near the growth site. Water temperature was recorded continuously and chlorophyll *a* concentration was determined every second week. In Loch Creran, individual growth was followed between May 2005 and July 2006. Flesh dry mass and shell length were also measured at each sampling date and the population was sampled 10 times during the survey. Water temperature and concentration in chlorophyll *a* were determined *ca.* each month.

For both sites, forcing variables of the DEB model were water temperature and chlorophyll *a*, which represents available food for oysters. Individual growth was simulated by the model and then compared to observed data. Three cases were studied:

- Case a : the model was calibrated for the Baie des Veys (see list of parameters in Annex 1),
- Case b: the model was validated on Loch Creran with parameters used for the Baie des Veys,

- Case c: the model was calibrated and a new simulation was conducted with a new set of parameters.

For case c, the calibration was done on the  $X_k$  and shape parameters. The  $X_k$  parameter is the half saturation coefficient of the functional response of assimilation to food concentration. The functional response is represented by the equation:

$$f = \frac{[X]}{[X] + X_k}$$

where  $X$  is food density (*i.e.* the concentration in chlorophyll  $a$  in  $\mu\text{g}\cdot\text{l}^{-1}$ ).

$X_k$  depends on the site, reflecting the variable composition of food in different environment and modulates the food really usable by the oyster.

The shape parameter allows to convert the individual flesh dry mass into shell length. It is usually specific of the species but can vary according the site.

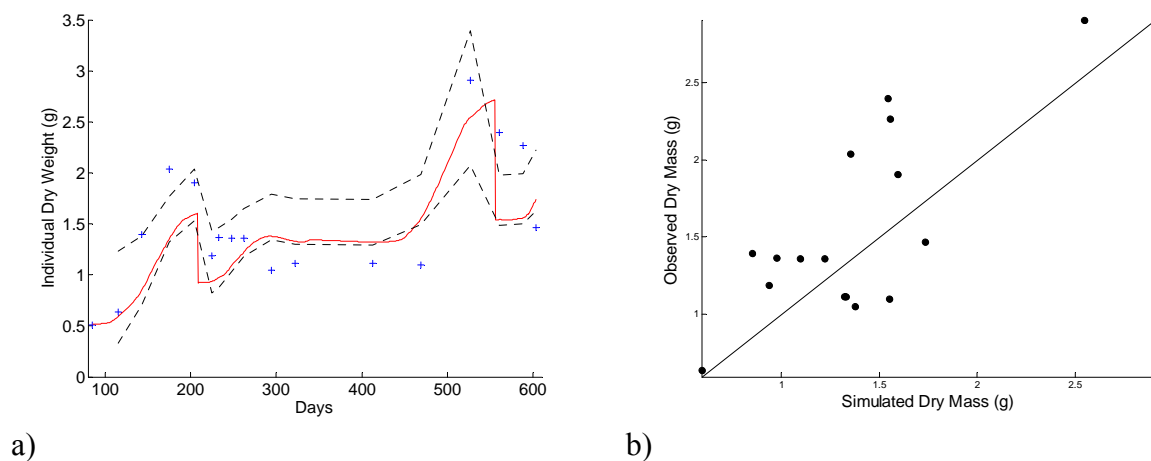
Both  $X_k$  and the shape are key parameters, classically used when a calibration has to be done.

For each simulation, the goodness of fit of the model was estimated by fitting a linear regression between observed and simulated values and comparing the resulting slope and intercept to 1 and 0, respectively. The regression equation was also used to show the reliability of model predictions through the estimation of 95% prediction limits.

