

The potential of spatial planning tools to support the ecosystem approach to aquaculture

FAO/Rome Expert Workshop
19–21 November 2008
Rome, Italy



Cover illustration by Emanuela D'Antoni.

This illustration aims to convey the main ecosystem approach to aquaculture (EAA) spatial scales (i.e. the farm, the aquaculture waterbody/watershed or aquaculture zone and the global market) and the power of Geographic Information Systems to spatially represent, integrate and analyze the natural and human environments at any scale. Shrimp aquaculture ponds in Mexico were used here as an example to highlight the need to address environmental and socio-economic issues within higher strategic planning and management frameworks as part of an EAA.

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The potential of spatial planning tools to support the ecosystem approach to aquaculture

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Preparation of this document

This publication is the proceedings of the Food and Agriculture Organization of the United Nations Expert Workshop *The potential of spatial planning tools to support the ecosystem approach to aquaculture* convened in Rome, Italy 19–21 November 2008. Fourteen internationally recognized experts representing different regions of the world and providing a wide range of expertise in the areas of aquaculture, natural resources management and environment, Geographic Information Systems, remote sensing, mapping, as well as social, economic, and legal aspects contributed to discussions on a review paper entitled *Status and potential of spatial planning tools, decision-making and modelling in implementing the ecosystem approach to aquaculture*.

The workshop was organized by the Aquaculture Service of the FAO Fisheries and Aquaculture Department. We would like to thank our many colleagues who kindly provided their papers, articles and technical reports for review. Special thanks go to Geoff Meaden and Lindsay Ross for their valuable edits and comments. The authors also thank, in alphabetical order: Cécile Brugère, Fabio Carocci, João Gomes Ferreira, Donna Hunter, Suan Pheng Kam, Alessandro Lovatelli, Philip Conrad Scott, Diego Valderrama, Luiz Vianna and Patrick White for their suggestions and additions. Also, we would like to thank Jeff Jenness for organizing the Global Lakes and Wetlands Database (GLWD) included in the present review. We acknowledge Tina Farmer and Françoise Schatto-Terribile for their assistance in quality control and FAO style. Emanuela D'Antoni prepared the cover and José Aguilar-Manjarrez and Doris Soto assisted in its design. The document layout specialist was Koen Ivens.

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Abstract

Attention is presently turning to the processes, methods and tools that allow practical implementation of the ecosystem approach to aquaculture (EAA). This will require the use of various tools and methodologies, including environmental impact assessments and risk analysis. Ecosystem-based management involves a transition from traditional sector-by-sector planning and decision-making to the more holistic approach of integrated natural resource management at different scales and for ecosystems that cross administrative boundaries. An essential element for the implementation of the EAA will be the use of spatial planning tools including Geographic Information Systems, remote sensing and mapping for data management, analysis, modelling and decision-making. These proceedings focus on the status and process of implementing these tools which, in turn, necessitate the development of capacity building, training and promotion of spatial planning among decision-makers and technical staff. The document is organized in two parts. The first, the workshop report, deals with the background of the EAA effort and the genesis of the workshop. Most importantly, it captures the salient contributions of participants from their formal presentations and general discussions. The main conclusions of a review of the status and potential of spatial planning tools, decision-making and modelling in implementing the EAA are also included. The review itself, along with an abstract, forms the second part.

Aguilar-Manjarrez, J.; Kapetsky, J.M.; Soto, D.

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Contents

Preparation of this document	iii
Abstract	iv
Genesis of the workshop	1
Workshop overview and findings	3
Workshop recommendations and the potential role of FAO	11
Annex 1 – Agenda	13
Annex 2 – List of participants	15
REVIEW	17
Status and potential of spatial planning tools, decision-making and modelling in implementing the ecosystem approach to aquaculture James McDaid Kapetsky, José Aguilar-Manjarrez and Doris Soto	

Genesis of the workshop

BACKGROUND

Building an ecosystem approach to aquaculture

Aquaculture growth worldwide involves the expansion of cultivated areas, a higher density of aquaculture installations and farmed individuals and more efficient use of feed resources produced outside of the immediate culture area. Such evolution of the sector could have negative impacts on the environment and on sections of the society if unregulated and badly managed. In 2006, the Aquaculture Service (FIRA) of the FAO Fisheries and Aquaculture Department initiated an effort to look into the development and application of the ecosystem approach to aquaculture.

An initial expert workshop co-organized with the Universitat de les Illes Balears (Palma de Mallorca, Spain) in May 2007 on “Building an ecosystem approach to aquaculture” agreed that: “*An ecosystem approach for aquaculture (EAA) is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems*”. Such a strategy should be guided by three main principles to ensure the contribution of aquaculture to sustainable development: (1) aquaculture should be developed in the context of ecosystem functions and services with no degradation of these beyond their resilience capacity; (2) aquaculture should improve human wellbeing and equity for all relevant stakeholders; and (3) aquaculture should be developed in the context of (and integrated to) other relevant sectors. At least three relevant geographical scales/levels for the application of EAA were identified and discussed: the farm; the waterbody and its watershed/aquaculture zone; and the global, market-trade scale.

The main output of the Mallorca workshop is the published proceedings; Soto, Aguilar-Manjarrez and Hishamunda (2008). Guidelines for EAA implementation are being developed as a follow-up to an Expert Workshop on “Guidelines for the implementation of an ecosystem approach to aquaculture (EAA)” that took place in FAO headquarters, Rome, Italy from 24–26 November 2008. The final general guidelines will be published in the FAO Technical Guidelines for Responsible Fisheries Series in 2010.

The present publication is the proceedings of the FAO Expert Workshop *The potential of spatial planning tools to support the ecosystem approach to aquaculture* convened in Rome, Italy 19–21 November 2008.

Attention is presently turning to the processes, methods and tools that allow practical implementation of the EAA. Such implementation will require the use of various tools and methodologies. Some relevant tools include environmental impact assessments, and risk analysis.

An essential element for the implementation of the EAA will be the use of spatial planning tools including Geographic Information Systems (GIS), remote sensing and mapping for data management, analysis, modelling and decision-making.

OBJECTIVES

The focus of discussion of the present workshop was a review on the *Status and potential of spatial planning tools to support the ecosystem approach to aquaculture* drafted by the Aquaculture Service (FIRA) of the Fisheries and Aquaculture Department, specifically by James McDaid Kapetsky, José Aguilar-Manjarrez, and Doris Soto.

Specific objectives of the EAA review and workshop were to:

1. Determine the status and potential of spatial planning tools, including decision-making and modelling, to support the ecosystem approach to aquaculture (EAA).
2. Identify gaps and recommend future activities to ensure that the potential of spatial planning tools is fully utilized in support of the EAA.

The workshop agenda is provided in Annex 1.

PARTICIPATION

The workshop was attended by fourteen internationally-recognized experts consisting of FAO staff and consultants representing different regions of the world and providing a wide range of expertise in the areas of aquaculture, natural resources management and environment, Geographic Information Systems, remote sensing and mapping. The socio-economic and legal sectors were also represented. The list of participants is provided in Annex 2.

Workshop overview and findings

OVERVIEW

The workshop consisted of plenary presentations and brainstorming discussions focused on spatial planning tools in the context of a wide a variety of aquaculture applications as well as others related to aquaculture, including natural resources, environmental management, economic and social realms as well as law and policy (see Annex 1).

The FAO Secretariat introduced the workshop by presenting an overview of an initial EAA framework and the Review mentioned below on the *Status and potential of spatial planning to support the EAA*. Additional presentations illustrating a wide range of GIS applications addressing different issues, environments, culture species, culture systems, scales, and regions were made by the participants. Thereafter, the participants jointly created a group presentation by selecting key material from the various presentations. The executive summary of the EAA review was also discussed and improved by participants. The group presentation and the executive summary were then presented to the FAO Fisheries and Aquaculture Department as a seminar for final discussions. The expert's discussions and recommendations have been integrated into a review entitled: *Status and potential of spatial planning tools, decision-making and modelling in implementing the ecosystem approach to aquaculture*. It is expected that the recommendations from the workshop will be used to develop ideas for: (a) the creation of a manual for decision-makers to illustrate the use of spatial planning tools to support EAA implementation; and (b) development of FIRA's activities on spatial planning tools in support of the EAA that will include technical assistance and training.

CONTRIBUTED PRESENTATIONS AND DISCUSSIONS

The presentations from participants offered a broad spectrum of issues and case study examples which were extremely useful in shaping ideas on the role of GIS to support the implementation of the EAA.

Ms D. Soto presented an overview of sustainability approaches in aquaculture and background information on the proposed EAA initiative and framework. She described the concepts, guiding principles and scales approaches for an EAA; she then summarized the results achieved so far on EAA and the potential next steps for EAA implementation.

Messrs J.M. Kapetsky and J. Aguilar-Manjarrez presented a wide ranging review covering the Status and potential of spatial planning tools to support the ecosystem approach to aquaculture. The main topics included data availability; environmental impacts of aquaculture; issues, geographic distribution and scales of applications; indicators of capacity and decision-making and modelling. They concluded that spatial tools are essential for the EAA to enable better understanding of the ecosystem, to generate scenarios illustrating the consequences of different management decisions on natural resources and economy and to facilitate multistakeholder participation in the planning processes. A priority objective is to spatially integrate socio-economics with ecosystems in recognizing that people are key components in the EAA.

Mr P. White (FAO consultant) presented "Development of programmatic EIAs and monitoring programs for clusters of small scale cage farmers in the Philippines – a case study" illustrated a methodology for the estimation of safe aquaculture carrying capacity, optimal site selection, and zoning of aquaculture parks for sustainable aquaculture development for small scale farmers (www.fao.org/fishery/gisfish/id/4840). From a

practical viewpoint, even with the availability of carrying capacity models, administrators and regulators must have the interest and political will to use the model outputs for zoning aquaculture. An important facet of the EAA is to forge a link between ecosystem management and aquaculture planning.

Mr L. Ross showcased the current work on GIS at the Institute of Aquaculture in Stirling, United Kingdom of Great Britain and Northern Ireland relating to the EAA development. Their programme has taken two directions: the strategic evaluation of large regions for aquaculture exploitation and development, and the use of GIS in detailed facility location and management within a site. GIS-based environmental impact modelling has also been developed, with special emphasis on coastal zone management. Currently, the group is focusing on environmental and socio-economic interactions of aquaculture, the relationship with biodiversity, and impacts of climate change. They adopt a holistic view of aquatic resource management and aquatic production and are working to integrate a range of GIS decision-making tools for multi-site assessment and management, including 2-D and hydrological models; and exploration of dynamic 3 dimensional plus time (4D) modelling tools (www.aqua.stir.ac.uk/GISAP/gis-group).

The use of spatial tools to globally assess the water resources of ecosystems for uses broader than aquaculture was presented by Mr J. Hoogeveen of the Water Development and Management Unit of the FAO Natural Resources and Environment Department (FAO-NRLW). The assessment is aimed to support integrated water use management of the main users: industry, agriculture, and domestic consumption, and works at a continental level. GIS is used in a modelling context as a check on reported water use statistics at the country level. Discussions emphasized the need to consider water quality as well as quantity, the applicability of water resources models to aquaculture and including aquaculture planning in more general water use planning.

A very practical need for spatial tools to assist in marine aquaculture development planning in the RECOFI region (www.fao.org/fishery/rfb/recofi/en) was presented by Mr Alessandro Lovatelli (FAO-FIRA). There is an increasing demand for products from aquaculture and fisheries in the region. A solution is to expand marine aquaculture, but there is resistance from other users of ocean space. Consequently, there is a need for marine aquaculture zoning and site selection with due consideration to other uses of the ecosystem. Building capacities to use spatial tools for marine aquaculture development and management in the region is required with the impetus coming from investors in marine aquaculture development. Finances are available.

The Fishery Information Technology Center (FITC) at the Department of Fisheries Thailand (DoF) is responsible for developing and maintaining computer networking, GIS, management information systems, and fisheries data collection and statistics reports. Work on GIS at the FITC is divided by culture environments: coastal, marine and freshwater. Projects presented by Mr P. Suvanachai mainly include the use of satellite imagery to inventory and monitor aquaculture and fisheries structures. Inventories derived from their spatial analysis are available via the Internet for public and/or internal use (<http://gis.fisheries.go.th/WWW/index.jsp>). DoF Thailand is committed to secure/sustain the use of GIS for fisheries and aquaculture at all administrative levels. The FITC, well-equipped with skilled manpower and data, could provide strong support to EAA related projects. The main impediments are the lack of appreciation of the benefits of spatial tools at the executive level, development of specialized GIS applications within sections of the DoF rather than as a centralized service, and lack of data standardization and harmonization.

A complementary review to the EAA on “Geographic information systems to support the ecosystem approach to fisheries” by Carocci *et al.* (2009) was presented by Mr Fabio Carocci (FAO-FIRF). The EAF review illustrates the use of GIS for a wide range of EAF-related projects, first via a range of example applications to address key issues in

fisheries management and then via a number of detailed case studies that illustrate the degree to which GIS is currently being used for EAF implementation. Overall, it was noted by participants that many parts of the review will be very useful not only for the EAF, but also for their relevance to the EAA. Noteworthy characteristics of the use of spatial tools to achieve the EAF are that issues and objectives guide implementation, and because capacities vary, the work is carried out through developing partnerships with FAO. Defining spatio-temporal boundaries is essential, and mapping and modelling of different scenarios is a key contribution to EAF implementation.

MAJOR FINDINGS AND CONCLUSIONS FROM PRESENTATIONS

Current status of GIS, remote sensing and mapping applications in aquaculture.

Expanding spatial awareness and realizing the analytical potential of GIS are key to making better informed decisions. Essentially, GIS takes data from different formats, sources and disciplines to make complex information about a location comprehensible, so that informed decisions could be made.

The presentations clearly illustrated that the rapid evolution of remote sensing and GIS based modelling and mapping have radically transformed our ability to detect, map, and model environmental and socio-economic related changes. GIS is now being used in several countries to regularly and systematically monitor aquaculture development. Remote sensing-based mapping of aquaculture is an FAO/FIRA activity. Data sharing within and across disciplines is crucial to the success of GIS advancements, but only a small proportion of potentially useful information is actually shared. Despite advances, there is still a need for facilitated data sharing agreements.

Relevance of GIS applications to EAA guiding principles in relation to scales and boundaries.

Current and past GIS applications relate well to the guiding principles of the EAA in that they deal with ecosystems and environments at all scales in the context of aquaculture development and management. GIS can support a decision-making process (including policy-making, planning and management) and can help evaluate how it influences the driving forces of development (such as population growth, climate change etc.). GIS can be used to monitor the results (human impacts) of development, and its impacts on the physical, social, and economic environment (environmental change). GIS is an excellent data visualization medium with an important role to play in stimulating discussion amongst stakeholders and GIS can be integrated into many aspects of governing and policy-making by using rules arising from management.

An essential step in implementing the EAA is the ability to work across administrative and ecosystem boundaries. Administrative boundaries seldom parallel ecosystem boundaries and legal boundaries frequently dictate quite different land uses. GIS has the ability to discern both kinds of boundaries and to intersect and integrate the data and analysis belonging to both realms.

Capacities to implement GIS.

Decision-makers, faced with data and output from GIS and other geospatial tools, often lack a basic understanding of these technologies, including both their limitations, strengths and the kinds of questions that can be addressed by them which would allow for operational use and informed decisions. The same range of understanding is required to decide on the level of adoption of GIS.

Synergies between the EAA and EAF and with other sectors.

Issues in aquaculture and fisheries can be quite different, but they have many kinds of data needs that are common to both. Similarly, data and technical innovations applied for other purposes such as coastal area management and water resources assessments

also can be useful for aquaculture. For the sake of economy as well as to promote cooperation, opportunities to realize synergies need to be pursued at all levels.

Suggested plans of action for FAO for the use of spatial planning tools to support EAA.

Thailand could serve as an immediate follow-on “pilot project” and model for the operational use of GIS for EAA because the DoF is committed to sustain the use of GIS for fisheries and aquaculture at all administrative levels, and the FITC at the DoF is well equipped with skilled manpower and data.

Additional findings and conclusions derived from the presentations are included in the conclusions to the review listed below.

CONCLUSIONS TO THE REVIEW ON STATUS AND POTENTIAL OF SPATIAL PLANNING TOOLS, DECISION-MAKING AND MODELLING IN IMPLEMENTING THE ECOSYSTEM APPROACH TO AQUACULTURE

The key findings are summarized and general agreements are listed below.

Background to the ecosystem approach to aquaculture.

The implementation of the EAA will require the use of various tools, methodologies, and guidelines that are very specific. These include adequate guidelines for aquaculture site selection, for integrated aquaculture, for aquaculture-based fisheries, etc. An essential element for the implementation of the EAA will be spatial planning tools for analysis, decision-making, modelling, and data management.

There are a number of key issues in the ecosystem approach planning and implementation cycle that require explicit consideration of spatial information about ecosystem components and properties. Furthermore, because of the interrelationships of inputs, resource use and outputs at the different scales, spatial data visualized within a GIS environment can help improve understanding of the interactions between aquaculture, other sectors and the ecosystem in question and allow for more spatially resolved analyses and integrated planning and management.

Spatially defined global ecosystems, their issues and relevance to the ecosystem approach to aquaculture.

An evaluation of the readiness of spatial planning tools to support the EAA is based on the perceptions that major ecoregions and ecosystems have to be spatially defined and their main issues known. Fundamental to knowing where, in what ways and for whom the EAA will be spatially supported requires knowledge of where the problems are, their magnitude and the administrative responsibilities for their mitigation.

Spatially defined global ecosystems are useful to the EAA by raising the awareness of aquaculture planners and practitioners to issues that must be taken into account for the further development of aquaculture and for the mitigation of the potential impacts of aquaculture on the environment. Many spatially defined ecosystems can be used for aquaculture planning. Issues associated with ecoregions and ecosystems need to be associated with the main issues in aquaculture in the same areas. Although many kinds of ecosystems are already defined, a considerable expenditure of time to evaluate the methods used and the actual relevance and quality of the data will be required in order to use them effectively for GIS in support of the EAA.

Spatial data to support the ecosystem approach to aquaculture.

In many cases ecosystem boundaries may not be already defined so spatial data will be required to do so, or to enhance existing ecosystem data with data specific to the needs of aquaculture. There are vast quantities of spatial data freely available that could be important for use in spatial analyses in support of the EAA. One of the early

and essential steps of implementing spatial analyses in support of the EAA at national levels will be to inventory and evaluate relevant spatial data at all resolutions.

The geography of aquaculture in relation to environments and potential impacts.

Globally comprehensive and comparative estimates of the potential impact of aquaculture on coastal (marine and brackishwater) and freshwater environments at the country level were developed. Likewise, an index-based approach was used to make comprehensive and comparative estimates of the environmental impacts on aquaculture at the same level. Estimates from each of these approaches are useful as a starting point to gauge where GIS in support of the EAA could be most usefully deployed. These results call attention to the need for improved ways to comprehensively and comparatively assess aquaculture's potential impact on the environment and the environment's impact on aquaculture. Spatially comprehensive inventories of aquaculture and its attributes are an essential requirement for implementing the EAA at national and sub-national levels.

Current status of GIS, remote sensing and mapping applications in aquaculture from an ecosystem viewpoint.

GIS has been implemented in a very broad variety of ecosystems and scales as well as in a wide range of culture systems. Spatial analysis experience in terms of addressing issues in the development of aquaculture and in aquaculture practice and management is good overall. Specific gaps in experience (i.e. know-how) are in economics and socioeconomics as well as in multisectoral planning for aquaculture. GIS is completely scaleable and can include ecosystem, administrative, and social, boundaries. The power of GIS is the capability to spatially integrate and analyze the natural and human as components of ecosystems. The most appropriate "scale" for the EAA and for GIS in support of the EAA is defined by the boundaries of the problem expressed both in ecosystem, economic, social and administrative terms. It is noteworthy that these kinds of spatial boundary differences are easily reconciled by spatial analyses.

Decision-making and modelling approaches for aquaculture development.

GIS can support decision-making and modelling within and among all boundaries associated with aquaculture development and management. There are many immediately available decision-making tools that could be used in support of the EAA within GIS and many aquaculture models (e.g. carrying capacity) can be run inside GIS, or be spatially related to aquaculture by GIS (see Figure 7.3a-d in Chapter 7). The latest methods and applications for GIS-based decision support can be taken from other sectors and adapted for use in the EAA.

Remote sensing in support of the EAA.

Remote sensing already provides historical and real-time information of demonstrated use to aquaculture and the potential for increased use is great. Data and software will become more widely available, user friendly, and accessible to managers rather than just to specialist remote-sensing scientists. Also, archived remote sensing data can be used to analyze change spatially and temporally. Therefore, it would be of utmost value if remote sensing data could be made more readily available to non specialists for the EAA.

Case studies of GIS, remote sensing and mapping applications in aquaculture in relation to EAA implementation.

Case studies that span all of the EAA principles and scales were selected and summarized in tabular format. These clearly demonstrate that spatial analyses

can be easily designed to meet a variety of EAA needs with respect to scales and principles.

Capacities of GIS to implement ecosystem approach to aquaculture.

The success of spatial tools in support of the EAA depends on interest, finances and capacities. With regard to the latter, there is a need to identify, qualify and quantify spatial analysis capacities at the country level in order to match training and technical support to the capacity to absorb them. Capacities appear to vary widely. For example, there are many countries for which there were no identifiable aquaculture GIS applications. Some of these countries are the most intensive users of the environment for aquaculture. GIS and spatial analytical techniques should be designed and delivered to match the requirements and levels of capacities of the users. This has to be done at the national level because such information is difficult to come by remotely.

The Internet is the most rapid and efficient pipeline for wide ranging technical assistance, for the exchange of data and to communicate in support of the EAA.

Advancing the use of spatial planning tools to support the EAA. Future activities in support of the EAA can be viewed as several major but related initiatives: (1) development of in-house innovative applications of spatial planning tools that can serve as core training materials that, in turn, can be deployed to EAA hotspots as needed, (2) capacity building that goes forward at all levels from global to sub-national, and (3) promotion at decision-making and technical levels.

In order to ensure that planning for the use of spatial tools and analyses in support of the EAA is well founded, more specific and more detailed preparatory work will have to follow this review including:

- Incorporating GIS-based social and economic analyses in aquaculture
- A further exploration and documentation of GIS-based decision support and risk analysis and catalogues of their respective tool boxes
- Innovative ways to identify needs and capacities at the national and sub-national levels
- Increasing capacities for training in spatial analyses (e.g. via the Internet).

In order to build capacity, there is a need to reach many small, globally dispersed audiences, Therefore, a broad strategy is required that takes advantage of common interests and synergies in the EAA principles and objectives that are shared by other organizations, some of whom could become potential partners.

The EAA is holistic and therefore promotion of spatial awareness has to be at the ecosystem level as well as all administrative levels and a broad audience has to be addressed that includes not only aquaculture administrators and the aquaculture industry, but also educators; and high-level decision-makers and NGOs.

The locations of aquaculture producers, processors, transporters and marketers are fundamental for defining aquacultures potential impacts on ecosystems and within administrative boundaries. Expansion and/or acceleration of the mapping component of the National Aquaculture Sector Overviews (www.fao.org/fishery/naso/search/en) could contribute greatly to the implementation of the EAA.

Expansion of the capabilities of FAO's GISFish Global Gateway to Geographic Information Systems (GIS), Remote Sensing and Mapping for Fisheries and Aquaculture (www.fao.org/fishery/gisfish) could provide an avenue for promotion of the EAA and for pipelining technical information and tools based on a Web infrastructure that already attracts users worldwide.

Investment in GIS should be made with a clear understanding of what should be accomplished with such capabilities, and the decision support needs of the stakeholders that GIS can fulfil. In many cases, GIS capabilities are primarily used as tools for

generating and displaying maps. However, the current state of spatial methods and technology, on the other hand, clearly indicates that GIS capabilities go far beyond data management and visualization alone.

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Workshop recommendations and the potential role of FAO

RECOMMENDATIONS

Participants concurred that there are many benefits that GIS can bring to EAA management processes, from simple mapping to sophisticated modelling. Presentations at the workshop as well as the review (Kapetsky, Aguilar-Manjarrez and Soto, 2010) demonstrated that GIS has the potential to support EAA. Therefore, the principal task is to determine the ways that spatial tools can be best implemented to support the EAA.

The workshop recommended that FAO should continue to promote the use of GIS and associated spatial tools to facilitate the implementation of EAA. However, an enabling environment is crucial to adopt the use of spatial tools to support the EAA. There is a need to gauge capacities (human resources, infrastructure, finances) at national and/or regional level to implement spatial tools in support of the EAA so that capacity building initiatives can be matched to capabilities.

Participants agreed that practical steps for the use of spatial tools are needed. Implementation of spatial tools in support of the EAA at national levels can come only through an awareness of benefits and a knowledge of their techniques. Thus, as a practical first step, development of a manual was recommended to illustrate the use of GIS to support EAA using a few case studies from different regions, environments, species and culture systems.

THE POTENTIAL ROLE OF FAO

FAO should continue efforts to define the role of spatial planning tools to support the EAA. The main follow-up activities to this workshop include the completion of one review paper on the “Status and potential of spatial planning tools, decision-making and modelling in implementing the ecosystem approach to aquaculture” and the meeting report being presented in these proceedings.

To better define the role of spatial planning tools for both the EAA and EAF, and as an immediate follow-up to these proceedings FAO should focus in developing projects for the practical implementation of the ecosystem approach to fisheries and aquaculture. Case studies of national implementation for the EA, or national opportunities for application of the ecosystem approach should be identified; e.g. finding sites for aquaculture has been and will be a challenge; therefore, as an initial first step, a case study focused on the use of spatial tools for zoning aquaculture in an EAA context would be particularly useful as a model that could be followed and improved elsewhere. Furthermore, zoning would also simplify and streamline the process of farm site selection.

In parallel to the above, from a more technical viewpoint, FAO should organize a much larger workshop to better define the use of spatial planning tools for both the EAA and EAF with about 25-30 international experts including top scientists in aquaculture, fisheries, production systems, ecosystem based management, economics and sociology, law and policy. The EAA and EAF FAO reviews would serve as discussion documents for this larger FIRA-FIRF workshop.

The results of the practical case studies for EAA implementation and/or the outputs of a larger workshop in the form of management options, strategies, technical guidelines and recommendations would be essential inputs to FAO member countries in their implementation of the EAA/EAF.

Annex 1 – Agenda

STATUS AND POTENTIAL OF GEOGRAPHIC INFORMATION SYSTEMS IN IMPLEMENTING THE ECOSYSTEM APPROACH TO AQUACULTURE

WEDNESDAY, 19 November morning – Opening of workshop and background

15:00-17:00

Agenda item	Presenter
Opening the meeting. Presentation of participants Adoption of the agenda	D. Soto and J. Aguilar-Manjarrez
Presentation of the EAA principles and general EAA guidance and advice <i>Coffee break</i>	D. Soto and P. White
A presentation on the review on the “Status and potential of geographic information systems, remote sensing and mapping to support implementation of EAA”	J. Kapetsky and J. Aguilar-Manjarrez

THURSDAY, 20 November – Role of spatial planning tools for EAA implementation

9:00-17:00

Wrap-up of previous day discussion	J. Kapetsky
Presentation on “A case study on the development of programmatic environmental impact assessment and monitoring programs for clusters of small scale cage farmers in the Philippines” <i>Coffee break</i>	P. White
Presentation on GIS applications at the Institute of Aquaculture in Stirling	L. Ross
Use of spatial tools to globally assess the water resources of ecosystems	J. Hoogeveen
Need for spatial tools to plan for marine aquaculture development in the RECOFI region (Arab Gulf)	A. Lovatelli
Presentation on the use of GIS at the Department of Fisheries Thailand <i>Lunch break</i>	P. Suvanachai
Working group discussion to wrap-up key findings	P. White

FRIDAY, 21 November – Synergies between EAA/EAF and wrap-up

9:00-17:00

Presentation on Review on “Geographic Information Systems to support ecosystem approach to fisheries”.	F. Carocci
Discussion – Synergies and strategies for cooperation and collaboration between EAA and EAF reviews. <i>Coffee break</i>	J. Kapetsky
Working group discussion – List recommendations discussed and agreed in the previous days. <i>Lunch break</i>	J. Aguilar-Manjarrez
Working group discussion – Agreement on major findings from the review on the “Status and potential of geographic information systems, remote sensing and mapping to support implementation of EAA” <i>Coffee break</i>	J. Kapetsky
Departmental seminar – Conclusions and recommendations: the way forward	J. Aguilar-Manjarrez and J. Kapetsky
<i>Adjourn</i>	

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Review

Status and potential of spatial planning tools, decision-making and modelling in implementing the ecosystem approach to aquaculture

Kapetsky, J.M., Aguilar-Manjarrez, J., and Soto, D. 2010. Status and potential of spatial planning tools, decision-making and modelling in implementing the ecosystem approach to aquaculture. In. J. Aguilar-Manjarrez, J.M. Kapetsky and D. Soto. The potential of spatial planning tools to support the ecosystem approach to aquaculture. FAO/Rome. Expert Workshop. 19–21 November 2008, Rome, Italy. *FAO Fisheries and Aquaculture Proceedings*. No. 17. Rome, FAO. pp. 19-176.

ABSTRACT

This review analyses and synthesizes information on the status of GIS, remote sensing and mapping applications in aquaculture in relation to the ecosystem approach to aquaculture (EAA). The review is global in expanse and extends from 1985 to the present. The introductory part of the review provides an overview of the EAA and then turns to an examination of the status of spatial analyses in aquaculture from a number of viewpoints relative to the EAA. A prime requisite for implementation of the EAA is to define ecosystems spatially. Thus, one vantage point is an overview of ecosystems already spatially defined. Another viewpoint is from the perspective of spatial data available to define ecosystems where ecosystem limits have not been previously established. Central to an ecosystem approach to management is the need to optimize benefits while minimizing impacts. With regard to the impacts, it is necessary to establish their magnitude and locations in order to plan for appropriate interventions. Thus, the potential impacts of aquaculture on the environment or of the environment on aquaculture are examined at a country level from a global perspective. Spatial tools and spatial analyses in aquaculture are mainly used to resolve aquaculture issues. Holistic studies of aquaculture in a broad ecosystems context are not usually encountered. The purpose of this review is to establish the state of the art in applying spatial analyses to issues in aquaculture from both an ecosystems and issues framework rather than from an issues-based framework alone. The status of spatial analyses in aquaculture relative to the EAA is considered from an applications viewpoint in several ways. These include the issues addressed by the applications, the scales at which applications have been carried out as well as the kinds of ecosystems included in the analyses. Spatial analyses are carried out in order to aid decision-making. Thus, another measure of the readiness of spatial analyses to support the EAA is an evaluation of the availability and use of decision-making tools and modelling in aquaculture. Training and technical assistance in spatial analyses at the country level will be required to support the EAA. Fundamental to planning for these needs is knowledge of capacity in GIS, remote sensing and mapping. Indicators of national capacity examined herein are numbers of Internet users, numbers of spatial analysis applications

and numbers of visits to the GISFish portal. Oftentimes issues can be resolved by considering the approaches used elsewhere. To this end, case studies and example applications have been assembled in an issues, environments, scales and ecosystems framework. Finally, conclusions are reached on the readiness of spatial analyses to support the EAA and recommendations for future activities are made.

CONTENTS

Abstract	19
List of tables	23
List of boxes	24
List of figures	25
Acronyms and abbreviations	28
1. Introduction	31
1.1 Objectives and overview	33
1.2 Scope and methodology	33
1.3 Approach	34
2. What is the ecosystem approach to aquaculture?	35
2.1 Background to the ecosystem approach to aquaculture	35
2.2 Conventional aquaculture management and the ecosystem approach	37
2.3 The EAA planning and implementation process	37
2.4 Spatial scales	38
2.5 EAA issues and the relevance of geographic information tools	39
3. Spatially defined global ecosystems, their issues and their relevance to the ecosystem approach to aquaculture	43
3.1 Ecosystems including both land and water	43
3.2 Aquatic ecosystems	48
3.3 Terrestrial ecosystems	52
3.4 Summary and conclusions	56
4. Spatial data to support the ecosystem approach to aquaculture	57
4.1 Earth browsers	62
4.2 Portals	62
4.3 General data sources	64
4.4 Specialized data sources	68
4.5 Summary and conclusions	73
5. The geography of aquaculture in relation to environments and potential impacts	75
5.1 Introduction, objectives and overview	75
5.2 Importance of aquaculture by total production	76
5.3 Importance of aquaculture by environment	77
5.4 Impacts of aquaculture in marine and brackishwater environments based on annual production	78
5.5 Impacts of aquaculture on marine and brackishwater environments based on annual production and length of shoreline	78
5.6 Potential impacts of aquaculture use on freshwater environments based on production by country	80
5.7 Potential impacts of aquaculture use on the freshwater environment based on production by country	81
5.8 Comparisons of the use of ecosystems by aquaculture among countries	82

5.9	Potential environmental impacts on aquaculture based on ecosystem vitality	83
5.10	Environmental impacts on aquaculture in relation to the intensity of aquaculture production	85
5.11	Summary and conclusions	86
6.	Current status of GIS, remote sensing and mapping applications in aquaculture from an ecosystem viewpoint	89
6.1	GIS, remote sensing and mapping applications related to aquaculture	89
6.2	An assessment of GIS, remote sensing and mapping applications to aquaculture as they relate to scales and ecosystems	91
6.3	Summary and conclusions	94
7.	GIS-based decision support tools and modelling for aquaculture development	97
7.1	Introduction	97
7.2	Implementing	97
7.3	Modelling	103
7.4	Decision support tools	108
7.5	Summary, discussion and conclusions	120
8.	Case studies of GIS, remote sensing and mapping applications in aquaculture in relation to EAA implementation	123
8.1	The relevance of GIS capabilities to EAA principles	123
8.2	The relationship of spatial analyses to support EAA principles	123
8.3	Case studies of GIS, remote sensing and mapping applications in aquaculture in relation to EAA principles and scales	124
8.4	Case studies for spatial decision support	131
8.5	Summary and conclusions	148
9.	Capacities to implement the ecosystem approach to aquaculture	149
9.1	Introduction	149
9.2	Aquaculture GIS applications by country	150
9.3	Access to the internet as a measure of capacity for spatial analyses in support of the EAA	151
9.4	Synergies between the ecosystem approach to aquaculture and the ecosystem approach to fisheries, and with other sectors	153
9.5	Summary and conclusions	153
10.	Advancing the use of spatial planning tools to support the EAA	155
10.1	Introduction	155
10.2	Future activities to implement spatial planning tools in support of the EAA	155
11.	Glossary	163
12.	References	167

List of tables

3.1	Summary of spatially defined global ecoregions and ecosystems relevant to the EAA and GIS in support to the EAA	44
4.1	Summary of Internet sites to acquire global spatial data to define ecosystems and their attributes	59
5.1	Summary by numbers of countries where aquaculture potentially/heavily impacts the environment coincident with potential environmental impacts on aquaculture	86
6.1	Numbers of spatial applications addressing main issues and sub-issues in the GISFish Aquaculture Database as of 1 March 2010	89
6.2	GIS aimed at the development of aquaculture, and GIS for practice and management	90
6.3	GIS for multisectoral development and management that includes aquaculture	91
6.4	Scale definitions	92
6.5	Scales relating to 159 spatial analysis applications in aquaculture among brackishwater, inland and marine environments	93
6.6	Ecosystems as the targets of 159 spatial analyses among marine, brackishwater and inland environments	94
7.1	GIS software to support decision-making	110
8.1	Case studies from GISFish and their relevance to EAA principles and scales	126
8.2	GIS applications in aquaculture according to the models and decision support used	132
8.3	Development scenarios for Huangdum Bay and Sanggou Bay	137

List of boxes

2.1	The principles of ecosystem approach to aquaculture	36
7.1	Examples of Web-based innovation projects in Aquaculture	115

List of figures

1.1	The overlay concept: the real world is portrayed by a series of layers in each of which one aspect of reality has been recorded	32
1.2	The key features of the remote sensing data collection process	32
2.1	The transition from a conventional approach to an ecosystems approach	37
2.2	EAA Planning and implementation process	38
3.1	Interactive map of the Environmental Performance Index countries in the Caribbean Region	46
3.2	Potential for open ocean aquaculture of cobia within the Global 200 Ecoregions	47
3.3	Global Map of Human Impacts to Marine Ecosystems	48
3.4	Fisheries catch abundance in Large Marine Ecosystems: 2000–2004	50
3.5	Final biogeographic framework: Realms and provinces. (a) Biogeographic realms with ecoregion boundaries outlined	51
3.6	World hypoxic and eutrophic areas	52
3.7	Last of the Wild, Version 2	53
3.8	Global extent of agriculture	54
3.9	Terrestrial ecoregions of the world	54
3.10	Hydrological data and maps based on shuttle elevation derivatives at multiple scales (HydroSHEDS)	55
4.1	A variety of aquaculture installations near Calbuco, Chile from Google Earth	62
4.2	Global lakes and wetlands	65
4.3	Freshwater fish species richness by basin	66
4.4	Visualization of the flow regime associated with Lake Tanganyika	68
4.5	Interactive map showing query function, a part of the World Database on Protected Areas	69
4.6	Global population density in 2000	70
4.7	Global distribution of highest risk disaster hotspots by hazard type	71
5.1	Ranges of total aquaculture production by country in 2005	76
5.2	The top 20 countries in aquaculture production and cumulative production in 2005	77
5.3	Global aquaculture production by environment in 2005	77
5.4	Top 20 countries in mariculture plus brackishwater production in 2005	78
5.5	Top 20 countries in intensity of brackishwater aquaculture in 2005 (tonnes per kilometre of shoreline)	79
5.6	Top 20 countries in intensity of mariculture production in 2005 (tonnes per kilometre of shoreline)	80
5.7	Top 20 countries in intensity of use of the coast for aquaculture in 2005 (mariculture + brackishwater production) (tonnes per kilometre of shoreline)	80
5.8	Use of the coastal environment for aquaculture in 2005 (tonnes per kilometre of shoreline)	81
5.9	Top 20 countries in freshwater aquaculture production and cumulative production in 2005	81
5.10	Top 20 countries in intensity of use of the freshwater area for aquaculture production in 2005 as tonnes/km ² of freshwater surface area	82

5.11	Intensity of use of the freshwater environment for aquaculture production in 2005 as tonnes/km ² of freshwater surface area	83
5.12	Numbers of environments used intensively for aquaculture among freshwater, brackishwater and marine environments	84
5.13	EPI categories heavily weighted on Ecosystem Vitality to estimate environmental impacts on aquaculture at the country level	85
5.14	Environmental impacts on aquaculture based on a 90 percent weight on Ecosystem Vitality in the Environmental Performance Index	85
5.15	NASO map for Italy showing location of farms by administrative units along with their characteristics (March 2010)	88
7.1	Schematic representation of the phases in a GIS project	98
7.2	A hierarchical modelling scheme to evaluate suitability of locations for aquaculture and agriculture and resolve associated conflicts, in the Sinaloa state of Mexico	103
7.3a	Embedding GIS into Spatial Analysis and Modelling	104
7.3b	Embedding spatial analysis and modelling into GIS	104
7.3c	Tight Coupling	104
7.3d	Loose Coupling	104
7.4	Modelled particulate carbon input to sediments (g C m ⁻² y ⁻¹) from fish culture at the Demonstration Site in Huangdun Bay under ambient current flow conditions (left), and an illustration of how dispersion for the same production level may change under slower hydrodynamic conditions (right).	105
7.5	3D hydrodynamic model and a particulate-tracking model coupled with a GIS to study the circulation patterns, dispersion processes and residence time in Mulroy Bay, a sea loch in the north-west of Ireland	106
7.6a	Potential yield (crops/yr) of pacu fed at 75 percent satiation and harvested at 600 g	107
7.6b	Potential yield (crops/yr) of African catfish – Commercial farming	107
7.7	Regionalized probabilities that Bangladeshi farmers will look favourably upon improved extensive polyculture of fish in ponds	108
7.8	Menu options of the MarGIS_UISCE application	113
7.9	Submerged fish farm model example, with main scene showing deposition state of carbon on the sea bottom near three fish farms of differing fish biomass	114
7.10	A simplified version of the Chilean Aquaculture Project portal illustrating Chlorophyll-a pigment concentration in the Gulf of Ancud and Corcovado, South of Puerto Montt in Chile	117
7.11	Information system for the request of Exploitation permits for aquaculture in Federal waterbodies in Brazil – SINAU	118
8.1a	Aquaculture zones 1 to 6	135
8.1b	Definition of Severe, High and Moderate impact for the SABBAC zone modelling. There are two rows of cages shown and different colours represent different amounts of waste flux (grams waste feed and faeces depositing on the bed per m ² per day)	135
8.2	General modelling framework used in SPEAR ecosystem models	136
8.3	Box layout of Sanggou Bay and the location of FARM simulation area	137
8.4	Conceptual model framework providing decision support for marine aquaculture in the Western Isles, Scotland. Decision rules at different levels of the model are set by environmental limits, engineering tolerances, national policy and regulatory drivers	139

8.5a	Cage suitability model for the Kames fish cage circular 250 cages designed for semi-exposed areas	140
8.5.b	Proportional Visual Sensitivity model for marine cage aquaculture development up to five kilometre distance around the Western Isles, Scotland	140
8.5c	GIS based particulate dispersion model for Loch Erisort and Loch Leurbost Fjord systems using maximum surface current speed as the forcing image. This sub-model shows the total waste footprint from multiple aquaculture sites with a resolution of one metre	141
8.5d	Current active fish farm locations in the Western Isles (indicated as cyan dots) overlaid on the overall model of Biodiversity sensitivity to aquaculture for the Western Isles	141
8.6	Method for the evaluation of potential areas for marine aquaculture	143
8.7a	Southern bay of the Florianópolis in Santa Catarina to test the aquaculture GIS-based models developed. Areas with potential were found along the western and eastern coastlines (proposed fish farm locations are presented in black polygons)	143
8.7b	One of the main hydroelectric reservoirs on the Parana river in Brazil used to demarcate inland aquaculture parks	143
8.8	Framework for developing and using decision-support tools for determining recommendation domains for freshwater pond aquaculture	144
8.9	Overall suitability for pond aquaculture for the Southern Region of Malawi	145
8.10	Geographic Information System of the Department of Fisheries Thailand. These selected farm ponds (highlighted in red) were randomly and spatially sampled using Hawth's Tool in ArcGIS®	147
9.1	Geographic distribution of numbers of GIS applications in aquaculture in GISFish among 50 countries (December 2009)	150
9.2	Visitors to GISFish by continent from May 2007 to September 2009	151
9.3	Top 20 countries visiting GISFish from May 2007 to September 2009	152
9.4	GISFish visitors map from May 2007 to September 2009	152
9.5	Internet users in each country (millions)	153

Acronyms and abbreviations

AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
AquaGIS	The Newfoundland and Labrador Aquaculture Geographic Information System
ASFA	Aquatic Sciences and Fisheries Abstracts
AWRD	African Water Resource Database
CCRF	Code of Conduct for Responsible Fisheries
CD-ROM	Compact disk – read only memory
CIESIN	Center for International Earth Science Information Network
DoF	Department of Fisheries
EA	Ecosystem approach
EAA	Ecosystem approach to aquaculture
EAF	Ecosystem approach to fisheries
EBM	Ecosystem-based management
EEZ	Exclusive economic zone
EIA	Environmental impact assessment
EPI	Environmental Performance Index
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
GAUL	Global Administrative Unit Layers
GCMD	Global Change Master Directory
GEO	Global Environment Outlook
GIS	Geographic Information System
GISFish	Global Gateway to Geographic Information Systems, remote sensing and mapping for fisheries and aquaculture
GIWA	Global International Water Assessment
GLWD	Global Lakes and Wetlands Database
GPS	Global positioning system
HAB	Harmful Algal Bloom
HII	Human influence index
IFREMER	Institut français de recherche pour l'exploitation de la mer (French Research Institute for the Exploitation of the Sea)
IMAR	Institute of Marine Research
IMS	Internet Map Server
IOCCG	International Ocean Color Coordinating Group
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KML	Keyhole Markup Language

LMEs	Large marine ecosystems
MCE	Multi-Criteria Evaluation
MEOW	Marine Ecoregions of the World
MERIS	Medium Resolution Imaging Spectrometer
MPAs	Marine protected areas
NASO	National Aquaculture Sector Overview
NOAA	National Oceanic and Atmospheric Administration (United States of America)
OWA	Order Weighted Average
PAGE	Pilot Analysis of Global Ecosystems
PLDM	Local Plans for Marine Aquaculture Development
SEA	Strategic Environmental Assessment
SMILE	Sustainable Mariculture in Northern Irish Loughs Ecosystems
SPEAR	Sustainable Options for People, Catchment and Aquatic Resources
SQL	System Query Language
SST	Sea Surface Temperature
UISCE	Understanding Irish Shellfish Culture Environments
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCS	Wildlife Conservation Society
WLC	Weighted Linear Combination
WWF	World Wide Fund for Nature

1. Introduction

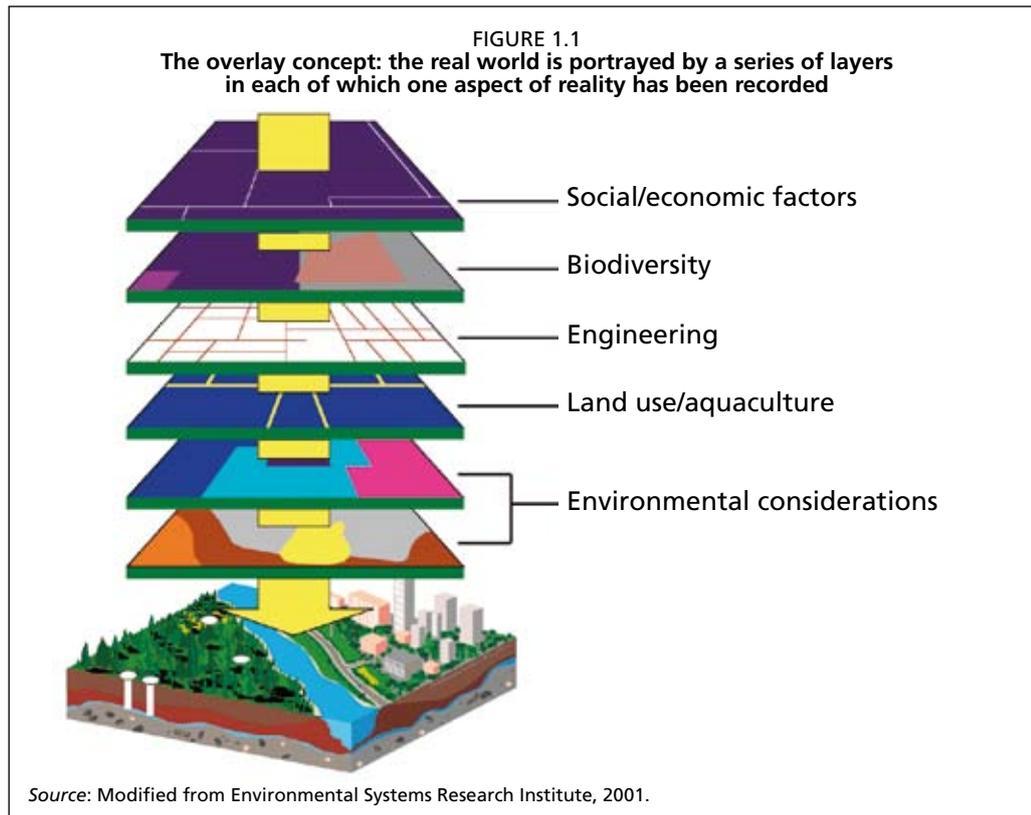
Further development of aquaculture is impeded by a variety of issues. A new way to conceptualize and address such issues is through an FAO initiative, the ecosystem approach to aquaculture (EAA). Many of the issues affecting aquaculture are entirely spatial in nature (e.g. siting and zoning), or have important spatial elements (estimating aquaculture potential, impacts of aquaculture on the environment, competition for space with other users). The EAA makes an additional demand on spatial planning tools and concepts – defining the environmental, social and economic boundaries of ecosystems and the interactions of these fundamental elements. However, many of the countries where aquaculture is important are not yet making use of spatial analyses to systematically and synoptically address issues in an ecosystem context through the use of spatial planning tools such as Geographic Information Systems (GIS), remote sensing and mapping.

Geographic information systems (GIS) are an integrated collection of computer software and data used to view and manage information about geographic places, analyse spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analysed (ESRI, 2001). Typically, a GIS is used for manipulating maps with linked databases. These maps may be represented as several different layers where each layer holds data about a particular kind of feature (Figure 1.1). Each feature is linked to a position on the graphical image of a map. Layers of data are organized in particular manner for study and statistical analysis. Various types of data sets, such as hydrology, road networks, urban mapping, land cover, and demographic data can contain a multitude of information about a specific feature, all tied together geographically to provide spatial context. In simplicity, a geographic information system is a computer-based tool that maps and analyzes features and events that occur on the earth.

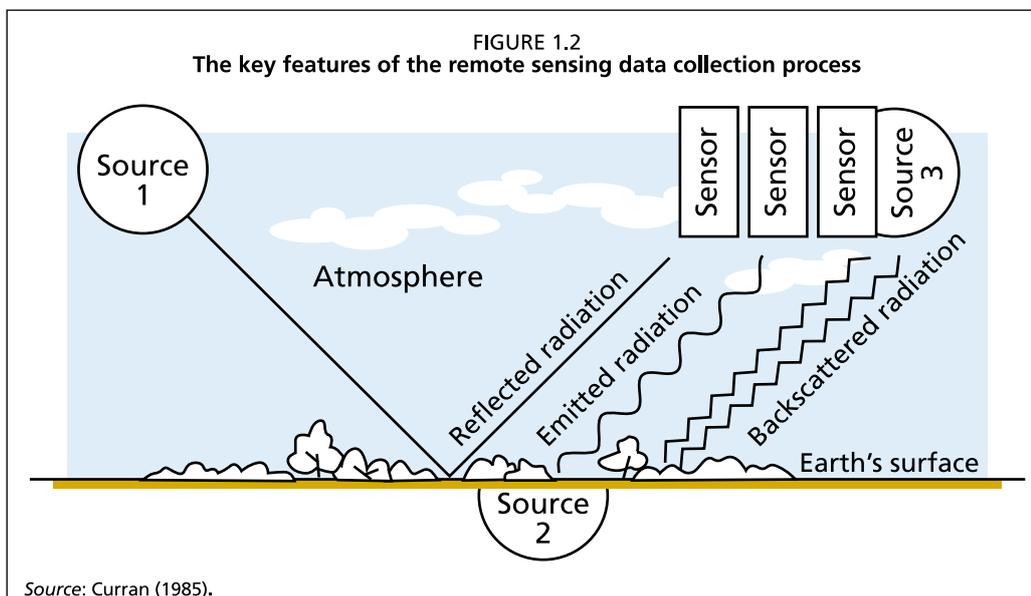
The geographic roots of GIS go back some 2 500 years and have their basis in geographic exploration, research and theory building. In the early 1960s the assembled geographic knowledge began to be formalized as computer tools functioning to input, store, edit, retrieve, analyze and output natural resources information. The first GIS was the Canada Geographic Information System and it marked the inception of world wide efforts to formalize and automate geographic principles to solve spatial problems. After more than 40 years of development, GIS is now a mainstay for addressing geographic problems in a wide variety fields apart from natural resources (DeMers, 2003).

Remote sensing implies collecting and interpreting information about the environment and the surface of the earth from a distance, primarily by sensing radiation that is naturally emitted or reflected by the earth's surface or from the atmosphere, or by sensing signals transmitted from a device and reflected back to it. Examples of remote-sensing methods include aerial photography, radar, and satellite imaging (ESRI, 2001; University of Nebraska-Lincoln, 2005).

The aim of environmental remote sensing is to utilize sensors, which are mounted on aerial platforms, to identify and/or measure parameters of an object according to variations in the electromagnetic radiation (EMR) emitted by, or reflected from the object. The energy which is sensed by the different remote sensing systems is a function of various parameters which might affect the energy before it is received by the sensors. This is shown in Figure 1.2 which indicates that EMR can be natural, either reflected light and other radiations from the sun (Source 1) or emitted heat from the earth (Source 2), or it can be man-made such as from a power station or a radar system.



The majority of the problems currently faced by world fisheries and aquaculture lie in the spatial domain, and fisheries and aquaculture management challenges extend over large geographic areas, including inland areas, coastal zones, and open oceans. As a result, remote sensing (from fixed coastal locations, aircraft and satellites) has been used to provide a large range of observation data to support fisheries and aquaculture management, which complement and extend data acquired from in-situ observations. Satellite remote sensing in particular provides a unique capability for regular, repeated observations of the entire globe or specific regions at different spatial scales. There is unprecedented availability of global and regional oceanographic and terrestrial remote sensing data and derived information products, which can meet many of the needs of fisheries and aquaculture managers.



Principles of the EAA have been recently defined (Soto, Aguilar-Manjarrez and Hishamunda, 2008) and guidelines for implementation are under development (Soto and Aguilar-Manjarrez, 2009). Attention is now turning to the processes, methods and tools that allow EAA principles to be translated into practical implementation. Clearly, an essential element of implementation will be the use of GIS, remote sensing and mapping, hereafter referred to as spatial planning tools. In recognition of the important role of spatial tools in support of the implementation of the EAA, an FAO Expert Workshop entitled “The Potential of Spatial Planning Tools to Support the Implementation of the ecosystem approach to aquaculture” was held in Rome just prior to the Guidelines Workshop mentioned above. A summary of the present review, while still in progress, was distributed at the spatial planning tools workshop (Aguilar-Manjarrez, Kapetsky and Soto, 2010).

Meanwhile, a parallel FAO initiative, the ecosystem approach to fisheries (EAF), is also underway. The EAF and EAA initiatives offer the opportunity to identify a number of mutually beneficial commonalities as bases for the development of synergies. These range from data and knowledge of species life histories and ecology to capacity building and a range of modeling tools.

In the realm of spatial analyses in support of the EAF, a Fisheries and Aquaculture Technical Paper entitled “Geographic Information Systems to support the ecosystem approach to fisheries: status, opportunities and challenges” has been produced (Carocci *et al.*, 2009). However, it is primarily intended to be a guide conveying the methods by which readers could approach their own adoption of GIS. In this regard, the EAF review is a valuable companion to the EAA review herein. Nevertheless, the scope of the EAF review differs from the present review in that the former assumes that GIS capacity already exists to support the EAF. In contrast, this review is an assessment of the readiness of spatial tools to support the EAA and also attempts to anticipate the locations and magnitudes of ecosystem problems in aquaculture. With this background, the objectives of this review are detailed in the section that follows.

1.1 OBJECTIVES AND OVERVIEW

The main objective of this review is to provide a measure of the general state of the readiness of GIS, remote sensing and mapping – the tools for spatial analyses – to support the FAO initiative on the ecosystem approach to aquaculture. An additional purpose is to provide a basis to plan for the kinds and locations of technical assistance and training in spatial analyses to support implementation of the EAA among FAO member countries. An underlying goal is to identify activities and organizations with which cooperation and joint initiatives or projects could be implemented for GIS in support of the EAA. Specifically, it is intended to:

- review the use of spatial tools as applied to aquaculture issues in the context of ecosystems;
- identify subject gaps in addressing issues and geographic gaps in the application of the tools to ecosystems; and
- define how spatial tools can help to achieve an ecosystems approach to aquaculture including EAA principles, scales, objectives and practices.

Given these objectives, the review is aimed at a broad audience that includes not only aquaculture decision-makers and spatial analysts as potential EAA implementors, but also the larger audience implicit in an ecosystems approach to aquaculture including all of the individuals and organizations involved with the sustainable use of land and water resources.

1.2 SCOPE AND METHODOLOGY

This review analyzes and synthesizes information on the status of GIS, remote sensing and mapping applications in aquaculture in relation to the EAA. Geographically, the review is global in its reach. Temporally the review extends from 1985, corresponding to

the earliest GIS applications in aquaculture, to the present. The records characterizing applications of GIS, remote sensing and mapping of the aquaculture portion of the GISFish Web Site were the main source of data to evaluate the status of spatial analyses pertaining to the EAA. The Internet was used to identify the data and information that are available to expand the use of spatial analyses in support of the EAA.

1.3 APPROACH

For the implementation of the EAA a fundamental requirement is to spatially define ecosystems both in terms of natural boundaries and jurisdictional and administrative responsibilities. The major use for spatial planning tools will be to establish ecosystem boundaries and to provide information for decision-making on uses of land and water that conflict with, compete or complement aquaculture.

Fundamental to knowing where, in what ways and for whom the EAA will be spatially supported as well as for planning for training and technical assistance is a knowledge of where the problems are located and their magnitude. These requirements can be addressed by considering:

- the potential impacts of aquaculture on the main environments, and
- environmental and human impacts on aquaculture
- ensuring that the impacts are comprehensively and comparatively quantified among countries

The readiness of spatial tools to address problems in implementation of the EAA can be assessed in several ways, basically by considering experience in:

- addressing the main spatial issues¹ in aquaculture
- assessing the relevance of GIS applications to EAA principles
- working at scales relevant to the EAA
- applying spatial tools in various kinds of ecosystems
- using decision-making tools and modelling

Other indications of the readiness of spatial tools to serve the EAA that relate to national capacities are:

- the geographic distribution of spatial tools applications among countries
- interest in GIS applications among continents and countries as measured by visits to GISFish, a portal dedicated to the spatial aspects of aquaculture and fisheries
- internet users among countries

The following chapters address these items.

¹ Kapetsky, J.M. and Aguilar-Manjarrez, J. 2005. Geographical Information Systems in aquaculture development and management from 1985 to 2002: an assessment. Proceedings of the Second International Symposium on GIS in Fisheries and Spatial Analyses, University of Sussex, England. 3–6

2. What is the ecosystem approach to aquaculture?¹

2.1 BACKGROUND TO THE ECOSYSTEM APPROACH TO AQUACULTURE

Aquaculture growth worldwide invariably involves (with differences amongst regions and economies) the expansion of cultivated areas, higher density of aquaculture installations and of farmed individuals, and use of feed resources often produced outside of the immediate area. Worldwide aquaculture has a growing social and economic impact through the production of food, livelihoods and income. Other positive effects on the ecosystem include for example the provision of seed for restocking of endangered or over exploited aquatic populations. However, badly managed aquaculture can affect ecosystem functioning and services with negative environmental, social and economic consequences. Additionally, aquaculture may be negatively affected by other human activities such as contamination of water supplies by agriculture or industrial activities.

In an attempt to control inadequate planned developments of the sector, or conversely to optimise aquaculture development, countries worldwide have implemented a diverse array of aquaculture regulations. These have varied from general rules such as banning the utilization of mangroves for aquaculture practices to very specific regulations such as the establishing of maximum production per area, regulations for disease control, use of drugs, etc. However, these regulations – neither on their own or taken together – provide a comprehensive framework ensuring a sustainable use of aquatic environments. That will happen when aquaculture is treated as an integral process within the ecosystem.

A team of experts at a workshop agreed upon the following definition in 2007²:

“An ecosystem approach to aquaculture is a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems”.

Most of the principles and associated ideas of EAA are not new. They can be found in Code of Conduct for Responsible Fisheries, CCRF (FAO, 1995) and in one form or another in the literature and guidance relating to sustainable development and integrated natural resource management such as Integrated Coastal Zone Management (ICZM) and Integrated Watershed Management (IWSM). There are however additions and shifts of emphases that make the ecosystem approach more comprehensive and balanced.

Both social and biophysical dimensions of ecosystems are tightly linked so that disruption in one is likely to cause disruption in the other and adverse impacts to both. There is a connection between biophysical and social dimensions of ecosystem resiliency. The EAA can be regarded as “the” strategy to ensure aquaculture contributes positively

¹ This chapter was contributed by Patrick White (Consultant, Akvaplan-niva AS. BP 411. Crest CEDEX 26402, France) and Doris Soto (Aquaculture Service (FIRA), FAO Fisheries and Aquaculture Department, Rome, Italy).

² Soto, D., Aguilar-Manjarrez, J. and Hishamunda, N. (eds). 2008. Building an ecosystem approach to aquaculture. FAO/Universitat de les Illes Balears Expert Workshop. 7–11 May 2007, Palma de Mallorca, Spain. *FAO Fisheries and Aquaculture Proceedings*. No. 14. Rome, FAO. 221p.

to sustainable development and should be guided by the three main principles which are also interlinked. Consequently, the EAA also echoes the development principles stated in the formulation of the ecosystem approach to fisheries (Garcia *et al.*, 2003) which has three main objectives within a hierarchical tree framework:

1. ensuring human well-being;
2. ensuring ecological well-being; and
3. facilitating the achievement of both, i.e. effective governance of the sector/areas where aquaculture occurs and has potential for development.

The EAA is based on the principles of sustainable development, where “sustainable” includes economic and social considerations, **not just environmental ones**.

BOX 2.1

The principles of the ecosystem approach to aquaculture

Principle 1

Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society.

Developing aquaculture in the context of ecosystem functions and services is a challenge that involves defining ecosystem boundaries (at least operationally), estimating environmental assimilative capacity, production carrying capacity and adapting farming according to it. This should be done for ecosystem services to be preserved or guaranteed. With more intensive aquaculture practices, monitoring and adaptive management is required.

Principle 2

Aquaculture should improve human well-being and equity for all relevant stakeholders.

This principle seeks to ensure that aquaculture provides equal opportunities for development, and that its benefits are properly shared, and that it does disadvantage any societal groups, especially the poorest. It should promote both food security and safety as key components of well-being.

Principle 3

Aquaculture should be developed in the context of other sectors, policies and goals.

This principle acknowledges the opportunity of coupling aquaculture activities with other production sectors in order to promote materials and energy recycling and better use of resources in general. This principle recognizes the interactions between aquaculture and the larger system, in particular, the influence of the surrounding natural and social environment on aquaculture practices and results. Aquaculture does not take place in isolation and in most cases is not the only human activity. In practice it often leads to a smaller impact on waterbodies than other human activities e.g. agriculture and industry. This principle also acknowledges the opportunity of coupling aquaculture activities with other producing sectors in order to promote materials and energy recycling and better use of resources in general.

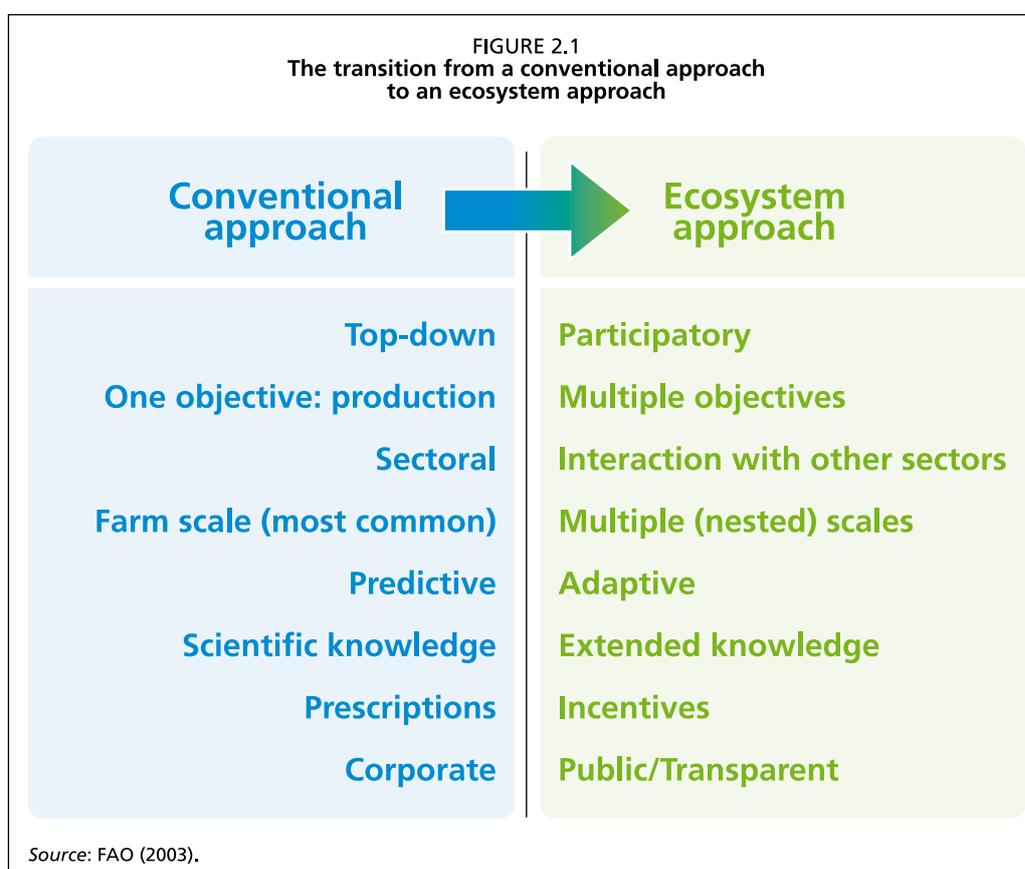
This principle is also a call for the development of multi-sectoral or integrated planning and management systems which take into account for other sectors policies and goals as well as to provide a framework and consistent cross-sectoral standards for the delivery of management and development initiatives to meet Principles 1 and 2.

2.2 CONVENTIONAL AQUACULTURE MANAGEMENT AND THE ECOSYSTEM APPROACH

Ecosystem-based management involves a transition from traditional sector-by-sector planning and decision-making to a more holistic approach of integrated natural resource management. Figure 2.1 outlines the differences in approach.

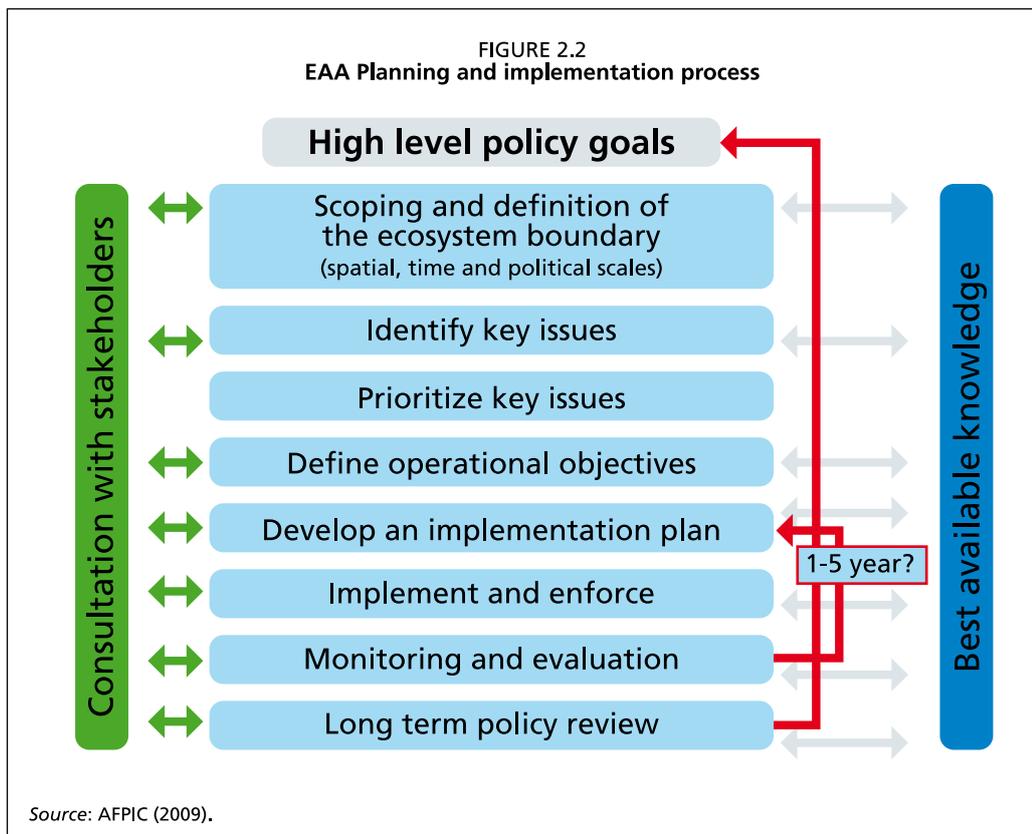
The FAO are presently preparing general guidelines targeting policy and decision-makers, on how to implement Article 9 of the Code of Conduct for Responsible Fisheries (CCRF) by using an ecosystem approach to aquaculture (FAO, 2010).

The ecosystem approach to aquaculture as a “strategy” should be the means to achieve or fulfill a higher level policy that reflects relevant local, national, regional and international development goals and agreements. The agreed policy should formulate a statement such as: “Aquaculture should promote sustainable development, equity, and resilience of interlinked social-ecological systems”. Implementing the EAA will help achieve this goal.



2.3 THE EAA PLANNING AND IMPLEMENTATION PROCESS

The steps to implement an EAA are depicted in Figure 2.2. To implement an EAA there must be an aquaculture policy in place (as noted above); this consists of a broad vision for the sector, reflecting its directions, priorities and development goals at various levels including provincial, national, regional and international. The second relevant step is the scoping and definition of ecosystem boundaries. In this step spatial planning tools (i.e. GIS, Remote Sensing and Mapping) are essential. The identification of issues, the prioritization of issues and setting of operational objectives are the following steps (Figure 2.2), spatial planning tools can also be useful in these steps, for example in providing spatial risk maps for the prioritization of issues (see also section 2.4 below). The development of an implementation plan can also require spatial tools because many or most issues have a spatial component and may require spatially explicit management (FAO, 2010).



Scoping and definition of the ecosystem boundary

When attempting to implement the EAA, there is a need to define ecosystem boundaries in space and time. In addition to deciding whether the planning and implementation of the strategy will cover the whole aquaculture sector of a country/ region, or (more typically) will address an aquaculture system or aquaculture area in a country/subregion.

Ecosystem boundaries may be delineated on geological, physical chemical, biological and ecological grounds, while socioeconomic and administrative boundaries outline the management area. In order to make these delimitations operational it is important to define the geographical area that the EAA will cover, which in turn will affect the scale and resolution of work. This will usually require some geographical information, from basic paper maps to more sophisticated geographic information databases and systems. In deciding geographic boundaries for ecosystems it is important to consider that much of the data that will be used will coincide with political boundaries.

Once the geographic area has been delimited, it is possible to identify stakeholders and proceed to identify the most relevant issues, prioritize them, define the operational objectives and develop the implementation plan (see Chapter 10).

2.4 SPATIAL SCALES

Areas to be managed can range from a tiny patch to whole continents. FAO (2006), discussing the EAA as an emerging issue, proposed the following scales/levels as relevant for its implementation/application: 1) at the farm level; 2) at the waterbody and its watershed/aquaculture zone; and 3) at the global, market-trade scale. The EAA framework should also apply to all productive scales (from small-scale to intensive, large scale farming) and should also consider temporal scales.

Farm scale

The individual farm is easy to locate and identify and local effects are often easy to assess although in cage aquaculture especially in open ecosystems, such as open seas,

it may be challenging to establish the boundary of potential effects. Most management practices are developed for this scale and most top down worldwide regulation measures worldwide apply at this scale. Also better management practices (BMPs) can be implemented at local levels and can be best monitored and assessed at this scale.

The watershed/aquaculture zone, geographic region

This geographic scale could include neighboring farms, clusters of farms, to massive areas that share a common waterbody or water source and that would benefit from coordinated management.

Some of the social and environmental problems (relating to principles 1 and 2) may be addressed at the individual farm level but most are cumulative, and are perhaps insignificant when considered at the individual farm level. However many problems can be highly significant in relation to the whole aquaculture sector. While the environmental and social impacts of a single farm could be marginal more attention needs to be paid to ecosystem effects of collectives or clusters of farms and their aggregate, potentially cumulative contribution at the watershed/zone scale, for example the development of eutrophication as a consequence of excessive nutrient outputs, or the dispersal of disease pathogens.

When the watershed boundaries go beyond political boundaries different authorities (even different countries) will need to be involved. The FAO Regional Fishery Bodies can play an important role in this respect as they may be able to provide the political platform for the cross-boundary implementation of the EAA (www.fao.org/fishery/rfb/search/en) when considering large common waterbodies/ecosystems, for instance, the Mediterranean Sea. Some of these Fishery Bodies have management mandates while others have advisory or management roles. Other examples of larger ecosystems are large marine ecosystems (LME), and marine protected areas (MPAs).

Wider regional and global scale

This scale refers to the global industry for certain commodity products (e.g. tilapia, salmon, shrimp, catfish) and also to global issues such as production, trade of fishmeal and fish oil for feeds, trade of aquaculture products, certification, technological advances, research and education of global relevance etc. Of particular importance is the supply of fish meal and fish oil in some areas of the world that are feed ingredients for fish and shrimp production in other areas beyond the region. This may mean that resources and energy are moving between different regions of the world with unexpected consequences. The sustainability of these resources and resilience of these systems is particularly important for the long-term sustainability of aquaculture.