## Results

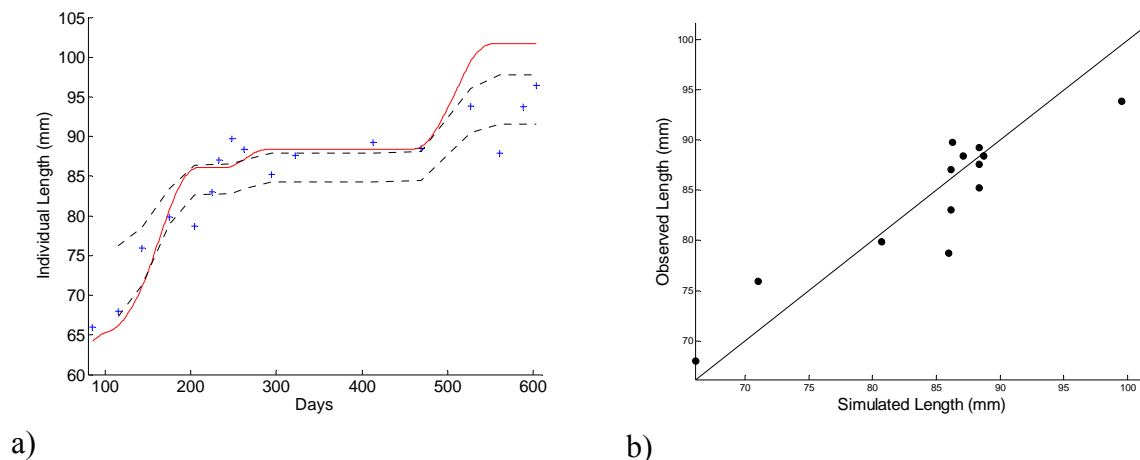
### *Case a: Calibration in the Baie des Veys*

For individual dry mass as well as for shell length, the model explains a significant part of variance in observations (Table 1 and 2). However, if the model reliability was classified excellent for individual dry mass, it was classified fair for shell length. Concerning dry mass, the model simulated well two spawning periods, which occurred at the end of July-beginning of August in 2002 and 2003 (Figure 1). The model under estimated growth during the spring period and over estimated growth during the fall and winter periods (September to March). For shell length, misfit of the model essentially appeared for larger individuals for which shell length is over estimated by the model (Figure 2).



**Figure 1: Application of the model to the Baie des Veys. a) Variation of observed values of individual dry mass (blue crosses), simulated values (red line) and confidence interval at 95% of**

predictions obtained with the linear regression between observed and simulated values (black dotted lines). b) Simulated vs. observed values of flesh dry mass.



**Figure 2: Application of the model to the Baie des Veys. a) Variation of observed values of individual shell length (blue crosses), simulated values (red line) and confidence interval at 95% of predictions obtained with the linear regression between observed and simulated values (black dotted lines). b) Simulated vs. observed values of shell length.**

**Table 1: Results of model performance for individual dry mass in the Baie des Veys.**

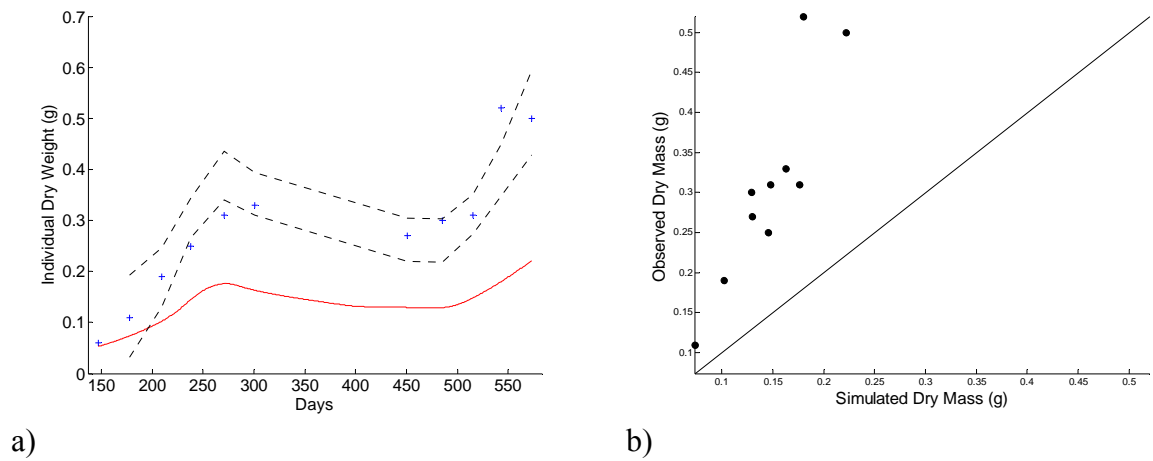
|   |        |                                |       |
|---|--------|--------------------------------|-------|
| n, number of independent observations used in test            |        | 14                             |       |
| <b>Model performance</b>                                      |        |                                |       |
| $r^2$ , % of variance   | 0.55   | p, on null hypothesis          | 0.001 |
| Regression intercept  | 0.19   | Standard error of intercept    | 0.34  |
| t (intercept different from 0)                                | 0.56   | p (intercept different from 0) | 0.58  |
| Regression slope  | 0.998  | Standard error of slope        | 0.24  |
| t (slope different from 1)                                    | 0.0048 | p (slope different from 1)     | 0.99  |
| <b>Model conclusion</b>                                       |        |                                |       |
| Model explains a significant part of variance in observations |        | YES                            |       |
| Model reliability class                                       |        | Excellent                      |       |