Assessment of progress towards an EAA at the global level entails evaluation of issues such as availability of agriculture and fisheries feed stock for aquaculture feeds, economic and social impacts of aquaculture on agricultural and fisheries resources, and impacts on the broader marine ecosystem and ecosystem services to society at large. At the global scale knowledge enhancement and dissemination of risk assessment tools, risk communication and other similar practices to deal with the management of uncertainties may be promoted. Developing global agreements on better management practices and facilitating dissemination of appropriate information to consumers, which allows them to differentiate between products according to such practices can also be relevant.

2.5 EAA ISSUES AND THE RELEVANCE OF GEOGRAPHIC INFORMATION TOOLS

There are a number of key issues in the planning and implementation cycle of the ecosystem approach that require explicit consideration of spatial information about ecosystem components and properties. Furthermore, because of the interrelationships of inputs, resource use and outputs at the different scales, spatial data visualized within

a GIS environment can greatly improve understanding of the interactions between aquaculture, other sectors and the ecosystem in question, allowing for more spatially resolved analyses and for better integrated planning and management.

Some of the issues that require geographical information tools include (see also Chapter 6):

Development of aquaculture

- Identification of suitable sites. The identification of suitable aquaculture sites or zones based on objective criteria for guiding the scale, location (and relocation) of aquaculture operations. Identification of new areas with development potential.
- Zoning or allocation of space is a mechanism for more integrated planning of aquaculture development as well as its regulation. It may be used either in planning to identify potential areas for aquaculture; or as a regulatory measure to control the development of aquaculture, or as a management measure for synchronized stocking, harvesting and treatment for disease.
- EAA planning for development. Planning sustainable aquaculture development entails an analysis of a wide range of factors including location of suitable sites for aquaculture, prevention of environmental impact on sensitive habitats and species, integration of aquaculture with other sectors and prevention of conflicts.

Aquaculture practice and management

- Aquaculture impacts at different scales. Large industrial farms can have relevant effects on the ecosystem. Individual small-scale farms may not impact the local environment where as clusters of small-scale farm can cumulatively affect the local environment and wider watershed.
- Aquaculture inventory. To undertake adequate planning and management of the industry it is necessary to make an assessment of the present status of the industry and record the location of existing (and abandoned) farms and farming areas. Remote sensing combined with ground-truthing can be used to identify the location and GIS to map the areas. These farming areas can then be compared to sensitive ecosystems and habitats to highlight potential impacts. The GIS identified farms can also be linked to the licensing process to identify unregistered or illegal farms.

Multisectoral development and management that includes aquaculture

- Transboundary issues. Ecosystem limits do not usually coincide with administrative limits. If the ecosystem boundaries are shared by administrative boundaries then potential for harmonised planning and management structures and measures can exist across the ecosystem. Definitions of ecosystem boundaries are also needed to help identify the relevant stakeholders and to address the different issues (Soto *et al.*, 2008).
- Integration issues. As aquaculture is a relatively new industry and is still growing rapidly, hence it can have conflicts with other more mature sectors. The third EAA guiding principle is essentially a call for more integrated planning and management systems, as has been advocated for many years through integrated coastal zone management and integrated watershed management. There is a need for integrated multisectoral development and management that includes the needs of aquaculture. There is also a need to manage aquaculture together with fisheries and to identify potential synergies and to minimise conflicts, particularly where spatial uses overlap.

GIS training and promotion of GIS

- Contribution of promotion, training and capacity building in spatial EAA is also a key contribution to overall implementation of the EAA

Spatial planning tools are relevant to the EAA because they may be used to organize, analyze and present information from a number of different sources. Thus, viewing from single interest or multiple use viewpoints is enhanced and in this mode spatial planning tools can make a very important contribution to EAA. GIS are becoming more readily available for this purpose. Use of remote sensing and GIS tools has the capacity to bring together experts from a variety of disciplines to address complex spatial problems. The capacity of RS and GIS to broadly view and spatially analyze competing and conflicting uses exists. Therefore, the principal task is to determine the ways that spatial tools can best be implemented to support the EAA in order to fully realize its potential. Included amongst these tasks are:

- Description and mapping is a basic starting point in the identification of many issues, especially with regard to resource use and allocation, and may also form the basis for specific planning interventions related to site selection criteria, and in some cases to zoning.
- Recent advances in RS have greatly enhanced our ability to describe and understand natural resources, facilitate planning of aquaculture development, support EIA and monitoring, and the use of GIS has greatly enhanced our ability to store, analyze and communicate this information.
- For local or broader sectoral planning the use of maps, field visits and “rapid appraisal” could be the most cost effective approach in the short term. Also the imagery from the earth browsers such as Google Earth has provided a free and readily available, valuable tool for use in developing country districts, towns and villages. Here planners who are allocating water and land space for aquaculture, can access a spatial planning tool for aquaculture in a low-cost and effective way. RS and sophisticated GIS are usually more suitable as higher level planning and management tools, i.e. where their cost can be effectively spread across sectors, and where the mechanisms for their maintenance can be more easily implemented.
- GIS can facilitate the task of bringing together the criteria for locating aquaculture and more broadly can define zones suitable for different activities or mixes of activities, including aquaculture.

More specific case studies and GIS applications are developed in the following chapters, that together illustrate the relevance of these tools for the analysis of different issues, for planning and for strategic decision-making. These are all very relevant elements of the EAA implementation process.

3. Spatially defined global ecosystems, their issues and their relevance to the ecosystem approach to aquaculture

In order to gauge development prospects for aquaculture there is a need to understand actual and potential impacts imposed on aquaculture from anthropogenic sources and through natural variation in the environment. It is also essential to have an appreciation of the status of ecosystems in which aquaculture resides, and to be able to identify the main issues affecting ecosystems because aquaculture issues have to be resolved in the light of broader issues. This chapter therefore has two objectives from which GIS practitioners and EAA implementors can benefit. The first is to provide an overview of various assessments of the state of, and associated issues of marine, coastal and terrestrial ecosystems mainly using global data. The second objective is to indicate how the ecosystems data are relevant to the EAA and in particular to spatial analyses in support of the EAA. With regard to spatially defined ecosystems, emphasis is placed on global data. This has several purposes. The first is that the global perspective is useful in order to place ecosystem issues in a geographic perspective that allows for worldwide comparisons. The second is that many countries will not have defined their ecosystems at national and sub-national levels. In these cases, in order to place aquaculture in the context of ecosystems, global data must be used. The compilation of spatially defined ecosystems as summarized in Table 3.1, is useful as a starting point for that purpose as is the spatial data overviewed in Chapter 4. The datasets, many supported by maps, are grouped according to their geographic coverage or category.

3.1 ECOSYSTEMS INCLUDING BOTH LAND AND WATER

The 2008 Environmental Performance Index (EPI) (available at <http://epi.yale.edu/Home>), a collaboration between Yale and Columbia Universities (United States of America), ranks 149 countries on 25 indicators tracked across six established policy categories: environmental health, air pollution, water resources, biodiversity and habitat, productive natural resources and climate change (Figure 3.1). The EPI identifies broadly-accepted targets for environmental performance and measures how close each country comes to these goals. As a quantitative gauge of pollution control and natural resource management results, the Index provides a powerful tool for improving policy-making and shifting environmental decision-making onto firmer analytic foundations (Esty *et al.*, 2008). Country level indicators among all categories and overall EPI score data are downloadable in Excel format (www.yale.edu/epi/files/2008EPI_Data.xls). Although, the EPI is spatial only to the country level, the indices offer the opportunity to infer the impact of the environment on aquaculture by a country level by re-weighting of indicators to favour ecosystem vitality as the most important criterion (Chapter 5) or to tailor an impact assessment based on a selection of indicators attuned the various aquaculture environments and systems.

TABLE 3.1
Summary of spatially defined global ecoregions and ecosystems relevant to the EAA and GIS in support to the EAA

Title	Author	Year	Technical documentation and scale	Uniform Resource Locator (URL)
Ecosystems including both land and water				
Environmental Performance Index	Esty <i>et al.</i>	2008	Country reports Excel files	http://epi.yale.edu/Home www.yale.edu/epi/files/2008EPI_Data.xls
The Global Environmental Outlook	UNEP	2007	Report on Land and Water	www.unep.org/geo/geo4/media
The GEO Data Portal	UNEP	2007	National, Subregional, Regional scales	www.unep.org/geo/GeoDataPortalBrochure.pdf
The Global 200: Priority Ecosystems for Global Conservation	Olson and Dinnerstein	2002	Excel files Global and continental scales	http://geodata.grid.unep.ch/extras/indicators.php www.worldwildlife.org/science/ecoregions/WWFBinaryitem4810.pdf
The coasts of our world: Ecological, economic and social importance	Martinez <i>et al.</i>	2007	Vector data 1 km grid cell size sources were used	www.worldwildlife.org/science/data/item6373.html www.rpdc.tas.gov.au/_data/assets/pdf_file/0006/123495/Martinez_et_al_2007_Coasts.pdf
Aquatic ecosystems				
Global International Water Assessment	UNEP	2006b	Attribute data should be available	www.unep.org/dewa/giwa www.unep.org/DEWA/GIWA/PUBLICATIONS/FINALREPORT
Global Map of Human Impacts on Marine Ecosystems	Halpern <i>et al.</i>	2008	Global GIS data variety of formats	www.nceas.ucsb.edu/globalmarine www.nceas.ucsb.edu/GlobalMarine/impacts www.unep.org/dewa/assessments/EcoSystems/water/Marine_Coastal_Ecosystems.pdf
Marine and Coastal Ecosystems and Human Well-Being	UNEP	2006a	Global Attribute data available	www.edc.uri.edu/lme/intro.htm
Large Marine Ecosystems	Sherman and Hempel	2008	Global report Global (vector)	www.edc.uri.edu/lme/intro.htm
Marine Ecoregions of the World (MEOW)	Spalding <i>et al.</i>	2007	Global Vector	www.worldwildlife.org/science/ecoregions/marine/WWFBinaryitem6091.pdf http://conserveonline.org/workspaces/ecoregional.shapefile
Eutrophication and Hypoxia in Coastal Areas: A Global Assessment of the State of Knowledge	Selman <i>et al.</i>	2008	Global and regional point locations. Spatial data and attribute data may be available upon request	http://pdf.wri.org/eutrophication_and_hypoxia_in_coastal_areas.pdf
In Dead Water – Merging of climate change with pollution, over-harvest, and infestations in the world's fishing grounds	Nellemann, Hain, and Alder	2008	Presumably spatial data and attribute data might be available upon request	www.grida.no/publications/rr/in-dead-water/

TABLE 3.1 Cont.
Summary of spatially defined global ecoregions and ecosystems relevant to the EAA and GIS in support to the EAA

Title	Author	Year	Technical documentation and scale	Uniform Resource Locator (URL)
Terrestrial ecosystems				
Last of the Wild, Version 2	WCS and CIESIN at Columbia University.	2009	Report 1 km grid cell size	http://sedac.ciesin.columbia.edu/wildareas/downloads.jsp#last
Pilot Analysis of Global Ecosystems (PAGE) - Agroecosystems	Wood, Sebastian and Scherr (2000). World Resources Institute and the International Food Policy Research Institute.	2000 2005	Report 9.2 km at the equator	www.ifpri.org/publication/pilot-analysis-global-ecosystems www.ifpri.org/pubs/books/page.htm
WWF Terrestrial ecoregions of the world	Olson <i>et al.</i>	2001	Documentation	www.worldwildlife.org/science/ecoregions/item1267.html
HydroSHEDS	Lehner, Verdin, and Jarvis	2008	Full GIS Database Documentation Available resolutions range from approx. 90 meters at the equator to approx. 10 km at the equator	www.worldwildlife.org/science/data/item6373.html http://hydrosheds.cr.usgs.gov http://gisdata.usgs.net/website/HydroSHEDS/viewer.php

Notes: Vector. A coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each vector feature, as opposed to a raster data model, which associates attributes with grid cells. Cell. The smallest unit of information in raster data, usually square in shape. In a map or GIS dataset, each cell represents a portion of the earth, such as a square meter or square mile, and usually has an attribute value associated with it, such as soil type or vegetation class. See Glossary in Chapter 11.

FIGURE 3.1
Interactive map of the Environmental Performance Index countries
in the Caribbean Region



The Global Environmental Outlook and the GEO Data Portal

The fourth “Global Environment Outlook: environment for development (GEO-4) assessment” is a comprehensive and authoritative UN report on environment, development and human well-being, providing incisive analysis and information for decision-making (UNEP, 2007). As overviews of issues there are two chapters of particular interest to the EAA, Chapter 3 on Land and Chapter 4 on Water in which aquaculture impacts are dealt with qualitatively mainly as they relate to the use of fishmeal in fish feeds, and thus an indication of the impact on marine ecosystems, as well as maps and graphs that preview the underlying data.

From the viewpoint of GIS in support of the EAA, the GEO Data Portal (www.unep.org/geo/Docs/GEODataPortalBrochure.pdf) gives access to a broad collection of harmonized environmental and socio-economic datasets from authoritative sources at global, regional, sub-regional and national levels, and allows for data analysis and the creation of maps, graphics and tables. Its on-line database currently holds more than 450 variables. The datasets can also be downloaded in a variety of formats, supporting further analysis and processing by the user. The contents of the Data Portal cover environmental themes such as climate, forests and freshwater and many others, as well as socioeconomic categories, including education, health, economy, population and environmental policies. A set of core indicators offers useful starting points for directed analyses pertinent to the EAA (e.g. Freshwater BOD); however, not all of the information is at country level. (<http://geodata.grid.unep.ch/extras/indicators.php>).

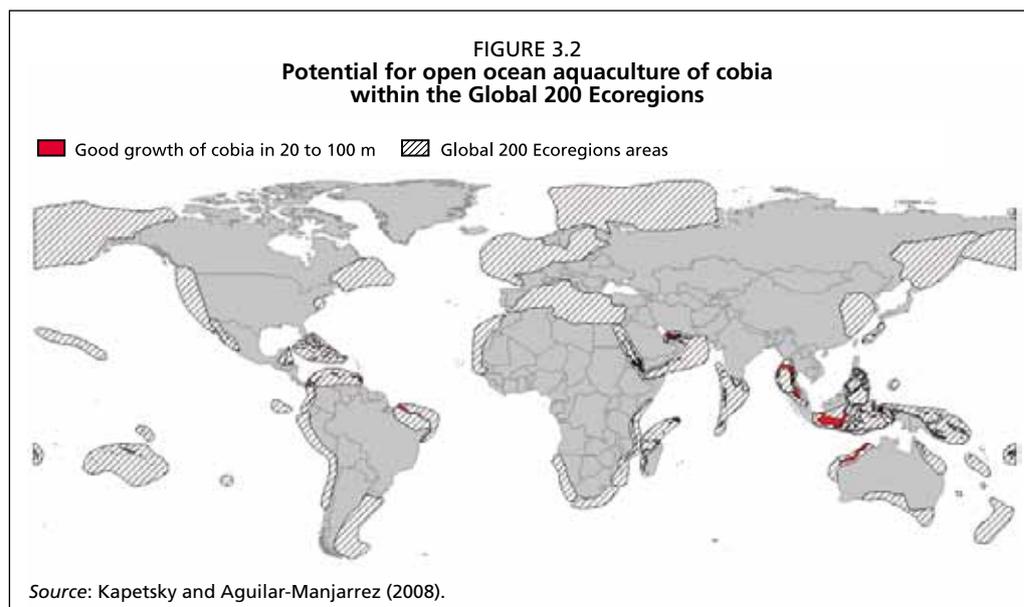
The Global 200: Priority Ecosystems for Global Conservation

Olson and Dinnerstein (2002) analyzed global patterns of biodiversity to identify a set of the Earth’s terrestrial, freshwater, and marine ecoregions that harbor exceptional biodiversity and are representative of its ecosystems. As a means of facilitating a representative analysis, the authors placed each of the Earth’s ecoregions within a system of 30 biomes and biogeographic realms. Biodiversity features were compared

among ecoregions to assess their irreplaceability or distinctiveness. These features included species richness, endemic species, unusual higher taxa, unusual ecological or evolutionary phenomena, and the global rarity of habitats. This process yielded 238 ecoregions—the Global 200—comprised of 142 terrestrial, 53 freshwater, and 43 marine priority ecoregions. Effective conservation in this set of ecoregions would help conserve the most outstanding and representative habitats for biodiversity on the planet. This dataset is useful for the EAA in that Olson and Dinnerstein have already identified areas of exceptional biodiversity importance in which, at first glance, special care should be taken for planning aquaculture development and for its operation.

From a GIS perspective, the Global 200 areas can be integrated with other measures of ecosystem status by incorporating the freely downloadable GIS database (www.worldwildlife.org/science/data/item6373.html).

The Global 200 Ecoregions were used by Kapetsky and Aguilar-Manjarrez (2008) as an example of spatial data in support of the EAA. The example was an estimate of the loss in potential area for open ocean culture of cobia, *Rachycentron canadum*, by excluding the Global 200 areas. About one-third of the global area with potential for good growth of the cobia, in sea cages at 25 to 100m depth would be excluded by using the Global 200 Ecoregions as a constraint (Figure 3.2).



The coasts of our world: Ecological, economic and social importance

Martinez *et al.* (2007) integrated the emerging information on the ecological, economic and social importance of the coasts at a global scale. They defined coastal regions to range from the continental shelf (to a depth of 200 m), the intertidal areas and adjacent land within 100 km inland of the coastline. They used the 1 km resolution Global Land Cover Characteristics Database to calculate the area covered by 11 different land cover classes (natural and human-altered ecosystems) within the 100 km limit. Cover of aquatic ecosystems was calculated based on several world databases.

Multivariate analyses grouped coastal countries according to their ecological, economic and social characteristics. Three criteria explained 55 percent of the variance: degree of conservation, ecosystem service product and demographic trends.

This study is valuable for integrating EAA economic and social perspectives. Each criterion has a country specific value and a world map integrates the results into eight classes for the criteria. Presumably the data could be obtained in database or spreadsheet formats by request to the authors.

3.2 AQUATIC ECOSYSTEMS

In overview, most of Earth (70.8 percent or 362 million km²) is covered by oceans and major seas. Marine systems are highly dynamic and tightly connected through a network of surface and deep-water currents. The physical properties of the water form stratified layers, and various processes cause tides, currents, fronts, gyres, etc. Upwellings break this stratification by mixing layers and creating vertical and lateral heterogeneity within the ocean biome. The total global coastlines exceed 1.6 million kilometres, and coastal ecosystems occur in 123 countries around the world (UNEP, 2006a).

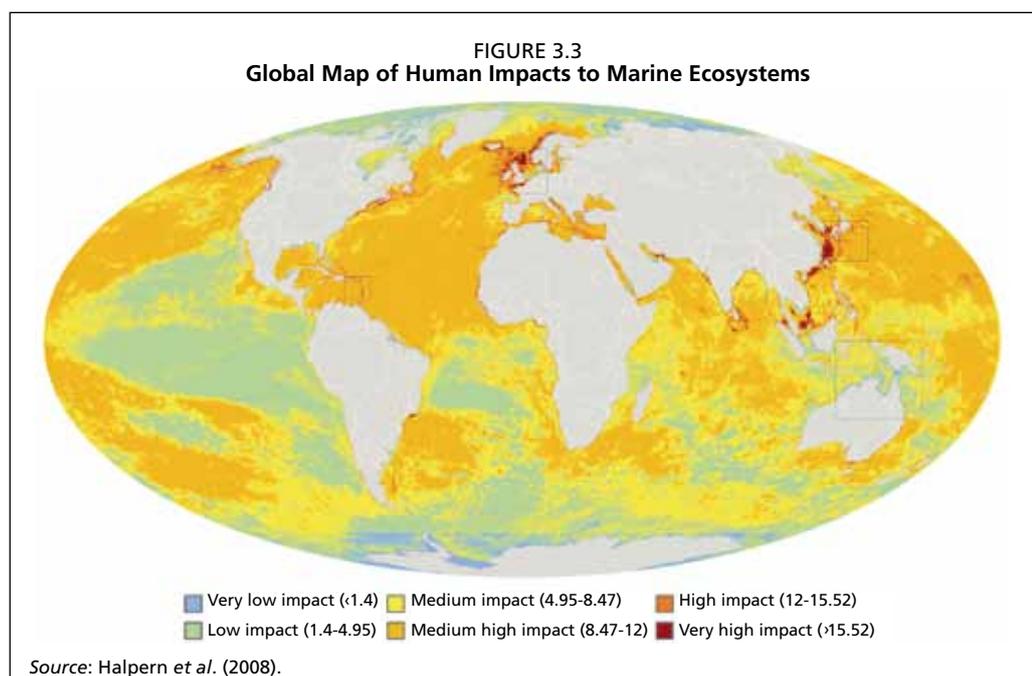
Global International Water Assessment (GIWA)

The Global International Waters Assessment (UNEP, 2006b) is a holistic and globally comparable assessment of transboundary aquatic resources in the majority of the world's international river basins and their adjacent seas, particularly in developing regions. Complex interactions between mankind and aquatic resources were studied within four specific major concerns: freshwater shortage, pollution, overfishing and habitat modification. Of importance to the EAA is that the GIWA project divided the continents and shallow-water seas of the world into 66 natural regions consisting of one or more international river basins and their adjacent Large Marine Ecosystems. Therefore there is a linkage between land and water. Another advantage is that the 66 natural regions are contiguous.

The GIWA Report presents the severity of 22 environmental and socio-economic water-related issues in all the studied regions. The global synopsis not only describes the current and future state of aquatic systems and their resources but also discusses the root causes and driving forces that create adverse environmental pressures, and draws policy related conclusions. The availability of the spatial data is unclear; however attribute data for each of the 66 regions and a global overview should be available. An important use would be to evaluate estimates of aquaculture potential against the water-related situations found within the 66 GIWA regions.

Global map of human impacts on marine ecosystems

The management and conservation of the world's oceans require synthesis of spatial data on the distribution and intensity of human activities and the overlap of their



impacts on marine ecosystems. An ecosystem-specific, multiscale spatial model to synthesize 17 global datasets of anthropogenic drivers of ecological change for 20 marine ecosystems was developed by Halpern *et al.* (2008). Their analysis indicates that no area is unaffected by human influence and that a large fraction (41 percent) is strongly affected by multiple drivers. However, large areas of relatively little human impact remain, particularly near the poles (Figure 3.3).

From an EEA perspective the analytical process and resulting maps provide flexible tools for regional and global efforts to allocate conservation resources; to implement ecosystem-based management; and to inform marine spatial planning, education, and basic research that pertain to mariculture and possibly to brackishwater culture environments. Maps that show inorganic and organic pollution as well as nutrient inputs are among the most potentially useful for mariculture. From a GIS viewpoint the data layers are set out (www.nceas.ucsb.edu/globalmarine/impacts) and the ecosystems data are downloadable in a number of GIS formats. (www.nceas.ucsb.edu/globalmarine/ecosystems).

Marine and coastal ecosystems and human well-being

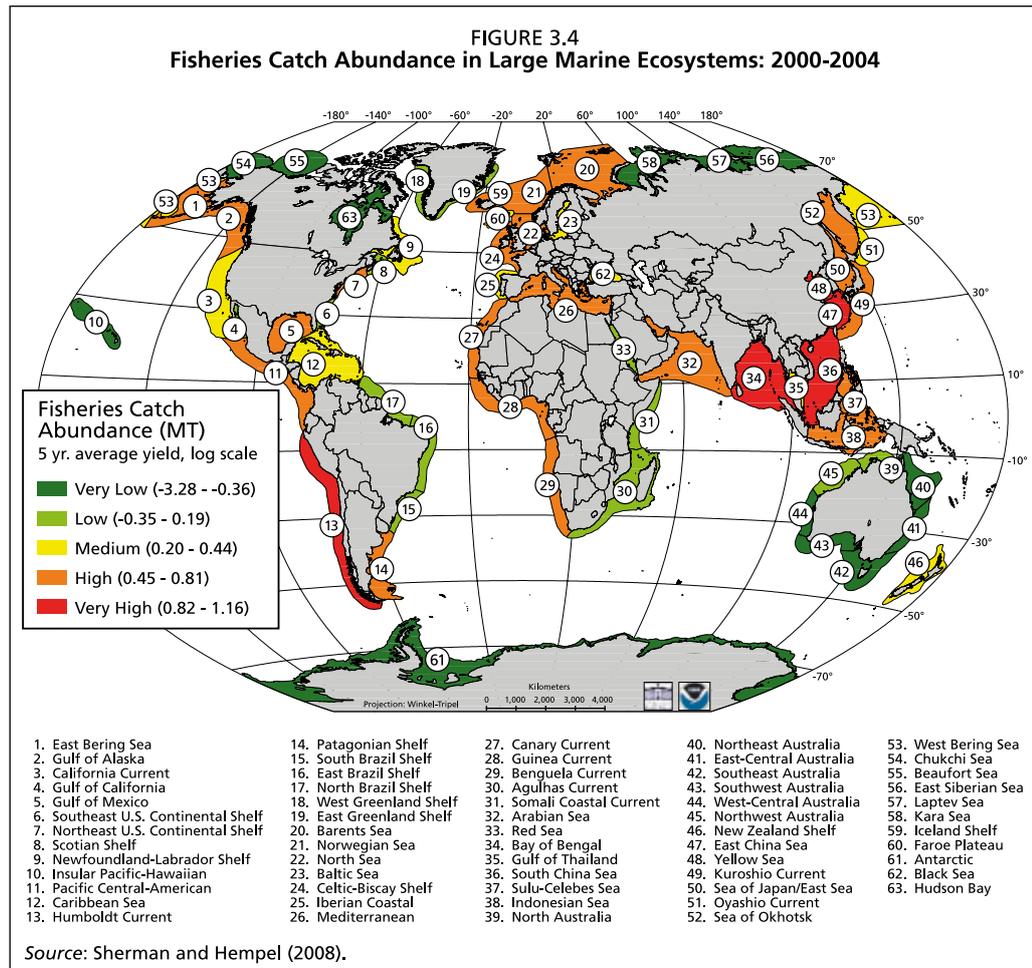
The Marine and Coastal Ecosystems and Human Well-being report (UNEP, 2006a) is a synthesis of the findings from the reports of the Millennium Ecosystem Assessment (MA) working groups (conditions and trends, scenarios, response and sub-global assessments) concerning marine and coastal ecosystems. The Millennium Ecosystem Assessment is an international initiative that began in 2001 under the auspices of the United Nations. The MA establishes a collaborative and scientific approach to assess ecosystems, the services they provide, and how changes in these services will impact upon human well-being. UNEP-WCMC and UNEP's Division of Early Warning and Assessment (DEWA) have coordinated the synthesis of this report in recognition that the loss of marine and coastal services has impacts on human well-being. The aim was to contribute to the dissemination of the information contained within the MA to decision-makers and a wide range of stakeholders of marine and coastal ecosystems through seven key messages. In addition it is envisaged the information contained within this synthesis report will contribute to larger international efforts such as the Global International Waters Assessment (GIWA), Global Biodiversity Outlook (GBO), the Global Marine Assessment (GMA), Global Environmental Outlook (GEO), the Regional Seas, and the Convention on Biological Diversity (CBD).

From an EAA viewpoint, this report is useful for examining issues relating to coastal and marine aquaculture. From a GIS viewpoint, it appears that there are no spatial data directly available; however, the Millennium Assessment itself may contain the data including the map of global coastal ecosystems.

Large marine ecosystems (LMEs)

Large marine ecosystems are regions of ocean space encompassing coastal areas from river basins and estuaries to the seaward boundaries of continental shelves and the outer margins of the major current systems. They are relatively large regions in the order of 200 000 km² or greater, characterized by distinct: bathymetry, hydrography, productivity, and trophically dependent populations (Sherman and Hempel, 2008). On a global scale, the 64 LMEs produce 95 percent of the world's annual marine fishery biomass yields. Within their waters, however, most of the global ocean pollution, overexploitation, and coastal habitat alteration occur. For 33 of the 63 LMEs, studies have been conducted of the principal driving forces affecting changes in biomass yields, these have been peer-reviewed and published in ten volumes (www.lme.noaa.gov). Based on lessons learned from these LME case studies, a five module strategy has been developed to provide science-based information for the monitoring, assessment, and management of LMEs. The modules are focused on LME: (1) productivity, (2)

fish and fisheries, (3) pollution and health, (4) socioeconomics, and (5) governance (www.lme.noaa.gov). Of interest as background and for orientation are the poster maps (www.edc.uri.edu/lme/maps.htm). Additionally, there are downloadable GIS data that include LME boundaries (2003) as lines and polygons and related data such as countries and coastlines (www.edc.uri.edu/lme/gisdata.htm). Obviously, these ecosystem spatial definitions, their attribute data and their relation to various uses such as fisheries (Figure 3.4) are of prime interest for the development and management of mariculture in the EAA context.

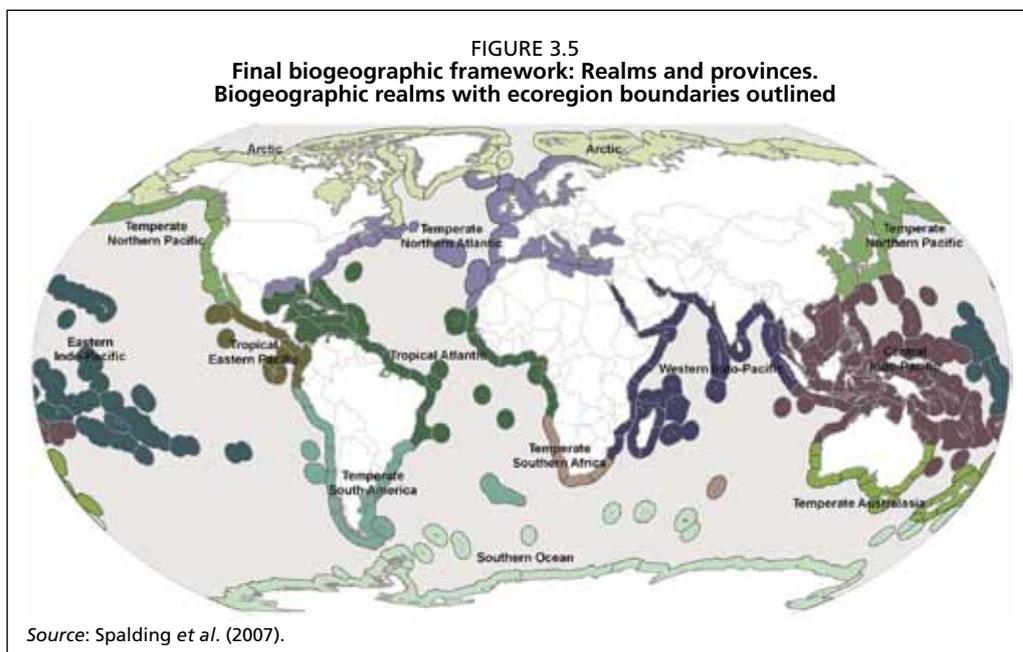


Marine Ecoregions of the World (MEOW)

The conservation and sustainable use of marine resources is a highlighted goal in a growing number of national and international policy agendas. Efforts to assess progress, as well as to strategically plan and prioritize new marine conservation measures, have been hampered by the lack of a detailed, comprehensive biogeographic system to classify the oceans. Spalding *et al.* (2007) describe a global system for coastal and shelf areas: the Marine Ecoregions of the World is a nested system of 12 realms, 62 provinces, and 232 ecoregions covering all coastal and shelf waters of the world shallower than 200 m. The map extends to 370 km (200 nm) offshore, or to the 200-m isobath where this lies further offshore (Figure 3.5).

Spalding *et al.* (op cit.) conclude that the MEOW classification provides a critical tool for marine conservation planning. It will enable gap analyses and assessments of representativeness in a global framework. It provides a level of detail that will support linkage to practical conservation interventions at the field level. Clearly, this classification will be useful to the EAA and particularly to GIS for Open Ocean

Aquaculture (OOA) because the MEOW corresponds closely to the EEZ areas of the world in which OOA will develop thus providing both an administrative and ecological context for that development. The MEOW shapefile is available at <http://conserveonline.org/workspaces/ecoregional.shapefile>.



Eutrophication and hypoxia in coastal areas: A global assessment of the state of Knowledge

Eutrophication -the overenrichment of waters by nutrients- threatens and degrades many coastal ecosystems around the world. The two most acute symptoms of eutrophication are hypoxia (or oxygen depletion) and harmful algal blooms, which among other things can destroy aquatic life in affected areas.

Of the 415 areas around the world identified as experiencing some form of eutrophication by Selman *et al.* (2008), 169 are hypoxic and only 13 systems are classified as “systems in recovery.”

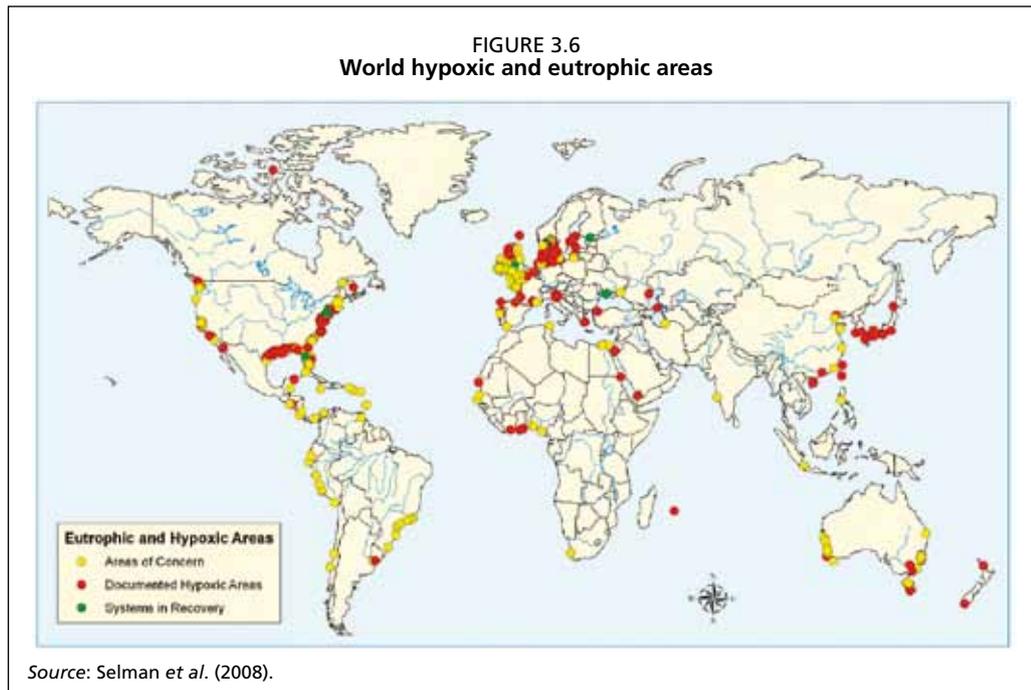
Mapping and research into the extent of eutrophication and its threats to human health and ecosystem services are improving, but there is still insufficient information in many regions of the world to establish the actual extent of eutrophication or identify the sources of nutrients.

From the viewpoint of the EAA, eutrophication may be positive for certain aquaculture systems (e.g. nitrogen enrichment benefiting filter feeders through plankton production); however, it may also involve risks as from hypoxia.

From the viewpoint of GIS in support of the EAA, a map in the report locates documented areas of hypoxia, areas of concern, and locations in recovery (Figure 3.6); however, these are only indicative of the actual locations and area expanses affected. The spatial data and attributes may be obtained from the World Resources Institute on request.

In dead water – Merging of climate change with pollution, over-harvest, and infestations in the world’s fishing grounds.

This UNEP report, titled as above, deals with the multiple and combined impacts of pollution; alien infestations; over-exploitation and climate change on the seas and oceans (Nellemann, Hain, and Alder, 2008). The worst concentration of cumulative impacts of climate change with existing pressures of over-harvest, bottom trawling,



invasive species, coastal development and pollution appear to be concentrated in 10–15 percent of the oceans concurrent with today's most important fishing grounds. The summary of the UNEP report synthesizes the issues and presents useful facts on the state of marine environments (www.grida.no/publications/rr/in-dead-water).

Global maps in the main report of particular interest include fish catch tonnes/km², tropical cyclone frequency, human development within 75 km of the coast, and marine invasive hotspots all of which have some relevance to the EAA. Presumably, the underlying spatial data could be obtained for spatial analyses in support of the EAA.

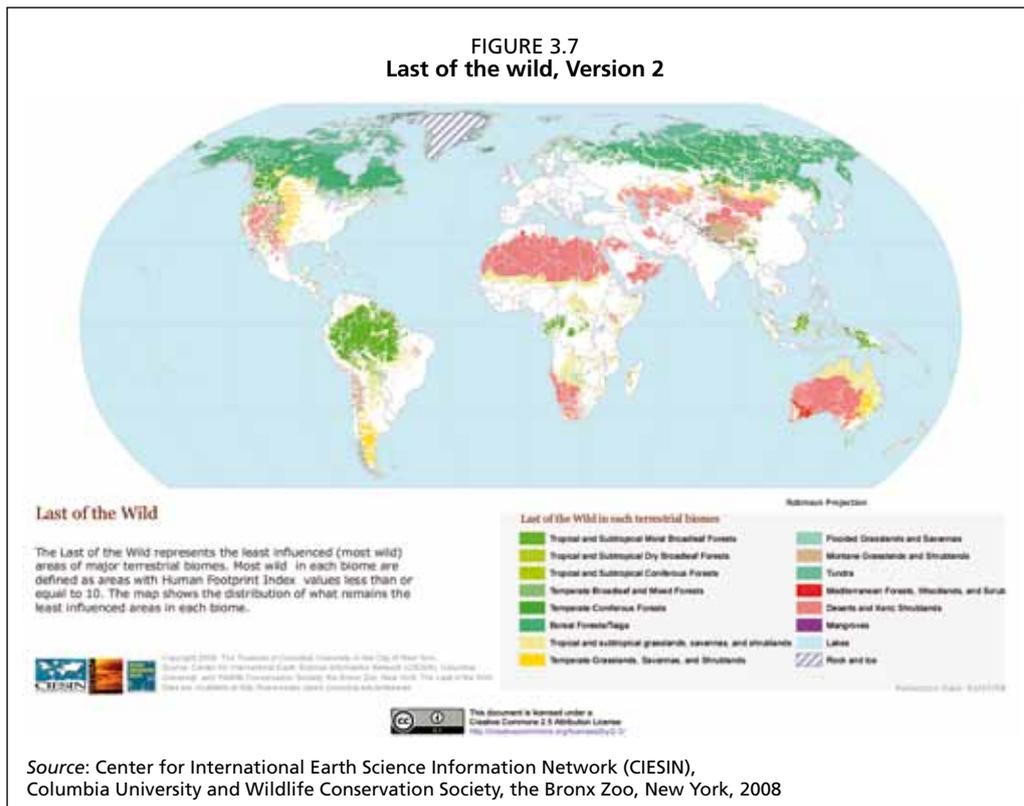
3.3 TERRESTRIAL ECOSYSTEMS

Last of the Wild, Version 2

Human influence is a global driver of ecological processes on the planet, on a par with climatic trends, geological forces, and astronomical variations. The Wildlife Conservation Society (WCS) and the Center for International Earth Science Information Network (CIESIN) at Columbia University have joined together to systematically map and measure the human influence on the Earth's land surface today. The Last of The Wild, Version Two (Figure 3.7) depicts human influence on terrestrial ecosystems using datasets compiled on or around 2000 (<http://sedac.ciesin.columbia.edu/wildareas>).

The Human Influence Index and Human Footprint are produced through an overlay of a number of global data layers that represent the location of various factors presumed to exert an influence on ecosystems: human population distribution, urban areas, roads, navigable rivers, and various agricultural land uses. The combined influence of these factors yields the Human Influence Index. The Human Influence Index (HII), in turn, is normalized by global biomes to create the Human Footprint (HF) dataset. HF values range from 1 to 100. The Last of the Wild data collection includes the Human Influence Index (HII) grids, Human Footprint grids, and The Last of the Wild vector data (<http://sedac.ciesin.columbia.edu/wildareas/downloads.jsp#last>). The datasets are available at global and continental scales. Global data are available in a geographic coordinate system at 30 arc-second grid cell size and Interrupted Goode Homolosine Projection (IGHP) at 1km grid cell size. Continental-level data is available only in

geographic coordinate system (GCS). Data are also available in ASCII (.asc) and ArcInfo Grids. The Last of the Wild vector data are available only in shapefile format. Details of how to use each format are in the readme.doc document included when zipfiles are downloaded. These data are especially relevant for the EAA because they can be used to infer expectations of environmental impacts on aquaculture that are not tied to administrative boundaries. From a GIS viewpoint the datasets are particularly valuable because of their ready availability and high resolution.



Pilot Analysis of Global Ecosystems (PAGE) – Agroecosystems

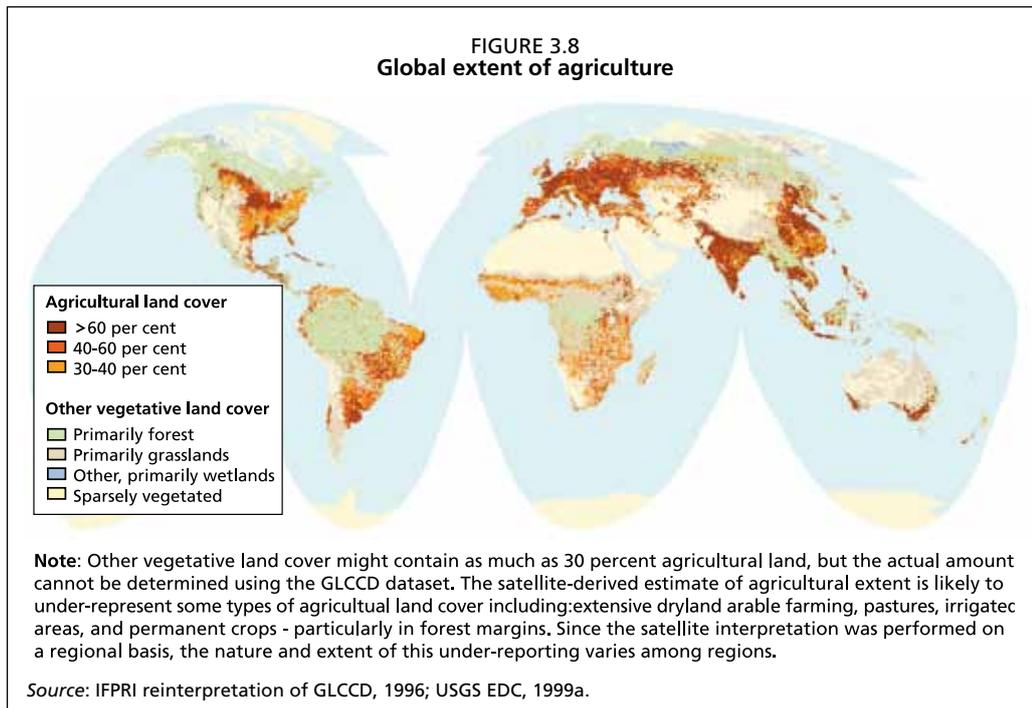
This analysis determines the extent of agricultural land use and assesses the status of agroecosystems on a global basis (Wood, Sebastian and Scherr, 2001) (Figure 3.8).

The report is the most comprehensive mapping of global agriculture to that date; however, with a publication in 2001, the material is now somewhat dated. The mapping is mainly global, but would be useful to place existing aquaculture and aquaculture potential in the context of agroecosystems. The study also shows ways to better understand and monitor changes in the capacity of the systems to provide sustainable goods and services.

From an EAA and GIS perspective, the Global Agroecosystems dataset has a resolution of about 9.2 km at the equator that is relatively coarse resolution. These data characterize agroecosystems in 17 classes, defined as “a biological and natural resource system managed by humans for the primary purpose of producing food as well as other socially valuable nonfood products and environmental services” (Wood, Sebastian and Scherr, op cit.).

WWF terrestrial ecoregions of the world

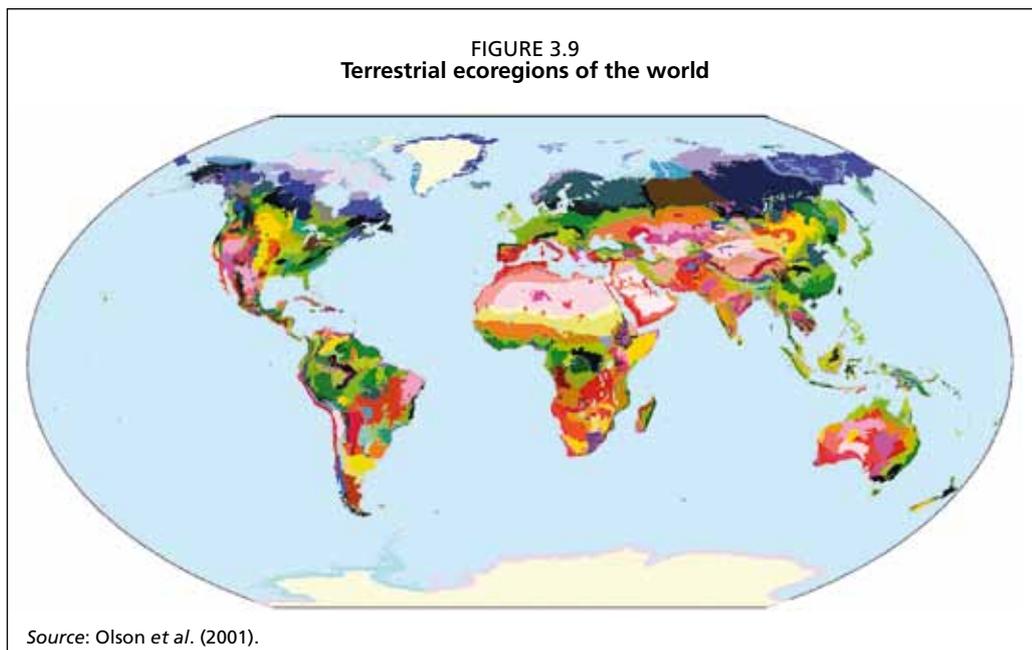
Terrestrial ecoregions of the world (www.worldwildlife.org/science/ecoregions/item1267.html), described by Olson *et al.* (2001) is an earlier spatial counterpart to the Freshwater Ecoregions of the World. The ecoregions approach is useful because ecoregions are likely to reflect the distribution of species and communities more



accurately than do units based on global and regional models derived from gross biophysical features, such as rainfall, temperature, or vegetation structure.

The terrestrial world is sub-divided into 14 biomes and eight biogeographic realms. Nested within these are 867 ecoregions (Figure 3.9).

The ecoregions map has been used as a biogeographic framework to highlight those areas of the world that are most distinctive or have high representation value and are therefore worthy of greater attention. Ecoregions were ranked by the distinctiveness of their biodiversity features, i.e. species endemism, the rarity of higher taxa, species richness, unusual ecological or evolutionary phenomena and global rarity of their habitat type. This ranking is important for spatial planning in support of the EAA in order to identify high value ecosystems. A spatial database is downloadable (www.worldwildlife.org/science/data/item6373.html).



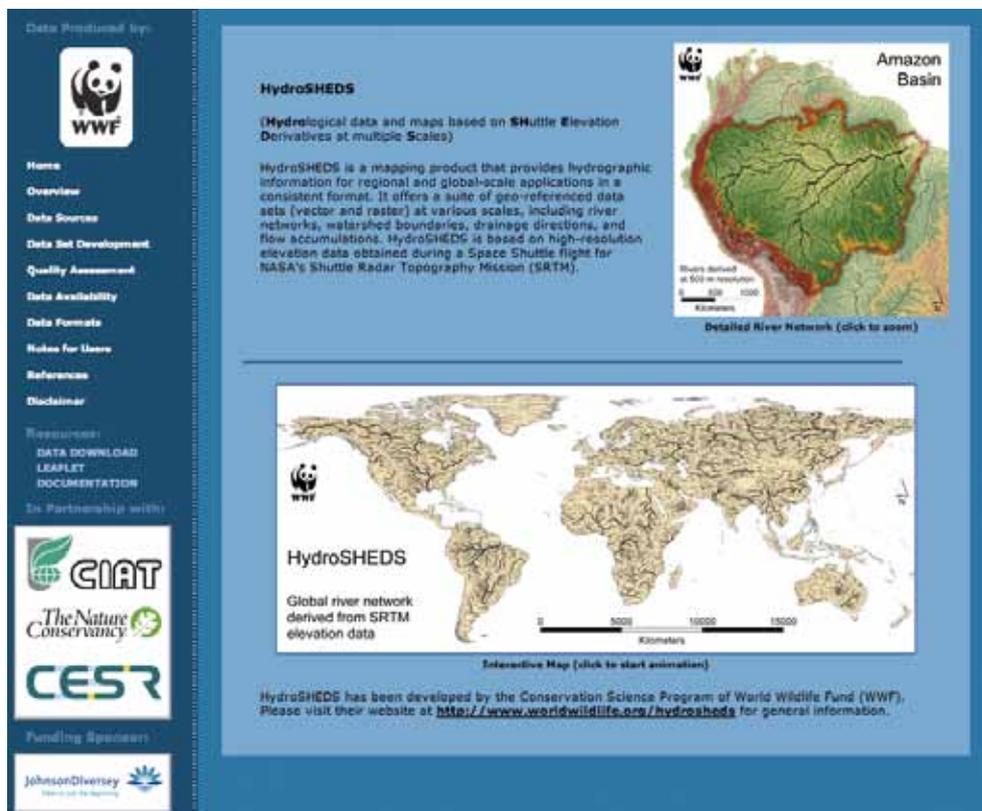
HydroSHEDS

Hydrological data and maps based on shuttle elevation derivatives at multiple scales (HydroSHEDS) are an innovative product that provide hydrographic information in a consistent and comprehensive format for regional and global-scale applications. They were developed by WWF’s Conservation Science Program and collaborators. HydroSHEDS offers a suite of geo-referenced data sets, including stream networks, watershed boundaries, drainage directions, and ancillary data layers such as flow accumulations, distances, and river topology information. The goal of developing HydroSHEDS was to generate key data layers to support regional and global watershed analyses, hydrological modeling, and freshwater conservation planning at a quality, resolution and extent that had previously been unachievable. Available resolutions range from 3 arc-second (approx. 90 meters at the equator) to 5 minute (approx. 10 km at the equator) with seamless near-global extent.

From the most basic level, HydroSHEDS will support the EAA by allowing creation of digital river and watershed maps.

These maps can then be coupled with a variety of other geo-spatial datasets or applied in computer simulations, such as hydrologic models, in order to estimate flow regimes important for aquaculture and to assess dangers to aquaculture from flows of poor quality water, or from flows that are inadequate or excessive. From a GIS viewpoint, a variety of data can be interactively selected and downloaded for any area of interest as shown in the global map below (Figure 3.10) (<http://hydrosheds.cr.usgs.gov>).

FIGURE 3.10
Hydrological data and maps based on shuttle elevation derivatives at multiple scales (HydroSHEDS)



Source: Lehner, Verdin and Jarvis (2008).

3.4 SUMMARY AND CONCLUSIONS

The first objective of this chapter was to provide mainly at global levels, an overview from a spatial viewpoint of various assessments and issues concerning the state of marine, coastal and terrestrial ecosystems. The second objective was to indicate how the ecosystems data are relevant to the EAA and in particular to spatial analyses in support of the EAA. One measure of relevance is provided by taking the global viewpoint: Each country can view its own issues in terms of those common to other countries and regions. Hopefully, this viewpoint would engender activities aimed at resolving shared problems among countries within regions. Compilations and definitions of ecoregions and ecosystems relevant to the EAA and to spatial planning tools for the EAA have been organized according to their coverage, i.e. ecosystems including both land and water, aquatic ecosystems and terrestrial ecosystems.

All of studies identified can be useful to the EAA in a qualitative way by raising the awareness of aquaculture planners and practitioners to issues and considerations that must be taken into account for the further development of aquaculture and for the mitigation of the potential impacts of aquaculture on the environment. An important additional benefit is that many of these are spatially explicit at global, regional and country levels. A few studies incorporate indices that are useful in assessing environmental impacts on aquaculture at the country level. Finally, many studies (or projects) offer readily available spatial and attribute data (or the possibility to acquire the data on request) of potential use to GIS, remote sensing and mapping in support of the EAA. The global datasets are a temporary substitute for country-level spatial data until higher resolution datasets can be developed. The usefulness of some of these datasets for spatial planning for the EAA has been demonstrated by their use in other chapters in this review and elsewhere. As shown by the many approaches to defining ecoregions and ecosystems, the criteria are many and the methods and data are oftentimes complex. Thus, although these data are “ready made”, a considerable expenditure of time to study and evaluate the approaches used and the actual relevance with regard to resolution and quality of the data will be required in order to use them effectively and responsibly for the EAA, or for GIS in support of the EAA.

4. Spatial data to support the ecosystem approach to aquaculture

Spatial data are indispensable for GIS to support the implementation of the EAA. Data needs, in turn, can be viewed in relation to the major uses for which the data are to be used within ecosystems. The major uses directly bearing on ecosystems are to:

- Estimate the potential impact of aquaculture on the environment including the natural, economic and social realms of ecosystems.
- Estimate the impact of natural and man-induced changes in the environment and ecosystems and their associated economic and social consequences for aquaculture.

These do not preclude other more specialized uses of spatial data for aquaculture that are implicit in the EAA. For example,

- Objectively identify optimal locations and use of natural resources.
- Identify and resolve conflicting uses of space and natural resources.
- Quantify production levels and match these to markets, infrastructure and socio-economic divers.

Implementing these tasks at the relevant scales, in turn, depends on the availability of several kinds of spatial and attribute data:

1. Ecosystems already defined and mapped.
2. Ecosystem parameters already defined, but not yet spatially integrated and mapped
3. Data to define aquaculture potential (e.g. environment, culture systems and (bioeconomic models).
4. Locations and characteristics of aquaculture (inventory, and for verification of estimates of potential).
5. Real-time data to support decisions on day to day aquaculture operations

Regarding the first of these data needs, ecosystems pre-defined globally, regionally and nationally, allows aquaculture to be placed in its proper ecological context, depending on the scale by which various kinds of aquaculture are located. Spatially defined ecosystems at the global scale most relevant to the EAA and GIS in support of the EAA have been described in Chapter 3. Regarding the remainder of the data needs, there will be many instances, especially at sub-national levels, where spatially defined data needed for ecosystems level work are of too coarse a resolution, or none will be available. In these instances additional spatial data will be needed to enhance already existing ecosystem data to meet the needs of aquaculture development and management.

The purpose of this chapter is to provide an overview of sources that can satisfy data needs mainly at global and national levels. The sources are the focus and the kinds of data are only generally indicated. This is because one source can contain data that could contribute to the various kinds of data needs enumerated above. Unfortunately, with the exception of GISFish, there is no comprehensive catalogue of spatial data targeted specifically to aquaculture at a global level; however, there are many Web sites

that are of use directly or that offer links to useful data of various types. Of course, our sources are not exhaustive. New sources are rapidly becoming available as, among others, satellite resolution increases and coverage expands in time and space and as the practical applications of spatial analyses become more common.

Sources to satisfy GIS for EAA data needs can be loosely categorized in the following ways:

- earth browsers (e.g. Google Earth, World Wind, Microsoft Virtual Earth) with georeferenced satellite image backdrops as well as various kinds of infrastructure layers that are the digital substitute for printed maps;
- portals as data catalogues (e.g. GISFish, FAO GeoNetwork; Ocean Portal);
- general data sources (e.g. Global Lakes and Wetlands Database; Africa Water Resources Database) to define ecosystems; and
- specialized data sources (e.g. Natural Disaster Hotspots and Risks; IPCC Data Distribution Centre; World Database on Protected Areas).

The sources are summarized in Table 4.1 and each covered in the following sections.

TABLE 4.1
Summary of Internet sites to acquire global spatial data to define ecosystems and their attributes

Internet site	* Technical description and scale	Uniform Resource Locator (URL)
Earth browsers		
Internet site	Technical description and scale	Uniform Resource Locator (URL)
Google Earth	Most land areas are covered in satellite imagery with a resolution of about 15 m per pixel. However, Google is actively replacing this base imagery with 2.5m SPOT Image imagery and several higher resolution datasets	http://earth.google.com
World Wind	World Wind allows any user to zoom from satellite altitude into any place on Earth, leveraging high resolution Landsat imagery and SRTM elevation data to experience Earth in visually rich 3D. Baseline resolutions: 500 m (Blue Marble Next Generation); 15 m (Landsat imagery; except for polar areas).	http://worldwind.arc.nasa.gov/download.html
Bing Maps (Microsoft Virtual Earth)	Bing Maps Platform (previously Microsoft Virtual Earth) is a geospatial mapping platform produced by Microsoft. It allows developers to create applications that layer location-relevant data on top of the Bing Maps map imagery. This includes imagery taken from satellite sensors, aerial cameras as well as Streetside imagery, 3D city models and terrain.	www.microsoft.com/maps
Portals		
GISFish	Wide range of data sources at different scales and resolutions	www.fao.org/fishery/gisfish/id/1134
Ocean Portal	Intended to assist users in locating web based data and information sources as well as to promote exchange of information and experience between users	www.iode.org/index.php
Conservation GeoPortal	It does not actually store maps and data, but rather the descriptions and links to those data resources	www.conservationmaps.org/Portal/ptk
Global Change Master Directory	Directory holds more than 22,000 data set descriptions	http://gcmd.nasa.gov/Aboutus/index.html
UN Atlas of the Oceans	Entry point to maps, statistics and online databases	www.oceansatlas.org
TerraLook	Images include recent high-resolution ASTER images, and Landsat images from three historical periods going back to the early '70s	http://terralook.cr.usgs.gov
General data sources useful to define ecosystems		
Global Administrative Unit Layers (GAUL)	Provides reliable spatial information on administrative units for all countries in the world providing a contribution to the standardization of the spatial dataset representing administrative units. - Vector format	www.foodsecinfoaction.org/News/news_06_06.htm
FAO GeoNetwork: GIS Gateway – Thematic Spatial Databases and Information Systems	Wide range of data sources at different scales and resolutions. Spatial from FAO, other UN Agencies, NGO's and other institutions	www.fao.org/geonetwork/srv/en/metadata.show?id=12691&currTab=simple www.fao.org/geonetwork/srv/en/main.home

* Note: See Glossary in Chapter 11.

TABLE 4.1 Cont.
Summary of Internet sites to acquire global spatial data to define ecosystems and their attributes

Internet site	Technical description and scale	Uniform Resource Locator (URL)
Global Lakes and Wetlands Database	Global scale (1:1 to 1:3 million resolution)	www.worldwildlife.org/science/data/GLWD_Data_Documentation.pdf www.worldwildlife.org/science/data/item1877.html
Watersheds of the World: A Special Collection of River Basin Data	Provides maps of land cover, population density and biodiversity for 154 basins and sub-basins around the world. It further contains 20 global maps portraying relevant water resources issues. As such, it is a crucial reference for anyone working on water management worldwide	http://earthtrends.wri.org/maps_spatial/watersheds/global.php http://multimedia.wri.org/watersheds_2003/index.html
African Water Resources Database	28 thematic data layers drawn from over 25 data sources, resulting in 156 unique datasets. Vector: 1:65 000 to 1:5 000 000 for a range of point, line and polygon features; Grid data 1 to 5 kilometres, with some 15 to 30 meter localized or 500 meter continental imagery.	www.fao.org/docrep/010/a1170e/a1170e00.htm
The Harmonized World Soil Database	30 arc-second raster database with over 15 000 different soil mapping units that combines existing regional and national updates of soil information worldwide	www.fao.org/nr/water/news/soil-db.html
Specialized data sources		
Ecosystems Based Management Tools Network – Data Clearinghouse	EBM tools include data collection and management tools; data processing tools; conceptual modeling tools; modelling and analysis tools; scenario visualization tools; decision support tools; project management tools; stakeholder communication and engagement tools; and monitoring and assessment tools.	www.ebmtools.org/data.html
World Database on Protected Areas	Most comprehensive global spatial dataset on marine and terrestrial protected areas available.	www.wdpa.org www.wdpa.org/AnnualRelease.aspx
Gridded Population of the World, Version 3	Consists of estimates of human population for the years 1990, 1995, and 2000 by grid cells that are approximately 5 km at the equator.	http://sedac.ciesin.columbia.edu/gpw/global.jsp
LandScan World Population Grids	Worldwide population database compiled on approximately 1 km ² latitude/longitude grid	www.ornl.gov/sci/landscan/landscanCommon/landscan_data-avail.html
Natural Disaster Hot Spots – Global Risk Analysis	The data zip archive includes an ASCII text file of the raster data set (*.asc), detailed metadata (*.htm), and projection information (*.prj).	www.ideo.columbia.edu/chrr/research/hotspots/coredata.html

TABLE 4.1 Cont.
Summary of Internet sites to acquire global spatial data to define ecosystems and their attributes

Internet site	Technical description and scale	Uniform Resource Locator (URL)
Data Distribution Centre (DDC) of the Intergovernmental Panel on Climate Change (IPCC)	The DDC provides climate, socio-economic and environmental data, both from the past and also in scenarios projected into the future. GIS Climate Change Scenarios. Currently the datasets can be downloaded in a GIS shapefile format	www.ipcc-data.org www.gisclimatechange.org/faqPage.do
Worldclim	WorldClim is a set of global climate layers (climate grids) with a spatial resolution of one square kilometre. IPPC 3rd Assessment data and future climate projections.	http://www.worldclim.org
Climpag	Climpag contains methodologies, tools for a better understanding and analysis of the effect of the variability of weather and climate on agriculture as well as data and maps. The Global climate grids are provided as comma separated value (csv) in .5°x.5° resolution.	www.worldclim.org/futdown.htm www.fao.org/hr/climpag
Shellfish Reefs at Risk	Global assessment of the distribution and condition of bivalve shellfish reefs that occur in temperate and subtropical estuaries. Presumably, the underlying spatial data could be obtained on request from the Nature Conservancy.	http://conservationline.org/library/shellfish-reefs-at-risk-report/@view.html

4.1 EARTH BROWSERS

Data accessed via stand-alone web browsers can be useful for mapping aquaculture (e.g. for use in FAO's National Aquaculture Sector Overview (NASO) inventory of aquaculture (www.fao.org/fishery/naso/search/en) and as a source of many important layers in an aquaculture management information system such as waterbodies, roads, and population centers, when imported into a GIS (Figure 4.1). Among the most useful of the earth browsers are Google Earth (<http://earth.google.com>), MSN Virtual Earth (<http://virtualearth.msn.com>) and World Wind (<http://nasa-world-wind.en.softonic.com>).

FIGURE 4.1
A variety of aquaculture installations
near Calbuco, Chile from Google Earth



Source: Google Earth (March 2010).

An advantage of some earth browsers is the ability to link directly to images from inside GIS software (e.g. Manifold GIS and Microsoft Virtual Earth) and to capture images as Keyhole Markup Language (KML) files for import to GIS (e.g. Google Earth). Limitations of the earth browsers include imagery or other layers that may be out of date or of unknown date, resolution too coarse to be of use for some kinds of aquaculture applications such as inventories or lack of complete coverage in cloud-prone areas of the world. Nevertheless, they should be the first step in a spatial data search where base maps and specialized layers are lacking.

4.2 PORTALS

Portals are access points, usually to the Internet, that consolidate links to various kinds of specialized information and data.

GISFish

GISFish is a "one stop" site from which to obtain the global experience on GIS, remote sensing and mapping as applied to fisheries and aquaculture (www.fao.org/fishery/gisfish). In October 2009 it was expanded to include marine fisheries. An important observation here is that GISFish itself provides a direct entry route into GIS, remote sensing and mapping for the EAA because of its dual emphasis on aquaculture and spatial analyses. GISFish sets out the issues in fisheries and aquaculture, and

demonstrates the benefits of using GIS, remote sensing and mapping to resolve them. The global experience provided by GISFish of most relevance to the EAA is captured in Issues, Publications, and, Data and Tools. Within GISFish there is a category called “Data Sources” that provides links to more than 40 sources of special interest to aquaculture. An analysis of the relevance of the material in GISFish to the EAA is in Chapter 6.

Ocean Portal

Ocean Portal is a high-level directory dealing very broadly with Ocean Data and Information related Web sites including data center data catalogs and broad categories of ocean data as starting points. (www.iode.org/index.php?Itemid=65&id=24&option=com_content&task=view). Its objective is to help scientists and other ocean experts in locating such data and information. In this regard, it is a portal from which to begin widely searching. For example, a search on the keyword “GIS” within the Ocean Portal revealed 209 links in the Data Resources category.

Conservation GeoPortal

The Conservation GeoPortal is a collaborative effort by and for the conservation community to facilitate the discovery and publishing of GIS data and maps, to support conservation decision-making and education (www.conservationmaps.org/Portal/ptk). It is primarily a data catalog, intended to provide a comprehensive listing of GIS datasets and map services relevant to biodiversity conservation. The Conservation GeoPortal does not actually store maps and data, but rather the descriptions and links to those resources. From an EAA and GIS perspective, this appears to be a new initiative with few actual links so far available.

Global Change Master Directory (GCMD)

The GCMD goal is to enable users to locate and obtain access to Earth science datasets and services relevant to global change and Earth science research. The GCMD database holds more than 25 000 descriptions of Earth science datasets and services covering all aspects of Earth and environmental sciences (<http://gcmd.nasa.gov/Aboutus/index.html>). From the EAA perspective, the GCMD is a portal through which to search for relevant studies and GIS data. The most promising categories include Earth Surface, Oceans, Climate Indicators and Human Dimensions.

UN Atlas of the Oceans

The UN Atlas of the Oceans is an Internet portal providing information relevant to the sustainable development of the oceans (www.oceansatlas.org/index.jsp). It is designed for policy-makers who need to become familiar with ocean issues and for scientists, students and resource managers who need access to databases and approaches to sustainability. The UN Atlas can also provide the ocean industry and stakeholders with pertinent information on a range of ocean matters.

TerraLook

TerraLook is an example of a portal dedicated to satellite remotely sensed imagery (available at <http://asterweb.jpl.nasa.gov/TerraLook.asp>). It includes a free tool and satellite data provided by NASA and the US Geological Survey. TerraLook provides time series of geo-referenced jpeg images plus image processing/GIS software. It is intended to provide easy access to satellite images for users with little or no prior experience, though it also proves useful for experienced users who want a quick image. The data includes global coverage layers of “best available” Landsat images from about 1975, 1990, 2000 (and, soon for 2005). ASTER data are also available, and access is provided to the entire ASTER archive of about 2 million images going back to 2000. While full

ASTER datasets cost about US\$ 100 per scene, these jpeg images are completely free. The open source tool supports basic image processing and GIS functions.

There are several advantages of TerraLook with respect to spatial analyses. One is the global coverage both spatially and temporally, thus allowing for change analysis. Another is that the data are already georeferenced and freely downloadable, but also can be manipulated by the associated tools. Finally, where other spatial data are scarce, TerraLook data could be used to make base maps.

4.3 GENERAL DATA SOURCES

General data sources have been created by various organizations for a broad variety of users, but the data may be used directly or modified for EAA spatial analyses, for example, to define ecosystems.

Global Administrative Unit Layers (GAUL)

Indispensable to any spatial effort in support of the EAA are geodata on administrative boundaries at all levels. Among the general uses are defining responsibilities for regulation of aquaculture. From a GIS viewpoint administrative boundaries provide a geographic basis for analysis of social and economic data in relation to ecosystem boundaries.

The Global Administrative Unit Layers (GAUL) is an initiative implemented by FAO within the EC-FAO Food Security Programme funded by the European Commission. The GAUL aims at compiling and disseminating the most reliable spatial information on administrative units for all the countries in the world, providing a contribution to the standardization of the spatial dataset representing administrative units. The GAUL always maintains global layers with a unified coding system at country, first (e.g. regions) and second administrative levels (e.g. districts). In addition, when the data is available, it provides layers on a country by country basis down to third, fourth and lower administrative levels.

Technical aspects of the GAUL are described by the EC-FAO Food Security Programme (FAO, 2008). The GAUL is updated annually and the most recent data (2009) are available via the FAO GeoNetwork (below) at www.fao.org/geonetwork/srv/en/metadata.show?id=12691&currTab=simple.

The GAUL dataset is for the benefit of the United Nations and other authorized international and national institutions/agencies.

FAO GeoNetwork

The GeoNetwork's purpose is:

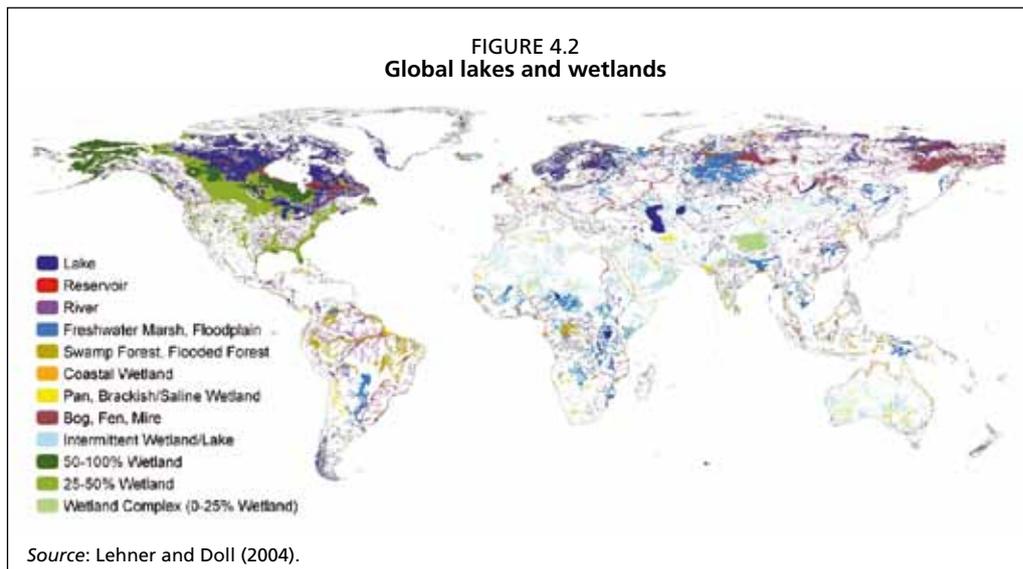
- to improve access to and integrated use of spatial data and information
- to support decision making
- to promote multidisciplinary approaches to sustainable development
- to enhance understanding of the benefits of geographic information

Of special interest are the "Data Collection" section where a number of core products of relevance to the EAA are available for download such as international boundaries, hydrosheds, global population density, and exclusive economic zones; and the "GIS Gateway" to access Thematic Spatial Databases and Information Systems" from different Departments at FAO (www.fao.org/geonetwork/srv/en/main.home).

Global Lakes and Wetlands Database (GLWD)

According to Lehner and Doll (2004), the GLWD lakes and reservoirs database covers a total of approximately 2.7 million km² or 2.0 percent of the global land surface area (except Antarctica and glaciated Greenland), while wetlands are estimated to reach about 8-10 million km², or 6.2–7.6 percent of the Earth's surface (Figure 4.2). An

extrapolation of GLWD data suggests that the total number of global lakes may reach or exceed 1.5 million for lakes ≥ 10 ha, and 15 million for lakes ≥ 1 ha. With these numbers, lakes may cover about 3.2 million km², or 2.4 percent of the total global terrestrial surface.



The GLWD has been created drawing upon a variety of existing maps, data and information. The combination of best available sources for lakes and wetlands on a global scale (1:1 to 1:3 million resolution), and the application of GIS functionality enabled the generation of a database which focuses in three coordinated levels on (1) large lakes and reservoirs, (2) smaller waterbodies, and (3) wetlands.

Level 1 (GLWD-1) comprises the shoreline polygons of the 3 067 largest lakes (area ≥ 50 km²) and 654 largest reservoirs (storage capacity ≥ 0.5 km³) worldwide, and includes extensive attribute data.

Level 2 (GLWD-2) comprises the shoreline polygons of permanent open waterbodies with a surface area ≥ 0.1 km² excluding the waterbodies contained in GLWD-1.

The approx. 250 000 polygons of GLWD-2 are attributed as lakes, reservoirs and rivers. Level 3 (GLWD-3) comprises lakes, reservoirs, rivers and different wetland types in the form of a global raster map at about 1 km resolution at the equator. GLWD-2 and GLWD-3 do not provide detailed descriptive attributes such as names or volumes.

The importance of the GLWD to the EAA is obvious: The waterbodies it contains represent the areas where aquaculture is already developed, or in which aquaculture has varying potential for development in inland waterbodies having surface areas greater than 100 ha. In other words, the GLWD provides a spatial framework in which to base a global inventory of aquaculture and on which to base comparative estimates of aquaculture potential at a global scale.