**Table 2: Results of model performance for individual shell length in the Baie des Veys.**

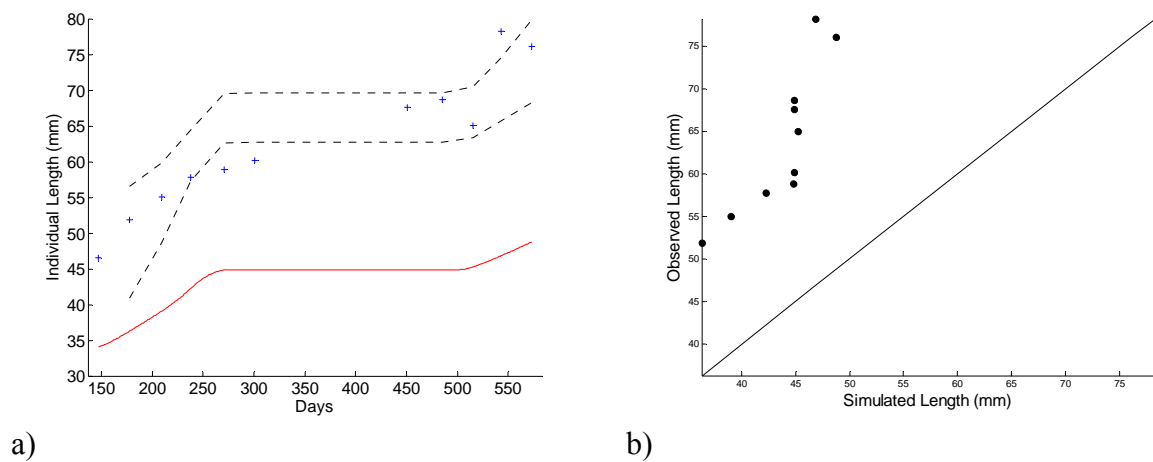
|   |       |                                |                      |
|---|-------|--------------------------------|----------------------|
| n, number of independent observations used in test            |       | 14                             |                      |
| <b>Model performance</b>                                      |       |                                |                      |
| $r^2$ , % of variance   | 0.80  | p, on null hypothesis          | $3.2 \times 10^{-6}$ |
| Regression intercept  | 29.07 | Standard error of intercept    | 7.69                 |
| t (intercept different from 0)                                | 3.78  | p (intercept different from 0) | 0.002                |
| Regression slope  | 0.65  | Standard error of slope        | 0.087                |
| t (slope different from 1)                                    | 4.09  | p (slope different from 1)     | 0.0011               |
| <b>Model conclusion</b>                                       |       |                                |                      |
| Model explains a significant part of variance in observations |       | YES                            |                      |
| Model reliability class                                       |       | Fair                           |                      |

**Case b: Validation in Loch Creran**

Regression models explain a significant part of the variance in observations for dry mass as for shell length (Table 3 and 4). For dry mass, the model class is good because the intercept was not significantly different from 0. However, the model largely under estimated the observed values (Figure 3). For shell length, the model class is fair because both the slope and the intercept were significantly different from 1 and 0, respectively. Simulated values were also largely under estimated compared to observed values (Figure 4). For both variables, prediction limits showed that the regression model between observed and simulated variables was reliable despite the poor ability of the model to reproduce observations.