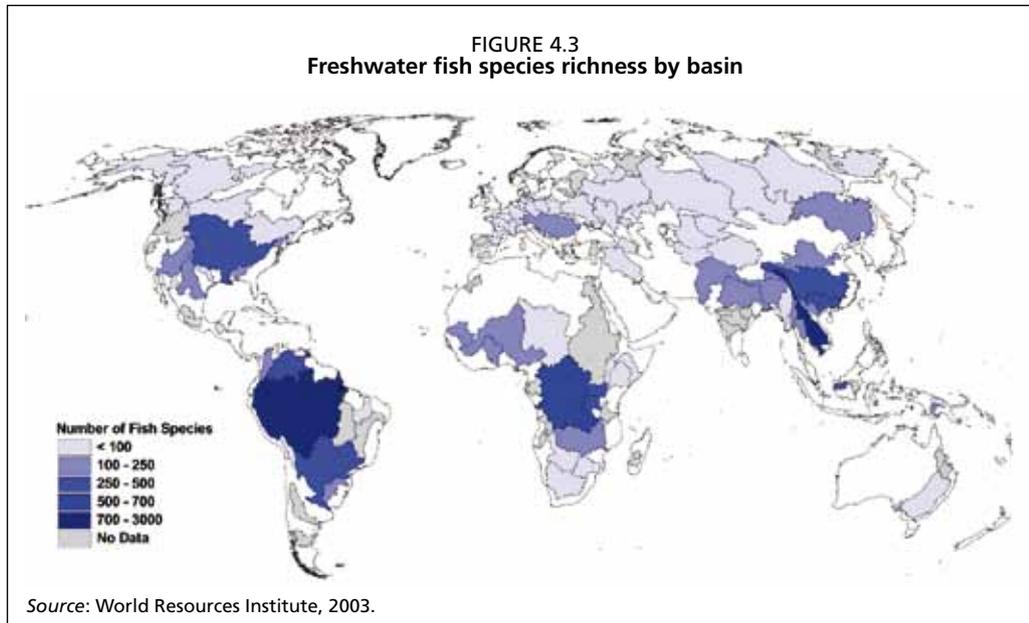
For GIS in support of the EAA, the GLWD is available for download as three separate ArcView layers (two polygon shapefiles and one grid; www.worldwildlife.org/science/data/item1877.html).

An example of the application of the GLWD data to a practical problem is provided in Chapter 5. Here freshwater surface area estimates by country are used to estimate the intensity of use of freshwaters for aquaculture.

Watersheds of the world: A special collection of river basin data

Watersheds of the World provides maps of land cover, population density and biodiversity for 154 river basins and sub-basins around the world (<http://earthtrends>).

wri.org/maps_spatial/watersheds/global.php). It lists indicators and variables for each of these basins and, where appropriate, provides links and references to relevant information. It further contains 20 global maps portraying relevant water resources issues or related resources (e.g. freshwater fishes, Figure 4.3). As such, it is a valuable reference for water management worldwide.



List of twenty downloadable global maps relating to Watersheds of the World

Primary Watersheds Map

Freshwater Fish Species Richness by Basin

Endemic Freshwater Fish Species by Basin

Endemic Bird Areas by Basin

Wetland Area by Basin

Cropland Area by Basin

Grassland, Savanna and Shrubland Area by Basin

Forest Cover by Basin

Remaining Original Forest Cover by Basin

Dryland Area by Basin

Urban and Industrial Area by Basin

Protected Area by Basin

Average Population Density by Basin

Degree of River Fragmentation and Flow Regulation by Basin

Annual Renewable Water Supply per Person by Basin for 1995 and Projections for 2025

Environmental Water Scarcity Index by Basin

Large Dams under Construction by Basin

Ramsar Sites by Basin

Virtual Water Flows

Selected Basins with IUCN and IWMI Projects

This map collection is designed to provide easy access to essential data and information at the basin level to support and promote the integrated management of water resources, and to increase the participation of stakeholders in the decision-making processes. Its ultimate goal is to promote resource management that allows for socially equitable economic development, and the sustainability of healthy ecosystems and their dependent

species. Clearly, the objectives of this data collection parallel those of the EAA and many of the maps could be considered as constraints or as factors aiding the development and management of aquaculture. Additionally, many of the maps are indicative of the environmental issues pertaining at basin level. Technical notes and sources on the maps are available for download (http://earthtrends.wri.org/maps_spatial/watersheds/notes.php) as are the maps themselves (www.iucn.org/about/work/programmes/water/wp_resources/wp_resources_eatlas/wp_resources_eatlas_download.cfm), but no download site for GIS data is provided. The GIS data can be obtained as a CD-ROM with a request made to the same Uniform Resource Locator (URL).

FAO African Water Resource Database (AWRD)

The African Water Resource Database (AWRD) data archive possibly represents the most comprehensive archive of water management and base resource mapping data ever compiled for Africa and that is available in the public domain (Jenness *et al.*, 2007a;b). The AWRD is a set of data and custom-designed tools, combined in a GIS analytical framework, aimed at facilitating responsible inland aquatic resource management with a specific focus on inland fisheries and aquaculture. The AWRD data archive includes an extensive collection of datasets covering the African continent including 28 thematic data layers drawn from over 25 data sources, resulting in 156 unique datasets. The core data layers include: various depictions of surface waterbodies; multiple watershed models; aquatic species; rivers; political boundaries; population density; soils; satellite imagery; and many other physiographic and climatological data types. The AWRD archival data have been specifically formatted to allow their direct utilization within any GIS software package conforming to Open-GIS standards.

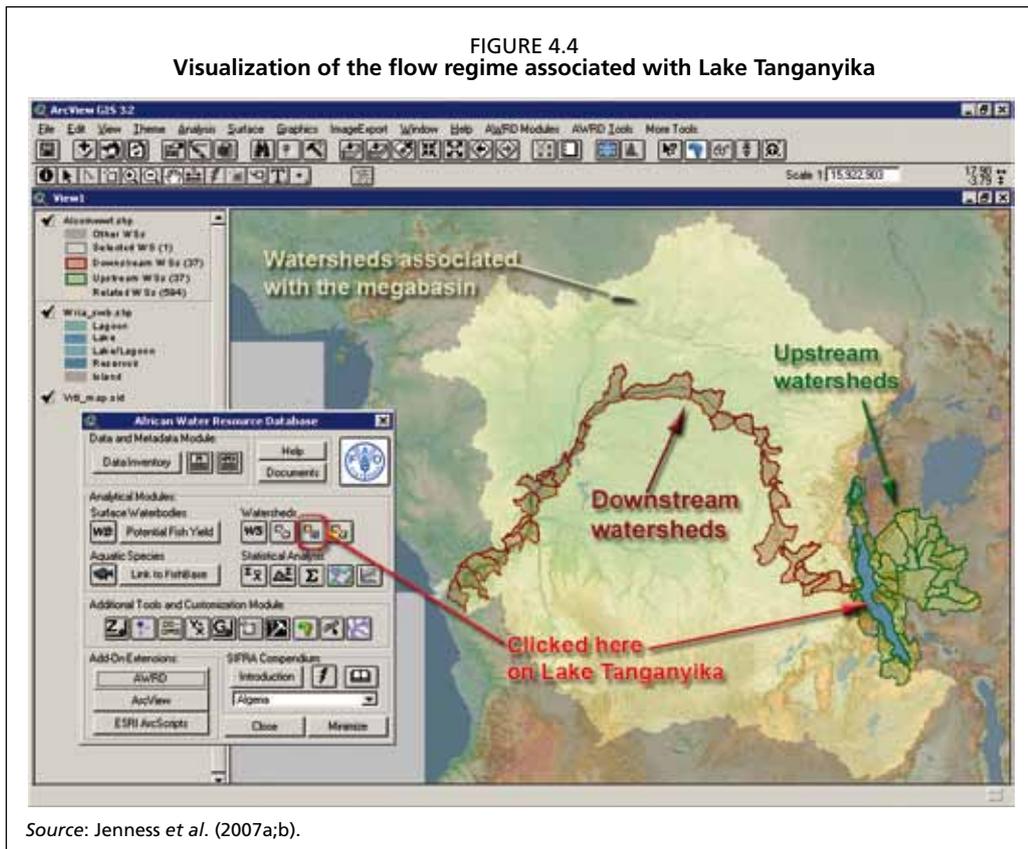
To display and analyse the AWRD archive, the AWRD also contains a large assortment of new custom applications and tools programmed to run under version 3 of the ArcView GIS software (ArcView 3.x). There are six analytical modules within the AWRD interface: 1) the Data and Metadata Module; 2) the Surface Waterbodies Module; 3) the Watershed Module; 4) the Aquatic Species Module; 5) the Statistical Analysis Module; and lastly, 6) the Additional Tools and Customization Module. Many of these tools come with simple and advanced options and allow the user to perform analyses on their own data.

The case studies presented in the AWRD publications (Jenness *et al.*, 2007a;b) illustrate how the AWRD archive and tools can be used to address key inland aquatic resource management issues such as the status of fishery resources and transboundary movements of aquatic species.

The Watersheds Module and related analytical tools represent perhaps the most comprehensive and intensive programming effort undertaken within the AWRD interface. This module offers a wide variety of tools specifically designed to analyse and visualize watersheds. The identification of “upstream watersheds” using the AWRD Watershed Module enables the spatial delineation of factors that directly or indirectly affect fishery potential. This tool can be of great value for assessing pollution from runoff of “upstream” watersheds into aquaculture ponds or residuals from aquaculture ponds into “downstream” watersheds. Analysis of invasive and introduced aquatic species is another area where this tool has great value because such introductions can have impacts both upstream and downstream within a hydrological system. Figure 4.4 shows upstream and downstream watersheds for Lake Tanganyika.

From an EAA perspective, the AWRD is a ready-made data package and analytical tool kit to define ecosystems and resolve issues in the context of freshwater aquaculture. Additionally, it is an already constituted tool for building spatial analytical capacities in support of the EAA.

FIGURE 4.4
Visualization of the flow regime associated with Lake Tanganyika



Source: Jenness et al. (2007a,b).

The Harmonized World Soil Database

The Harmonized World Soil Database (version 1.1, 2009) is a 30 arc-second raster database with over 15 000 different soil mapping units that combines existing regional and national updates of soil information worldwide (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009). The resulting raster database consists of 21 600 rows and 43 200 columns, which are linked to harmonized soil property data. The use of a standardized structure allows for the linkage of the attribute data with the raster map to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry).

4.4 SPECIALIZED DATA SOURCES

Specialized data sources are those that can be used to create GIS layers within spatially defined ecosystems. One example of specialized data sources pertaining to GIS, remote sensing and mapping for marine aquaculture development and management at Economic Exclusive Zone (EEZ) scales are those listed by Kapetsky and Aguilar (2007). However, the data covered in this section are mainly available globally.

Ecosystems Based Management Tools Network – Data Clearinghouse

A portal with mainly data of interest to the United States of America and Canada (www.ebmttools.org/data.html). The tools, all of which are applicable to some extent globally, are covered in some detail in Chapter 7.

World Database on Protected Areas

The World Database on Protected Areas (WDPA) is compiled from multiple sources and is the most comprehensive global dataset on marine and terrestrial protected areas available (www.wdpa.org). It is a joint venture of UNEP and IUCN, produced

by UNEP-WCMC and the IUCN World Commission on Protected Areas (IUCN-WCPA) in association with governments and collaborating NGOs. The WDPA stores key information about protected areas such as name, designation or convention, total area (including marine area), date of establishment, legal status and IUCN Protected Areas Management Category. It also stores the spatial boundary and/or location (where available) for each protected area in a GIS. The online WDPA allows users to search by protected area name, country, and international programme or convention (Figure 4.5).

FIGURE 4.5
Interactive map showing query function, a part of the World Database
on Protected Areas



Source: UNEP-WCMC, 2009.

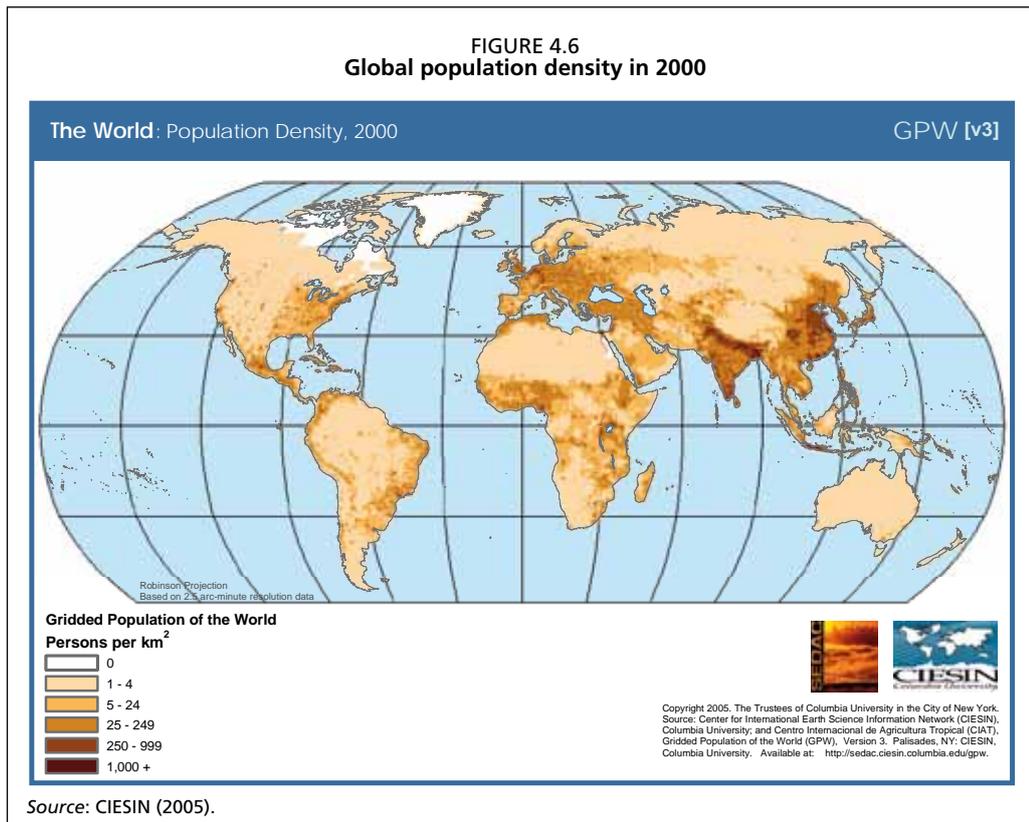
From an EAA perspective the WDPA provides indications of no-go areas with regard to aquaculture development. From a GIS viewpoint, spatial data on protected areas can be downloaded and can serve as a constraint layer on estimates of aquaculture potential. The WDPA is in the course of being redesigned into a web-enabled spatial database platform with custom data editing, downloading and analysis facilities. The data are updated annually and the most recent data set (2009) is available at www.wdpa.org/AnnualRelease.aspx

Gridded Population of the World, Version 3

The Gridded Population of the World (GPWv3) (CIESIN, 2005) consists of estimates of human population for the years 1990, 1995, and 2000 by grid cells that are approximately 5 km at the equator, and some associated datasets dated circa 2000 (Figure 4.6). The data products include population count grids (raw counts), population density grids (per square km), land area grids (actual area net of ice and water), mean administrative unit area grids, centroids, a national identifier grid, national boundaries, and coastlines. These products vary in GIS-compatible data formats and geographic extents (global, continent [Antarctica not included], and country levels).

A proportional allocation gridding algorithm, utilizing more than 300 000 national and sub-national administrative units, is used to assign population values to grid cells.

FIGURE 4.6
Global population density in 2000



LandScan Worldwide Population Grids

The LandScan™ Dataset comprises a worldwide population database compiled on an approximately 1 km² latitude/longitude grid. Thus, the LandScan data are at a higher resolution than the Gridded Population of the World data described above and for that reason more applicable to national and sub-national levels for the EAA. For the LandScan datasets, census counts (at sub-national level) were apportioned to each grid cell based on likelihood coefficients, which are based on proximity to roads, slope, land cover, nighttime lights, and other information. The LandScan Dataset files are available via the internet in ESRI grid format by continent and for the world, and in ESRI raster binary format for the world.

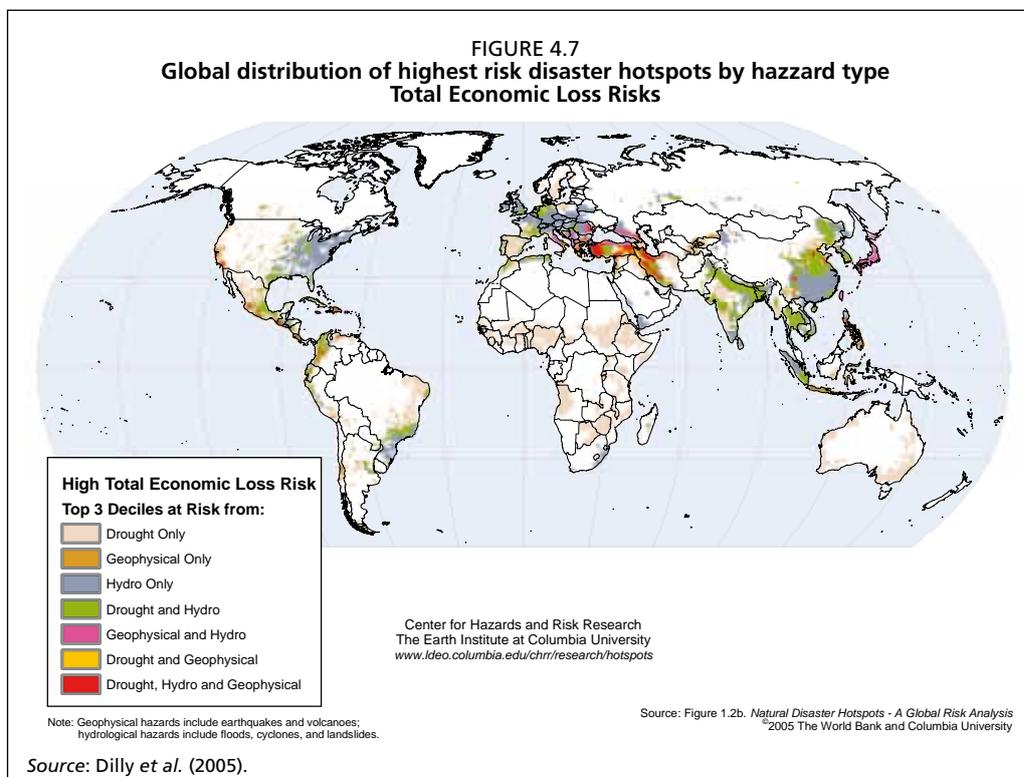
LandScan datasets are released annually, with each new release superseding the previous. LandScan dataset licenses are available free of charge for U.S. Federal Government, for United Nations Humanitarian efforts, and educational research use.

Natural Disaster Hotspots; Global Risk Analysis

This is a set of global geospatial data on six major natural hazards and associated risks of mortality and economic loss provided by the Center for Hazards and Risk Research at Columbia University, United States of America. (Dilly *et al.* (2005) have assessed the global risks of two disaster-related outcomes: mortality and economic losses. They estimated risk levels by combining hazard exposure with historical vulnerability for two indicators of elements at risk—gridded population and Gross Domestic Product (GDP) per unit area—for the six major natural hazards of: earthquakes, volcanoes, landslides, floods, drought, and cyclones. By calculating relative risks for each grid cell rather than for countries as a whole, they have been able to estimate risk levels at sub-national scales.

These datasets are especially valuable for the EAA because risks to aquaculture can be inferred both as environmental impacts and in economic terms on grid cells of approximately 5 km width at the equator (Figure 4.7). For GIS in support of the EAA, these data provide additional layers with which to assess natural environmental impacts

that are readily available for download as gridded datasets (www.ldeo.columbia.edu/chrr/research/hotspots/coredata.html) and that can be previewed as maps ([Figure 4.6](http://www.ldeo.columbia.edu/chrr/research/hotspots/maps.html)) (www.ldeo.columbia.edu/chrr/research/hotspots/maps.html).



The Data Distribution Centre (DDC) of the Intergovernmental Panel on Climate Change (IPCC)

The DDC offers access to baseline and scenario data for representing the evolution of climatic, socio-economic, and other environmental conditions. (www.ipcc-data.org/). The data are provided by co-operating modelling and analysis centres. The DDC also provides technical guidelines on the selection and use of different types of data and scenarios in research and assessment. The DDC is designed primarily for climate change researchers, but materials available from the site may also be of interest to educators, governmental and non-governmental organisations, and the general public.

Analysis of climate impacts, adaptation, and vulnerability involves a set of activities designed to identify the effects of climate variability and change, to evaluate and communicate uncertainties, and to examine possible adaptive responses. Methods for analysis of impacts, adaptation, and vulnerability have evolved over the past decade, and a large array of methods and tools are now available for use in specific sectors, at different scales of analysis, and in contrasting environmental and socio-economic contexts. Most assessments of the impacts of future climate change are based on the results of impact models that rely on quantitative climatic and non-climatic data and scenarios. The identification, selection, and application of baseline and scenario data are crucial steps in the analytical process. The great diversity of the data required and the need to maintain consistency between different scenario elements can pose substantial challenges to researchers. The IPCC DDC seeks to provide access to such data and scenarios and to offer guidance on their application.

Several other centers provide global climate change model outputs among which is the US National Center for Climate Research that makes available outputs in GIS formats. This center uses the Community Climate System Model (CCSM). The CCSM is a coupled climate model for simulating the earth's climate system.

Composed of four separate models simultaneously simulating the earth's atmosphere, ocean, land surface and sea-ice, and one central coupler component, the CCSM allows researchers to conduct fundamental research into the earth's past, present and future climate states. A GIS-oriented Frequently Asked Questions (FAQ) is available (www.gisclimatechange.org/faqPage.do) and data are available for download after initial registration and login.

WORLDCLIM

WorldClim is a set of global climate layers (climate grids) with a spatial resolution of one square kilometre. The climate elements considered are monthly precipitation and mean, minimum, and maximum temperature. The data can be used for mapping and spatial modeling in a GIS or other computer program. The data are described by Hijmans *et al.* (2005). The attraction of these data for spatial analyses in support of the EAA is their high resolution for such tasks as estimating changes in future temperature-based growth rates of cultured organisms and effects of water availability on inland aquaculture. Download possibilities include IPCC 3rd Assessment data (www.worldclim.org/futdown.htm). Future climate projections, calibrated and statistically downscaled using the WorldClim data for 'current' conditions and projected future climate by climate model (e.g. CCCMA), emission scenario (e.g. the a2a model emission scenario), year (e.g. 2050) and spatial resolution (e.g. approximately 1 km at the equator) are available at www.worldclim.org/futdown.htm. All data are in generic grid format.

Climpag

Climpag is aimed at bringing together the various aspects and interactions between weather, climate and agriculture in the general context of food security. As per FAO basic texts, the word agriculture includes crops and grasslands, livestock husbandry, forestry and fisheries.

Climpag contains methodologies, tools for a better understanding and analysis of the effect of the variability of weather and climate on agriculture as well as data and maps (www.fao.org/nr/climpag).

Perhaps of greatest interest are:

- Rainfall maps. These maps indicate respectively: the monthly total rainfall amount (in millimeters), and the monthly rainfall percentage of normals (in percentage).
- Global climate grids. These grids are based on Koeppen climatologies and the climatic net primary production maps of FAO are based on different periods and precipitation datasets. All data are provided as comma separated value (csv) in .5°x.5° resolution. Furthermore some derived information like temperature of the coldest and warmest months, Martonnes aridity index and Gorczynskis continentality index are provided (www.fao.org/nr/climpag/globgrids/KC_commondata_en.asp).
- WebLocClim. This Local Monthly Climate Estimator was developed to provide an estimate of climatic conditions at locations for which no observations are available. To achieve this, the programme uses the 28 800 stations of FAOCLIM 2.0, the global agroclimatic database maintained by the Agrometeorology Group of FAO (www.fao.org/nr/climpag/locclim/locclim_en.asp).

Climpag and WorldClim are different so they could be considered as being complementary, Climpag is a portal on climate (variability) and agriculture with all methodologies, data, tools, and examples related to these whilst WorldClim provides climate datasets. Another big difference is that in Climpag you can download real-time data (monthly at country level) and maps (e.g. Rainfall for Africa).

Shellfish reefs at risk

This is the first global assessment of the distribution and condition of bivalve shellfish reefs that occur in temperate and subtropical estuaries (Beck *et al.*, 2009). The assessment is focused primarily on biogenic reefs formed by oysters within their native ranges, but also includes observations about mussels that form beds and provide other ecosystem services. Quantitative and qualitative data were compiled about these reef forming species from published literature as well as from expert surveys, direct observations and from derived condition estimates for oyster reefs in 144 estuaries and 40 ecoregions around the world .

There are several implications for the EAA from these data, one of which would be reef areas to avoid for aquaculture development, but also areas near which to develop reef re-stocking shellfish culture installations. Presumably, the underlying spatial data could be obtained on request from the Nature Conservancy (<http://conserveonline.org>).

4.5 SUMMARY AND CONCLUSIONS

The purpose of this chapter was to provide an overview of sources that can satisfy spatial data needs for the implementation of the EAA. The list of sources is not exhaustive and most sources pertain to global and national level spatial data. Nevertheless, these sources are indicative of the kinds of data that, at higher resolutions, would be required to support the EAA at levels below the national level. Data sources were assembled in four categories (1) Earth browsers, (2) Portals (3) Generalized data, and (4) Specialized data. Specifically, spatial data are required to define ecosystems where no such definitions already exists at a useful scale, or to enhance already existing ecosystem data with data specific to the needs of aquaculture. The fundamental tasks that rely on spatial data are to estimate the potential impact of aquaculture on the environment and ecosystems and to estimate the impact on aquaculture of natural and man-induced changes to the environment in an ecosystems specific context. Real time management of aquaculture operations is another task relying in part on remote sensing data.

It is fair to conclude that there are huge quantities of spatial data freely available that could be important for use in spatial analyses in support of the EAA. Many of these datasets could be useful at national and sub-national levels. But like the ecoregions and ecosystems already defined (Chapter 3), considerable effort will be required to determine quality and applicability relative to resolution, and spatial and temporal coverage at national and sub-national levels. One of the early and essential steps of implementing spatial analyses in support of the EAA at national levels will be to inventory and evaluate relevant spatial data at a range of resolutions.

5. The geography of aquaculture in relation to environments and potential impacts

5.1 INTRODUCTION, OBJECTIVES AND OVERVIEW

According to FAO (www.fao.org/fishery/topic/14894/en) major environmental impacts of aquaculture have been associated mainly with high-input high-output intensive production systems (e.g. culture of salmonids in raceways and cages) the effects of which included discharge of suspended solids, nutrient and organic enrichment of recipient waters resulting in build-up of anoxic sediments, changes in benthic communities (alteration of seabed fauna and flora communities) and the eutrophication of lakes. Large-scale shrimp culture has resulted in physical degradation of coastal habitats, for example, through conversion of mangrove forests and destruction of wetlands, salinization of agricultural and drinking water supplies, and land subsidence due to groundwater abstraction. However, misapplication of husbandry and disease management chemicals, collection of seed from the wild (bycatch of non-target species occurring in the collection of wild seed) and use of fishery resources as feed inputs, are also causing concern. Mollusc culture has been held responsible for local anoxia of bottom sediments and increased siltation. Additionally, the environmental costs of aquaculture have been examined by Bartley *et al.* (2007) and a regional evaluation of environmental impact assessment and monitoring in aquaculture covering Africa, Asia-Pacific, Europe and North America, and Latin America) was made by FAO (2009). But to date there has been no globally comprehensive and comparable assessment of aquaculture's impact on the environment nor of environmental impacts on aquaculture.

Central to an ecosystem approach to the management of aquaculture is the need to optimize benefits while minimizing impacts. With regard to the environmental impacts of aquaculture, it is necessary to establish their magnitude and locations in order to plan for the appropriate ameliorative interventions. Specifically, for this review, it is essential to ascertain in which countries and in which environments spatial planning tools could contribute most to the EAA and to design the appropriate training and technical assistance. For the same reason it is necessary to establish the effects of the environment on aquaculture. Accordingly, the objectives of this chapter are to:

- estimate the relative intensity of use that aquaculture makes of the freshwater, brackishwater and marine environments at the country level, and from a global perspective, in a comprehensive and comparative manner; and
- estimate the relative intensity of the impact of the environment on aquaculture, also at a country and global level in a comprehensive and comparative manner.

As an overview of the chapter, the aquaculture production data used from FAO FishStat Plus (FAO, 2007) and the base year is 2005. Although these data are not the most recent, they are complete for all countries with significant aquaculture production and the 2005 production data do not differ significantly from the 2007 country level production data as shown by a correlation coefficient of 0.99. The environmental/aquaculture impact analyses are based on the assumption that the quantity of aquaculture production is directly related to the potential impact of aquaculture on the environment and by inference on ecosystems. As detailed below, this assumption is strengthened by relating

production to specific environments and by considering production in each environment in terms of its expanse. The analysis of aquaculture's impacts is comprehensive because it includes all countries with aquaculture production and it is comparative because all countries have been treated in the same way by using a common data base.

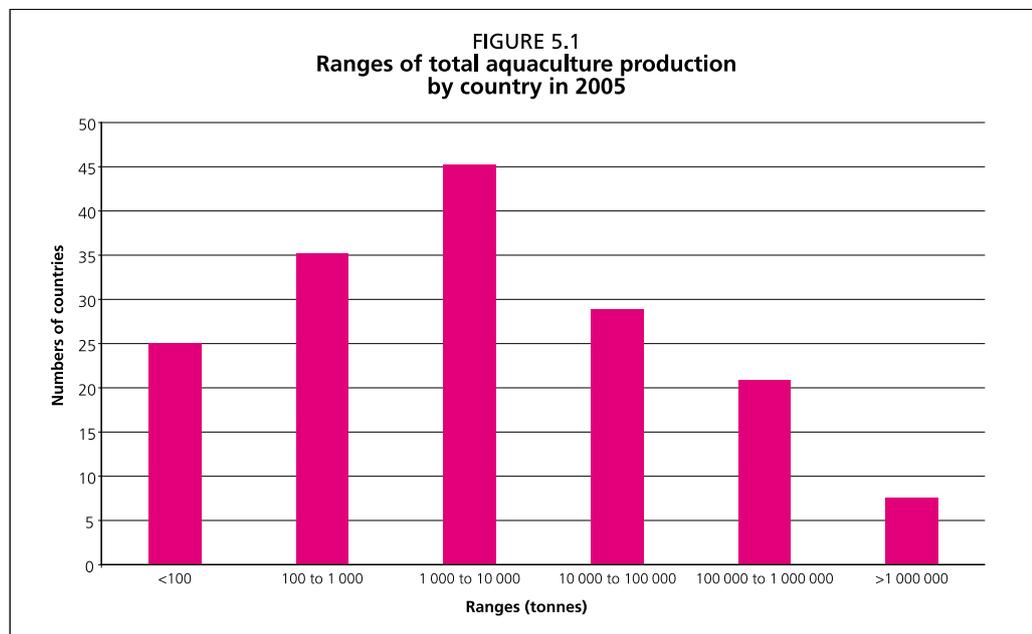
In order to provide a point of comparison, the country level overall aquaculture production and by main environments (brackishwater, freshwater and marine)¹ is established. Then, the relative intensity of use of the environments by aquaculture is estimated by expressing brackishwater and mariculture production as a function of the shoreline length of each country. The intensity of use of the freshwater environment is estimated by expressing freshwater aquaculture production as a function of total freshwater surface area in each country. Countries which make relatively intensive use of one, two and three environments for aquaculture are identified. A different approach is taken to estimate the potential environmental impacts on aquaculture, The Environmental Performance Index (EPI) is employed. The intensity of environmental impacts on aquaculture is estimated by placing a heavy weighting on a country's ecosystem vitality as measured by its EPI index. Finally, the countries in which the use of the environments for aquaculture is most intensive are compared with the countries in which the environmental impacts on aquaculture are most heavy.

5.2 IMPORTANCE OF AQUACULTURE BY TOTAL PRODUCTION

In 2005 there were 163 countries listed by FAO FishStat Plus (FAO, 2007) with at least one tonne of aquaculture production. Total production was nearly 63 million tonnes.

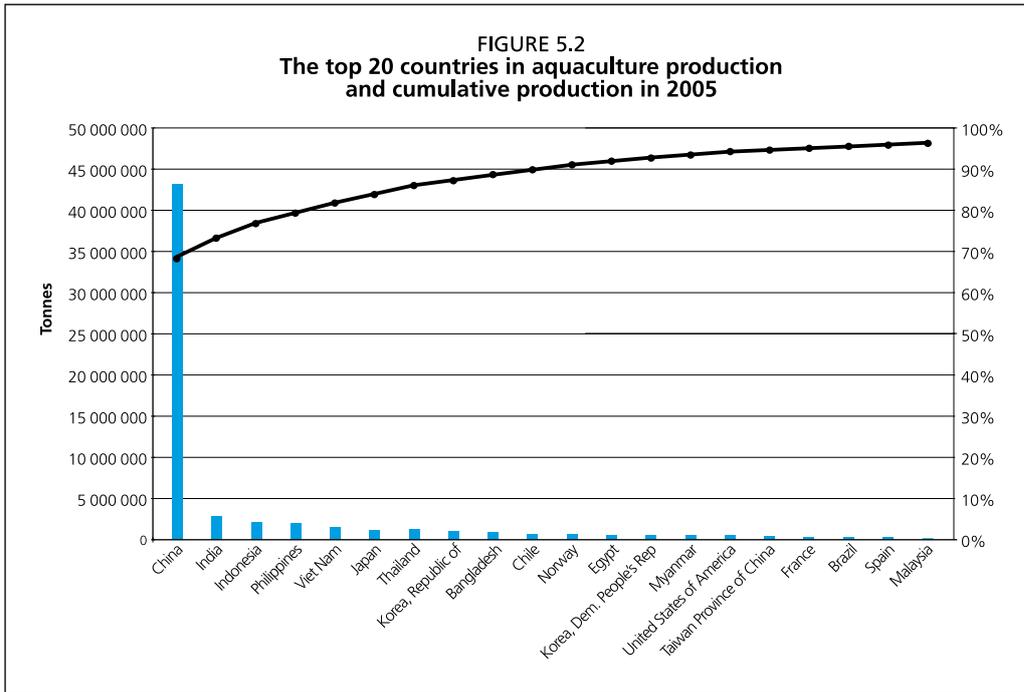
Most countries produce from 1 000 to 10 000 tonnes and the majority of countries are relatively small producers (Figure 5.1).

World aquaculture is dominated by China with 69 percent of the global total and by a



relatively small number of additional countries. Production of the top 20 countries together accounts for 96 percent of the global total leaving 143 countries to produce the remaining 4 percent (Figure 5.2). Given this situation, on the face of it, it would seem that with the potential impact of aquaculture equated to quantity of annual production, only a relatively small number of countries are impacting the environment through aquaculture.

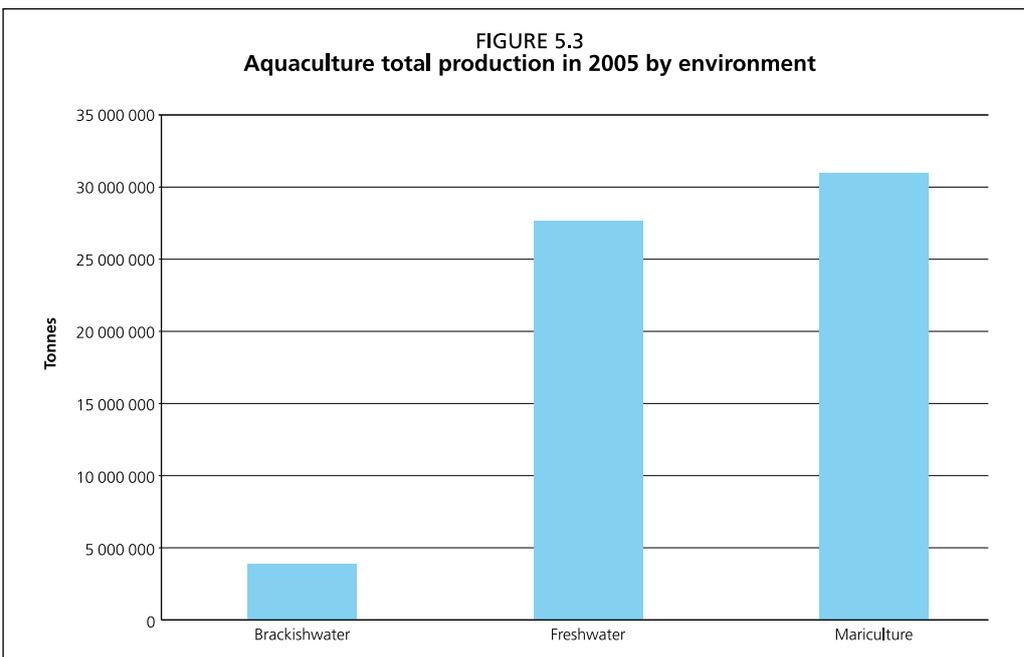
¹ 1 Main environments classified according to FAO FishStat Plus (FAO, 2007).