**Figure 3: Application of the model to Loch Creran with parameters from the Baie des Veys. a) Variation of observed values of individual dry mass (blue crosses), simulated values (red line) and confidence interval at 95% of predictions obtained with the linear regression between observed and simulated values (black dotted lines). b) Simulated vs. observed values of flesh dry mass.**



**Figure 4: Application of the model to Loch Creran with parameters from the Baie des Veys. a) Variation of observed values of individual shell length (blue crosses), simulated values (red line) and confidence interval at 95% of predictions obtained with the linear regression between observed and simulated values (black dotted lines). b) Simulated vs. observed values of shell length.**

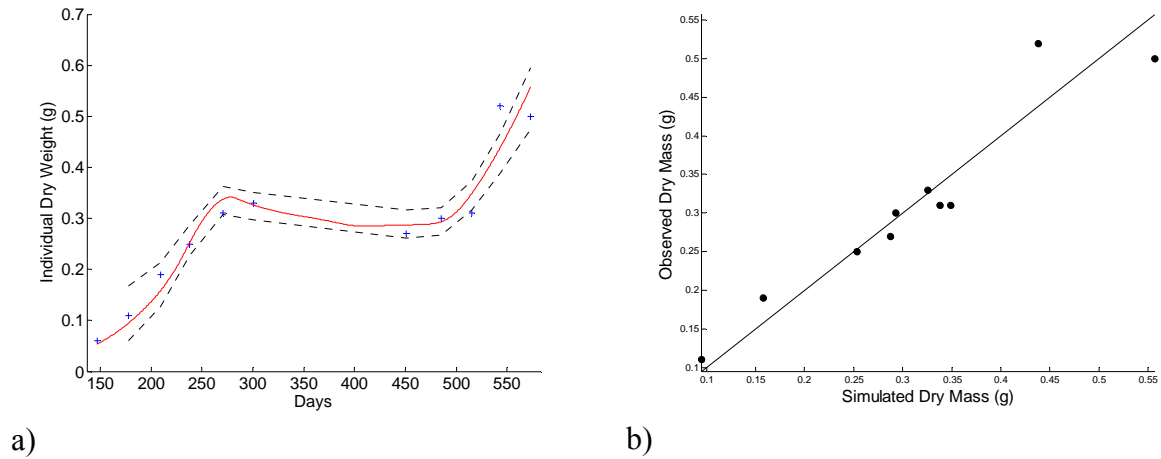
**Table 3: Results of model performance for individual dry mass in Loch Creran with parameters from the Baie des Veys.**

|   |       |                                  |                       |
|---|-------|----------------------------------|-----------------------|
| $n$ , number of independent observations used in test         | 8     |                                  |                       |
| <b>Model performance</b>                                      |       |                                  |                       |
| $r^2$ , % of variance   | 0.81  | $p$ , on null hypothesis         | $3.49 \times 10^{-4}$ |
| Regression intercept  | -0.09 | Standard error of intercept      | 0.07                  |
| $t$ (intercept different from 0)                              | 1.26  | $p$ (intercept different from 0) | 0.24                  |
| Regression slope  | 2.69  | Standard error of slope          | 0.45                  |
| $t$ (slope different from 1)                                  | 3.73  | $p$ (slope different from 1)     | 0.006                 |
| <b>Model conclusion</b>                                       |       |                                  |                       |
| Model explains a significant part of variance in observations | YES   |                                  |                       |
| Model reliability class                                       | Good  |                                  |                       |

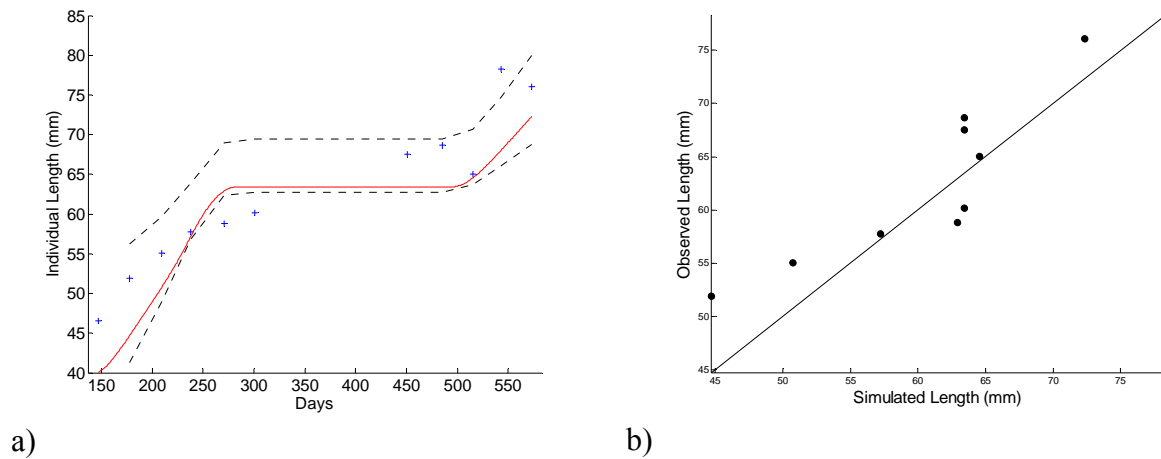
**Table 4: Results of model performance for individual shell length in Loch Creran with parameters from the Baie des Veys.**