5.3 IMPORTANCE OF AQUACULTURE BY ENVIRONMENT

Considered by environment, mariculture production from a total of 87 countries dominates aquaculture with 50 percent of the total produced (Figure 5.3). Nearly all of mariculture is located in sheltered areas in close proximity to the coastline. Therefore, it follows that coastal marine ecosystems, including bays and the outer portions of estuaries, are much more influenced environmentally by mariculture than is the open ocean.

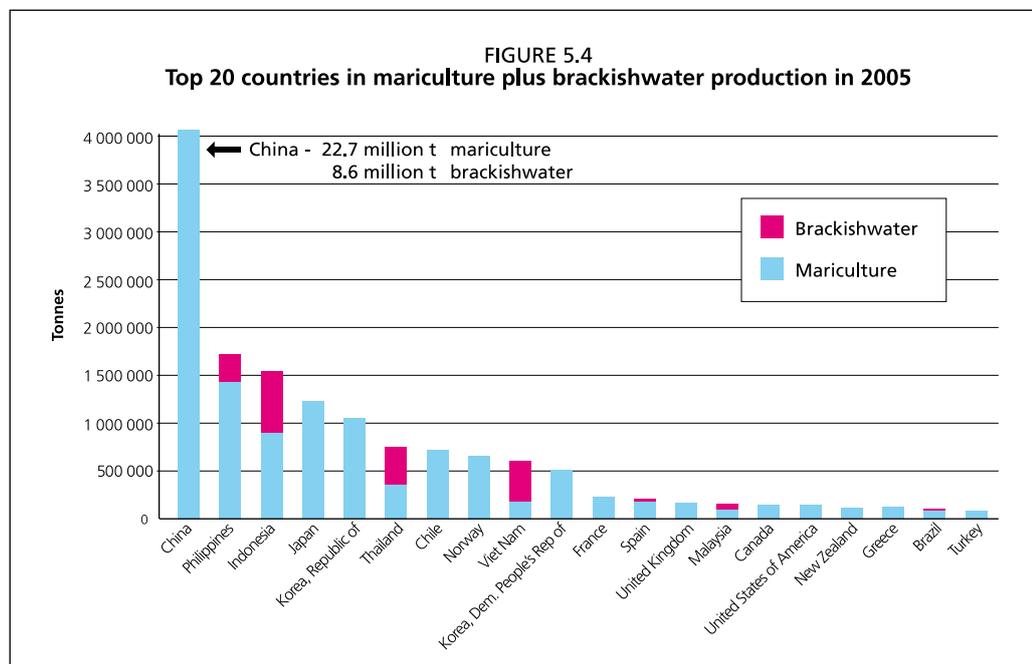
Brackishwater aquaculture from a total of 57 countries accounts for only 6 percent of total production. Brackishwater aquaculture is practiced within the coastal shoreline in estuaries, fjords, coastal lagoons, and associated systems such as mangroves and marshes. Thus, when considered globally, the impact of brackishwater aquaculture on the environment is much less than that of mariculture because of its much lower production. Freshwater aquaculture accounts for 44 percent of the total and is dealt with separately in section 5.6.



5.4 IMPACTS OF AQUACULTURE IN MARINE AND BRACKISHWATER ENVIRONMENTS BASED ON ANNUAL PRODUCTION

Of the 87 countries with mariculture production and of the 57 countries with brackishwater production, there are 34 countries with both mariculture production and brackishwater production. Therefore, aquaculture in these countries impacts both the near shore marine environment and the brackishwater environment. There are 53 countries with mariculture production, but with no brackishwater production. Aquaculture in these countries presumably impacts only the near shore marine environment. Conversely, there are 23 countries with brackishwater production, but no mariculture production. Aquaculture in these countries impacts only the brackishwater environment. In total, aquaculture in 110 countries impacts the near shore marine environment, the brackishwater environment, or both.

In production terms, about 56 percent of total aquaculture output from the 110 countries is generated at or near the coastline (50 percent marine + 6 percent brackishwater). Thus, on the face of it, coastal ecosystems, in both brackishwater and marine environments, are relatively heavily used by aquaculture among countries which are the most productive in these environments. In this regard, China produced nearly equal amounts in mariculture and brackishwater culture, 22.7 and 23.5 million tonnes, respectively, equivalent to 67 percent of the total world mariculture and brackishwater production together. An additional 19 countries, together with China, account for 97 percent of the global production (Figure 5.4). Not all of these countries declare both marine and brackishwater production. Among the top 20 countries, seven do not report brackishwater production and two report brackishwater production, but no marine production (Figure 5.4). This situation, in which marine and brackishwater production are concentrated in coastal areas, gives ample reason for considering mariculture together with brackishwater culture in terms of environmental impacts, and eventually in terms of the ecosystems in which they reside.

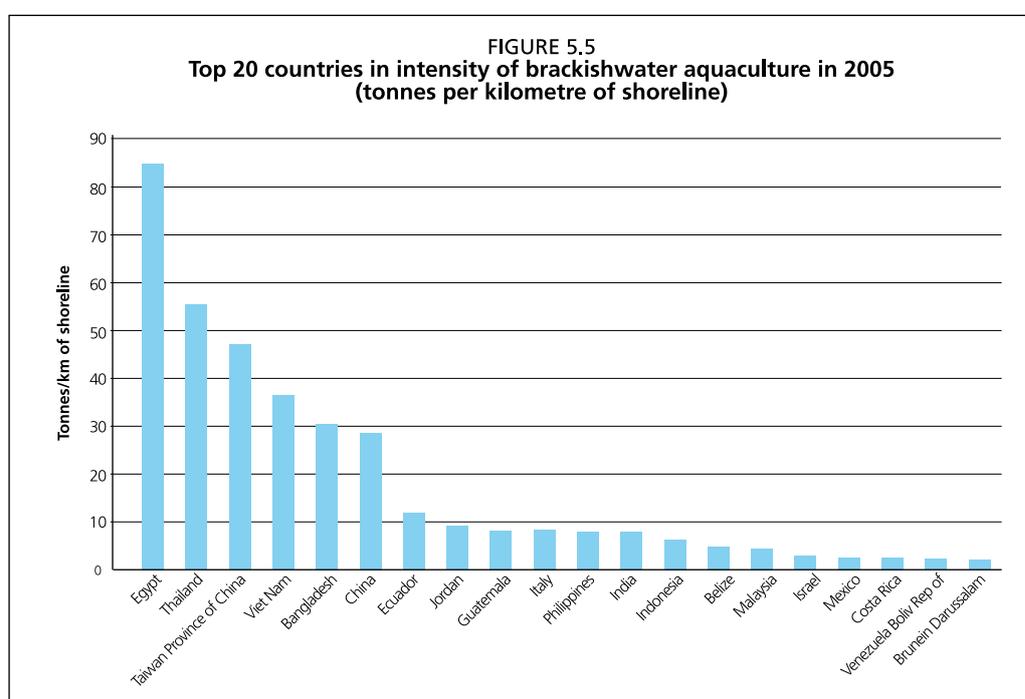


5.5 IMPACTS OF AQUACULTURE ON MARINE AND BRACKISHWATER ENVIRONMENTS BASED ON ANNUAL PRODUCTION AND LENGTH OF SHORELINE

This situation, that both mariculture and brackishwater culture affect the coastal environment, the former near shore and the latter within the shoreline, provides a new way to assess the relative spatial impact of aquaculture on coastal ecosystems at a country level. The basic assumption that allows this new approach is that both mariculture and brackishwater aquaculture are proximate to the coast and therefore

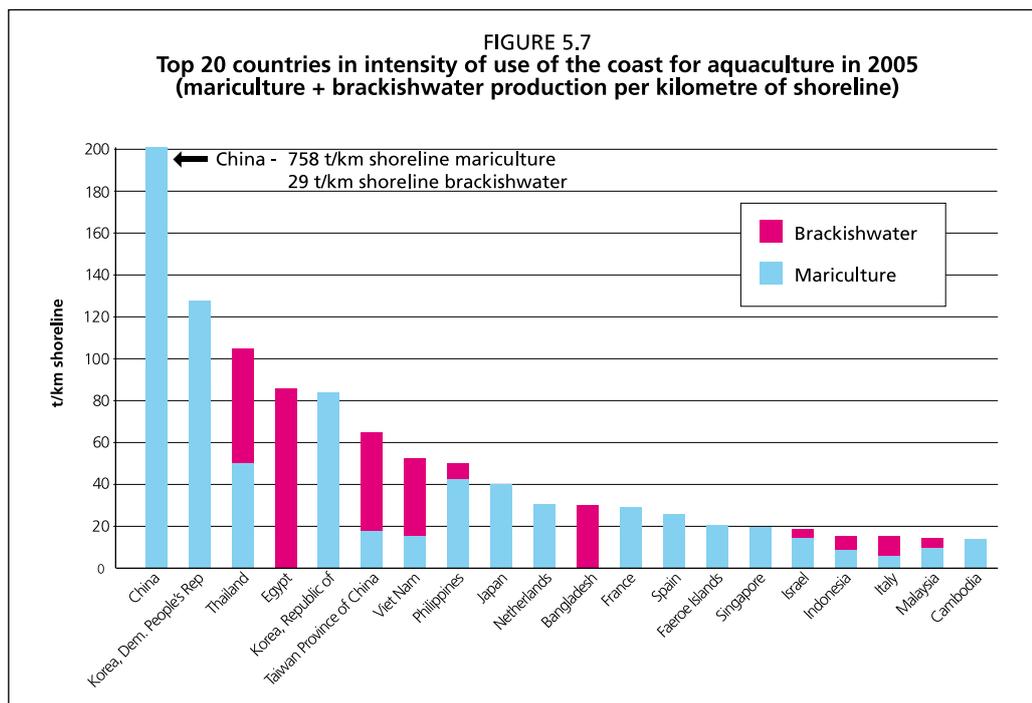
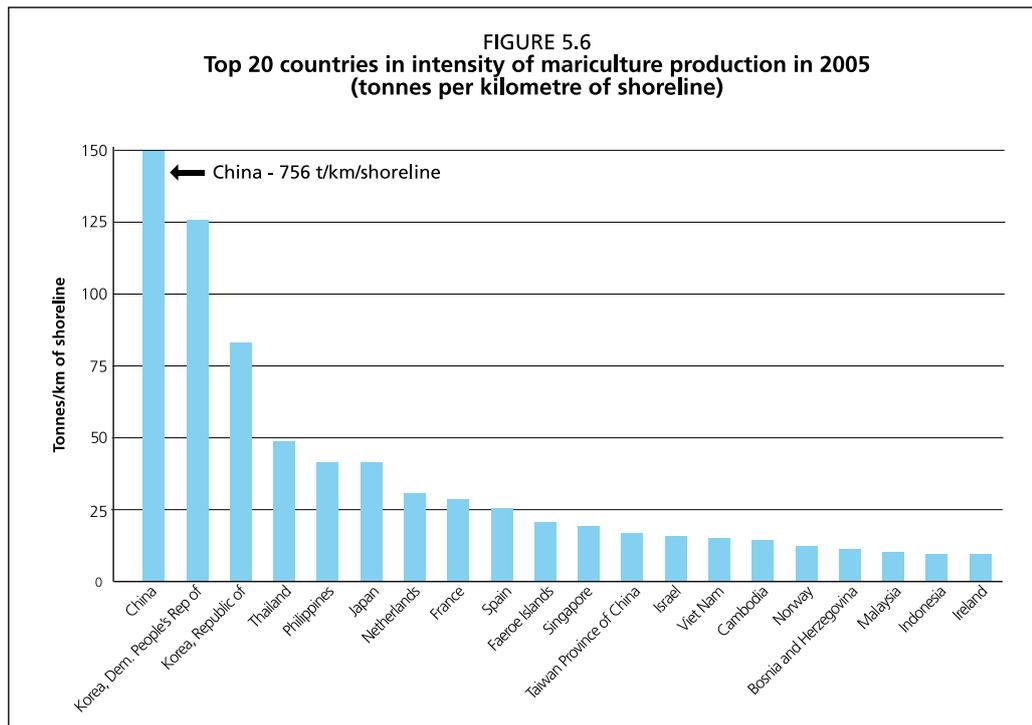
their main impacts are on coastal ecosystems.

The approach made here is to introduce shoreline length as a spatial parameter. Shoreline length was obtained from the World Fact Book (www.cia.gov/library/publications/the-world-factbook/fields/2060.html?countryName=World&countryCode=xx®ionCode=oc&#xx) The consideration of aquaculture production relative to shoreline length provides an indication of the relative intensity of use made of coastal ecosystems by aquaculture as measured in terms of tonnes per kilometre of shoreline. Relative intensity of use can then be interpreted as a measure of the environmental impact of aquaculture. An important benefit of this approach is that the results are both comprehensive and comparative globally among all aquaculture producing countries. Of the 57 countries reporting brackishwater aquaculture in 2005, there are 24 that have an intensity of use of the coastal environment of at least 1 tonne per kilometre of shoreline. Of those, there are seven countries that range from 12 to 85 tonnes per kilometre of shoreline. Egypt ranks highest and other important countries among the top 20 are Thailand and the Taiwan Province of China (Figure 5.5).



It is noteworthy that China ranks sixth when considered in this way and conversely, other countries that are relatively unimportant in overall production gain in importance (e.g. Jordan, Belize).

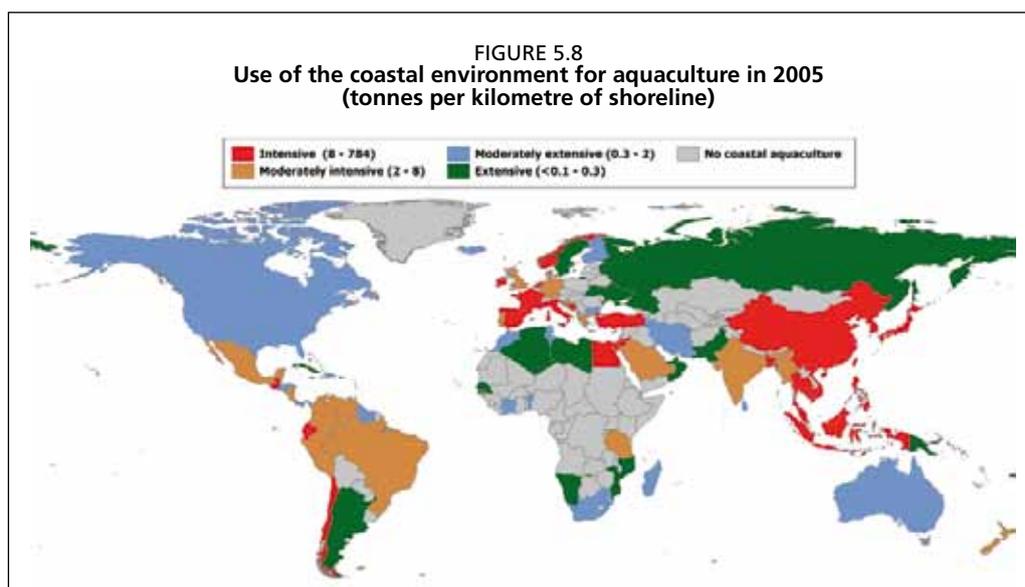
In comparison with brackishwater culture relative to shoreline length, there are 55 countries with a mariculture output of at least 1 tonne per kilometre of shoreline. Of these, China has an exceptionally high output of 726 tonnes per kilometre of shoreline. Among the top 20, after China, outputs range from 126 to 9 tonnes per kilometre of shoreline. (Figure 5.6). As with brackishwater production, several territories and countries that otherwise would not be important emerge when production is considered as a function of length of shoreline (e.g. Faeroe Islands, Israel, Ireland). The environmental impacts of mariculture and brackishwater culture come together on the coast. A measure of the environmental impact of these two culture categories, expressed in terms of intensity, is apparent by adding mariculture and brackishwater production, each in terms of tonnes per kilometre of shoreline. China is by far the world leader in this category with 784 tonnes per kilometre of shoreline (Figure 5.7). Clusters of countries using the coastal environment for aquaculture either intensively or moderately intensively are in Asia, western Europe, and Latin America (Figure 5.8).



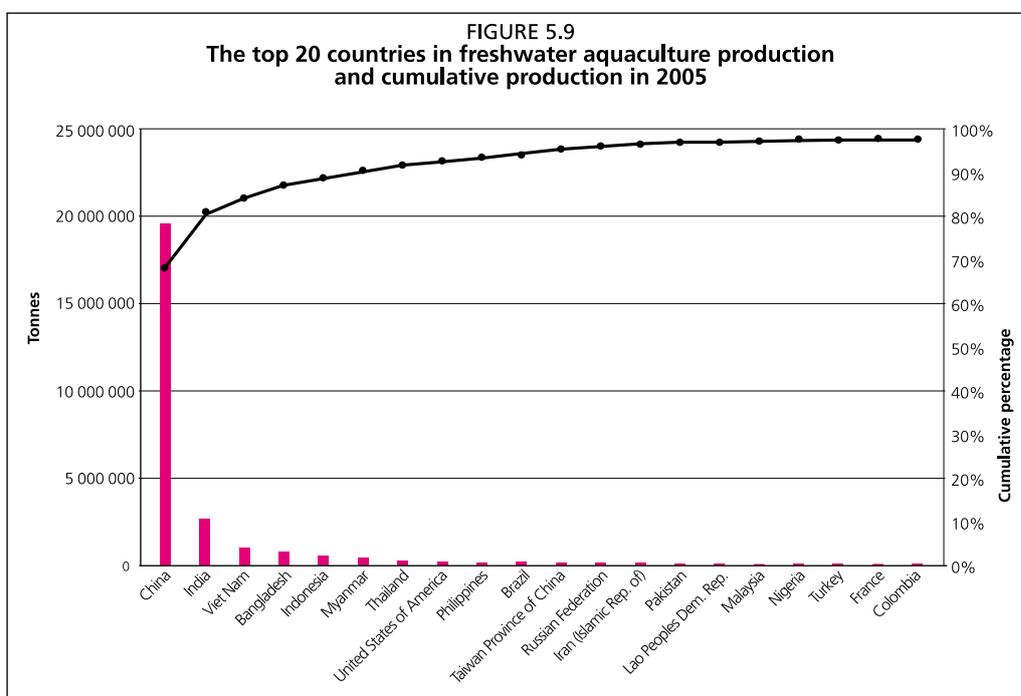
5.6 POTENTIAL IMPACTS OF AQUACULTURE USE ON FRESHWATER ENVIRONMENTS BASED ON PRODUCTION BY COUNTRY

Freshwater aquaculture from a total of 143 countries accounts for 46 percent of total aquaculture production (Figure 5.3). It is carried out in a wide variety of natural ecosystems such as rivers and lakes, plus in artificial ecosystems having variable environmental controls on the culture environment such as in reservoirs, ponds, raceways and silos as well as in closed systems. In contrast to much of mariculture and brackishwater aquaculture, freshwater aquaculture may combine species from several trophic levels within the same culture system.

Freshwater aquaculture is based on animals that are fed or on those that partially or



completely extract their feed from the environment (phyto- and zooplankton in the water column, benthic plants and animals). Therefore, the potential impact of aquaculture on freshwater ecosystems can be highly variable depending on the species, culture system and associated levels of inputs and outputs as well as on the location within the ecosystem. The top 20 countries in freshwater production account for 98 percent of global production (Figure 5.9). China, with 72 percent of global production, dwarfs the output of the next most important countries, India and Viet Nam.



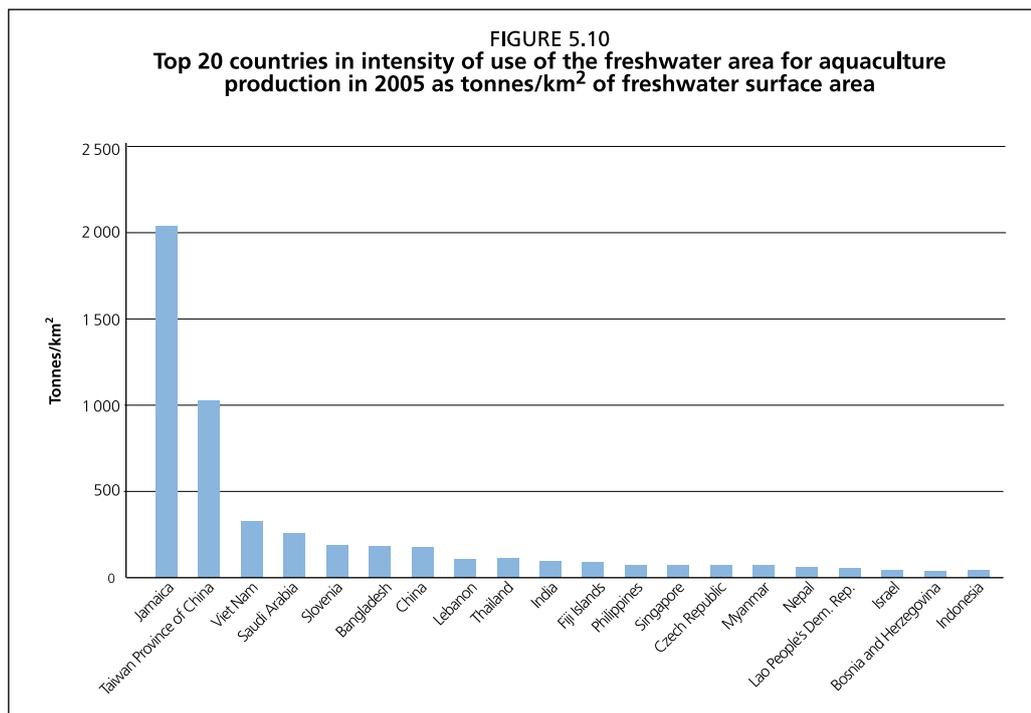
5.7 POTENTIAL IMPACTS OF AQUACULTURE USE ON THE FRESHWATER ENVIRONMENT BASED ON PRODUCTION BY COUNTRY

As with mariculture and brackishwater culture, freshwater aquaculture production can be considered here in spatial terms. Production is carried out in a wide variety of natural ecosystems such as rivers and lakes and in artificial ecosystems with differing amounts of control on the culture environment such as reservoirs, ponds, raceways and silos. In

this section, the combined surface areas of lakes, reservoirs and rivers are used as the spatial indicator of the total freshwater area of a country. The data have been derived by clipping Levels 1 and 2 of the Global Lakes and Wetlands Database (GLWD) (Lehner and Doll, 2004) with country boundaries based on Global Administrative Unit Layers (FAO, 2008). The GLWD is described in more detail in Chapter 4.

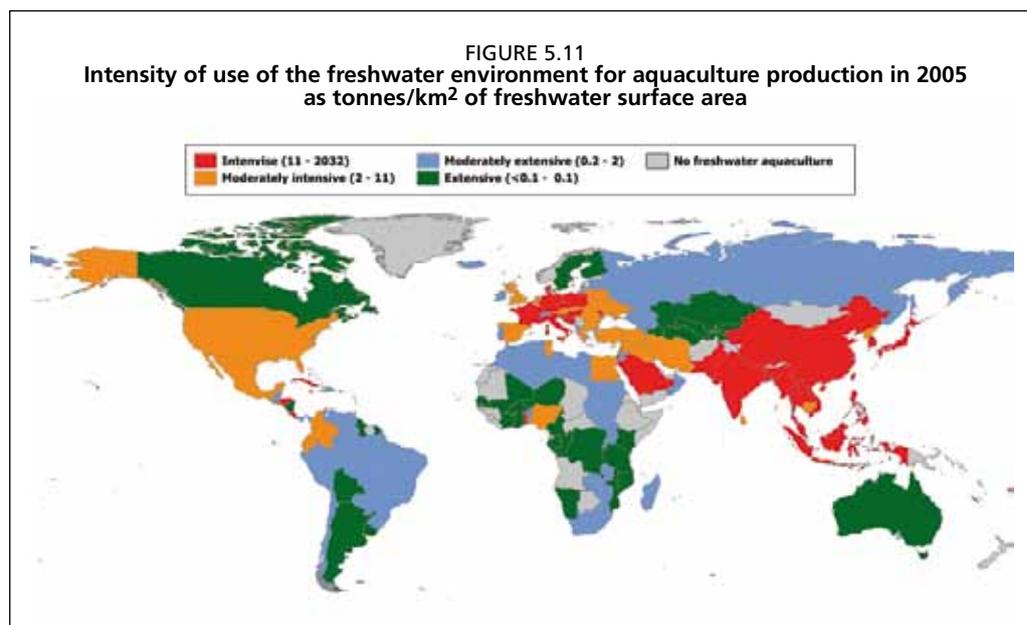
The basic assumption for this analysis is that the total freshwater surface area of a country, as estimated using the GLWD, is a measure of freshwater area in which aquaculture is, or can be developed. It follows then that production as a function of total freshwater surface area is a measure of the intensity of use of the freshwater environment for aquaculture. For example, at one extreme countries with relatively large expanses of freshwater and relatively low aquaculture production would be low intensity users of freshwater for aquaculture.

When aquaculture production is considered as a function of freshwater surface area, a far different picture from production per country emerges. Using this approach, Jamaica and Taiwan Province of China are by far the most intensive users of freshwaters for aquaculture with 2 032 tonnes/km² of freshwater surface (tonnes/km²) and 1 025 tonnes/km², respectively and China drops to sixth place with 176 tonnes/km² (Figure 5.10). Clusters of intensive and moderately intensive use of the freshwater environment for aquaculture are in Asia, Europe, the Middle East, northwestern Latin America and North America (Figure 5.11).



5.8 COMPARISONS OF THE USE OF ECOSYSTEMS BY AQUACULTURE AMONG COUNTRIES

The objective in this section is to estimate the intensity of use of the marine, brackishwater and freshwater environments for aquaculture in spatial terms. The discussion requirements are that the estimates are comprehensive in the sense of including all aquaculture countries and comparable among them, but straightforward in interpretation. As was stated previously, intensity of use of the coastal environment was calculated as mariculture and brackishwater annual production per kilometer of shoreline length.. In contrast, intensity of use of freshwater environments for aquaculture was calculated annual freshwater production per country as a function of freshwater surface area. The linear and area-wise estimates of



intensity of use are not additive. Additionally, because the data are highly skewed, means and standard deviations of production would provide biased pictures of intensity of use. The problems of additivity and skewness have been resolved by casting the data into quartiles.

Countries that make the most intensive use of inland, coastal and marine ecosystems for aquaculture are of the most interest here. That is, those that potentially make the most impact on the environment. The degree of aquaculture intensity has been classified as follows:

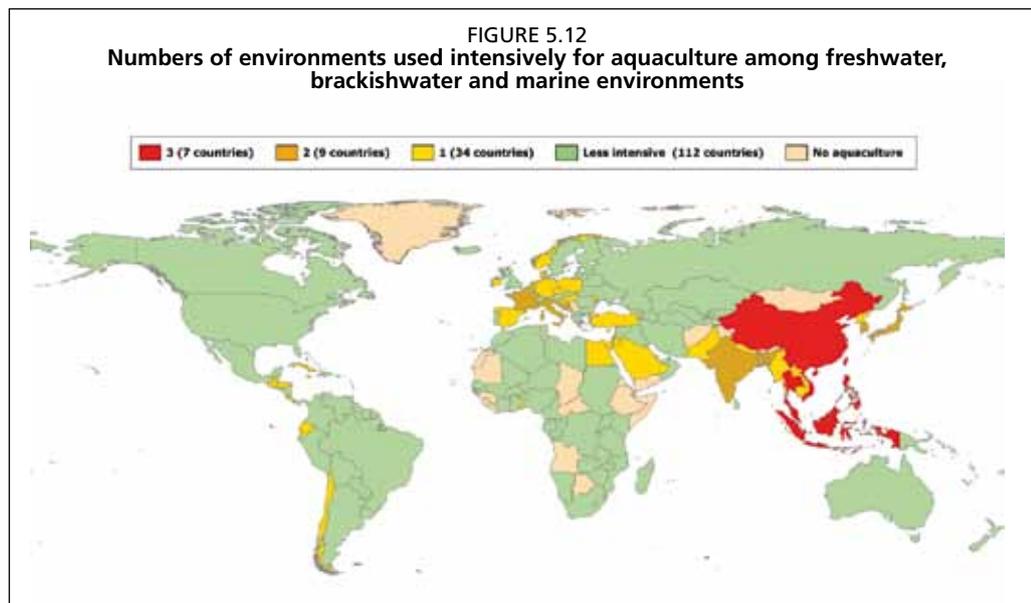
- Intensive – 4th quartile (76th to 100th percentile)
- Moderately intensive – 3rd quartile (51th to 75th percentile)
- Moderately extensive – 2nd quartile (26th to 50th percentile)
- Extensive – 1st quartile (0 to 25th percentile)

The use of the terms “intensive” and “extensive” are not meant to imply the very specific definitions assigned to them in FAO Glossary of Aquaculture (www.fao.org/fi/glossary/aquaculture/default.asp). Rather these terms as used herein simply to provide an alternative, comparative quantitative meaning to quartiles as mathematical terms.

In overview, there are 36 countries in the relatively intensive freshwater aquaculture category, 22 countries with relatively intensive mariculture, and 15 in the relatively intensive brackishwater category. Viewed another way, of the 163 countries that reported aquaculture production in 2005, there are 50 that make relatively intensive use of ecosystems in at least one of the three main environments. Among those 50 countries, there are seven countries that make intensive use of ecosystems for aquaculture in all three environments, nine countries that use ecosystems intensively in two of three environments, and the remainder, 34, make intensive use of only one of the three environments (Figure 5.12) in which aquaculture is relatively intensive).

5.9 POTENTIAL ENVIRONMENTAL IMPACTS ON AQUACULTURE BASED ON ECOSYSTEM VITALITY

Just as aquaculture impacts the environment and the ecosystems within it, so do natural events and human activities impact aquaculture. The purpose of this section is to rank countries in a comprehensive and comparable way as to their actual or potential environmental impacts on aquaculture. The approach is to use a ready-made indicator as a starting point, the Environmental Performance Index 2008 that was described in Chapter 3 (page 43).



The 2008 Environmental Performance Index (EPI) (overview available at <http://sedac.ciesin.columbia.edu/es/epi/papers/2008EPIPolicymakerSummary.pdf>) ranks 149 countries on 25 indicators relating to six established policy categories: Environmental Health, Air Pollution, Water Resources, Biodiversity and Habitat, Productive Natural Resources, and Climate Change. The EPI identifies broadly-accepted targets for environmental performance and it measures how close each country comes to these goals.

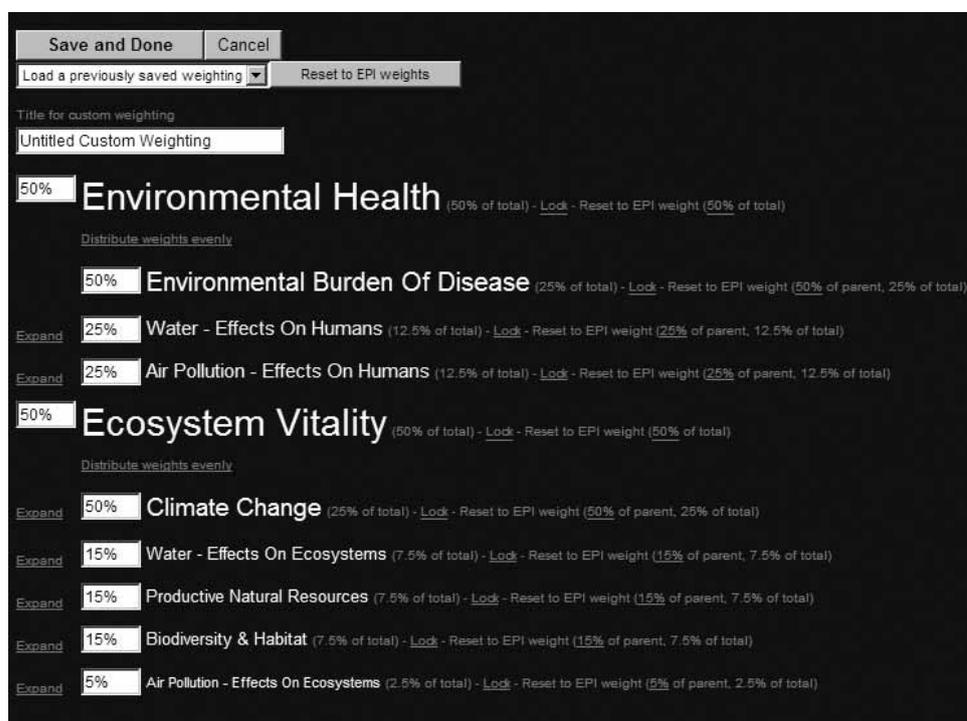
The EPI builds on measures relevant to the goals of reducing environmental stresses on human health, which is called the Environmental Health objective. More importantly from an aquaculture viewpoint, it also includes measures relevant to the goal of reducing the loss or degradation of ecosystems and natural resources. This is called the Ecosystem Vitality objective.

For the purpose of estimating environmental impacts on aquaculture, the default weight on Environmental Vitality, bearing directly on factors that can environmentally impact aquaculture (Figure 5.13) (http://epi.yale.edu/chart/new_weighting/RankingsModule_2), was increased from the 50 percent to 90 percent. Accordingly, the weight on Environmental Health, bearing only indirectly on aquaculture, was reduced from 50 percent to 10 percent (Figure 5.13).

The assumption is that environmental impacts on aquaculture vary inversely with the EPI's estimates of ecosystem vitality when Ecosystem Vitality is weighted at 90 percent. In other words, countries with high re-weighted EPI scores impact aquaculture relatively lightly and those with low scores actually or potentially impact aquaculture relatively heavily. Actual impacts could be in those countries where aquaculture production is presently important and potential impacts would be in countries where aquaculture is presently little developed. The procedure uses quartiles to cast the EPI scores into four relative impact categories with respect to environmental impacts on aquaculture: heavy, moderately heavy, moderately light, and light. Of the 163 aquaculture countries, it is possible to derive re-weighted EPI scores available for 132 of them.

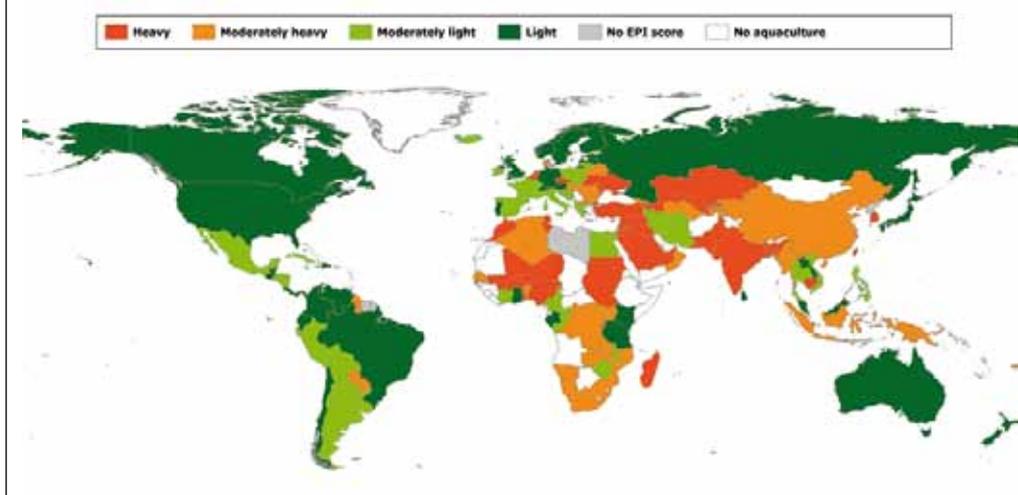
The geographic distribution of environmental impacts on aquaculture at the country level is shown in Figure 5.14. Countries actually or potentially with heavily or moderately heavy impacts on aquaculture are mainly in Asia and Africa, Eastern Europe and the Middle East. The countries and territories for which there are no EPI scores are mainly those in which the intensity of aquaculture production is low. The exceptions are the Democratic Republic of Korea, Singapore and the Faeroe Islands.

FIGURE 5.13
EPI categories heavily weighted on Ecosystem Vitality to estimate environmental impacts on aquaculture at the country level



Source: Socio-economic data and applications center (2009).

FIGURE 5.14
Environmental impacts on aquaculture based on a 90 percent weight on Ecosystem Vitality in the Environmental Performance Index



5.10 ENVIRONMENTAL IMPACTS ON AQUACULTURE IN RELATION TO THE INTENSITY OF AQUACULTURE PRODUCTION

Successful aquaculture development and management depend on anticipating and mitigating environmental problems both from- and on aquaculture. The objective of this section is to define the relationship between those countries in which aquaculture is most intensively practiced (Section 5.8, Figure 5.11) and those for which the impact of the environment on aquaculture has been estimated using the re-weighted Ecosystem Vitality category of the EPI (Section 5.9, Figure 5.14). For this purpose, the

countries where aquaculture is most intensively practiced in each environment (4th quartile countries – Figure 5.11) have been assigned the re-weighted EPI scores in the four impact categories.

TABLE 5.1

Summary by numbers of countries where aquaculture potentially/heavily impacts the environment coincident with potential environmental impacts on aquaculture

Number of environments potentially heavily impacted by aquaculture	Total number of countries*	Potential environmental impact on aquaculture			
		Heavy	Moderately heavy	Moderately light	Light
3	7	1	2	3	1
2	9	3	2	3	1
1	31	10	5	8	8
Total	47	14	9	14	10

*There are three countries in this group without an environmental impact score Democratic People's Republic of Korea, Singapore and the Faeroe Islands

Among countries in which aquaculture is intensively practiced in three environments, there is one country, Malaysia, where the environmental impact on aquaculture is relatively light, three countries where it is moderately light, Thailand, Viet Nam and the Philippines, and two countries where it is moderately heavy, China and Indonesia, and one country, Taiwan Province of China, where it is heavy (Table 5.1). Among countries where aquaculture is practiced intensively in two environments, the environmental impact on aquaculture is evenly distributed among the categories, but there are three countries, the Republic of Korea, India, and Bangladesh, where the environmental impact on aquaculture is in the heavy category (Table 5.1). Looking at the countries where aquaculture is intensively practiced in only one environment the impact of the environment on aquaculture is relatively evenly distributed between heavy and light. There are ten countries in which the environmental impact on aquaculture is heavy (Table 5.1).

5.11 SUMMARY AND CONCLUSIONS

Aquaculture's impact on the marine, brackishwater and freshwater environments was estimated based on the assumption that the quantity of production in each of those environments is directly related to the intensity of impact on those environments. By inference, the potential impact of aquaculture on the three environments could be extended to the ecosystems associated with those environments. This assumption was used to make a globally comprehensive and comparable analysis of the intensity of the use of the freshwater, brackishwater and marine environments by aquaculture at the country level. Also, the converse, the environmental impact on aquaculture, was estimated at the country level using the Environmental Performance Index with a 90 percent weight on Ecosystem Vitality. These results support the main objective of this chapter that was to identify the countries in which GIS, remote sensing and mapping could be most usefully deployed in support of the EAA. As a first priority those are the countries in which aquaculture's impact on ecosystems is most intensive and in which environmental impacts on aquaculture are most heavy.

There are several considerations relating to these estimates. The first is that they are indicative. They provide a starting point for further investigations at national and sub-national levels and they should be verified by in-country data. The second is that capabilities and capacities to support spatial planning for the EAA vary among countries. Thus, some of those countries identified as intensively using environments for aquaculture, or in which aquaculture may be heavily impacted by the environment, may already be dealing effectively with these issues. A partial measure of how effective

countries have been in dealing with such impacts is contained in the evaluation of environmental impacts assessment and monitoring by FAO (2009). One strategy to advance the use of spatial planning tools for aquaculture would be to enlist the support of the most capable and advanced countries to help those that are less advantaged.

From a geographic perspective the results can be summarized in the following ways:

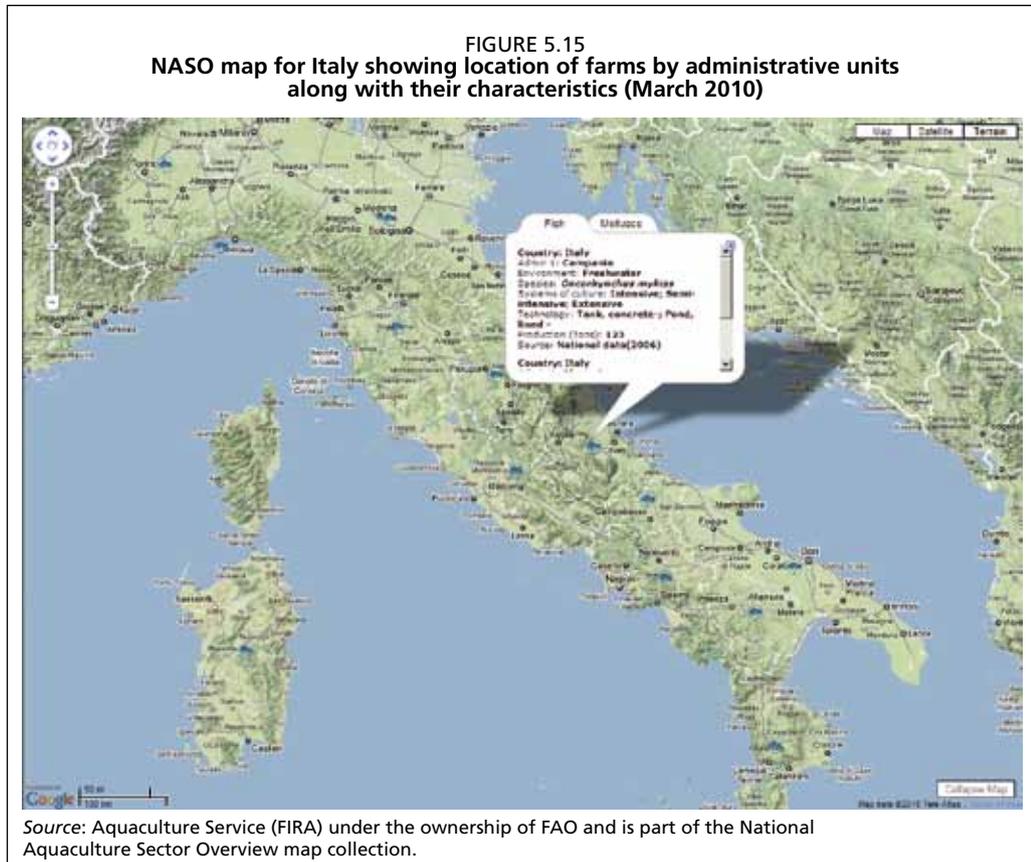
- Of the 163 countries that reported aquaculture production in 2005, there were seven countries that made intensive use of ecosystems for aquaculture in all three environments, nine countries that used ecosystems intensively in two of the three environments, and the remainder, 34 that made intensive use of only one of the three environments (Figure 5.12).
- The potential environmental impacts of mariculture and brackishwater aquaculture mainly affect on coastal ecosystems. Clusters of countries intensively and moderately intensively using the coastal environment for aquaculture are in Asia, west Europe, and Latin America (Figure. 5.8).
- Clusters of countries intensively and moderately intensively using the freshwater environment for aquaculture are in Asia, Europe, the Middle East, north-western Latin America and North America (Figure. 5.11).
- Countries in which environmental impacts on aquaculture are actually or potentially heavy or moderately heavy are mainly in Asia and Africa, Eastern Europe and the Middle East (Figure 5.14).
- Among the countries intensively using at least one of the three environments for aquaculture, the environmental impacts on aquaculture are fairly evenly distributed in the range from heavy to light impacts (Table 5.1).
- These estimates of the potential impact of aquaculture on environments and of environmental impacts on aquaculture are indicative, but nevertheless provide useful starting points to gauge in which regions and which countries GIS support of the EAA could be most usefully deployed.

Before an EAA GIS-based plan can be implemented at country level, the extent to which GIS is already being used in support of the EAA has to be established as well as the capacity to expand GIS activities in support of the EAA. The assessment of GIS applications in aquaculture (Chapter 8) casts some light on this, but direct contact with each fisheries – aquaculture entity in each country is required to better substantiate activities and capacities.

These results call attention to the need for improved ways to comprehensively comparatively assess aquaculture's impact on the environment and the environment's impact on aquaculture. Refinement of the estimates by the three major environments within the countries is possible using FAO FishStat Plus (FAO, 2007) data in several ways, firstly by separating extractive and fed aquaculture that impact the environment separately. Secondly, culture methods and environments are often unique for a species (e.g. cages for Atlantic salmon in brackish and temperate marine waters) so that specific kinds of impacts can be inferred. The assumption is that countries producing the same species and using the same culture systems share the same or similar environmental problems and could benefit from the same kinds of GIS, remote sensing and mapping interventions. However, this approach does not satisfy the need to know the "where" of the impacts. This can be accomplished only by comprehensive inventories of aquaculture.

At watershed, aquaculture zone and farm scales there is no substitute for a spatial inventory of aquaculture with at least attributes that include species, culture systems, and production being recorded, in order to estimate impacts on the environment and ecosystems. Countries need to make this activity a priority in their implementation of the EAA. For a relatively inexpensive initiative, the benefits can be great. Thailand already provides one example of such an implementation as mentioned in the Workshop

Report of this document and also available on the Internet (<http://gis.fisheries.go.th/WWW/index.jsp>). An excellent starting point for a spatial inventory of aquaculture with attributes that include species, culture systems, and production are the FAO National Aquaculture Sector Overviews (NASOs) (www.fao.org/fishery/collection/naso/en). Figure 5.15 illustrates one of the NASO maps being constructed for Italy as an example.



The National Aquaculture Sector Overview (NASO) collection provides a general overview of the aquaculture sector of FAO member countries. The NASOs contain summarized information on the history of aquaculture; human resources involved in the sector; farming systems distribution and characteristics; main cultured species contributing to national production; production statistics; description of the main domestic markets and trade; promotion and management of the sector; and development trends and issues at the national level. The information provided in the NASOs has been primarily provided by experts on aquaculture and by national authorities and, supplemented by graphs created by FAO to illustrate reported production statistics. Ninety eight NASOs have been published on the FAO Web site so far. NASO is part of FAO Fisheries and Aquaculture Department regular programme and it was decided to update the online documents every four to five years.

The NASO initiative offers a good starting point for implementing GIS in support of the EAA and finances should be allocated to accelerate the effort especially among the countries which have been identified herein as most intensively using the environments for aquaculture and in which aquaculture is most heavily impacted by the environment.

6. Current status of GIS, remote sensing and mapping applications in aquaculture from an ecosystem viewpoint

The purpose of this chapter is to provide an overview of GIS, Remote Sensing and mapping experience in terms of aquaculture applications relating to ecosystems and in particular to the EAA. The underlying objectives are to gauge the spatial analytical experience that could be brought to bear to support the EAA and to draw attention to technical and geographic gaps. Indicators include the types, breadth and numbers of spatial issues addressed, the numbers of spatial applications in aquaculture, the ecosystems at which or in which aquaculture spatial applications have been carried out, and the scales of the applications.

6.1 GIS, REMOTE SENSING AND MAPPING APPLICATIONS RELATED TO AQUACULTURE

Spatial issues in marine aquaculture and examples of GIS, remote sensing and mapping applications that have addressed those issues already have been reviewed by Kapetsky and Aguilar (2007). Their review is expanded on herein by assigning GIS, remote sensing and mapping records on aquaculture applications from the FAO GISFish Aquaculture Database to spatial issues in aquaculture (Table 6.1).

TABLE 6.1
Numbers of spatial applications addressing main issues and sub-issues in the GISFish Aquaculture Database as of 1 March, 2010

GIS training and promotion of GIS (8 percent)	
Training	9
Promotion	22
Total	31
GIS aimed at development of aquaculture (53 percent)	
Suitability of site and zoning	107
Strategic planning for development	74
Anticipating the consequences of aquaculture	115
Economics	4
Total	195
GIS for aquaculture practice and management (32 percent)	
Inventory and monitoring of aquaculture and the environment	79
Environmental Impacts of aquaculture	26
Restoration of aquaculture habitats	8
Web-Based Aquaculture information system	5
Total	114

TABLE 6.1 Cont.

Numbers of spatial applications addressing main issues and sub-issues in the GISFish Aquaculture Database as of 1 March, 2010

GIS for multisectoral development and management that includes aquaculture (7 percent)	
Management of aquaculture together with fisheries	9
Planning for aquaculture among other uses of land and water	16
Total	25
Not specified	1
Grand total	366

All four main issues, along with their sub-issues, bear directly on the EAA; however, as can be seen in Table 6.1, the numbers of applications among the main issues are quite uneven. Particularly lacking are holistic applications dealing with aquaculture in the context of multidisciplinary approaches to management and specifically management of aquaculture together with fisheries. This lack of attention to the broader aspects of the development and management of aquaculture suggests that integration with other complementary uses of land and water along with attention to competing and conflicting uses, in short, “spatial awareness” should be priorities for training in spatial analyses.

Clearly, promotion and training are key activities in increasing the capacity to use spatial tools in order to implement the EAA. This category has received relatively little representation as an issue (Table 6.1). In order to be successfully and widely applied, all of the spatial initiatives in the EAA will require training and promotion underpinnings. This, too, suggests that more emphasis will have to be brought to bear on training. In this regard, the Web Resources Database of GISFish that tracks opportunities for formal training, self-training (distance learning, on-line free courses) and freeware shows that there are many possibilities for formal and self-training in spatial tools and analyses that could be applied to aquaculture issues and to the EAA (available at www.fao.org/fishery/gisfish/id/1032). Thus, an important task will be to design and organize training using the most readily available and least costly means available, such as those found on the Internet.

In contrast to the main issues of training and multisectoral management, GIS aimed at the development of aquaculture and GIS for aquaculture practice and management have received much more attention. The former accounts for about one-half of the applications while the latter accounts for one-third (Table 6.1). Within these two categories of issues, in relative terms there are noticeable gaps. The important issues of anticipating the consequences of aquaculture and of aquaculture economics are relatively under-represented in the development category while in the practice and management category restoration and aquaculture information systems are poorly represented (Table 6.2).

TABLE 6.2

GIS aimed at the development of aquaculture, and GIS for practice and management

GIS aimed at the development of aquaculture (53 percent of total applications)		
Suitability of site and zoning	107	54%
Strategic planning for development	74	37%
Anticipating the consequences of aquaculture	15	8%
Economics	4	2%
Total	195	100%

TABLE 6.2 Cont.

GIS aimed at the development of aquaculture, and GIS for practice and management

GIS for aquaculture practice and management (33% of total aquaculture applications)		
Inventory and monitoring of aquaculture and the environment	79	67%
Environmental Impacts of aquaculture	26	22%
GIS aimed at the development of aquaculture (53 percent of total applications)		
Restoration of aquaculture habitats	8	7%
Web-Based Aquaculture information system	5	4%
Total	114	100%

Because aquaculture and fisheries have many interests in common and in many instances occupy the same space, it would be thought that applications dealing with aquaculture and fisheries would receive more attention. Clearly, as shown in Table 6.3, this is not the case.

TABLE 6.3

GIS for multisectoral development and management that includes aquaculture

GIS for multisectoral development and management that includes aquaculture (5 percent of total aquaculture applications)		
Management of aquaculture together with fisheries	9	36%
Planning for aquaculture among other uses of land and water	16	64%
Total	25	100%

In this regard, an additional resource for the implementation of spatial analyses in support of the EAA that should not be overlooked is the availability of issues-related applications of spatial tools in inland fisheries (GISFish-Inland Fisheries Main Issues from Database available at www.fao.org/fishery/gisfish/id/2384). The count of inland records of potential use was nearly 250 in June, 2009. An important point about the inland applications is that, relative to aquaculture, they are very ecologically oriented and particularly numerous with regard to habitats, and that aquaculture and inland fisheries occur together in the same ecosystems and employ the same basic spatial and attribute data for analyses.

In summary, there are gaps in experience that can be made up by careful design of training programs to match issues. Overall, aquaculture applications of spatial tools from an issues viewpoint can be said to be mainly inward focused, not outward looking and holistic as the EAA demands. This outcome points to the need not only for technical training, but also for training in “spatial awareness” of competing, conflicting and complementary uses of land and water in an ecosystems context.

6.2 AN ASSESSMENT OF GIS, REMOTE SENSING AND MAPPING APPLICATIONS TO AQUACULTURE AS THEY RELATE TO SCALES AND ECOSYSTEMS

The objectives here are to assess GIS, remote sensing and mapping applications in aquaculture in the context of the ecosystems to which they pertain and in relation to the scales that they have encompassed.

Data and methods

Using the GISFish Aquaculture Database (www.fao.org/fishery/gisfish) from 1998 to October, 2007, 191 records in all, were examined. Of these, 159 records were classified both according to the kind of ecosystem involved and with regard to the scale of the application. The others were either too vague with regard to scale or ecosystem, or did not pertain (e.g. reviews). Although this sample is somewhat dated, there are only

25 additional entries for 2008 and 2009 and they are unlikely to be greatly different the records that were used for the survey. Names of ecosystems were tabulated according to their literal use in titles, abstracts and full papers or reports. Ecosystem names are often based on the geographic name of the place under investigation (e.g. Charlotte Harbor is a harbor). In a few cases local names for systems were converted to a more common ecosystem name, if a satisfactory definition could be found (e.g. lough to lagoon).

Experts at the FAO Workshop on “Building an ecosystem approach to aquaculture (EAA): Initial steps for guidelines”¹ (Soto, Aguilar-Manjarrez and Hishamunda, 2008) identified four scales/levels of EAA application: the farm; the waterbody and its watershed; the aquaculture zone or region; and the global, market-trade level. The EAA scales are easily accommodated by GIS, remote sensing and mapping as applied to aquaculture, this being because GIS is capable of being applied at any scale. Practically, many spatial applications in aquaculture deal primarily with a natural or an artificial waterbody in its entirety or in part. Otherwise, the geographic reach of many applications is most often defined by some extra-national, national or sub-national level of administration, or national level of administration, or sub-national clusters of administrations.

For the present survey the following seven scales were recognized (Table 6.4):

TABLE 6.4

Scale definitions

Scale	Description
Local	Generally a natural or artificial ecosystem or a third-level administrative area
State or Province	The second level of administration below national
Region within a country	Generally an area occupying an appreciable part of a country and/or including more than one state or province
National	An application covering the entire country
Region among countries	Covering two or more countries
Continental	Covering all of the countries of a continent
Global	Including all countries with aquaculture

Scales of GIS, remote sensing and mapping applications in aquaculture

Applications that were local (64 percent) or at the state or province level (first level sub-national administrative area) (21 percent) were the most prevalent in all three environments (Table 6.5); however, other scales also were represented, notably regions among countries, albeit in relatively low numbers. It is encouraging that there were ten national level studies suggesting that many kinds of ecosystems were implicitly or explicitly covered.

The local scale would correspond approximately to the farm and waterbody/watershed scale of the EAA. There are relatively fewer GIS applications that cover larger areas such as continents and worldwide, i.e. that correspond to the EAA global market-trade scale. These results are consistent with the idea that most GIS applications in support of the EAA would be at the farm cluster/aquaculture zone and waterbody/watershed scale. Therefore, relative to expected EEA needs at farm and waterbody/watershed scales, the GIS experience at the corresponding local scale is relatively good. That outcome is positive because most issues and most spatial applications to address them are expected to be at these scales.

¹ Soto, D. & Aguilar-Manjarrez, J. 2009. FAO Expert Workshop on Guidelines for the implementation of an ecosystem approach to aquaculture (EAA). FAO Aquaculture Newsletter No. 42. pp 8–9.

TABLE 6.5
Scales relating to 159 spatial analysis applications in aquaculture among brackishwater, inland and marine environments

Scale	All	Brackishwater	Inland	Marine	Grand Total				
Local	-	36	67%	11	55%	55	67%	102	64%
State or province	-	16	30%	3	15%	15	18%	34	21%
Region in country	-	1	2%	0	0%	0	0%	1	1%
National	-	1	2%	1	5%	8	10%	10	6%
Region among countries	-	-	-	3	15%	3	4%	6	4%
Continental	-	-	-	1	5%	-	-	1	1%
Global	3	-	-	1	5%	1	1%	5	3%
Grand Total	3	54	-	20	-	82	-	159	100%

That so many applications were local or at the state or provincial level suggests that higher level planning for aquaculture, either at the national level or at the level of lake or river basin, is not taking advantage of spatial tools. This may be another manifestation of the lack of attention by the aquaculture sector to competing, conflicting and complementary uses of land and water. A solution is the promotion of the spatial needs of aquaculture among a broad range of users of land and water, and training in spatial awareness of users of land and water for aquaculture.

Ecosystems included in GIS, remote sensing and mapping applications in aquaculture

Regarding ecosystems, 13 of the 159 applications included a second ecosystem in the spatial analysis; however, these were ecosystems adjacent to the primary ecosystem. In the same light, although ponds are artificial ecosystems and predominate among the brackishwater and inland ecosystems as the targets of spatial analyses, many brackishwater and inland applications involve site selection for ponds so that the surrounding ecosystems (e.g. mangroves, creeks, rivers) also are taken into account in the application.

In all, 22 kinds of ecosystems related to the 159 applications. Three applications (2 percent) among the 159 were global in extent and implicitly included all aquaculture ecosystems (Table 6.6). Ecosystems in the marine environment accounted for 52 percent of the applications while brackishwaters accounted for 34 percent and the inland environment for 13 percent. In comparison, global aquaculture production in 2005 was about 50 percent from mariculture, 44 percent from freshwater and the remainder from brackishwater (FAO, 2007). Thus, numbers of GIS applications in the brackishwaters and freshwater environments are not proportional to production. For example, brackishwaters GIS applications (34% of the total) are many more than would be expected from the relative importance of brackishwater production (6% of total production). This may be accounted for in part by the relative high value of aquacultured products from brackishwaters. Similarly, GIS applications in freshwaters are less than would be expected based on global freshwater tonnage. This, too, may be due in part to the lower value of freshwater aquaculture products in comparison with those from marine and brackishwaters. This is not necessarily a gap. The results simply show that the distribution of applications among the three environments may be heavily influenced by economic considerations.

In the marine realm, bays were most frequently the targets of spatial studies (43 percent) followed by marine coastal ecosystems (38 percent). This latter ecosystem designation results from applications in which more specific identifications of ecosystems were not made. In contrast, the marine offshore designation (12 percent) consistently refers to offshore culture of fish in cages or of mussels on longlines. In brackishwaters, ponds were the most prevalent ecosystems (50 percent). These ponds are artificial ecosystems constructed mainly for penaeid shrimp culture. Estuaries (26

percent) were the second-ranking kind of ecosystem in brackishwaters. In inland areas artificial ponds (40 percent), too, were the prevalent ecosystem followed by lakes (20 percent).

TABLE 6.6
Ecosystems as the targets of 159 spatial analyses among marine, brackishwater and inland environments

Ecosystem	All	Brackishwater	Inland	Marine	Grand Total	
ponds, brackish	-	27	50%	-	27	
estuary	-	14	26%	-	14	
lagoon	-	5	9%	-	5	
mangroves	-	4	7%	-	4	
sound	-	3	6%	-	3	
fjord	-	1	2%	-	1	
ponds, inland	-	-	8	40%	8	
lake	-	-	4	20%	4	
river	-	-	2	10%	2	
river basin	-	-	2	10%	2	
creek basin	-	-	1	5%	1	
floodplain	-	-	1	5%	1	
reservoir	-	-	1	5%	1	
surface waterbodies	-	-	1	5%	1	
bay	-	-	-	35	43%	35
marine, coastal	-	-	-	31	38%	31
marine, offshore	-	-	-	10	12%	10
land-based marine	-	-	-	2	2%	2
canal, marine waters	-	-	-	1	1%	1
gulf	-	-	-	1	1%	1
harbour	-	-	-	1	1%	1
ponds, marine	-	-	-	1	1%	1
global, all ecosystems	3	-	-	-	3	
Grand Total	3	54	20	82	159	
	2%	34%	13%	52%		

Looked at from a broad viewpoint, it can be said that nearly all applications of GIS, remote sensing and mapping in aquaculture include one or more ecosystems. For example, as shown in Table 6.6, aquaculture applications have operated in all varieties of “natural” waterbodies generally referred to as “ecosystems” (e.g. rivers, lakes, bays, estuaries) as well as in artificial waterbodies that may also be considered as ecosystems such as reservoirs, and ponds. It can be concluded that there is ample experience in the application of spatial analyses among natural and artificial ecosystems; however, as shown by the relative attention to main- and sub-issues (Table 6.2), there is relatively limited experience in dealing spatially with the social and economic components of ecosystems. Finally, the results are somewhat subjective because of the varying amount of information about each application conveyed by the title, abstract, or full report or paper. Also, some ecosystems could probably be combined (e.g. coastal lagoon and sound).

6.3 SUMMARY AND CONCLUSIONS

The purpose of this chapter was to provide an overview of spatial analysis experience in terms of spatial applications in aquaculture that relate to ecosystems and particularly to EAA. The underlying objective was to gauge the experience that could be brought to bear to support the EAA and to draw attention to technical and geographic gaps. Indicators included kinds and numbers of issues addressed, the geographic scales of the applications, and the kinds of ecosystems in which applications were carried out.

Regarding the issues addressed, experience is relatively good in the realms of spatial analyses for the development of aquaculture and for aquaculture practice and management. However, within these broad categories, experience is relatively weak in aquaculture economics. Experience in the main category issue of multisectoral planning and management is also relatively weak. The relatively poor showing of GIS applications aimed in this direction probably reflects the overall poor integration of aquaculture into land and water use planning, but, specifically with regards to spatial analyses, also could be indicative of a lack of awareness of GIS capabilities to support resolution of competition and conflicts for space and resources.

Clearly, promotion and training are key activities in increasing the capacity to use spatial tools for the implementation the EAA. One need for training, that of “spatial awareness”, is indicated by the apparent lack of use of GIS for aquaculture in broader planning. This kind of training is appropriate both at management and technical levels. The other kind of training that is required is at the technical level. The GISFish database covers a range of training opportunities including self-training with analytical freeware. However, resolving real-world issues should be the basis for the design of the technical training programs. Underlying this is a need to promote communication between managers and GIS analysts. An important consideration in designing training and promotion is to take a global view in order to recognize common needs and capacities so as to be able to realize efficiencies in the delivery of the training and technical assistance.

Fundamentally, since GIS can be applied at any scale. Any scale recognized by the EAA can be accommodated for spatial analyses. Scales among a sample of 159 applications within the three main environments – marine, brackishwater and freshwater – were broad and ranged from local to global. In all three environments the local scale was the most prevalent scale of application followed by the first level sub-national administrative boundary. In terms of the EAA scales, GIS applications applied to the farm, aquaculture zone or region are among the most numerous. That outcome is positive because most issues and most spatial applications to address them are expected to be at those scales. However, as shown by the relative numbers of applications among the main- and sub-issues (Section 6.2), there is relatively limited experience in dealing spatially with the social and economic components of ecosystems. Because the EAA is holistic and importantly includes these very two components, then it is clear that when priorities for training and promotion of GIS in the EAA are considered, they should include spatial analyses of the social and economic elements of ecosystems. Training and promotion in these two spheres will lead to a more widespread appreciation of the need for spatial analyses in general that will benefit not only the aquaculture sector, but all users of land and water resources.

7. GIS-based decision support tools and modelling for aquaculture development

7.1 INTRODUCTION

This section provides an overview of GIS-based decision support tools and models available to address key issues (e.g. site selection) and support decision-making activities for aquaculture development and management. First, the basics for decision-making in GIS are presented. Following this, a brief description of the various GIS-based models currently in existence is provided, highlighting particular features which have general relevance to the field of the ecosystem approach to aquaculture (EAA). The chapter concentrates on the currently available models representative of general types such as particulate waste distribution models, and dynamic flow models. General software descriptions are given and selected case studies are used to briefly describe the status and potential of these approaches. Some of the advantages, disadvantages and limitations of the decision support tools and models in addressing questions pertaining to EAA are discussed. The chapter concludes with some recommendations for introducing and implementing decision support tools and models to support EAA. This review is by no means exhaustive but it attempts to broadly capture the main model types that are well known, are widely available and that show potential as tools in this context – e.g. attention in this chapter is focused on GIS tools, however, there are a vast number of additional tools such as ecosystem-based modelling tools that would need to be assessed. Remote sensing and mapping are also briefly described in this chapter as two distinct approaches to spatial decision making and suggested reference are provided.

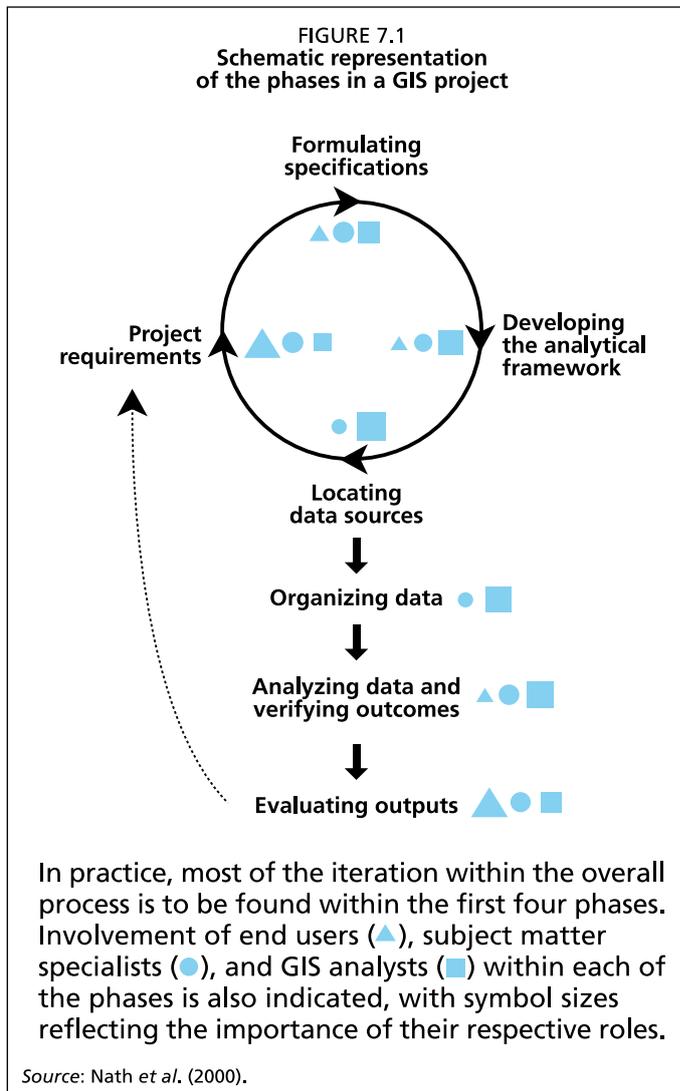
7.2 IMPLEMENTING

The basic considerations which are necessary in setting up a GIS for the development and management of aquaculture and inland fisheries are outlined by Meaden and Kapetsky (1991) and Meaden and Do Chi (1996) provide a similar outline for marine fisheries. Such considerations are still valid to date and include: Why is a GIS Needed? How can GIS fit into an Organization? What are the financial considerations? What sort of GIS configuration should we adopt? What sort of software should we choose? What are our personnel needs? What are the procedures for setting up the GIS?. A new FAO Technical manual on “Geographic information systems and remote sensing in fisheries and aquaculture” is currently in preparation and will be made available in late 2010. This new manual is an update to the work by Meaden and Kapetsky (1991) and Meaden and Do Chi (1996).

A complementary document to this review and especially this chapter is a study by Carocci *et al.* (2009) on Geographic Information Systems to support the ecosystem approach to fisheries.

Decision-making is a process, so there are a number of alternative ways to organize the sequence of activities in the decision-making process, however, Nath *et al.* (2000) noted that applications of GIS for spatial decision support in aquaculture generally consist of seven phases: 1. Identifying project requirements, 2. Formulating specifications, 3. Developing the analytical framework, 4. Locating data sources, 5. Organizing and manipulating data for input, 6. Analysing data and verifying

outcomes, and 7. Evaluating outputs. These seven phases are presented together with details of the degree of involvement of each category of personnel, associated activities and analytical procedures (Figure 7.1).



The seven phases can be summarized as follows:

1. Identifying project requirements

The process of identifying project requirements for a GIS is essentially a multiple stakeholder decision-making situation. This is because such work is invariably executed by a group of subject matter experts and analysts, and because results of the analyses are potentially useful to a range of decision-makers. Once project personnel, particularly end users, have had an opportunity to present their spatial decision support needs, discussions can begin on how GIS tools can address these needs, and clarify the limitations of such tools (e.g. spatial data availability and quality, software and hardware resources that may be needed, cost and time constraints, etc.).

2. Formulating specifications

Once an overall understanding of project requirements has been developed among team members, it is helpful to develop a listing of more functional specifications corresponding to each of the requirements that have been identified, for instance, if the project requires that the final GIS be interactive (implying that the end users can explore alternate scenarios on their own).

3. Developing the analytical framework

Development of the analytical framework for a GIS project must consider how end-users needs will be addressed. Several methods have been used, either singly or in combination, by GIS practitioners to integrate spatial information into a useful format for analysis and decision-making. Some of the main analytical methods that have been used in aquaculture GIS include: Arithmetic operators; Classification; Interpolation; Simple overlay; Weighted overlay; Neighbourhood analysis; Connectivity analysis; Hierarchical models and Multi-objective land allocation.

4. Locating data sources

Once the analytical framework has been developed, it is necessary to identify data sources to be used in the project. This phase is largely restricted to GIS analysts, although subject matter specialists often provide helpful advice. Information for spatial decision-making and analysis is varied, and will usually consist of data describing the biophysical, economic, social and infrastructural environments. These data can come from a variety of sources ranging from primary data gathered in the field or satellite scenes to all forms of secondary data, including textual

databases and reports. It is generally both costly and time consuming to collect field (primary) data first hand, therefore, all GIS practitioners attempt to locate the data they need from existing secondary sources, either in paper or digital form. The initial consideration is identifying what data are needed for the overall analysis. This is followed by attempts to source the data, and to assess their age, scale, quality and relative cost.

5. Organizing and manipulating data for input

Collected datasets must be organized and manipulated for use in the target GIS. This phase is also largely restricted to GIS analysts, although depending on the type of application, occasional interaction with subject matter specialists may be warranted. Some of the key activities that occur in this phase include verification of data quality, data consolidation and reformatting, georeferencing and reprojection and database construction.

6. Analysing data and verifying outcomes

Activities that may be encountered in analyzing data and verifying outcomes include executing analytical methods (i.e. overlays, model runs and/or other querying knowledge based systems, etc.), importing and exporting data as needed (e.g. intermediate GIS outputs which are required by other components within the overall analytical framework), computation of relevant statistics (e.g. means, standard deviations, ranges, classes, etc.), generation of output information (e.g. maps, tables, graphs, and reports), and verification of outcomes. Field verification as part of any GIS work is absolutely essential, both for quality control of certain data sources (as previously discussed) and for testing the outcomes of models (or other analytical tools).

7. Evaluating outputs

In the final phase of a GIS project, outputs generated are jointly evaluated by the overall team (i.e. end users, subject matter specialists and analysts. Several activities are likely to be encountered during this phase, including a summary review of key findings, more detailed examination of individual components of the project together with their underlying assumptions, limitations (if any) of the findings, and an evaluation of the degree to which each of the original requirements of the project have been met. The results of the latter activity provide a useful means of assessing the success of the project. However, it is often the case that outputs from a GIS project are not put to immediate use, but form a component of a larger (or later) decision making process (e.g. development of new policies and/or of development plans pertaining to).

It should be noted that the phases involved in any GIS study occur iteratively in the sense that project personnel may often conduct a pilot-scale study with available information, and then successively enhance and/or refine the analysis until a satisfactory end point is reached.

Implementing GIS presents a unique set of challenges. Even well-funded GIS projects can fail because of poor planning. In a recent study, Tomlinson (2008) outlined a 10-stage process for successfully deploying GIS from an "enterprise viewpoint" as follows: 1. Consider the strategic purpose; 2. Plan for the planning; 3. Determine technology requirements; 4. Determine the end products; 5. Define the system scope; 6. Create a data design; 7. Choose a data model; 8. Determine system requirements; 9. Analyze benefits and costs and 10. Make an implementation plan.

A complementary publication to the present review is that of Ross, Handisyde, and Nimmo (2009) on "Spatial decision support in aquaculture: the role of geographical information systems and remote sensing" The review is divided in five main sections: (1) Spatial planning context; (2) Database construction and project methodology;

(3) Decision support systems and tools; (4) Selected applications and examples of geographical information systems in aquaculture (e.g. case study: climate change; case study: multi-site coastal zone planning); and (5) Summary and future trends.

A few topics and analytical methods are presented here in more detail because they represent key elements of a GIS project.