|   |        |                                  |        |
|---|--------|----------------------------------|--------|
| $n$ , number of independent observations used in test         | 8      |                                  |        |
| <b>Model performance</b>                                      |        |                                  |        |
| $r^2$ , % of variance   | 0.73   | $p$ , on null hypothesis         | 0.0018 |
| Regression intercept  | -25.04 | Standard error of intercept      | 19.43  |
| $t$ (intercept different from 0)                              | 1.29   | $p$ (intercept different from 0) | 0.24   |
| Regression slope  | 2.03   | Standard error of slope          | 0.44   |
| $t$ (slope different from 1)                                  | 2.33   | $p$ (slope different from 1)     | 0.048  |
| <b>Model conclusion</b>                                       |        |                                  |        |
| Model explains a significant part of variance in observations | YES    |                                  |        |
| Model reliability class                                       | Fair   |                                  |        |

### *Case c: Calibration in Loch Creran*



**Figure 5: Application of the model to Loch Creran after a new calibration. a) Variation of observed values of individual dry mass (blue crosses), simulated values (red line) and confidence interval at 95% of predictions obtained with the linear regression between observed and simulated values (black dotted lines). b) Simulated vs. observed values of flesh dry mass.** Results showed that the model was classified as excellent for dry mass and shell length. For both variables, the model reproduced well observations (Figure 5 and 6) and the regression models were highly significant with slopes and intercepts not significantly different from 1 and 0, respectively (Table 5 and 6).



**Figure 6: Application of the model to Loch Creran after a new calibration. a) Variation of observed values of individual shell length (blue crosses), simulated values (red line) and confidence interval at 95% of predictions obtained with the linear regression between observed and simulated values (black dotted lines). b) Simulated vs. observed values of shell length.**

**Table 5: Results of model performance for individual dry mass in Loch Creran after a new calibration.**

|  |       |                                       |                       |
|--|-------|---------------------------------------|-----------------------|
| <i>n</i> , number of independent observations used in test | 8     |                                       |                       |
| <b>Model performance</b>                                   |       |                                       |                       |
| $r^2$ , % of variance                                      | 0.91  | <i>p</i> , on null hypothesis         | $1.89 \times 10^{-5}$ |
| Regression intercept                                       | 0.027 | Standard error of intercept           | 0.034                 |
| <i>t</i> (intercept different from 0)                      | 0.80  | <i>p</i> (intercept different from 0) | 0.45                  |
| Regression slope   | 0.91  | Standard error of slope               | 0.10                  |

|   |           |                                   |      |
|---|-----------|-----------------------------------|------|
| <i>t</i> (slope different from 1)                             | 0.87      | <i>p</i> (slope different from 1) | 0.41 |
| <b>Model conclusion</b>                                       |           |                                   |      |
| Model explains a significant part of variance in observations | YES       |                                   |      |
| Model reliability class                                       | Excellent |                                   |      |

**Table 6: Results of model performance for individual shell length in Loch Creran after a new calibration.**

|   |           |                                       |        |
|---|-----------|---------------------------------------|--------|
| <i>n</i> , number of independent observations used in test    | 8         |                                       |        |
| <b>Model performance</b>                                      |           |                                       |        |
| $r^2$ , % of variance   | 0.74      | <i>p</i> , on null hypothesis         | 0.0013 |
| Regression intercept  | 7.13      | Standard error of intercept           | 11.86  |
| <i>t</i> (intercept different from 0)                         | 0.60      | <i>p</i> (intercept different from 0) | 0.56   |
| Regression slope  | 0.93      | Standard error of slope               | 0.19   |
| <i>t</i> (slope different from 1)                             | 0.36      | <i>p</i> (slope different from 1)     | 0.73   |
| <b>Model conclusion</b>                                       |           |                                       |        |
| Model explains a significant part of variance in observations | YES       |                                       |        |
| Model reliability class                                       | Excellent |                                       |        |

### References

Kooijman, S.A.L.M., 2000. Dynamic energy and mass budgets in biological systems, Cambridge University Press, Cambridge.

Portilla, E., Tett, P. 2007. Assessing goodness of fit for ECASA models. 22 p.

Pouvreau, S., Bourles, Y., Lefebvre, S., Gangnery, A., Alunno-Bruscia, M. 2006. Application of a dynamic energy budget model to the Pacific oyster, *Crassostrea gigas*, reared under various controlled conditions. J. Sea Res. 56, 156-167.

Van der Veer, H.W., Cardoso, J.F., van der Meer, J. 2006. Estimation of DEB parameters for various North Atlantic bivalve species. J. Sea Res. 56, 107-124.

**Annex 1: List of parameters and initial conditions used for the different case study.**

**Case a: Calibration of the model in the Baie des Veys.**

**Case b: Validation of the model in Loch Creran.**

**Case c: Calibration of the model in Loch Creran.**

| Parameters   | Symbol             | Unit                             | Value<br>Case a | Value<br>Case b | Value<br>Case c |
|--|--------------------|----------------------------------|-----------------|-----------------|-----------------|
| Half saturation coefficient  | $X_K$              | $\mu\text{g.l}^{-1}$             | 5.5             | -               | 3.2             |
| Max. surf. area-specific assimilation rate                           | $\{\dot{p}_{Am}\}$ | $\text{J.cm}^{-2}.\text{d}^{-1}$ | 420             | -               | -               |
| Volume-specific maintenance costs                                    | $[\dot{p}_M]$      | $\text{J.cm}^{-3}.\text{d}^{-1}$ | 24              | -               | -               |
| Maximum storage density  | $[E_M]$            | $\text{J.cm}^{-3}$               | 2295            | -               | -               |
| Volume-specific cost for structure                                   | $[E_G]$            | $\text{J.cm}^{-3}$               | 1900            | -               | -               |
| Structural volume at puberty   | $V_p$              | $\text{cm}^3$                    | 0.3             | -               | -               |
| Fraction of energy utilisation rate spent on maintenance plus growth | $\kappa$           | -                                | 0.45            | -               | -               |
| Shape coefficient  | $\delta_m$         | -                                | 0.2             | -               | 0.17            |
| Arrhenius temperature  | $T_A$              | $^{\circ}\text{K}$               | 5800            | -               | -               |
| Reference temperature  | $T_I$              | $^{\circ}\text{K}$               | 293             | -               | -               |
| Lower boundary of tolerance range                                    | $T_L$              | $^{\circ}\text{K}$               | 281             | -               | -               |
| Upper boundary of tolerance range                                    | $T_H$              | $^{\circ}\text{K}$               | 305             | -               | -               |
| Rate of decrease at lower boundary                                   | $T_{AL}$           | $^{\circ}\text{K}$               | 75000           | -               | -               |
| Rate of decrease at upper boundary                                   | $T_{AH}$           | $^{\circ}\text{K}$               | 30000           | -               | -               |
| Fraction of reproduction energy fixed in eggs                        | $\kappa_R$         | -                                | 0.7             | -               | -               |
| Energy content of reserves (in ash-free dry mass)                    | $\mu_E$            | $\text{J.mg}^{-1}$               | 17.5            | -               | -               |
| Gonado-somatic threshold for triggering spawning                     | $R_{GS}$           | %                                | 37              | -               | -               |
| Temperature for triggering spawning                                  | $T_s$              | $^{\circ}\text{C}$               | 18.5            | -               | -               |
| <i>Initial conditions</i>  |                    |                                  |                 |                 |                 |
| Structural volume  | V                  | J                                | 4000            | 600             | 600             |
| Energy storage   | E                  | J                                | 1800            | 100             | 100             |
| Energy for development and reproduction                              | $E_R$              | J                                | 2500            | 0               | 0               |