Geographical data

Geographical or spatial data are defined as undigested, unorganized, and unevaluated material that can be associated with a location. Data are of little value in and of themselves. To be useful they must be transformed into information. When data are organized, presented, analyzed, interpreted, and considered useful for a particular decision problem, they become information. Geographical information is defined as georeferenced data that have been processed into a form that is meaningful and of real or perceived value to decision-makers. Decision problems that involve geographical data and information are referred to as spatial decision problems (Malkzewski, 1999; Heywood, Cornelius and Carver, 2006).

Data are progressively converted into information to support the decision situation or decision problem. The decision situation determines the need and nature of the information required. To this end, it is useful to make a distinction between hard and soft information used for decision-making, sometimes referred to as objective and subjective information. Hard information is derived from reported facts, quantitative estimates, and systematic opinion surveys. Soft information represents the opinions of decision-makers. Any spatial decision-making must focus on a mix of hard and soft information. Central to spatial decision-making is the way in which these two types of information are combined to strike a balance for the desired level of predictability of the outcome. Decision problems can be categorized on a continuum ranging from predictable situations (perfect information) to situations that cannot be predicted (no information). The former is referred to as certainty or deterministic situation while the later is a decision problem under uncertainty. Uncertainty can be further categorized as stochastic (probabilistic) information and imprecise information (fuzzy decisions).

Classification

It is almost always the case that the source data, whether in real or integer format, will need to be further classified before further use. Classification is an essential part of any data reduction process, whereby complex sets of observations are made understandable. Although any classification process involves some loss of information, a good scheme not only aims to minimize this loss, but by identifying natural groups that have common properties, provides a convenient means of information handling and transfer (Burrough, 1986). Further, in any classification process, care must be taken to preserve the appropriate level of detail needed for sensible decision-making at a later stage (Burrough, 1986; Aguilar-Manjarrez, 1992; 1996; Ross, 1998).

Classification includes the use of “thresholds” for each data source to cast them into suitability classes for further modelling (e.g. high, medium, low suitability habitat for clams). Thresholds will entirely depend upon the nature of the project and are determined by the experts conducting the study using literature and consulting with other relevant experts. The source data together with their corresponding thresholds provide the basis for a GIS analysis.

As an example of classification the thresholds relating temperature to growth were determined by Kapetsky and Aguilar (2007) as one of the key criteria to estimate open ocean aquaculture potential for Cobia in the Atlantic and Gulf of Mexico and Puerto Rico-US Virgin Islands. Thresholds for cobia were based on Ueng *et al.* (2001) and M.J. Osterling (personal communication, 2005). Ueng *et al.* (2001) state that cobia growth

rates were highest from 28 to 32 °C and that growth decreased below 20 °C. They concluded that half of the growth rate variation was due to temperature variation. M.J. Osterling (personal communication, 2005) noted that cobia can be grown at temperatures from 21 to 28 °C and that better growth was attained at higher temperatures. He and others have observed that feed intake is reduced at temperatures below 20 °C.

Aguilar-Manjarrez (1996) provides an exhaustive review of five methods that have been explored to classify data on land types for various uses that are equally relevant for classifying aquaculture data:

- The FAO land evaluation methodology which assesses land suitability in terms of an attribute set corresponding to different activities (e.g. very suitable (VS), suitable (S), moderately suitable (MS) and unsuitable (US)).
- The limitation method in which each land characteristic is evaluated on a relative scale of limitations (e.g. in the example above by Kapetsky and Aguilar (2007) the temperature thresholds were set using a limitation method for Cobia as < 20 °C, no feeding; 20-25 °C, growth; >25 °C better growth);
- The parametric method in which limitation levels for each characteristic are rated on a scale of 0 to 1, from which a land index (%) is calculated as the product of the individual rating values of all characteristics (e.g.. suitability scores are defined on an arbitrary scale ‘between’ 0 and 1, where 0 defines a non-suitable area, and 1, the most suitable. This method provides a distinct advantage over traditional Boolean logic where an element must belong to a ‘crisp’ set (0 or 1) as it allows the discrimination of levels of suitability as opposed to a simple binary classification).
- The Boolean method which assumes that all questions related to land use suitability can be answered in a binary fashion, and that all important changes occur at a defined class boundary (an element must belong to a ‘crisp’ set (0 or 1), e.g. protected areas that are excluded for any aquaculture development altogether would be defined as 0);
- The fuzzy classification is usually defined on a continuous scale from zero to one, where zero is non-membership and one is full membership. Fuzzy classification may also be applied to geographic objects themselves, so that an object’s boundary is treated as a gradated area rather than an exact line. In GIS, fuzzy classification has been used in the analysis of soil, vegetation, and other phenomena that tend to change gradually in their physical composition and for which attributes are often partly qualitative in nature. (e.g. according to ICLARM and GTZ (1991), the most suitable slopes for large ponds (1-5 ha) in Africa should not exceed 1-2 percent. However, for small-scale farms where most ponds will be from 0.01-0.05 ha, slopes up to 5 percent are most favourable, thus the slope classification would range from 1-8 percent).

For GIS applications, all of the above methods can be used to classify source data into a point scale of suitability (with zero or one being the least suitable). However, the choice among classification and threshold methods to use is entirely dependent on the type of data and intended uses of the output information. From a GIS viewpoint classification and thresholds also allows normalization of all data layers, an essential pre-requisite for further modelling. From an EAA viewpoint, thresholds are useful in examining issues related to aquaculture and allow for the inclusion of policy decisions (e.g. pollution thresholds; carrying capacity limits, etc).

Multi-criteria evaluation

Decision-analysis is a set of systematic procedures for analyzing complex decision problems. The basic strategy is to divide the decision problem into small, understandable parts; analyze each part; and integrate the parts in a logical manner to produce a meaningful solution (Malczewski, 1999).

In a multi-criteria evaluation (MCE), an attempt is made to combine a set of criteria to achieve a single composite basis for a decision according to a specific objective. For example, a decision may need to be made about what areas are the most suitable for pond fish farming. Criteria, i.e. production variables that affect location, might include availability of water, soils types, slope gradient, proximity to roads, exclusion of reserved lands, and so on. Through a multi-criteria evaluation, these criteria representing suitability may be combined to form suitability maps from which the final choice will be made.

Over the last decade, a number of multi-criteria methods have been implemented in the GIS environment including: the Boolean procedure; weighted linear combination (WLC), ideal point methods, concordance analysis, Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), Order Weighted Average (OWA) and recently the Linguistic Quantifier Ordered Weighted Averaging. Among these procedures, the WLC and Boolean overlay operation are considered the most straightforward and have traditionally dominated the use of GIS as decision support tools (Malczewski; 2006).

In the Boolean procedure there are no weightings assigned to criteria. This combination procedure also carries the lowest possible risk since the only areas considered suitable in the result are those considered suitable in all criteria. The Weighted Linear Combination (WLC) is characterized by full tradeoff between factors and average level of risk. Factor weights (not used at all in the case of Boolean procedure), are very important in WLC because they determine how individual location factors will tradeoff relative to each other. In this case, the higher the factor weight the more influence that factor has on the final suitability map.

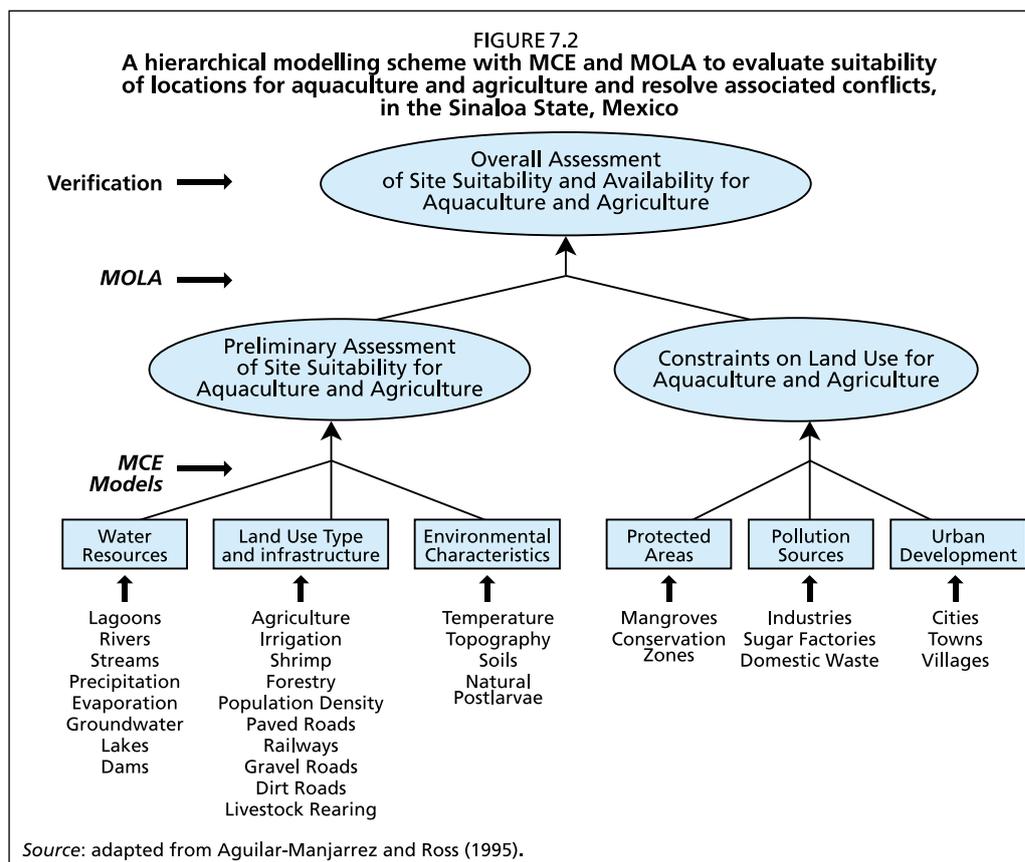
The Analytical Hierarchy Process (AHP) is a flexible and yet structured methodology for analyzing and solving complex decision problems by structuring them into a hierarchical framework (Saaty, 1980; 2001; 2004). The first step in the AHP procedure is to decompose the decision problem into a hierarchy that consists of the most important elements of the decision problem. In developing a hierarchy, the top level is the ultimate goal of the decision at hand. The hierarchy then descends from the general goal to the more specific elements of the problem until a level of attributes is reached. Although the hierarchical structure typically consists of goal, objectives, attributes and alternatives, a variety of elements relevant to a particular decision problem and a different combination of these elements can be used to represent the problem. Figure 7.2 illustrates a hierarchical modelling scheme to evaluate suitability of locations for aquaculture and agriculture and resolve associated conflicts, in Sinaloa State, Mexi

The AHP is concerned with measuring tangibles and intangibles, it is a tool for articulating our understanding of a decision problem. The AHP is particularly useful for EAA because it makes it possible for people to debate and combine their judgements.

The Order Weighted Average (OWA) technique assumes both factors and constraints as in the WLC method. However, in addition to factor weights, order weights are used. This second set of weights will allow for direct control over the levels of tradeoff and risk. The degree of overall tradeoff is the degree to which factor/tradeoff weights are applied in the combination procedure; the influence of these weights, from none to full, is governed by the set of order weights. Order weights are a set of weights assigned not to factors themselves but to the rank order position of factor values for a given location (pixel). The factor with the lowest suitability score, after factor weights are applied, is given the first order weight, the factor with the next lowest suitability score is given the second order weight, and so on.

Borowshaki and Malkzewski (2008) propose a new GIS-multicriteria evaluation (MCE) system through implementation of AHP_OWA within ArcGIS, capable of integrating linguistic labels within conventional AHP for spatial decision-making. They suggest that the proposed GIS-MCE would simplify the definition of decision strategies and facilitate an exploratory analysis of multiple criteria by incorporating

qualitative information within the analysis. To illustrate the application of AHP_OWA in a real-world decision problem, the authors used data for a land suitability problem in Arva and Ilderton region, north of London, Ontario, Canada. One of the few applications using the OWA approach in aquaculture so far has been that conducted for a site selection analysis for oyster culture in the southern bay of the Florianópolis in Brazil (SEAP, 2007). This new AHP_OWA approach is useful for EAA in that it can assist in combining the right balance between the amount of hard and soft information used in the decision-making process.



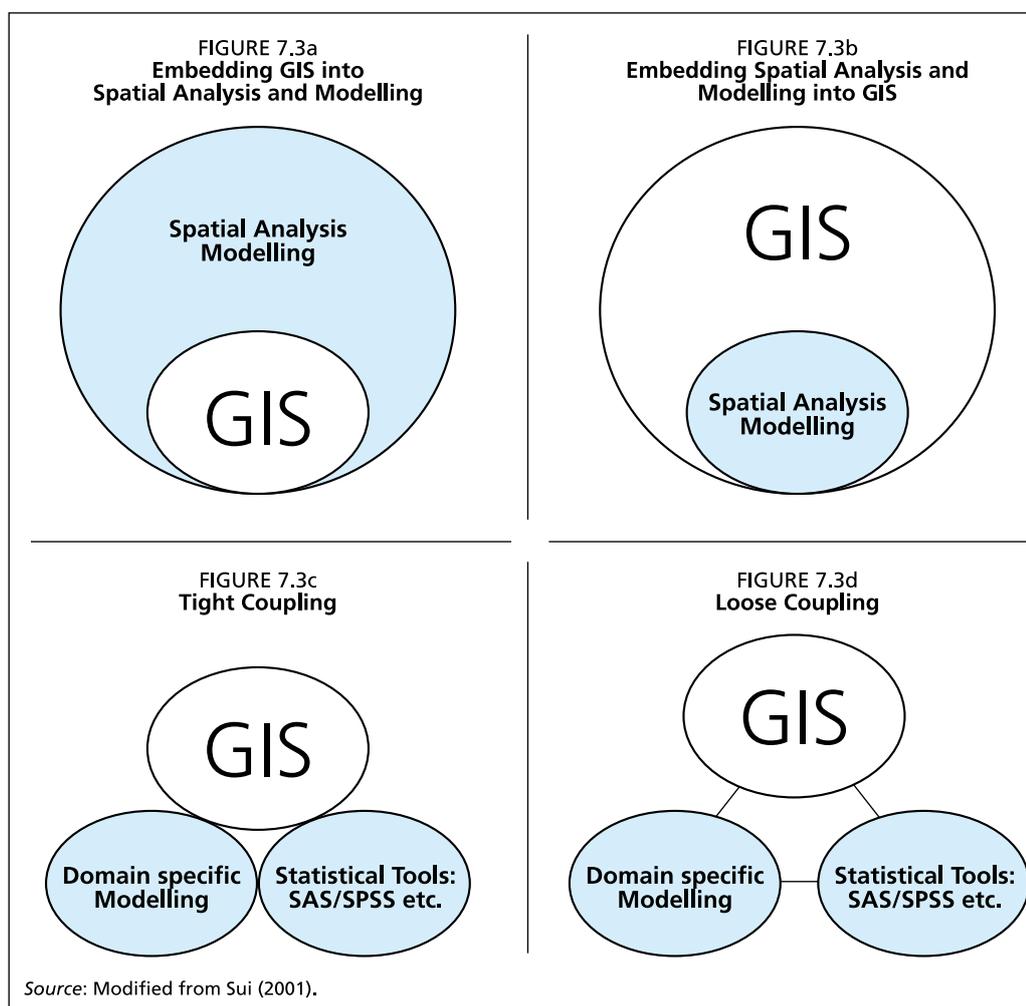
In summary, decision-making is a sequential process. Any decision-making process begins with the definition of the problem or the objective to be reached. Once the decision problem is defined, what follows is setting up a set of criteria that reflect all aspects of the problem. The purpose of weights is to express the importance or preference of each criterion relative to other criteria. Alternatives are often determined by constraints, which limit the decision space of feasible alternatives. Decision rules integrate criteria, weights and preferences to generate an overall assessment of the alternatives. Recommendations are based on a ranking of the alternatives, with reference to possible uncertainties or sensitivities. Sensitivities are changes in the input of the analysis that bias the outcome.

7.3 MODELLING

For the purpose of this report, the term “model” is defined as a simplified representation of reality used to simulate a process, understand a situation, predict an outcome, or analyse a problem. A model can be viewed as a selective approximation, which, by elimination of incidental detail, allows some fundamental aspects of the real world to appear or be tested (Crespi and Coche, 2008).

Four strategies are used to integrate GIS with spatial analysis and modelling. These are: embedding GIS into analysis and modelling; embedding analysis and modelling into GIS; tight coupling; and loose coupling (Figures 7.3a-d).

An overview is given below of some of the GIS related modelling approaches in aquaculture in the context of their potential to support the EAA.

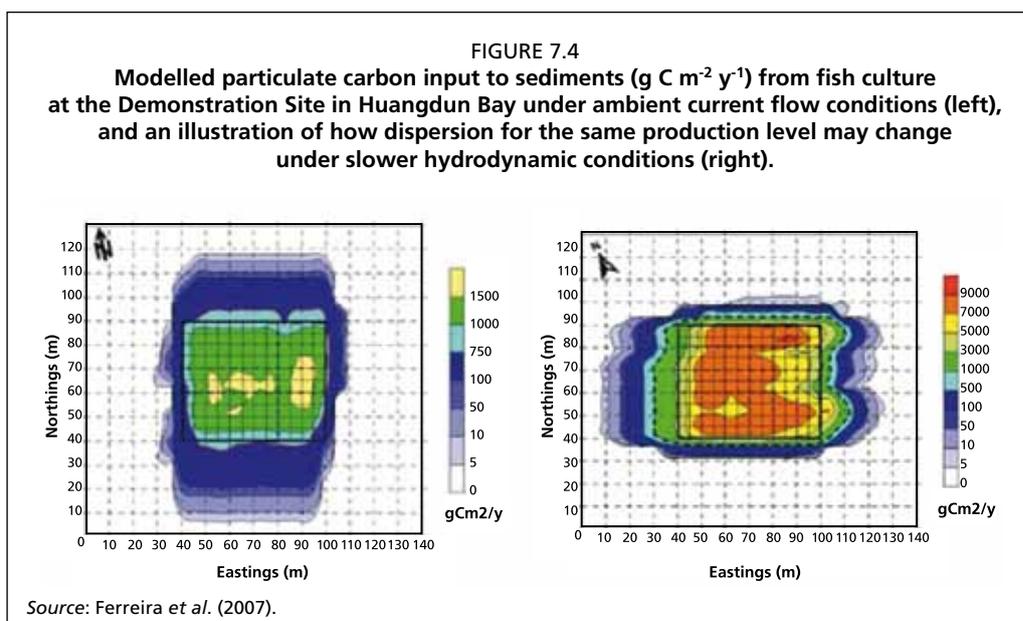


Particulate waste dispersion model

Waste production from aquaculture activities is probably perceived to be one of the most controversial and detrimental impacts from aquaculture on the environment. Literature is conflicting in terms of the magnitude of the effects. It has been proposed that these impacts may not in fact be too detrimental as only as small fraction of the total nutrients are added to coastal waters (Black, 2001).

Models for dispersion of fish wastes have been under development at the Institute of Aquaculture in Stirling since the early 1990's. The model of dispersion of particulate wastes has developed through a series of stages, from simple spreadsheet-based calculations (Telfer, 1995) to more complex spreadsheet models using GIS functions (Walls, 1996; Perez *et al.*, 2002; Brooker, 2002;) to a fully integrated GIS dispersion model (Corner *et al.*, 2006), and through to a complex spreadsheet particulate model (Kimber, 2007). More recently, Hunter, Telfer and Ross (2006; 2007) and Hunter (2009) have developed multi-site particulate dispersion models for marine cage fish culture in Scotland at one metre resolution. The model was run on a range of coastal fjord systems and demonstrated the variation in particulate waste dispersion patterns in each fjord system. Hunter's particulate model proved to be effective and rapid to deploy in multiple sites, and with further refinements this model could further extend the capabilities of current waste dispersal modelling.

A practical example of the particulate waste model developed by Corner *et al.* (2006) was applied at a demonstration site in Huangdun Bay, China (Figure 7.4). The main emphasis was on the simulation of the trajectory of the wasted food and metabolic products. This allowed for the determination of organic enrichment of the sediment below the fish cages, which in turn can be used to predict changes to benthic biodiversity through empirically derived calibration curves. Such enrichment footprints are used for the environmental regulation of cage fish farming in many countries (Ferreira *et al.*, 2007; Nobre *et al.*, 2010).



Particulate waste dispersion models are particularly valuable for supporting Principle 1 of the EAA because they are useful for examining: severity and extent of sediment footprints, zone of impact, overall impact between farms, distances between farms, and sensitive habitats. From a GIS viewpoint, it is clear that GIS has the capability to take waste modelling forward.

Hydrodynamic models

Two hydrodynamic models were coupled with a shellfish growth model in a study by Ferreira *et al.* (2007) in the Irish Lough ecosystems. The “Delft3D-FLOW” hydrodynamic model was used to simulate the tidal, wind and ocean currents in the study area and the “Delft3D-WAQ/ECO” was been adopted for detailed simulation of water and sediment quality as well as algae growth and species composition.

Ferreira *et al.* (2008) conducted hydrodynamic modelling in a study using different spatial and temporal resolutions in two contrasting coastal systems in China. Hydrodynamic simulation was required to provide the various water quality and ecological models with flow fields in order to facilitate the simulation of water transport in these models.

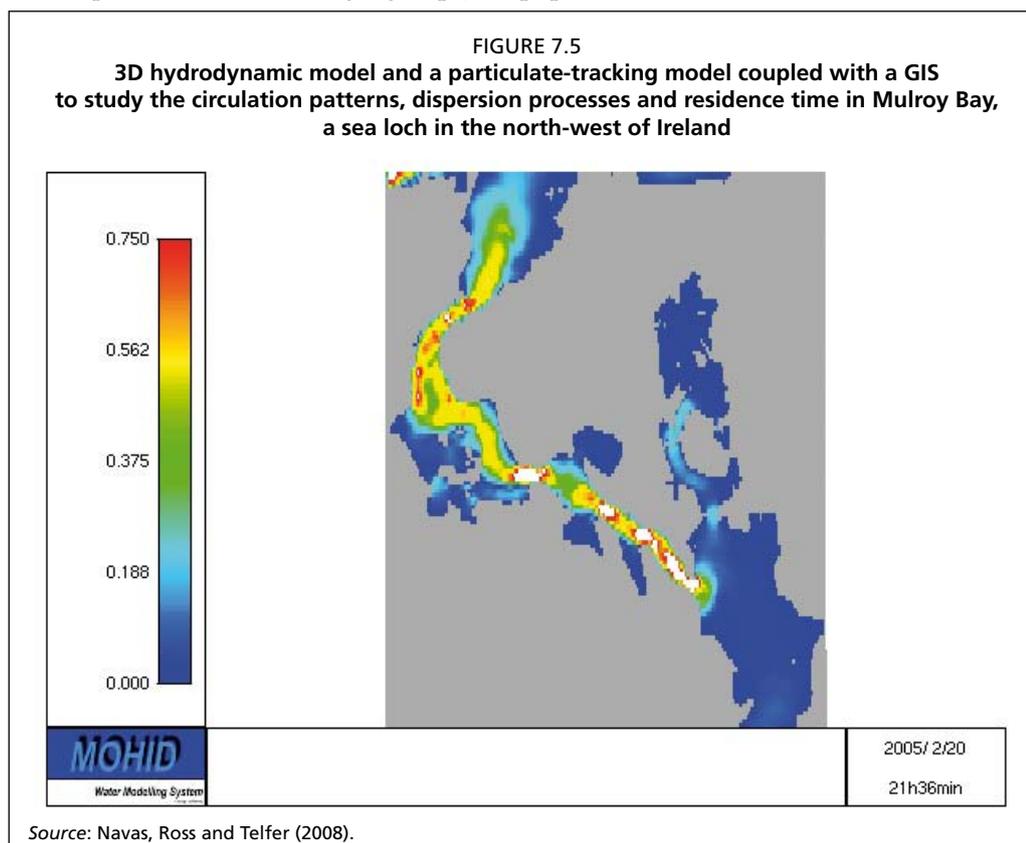
Longdilla, Healya, and Black (2008) developed an integrated GIS approach for sustainable aquaculture management area site selection within the Bay of Plenty, New Zealand, with specific reference to suspended mussel (*Perna canaliculus*) aquaculture. Wind and tidally forced current speeds throughout the Bay were determined from a 3-dimensional baroclinic numerical hydrodynamic model.

More recently, Navas, Ross and Telfer (2008) have set out to evaluate the use of a 3D hydrodynamic model and a particulate-tracking model coupled with a GIS to study the circulation patterns, dispersion processes and residence time

in an Irish fjord, and area of restricted exchange, geometrically complicated and host to many important aquaculture activities (Figure 7.5). The hydrodynamic model was calibrated and validated by comparison with sea surface and water flow measurement data collected in 2005 at two stations along the fjord. The model provided spatial and temporal information on circulation and renewal time and helped to determine the influence of winds on circulation patterns.

Note: The full animation can be seen at:

www.aqua.stir.ac.uk/GISAP/gis-group/juan.php



Another good example of Hydrographic modelling of value to EAA is a study by White (2009) carrying out an Environmental Impact Assessment and monitoring of small-scale cage farms in Bolinao, Philippines. Hydrographic modelling was used to assess residence time and predictive modelling was used to estimate impact on the sediments and to identify the optimal areas for siting aquaculture zones and distances between these zones.

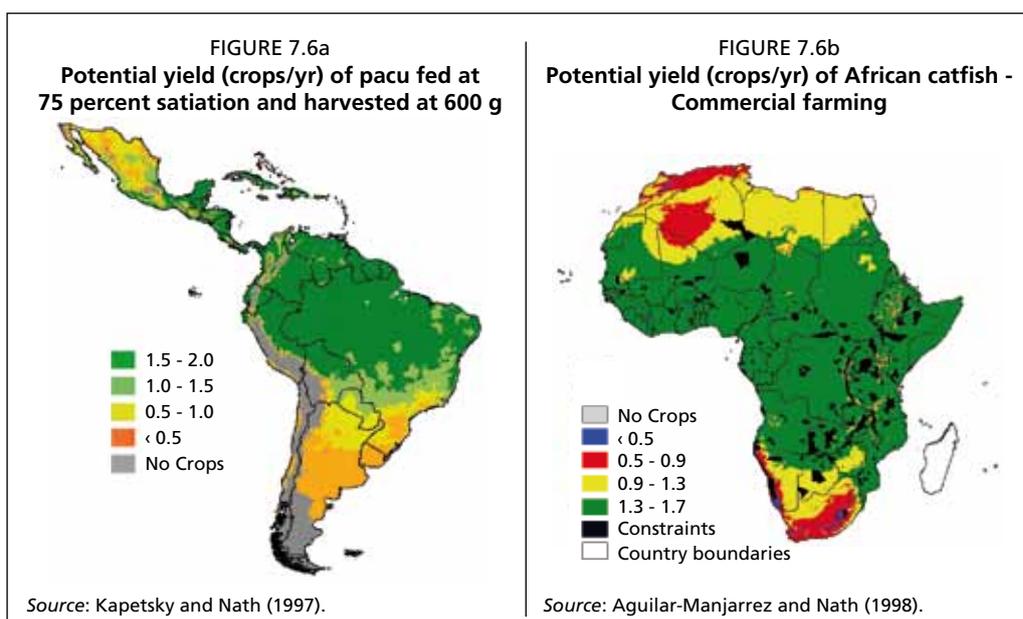
Hydrodynamic models are useful for the EAA because they can be used to resolve a number of relevant issues for aquaculture such as flushing and dispersion and residence time of particles (e.g. nutrients); pollution patterns, sea lice life cycle, etc. Also, the dynamic nature of these simulations make them particularly valuable for facilitating policy decisions.

Growth models

A step in coupling GIS with fish growth models was taken by Kapetsky and Nath (1997) and by Aguilar-Manjarrez and Nath (1998) to assess fish farming potential in Latin America and Africa respectively. Two simulation models were used in these studies. The first of these was used to generate mean monthly water temperature profiles across each continent. This output was then used, among other input parameters, in a bioenergetics model to estimate fish yield potential (in crops per year) for indicator

species under small-scale and commercial farming conditions (Figures 7.6a,b). The resulting output was exported to GIS for further analysis and manipulation. Suitability maps from the farming system models were overlaid with those from the bioenergetics model to reach a combined evaluation that indicated the coincidence of each land quality suitability class with a range of yield potential.

From a EAA viewpoint, these studies are useful for examining spatial issues related to the development of aquaculture and illustrate how quantitative estimates of potential can be derived to show where and how much potential is available. From a GIS perspective, these studies are noteworthy because they managed to incorporate a bioenergetics model into the GIS to predict, for the first time, fish yields across Latin America and Africa. A follow-up to these studies could look at climate changes implications on growth.



Note: Figures 7.6a,b are outputs from the bioenergetics model. The outputs of the farming systems models (not shown in these figures) included land quality factors such as water resources, soils, population density, etc.

Biodiversity

Seeking the sustainable development of marine cage siting for aquaculture, Hunter (2009) developed a GIS-based model to show the distribution of important areas for biodiversity in coastal areas of the Western Isles in Scotland. The area is host to a wide variety of diverse habitats and species but is also a significant area for aquaculture in Scotland. GIS was used to develop species distribution and habitat suitability models to establish the interaction of biodiversity with aquaculture and the potential consequences of aquaculture development. A number of biodiversity indicators of sensitivity were included in the model, including endangered species, species sensitive to aquaculture, protected areas, fish spawning and nursery areas and species important to the Western Isles. The combination of these models highlighted areas of low and high biodiversity and the consequences that aquaculture development would have on the biodiversity of the area.

It is realistic to expect that aquaculture, being a human activity, will lead to some loss of biodiversity or affect ecosystems services to some extent. Thus from an EAA perspective this study is particularly useful because it used biodiversity indicators to assess the ability of coastal sites to incorporate aquaculture activities whilst still ensuring that the relevant biodiversity criteria such as endangered species are considered. From

a GIS viewpoint this study is innovative because it deals with a combination of species and groups of indicator species and with very little modification these models could also be developed to cover the entire Scottish coastline and if relevant data is also available they could be applied in any coastal locations worldwide.

ECASA Toolbox

ECASA an ecosystem approach to sustainable aquaculture toolbox is an innovative environmental management resource developed specifically for European marine aquaculture. The toolbox has evolved over the course of the ECASA project with the aim of answering the needs of industry, regulators and environmental managers involved in marine aquaculture. The ECASA toolbox is an internet based source of information on a range of indicators, models and procedures that can be applied to shell-fish and fin-fish aquaculture, informing on Environmental Impact Assessment and effective site selection (www.ecasa.org.uk). A number of the models have been used in the case studies presented in this chapter (e.g. DEPOMOD), and they are a rich source of information.

Bayesian network modelling

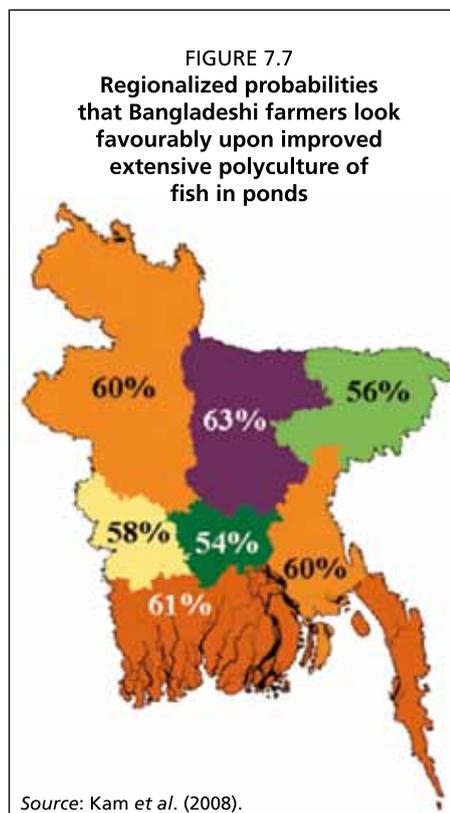
The use of GIS requires quantifiable data that are comprehensively mapped over the area of interest. Many factors that determine whether a particular aquaculture technology is sustainably adopted – particularly social, cultural and institutional factors – are not readily quantifiable, let alone mapped. In many situations these “soft” factors have an overriding influence on technology adoption yet in general they are usually excluded from GIS analysis and modelling. One noteworthy example that has overcome this problem is a GIS based study on fish farming in Bangladesh by Kam *et al.* (2008). The study describes the use of modelling tools based on Bayesian networks (BN) to incorporate factors of a qualitative nature that influence farmers’ perceptions about a particular aquaculture technology. The outcome of the Bayesian modelling is a reading of the probability of farmers’ positive versus negative perception of the target technology, which indicates the likelihood that they will adopt it (Figure 7.7).

At present, the overall social, economic and environmental effects of aquaculture are rarely considered all together to determine the final balance and to decide positively or negatively on a project. Therefore, the study by Kam *et al.* (2008) is important to EAA because it illustrates how GIS can be used to address the well-being of relevant stakeholders, especially the rural and poorest groups, and how they will benefit (or at least will not deteriorate), especially if there are environmental costs.

7.4 DECISION SUPPORT TOOLS

These days, dozens of software systems offer GIS decision-making capabilities. The range and number available sometimes make it difficult to discern the differences among systems and the strengths and limitations of each. The interesting point to remember is that there are at least as many different types of GIS software systems as there are decision-making processes.

Particular GIS software systems are often specialized to suit certain types of decision-



making. That is, they are customized to meet specific needs, e.g. to demographic forecasting, transportation planning, environmental resource analysis, urban planning, fisheries, aquaculture, coastal zone management, and so on. These systems may respond well to individual problems, but they are also limiting. Special-purpose GIS designed for airport planning and maintenance, for instance, will not be well suited to demographic modelling.

Other software systems are not so specialized. The Intergraph Corporation's MGE/MGA system or ArcGIS (produced by the Environmental Systems Research Institute) have become well-known because they can be used in a wide number of applications. These general purpose systems also offer features that can be customized or made available as add-on extensions to meet various individual needs.

Other systems such as MapInfo attempt to provide functions that will be of value in one or more of the broad application domains, for instance in demographic analysis or marketing research. Yet quite apart from these more general systems, there are dozens of very specialized software systems that are best suited to one task, one application, or even to just one part of a broader decision-making process, for example for storing maintenance records of a highway system or for planning the expansion of an electric distribution network.

Table 7.1 is a list of GIS and Decision Analysis software products that support many of the spatial decision analysis techniques and methods relevant to aquaculture.

Belton and Stewart (2002) state that software is essential for effective multi-criteria analysis. In this way the facilitator, analyst and decision-maker are free from the technical implementation details and are able to focus on the fundamental value judgment and choices. They conclude that although it is possible to set-up macros in a spreadsheet to achieve this, it is more convenient to use specially designed software. Janssen and van Herwijnen (2006) compiled a list of software tools (a few which are built into GIS) to support multi-criteria analysis that may aid aquaculture activities (siting, zoning, monitoring, etc). The list becomes rapidly outdated. Therefore, other listings of MCE software can be found at www.lionhrtpub.com/orms/ORMS-search.shtml.

Not all the GIS software listed in Table 7.1 are described below, and instead, the main GIS softwares used in aquaculture so far are described along with recent examples that are most relevant to EAA.

Idrisi

To date, IDRISI is still the industry leader for the development of decision support software. Based within the Graduate School of Geography at Clark University, Clark Labs is known for pioneering advancements in areas such as decision support, uncertainty management, classifier development, change and time series analysis, and dynamic modelling. Clark Labs is best known for its flagship product, the IDRISI GIS and Image Processing software. Over the past several years, the research staff at the Clark Labs have been specifically concerned with the use of GIS as a direct extension of the human decision-making process—most particularly in the context of resource allocation decisions. In 1993, IDRISI introduced the first instance of Multi-Criteria and Multi-Objective decision making tools in GIS.

Clark Labs worked with Conservation International over a period of several years to develop a modelling environment that could be used for a variety of land change scenarios and contexts. This cutting-edge tool, the Land Change Modeler for Ecological Sustainability, was released within the IDRISI software in 2006. In 2007, Clark Labs developed the Land Change Modeler as an extension for ArcGIS, broadening the accessibility of this

1 DEPOMOD is a particle tracking model used for predicting the sinking and resuspension flux of particulate waste material (and special components such as medicines) from fish farms and the benthic community impact of that flux.

important tool for users concerned with land change, conservation and biodiversity. IDRISI's pioneering advancements in decision support, uncertainty management, classifier development, change and time series analysis, and dynamic modelling are all useful in supporting EAA. The new Land Change Modeler will be particularly valuable tool for predicting the interactions between aquaculture and biodiversity.

There are a vast number of examples of GIS applications for aquaculture that have benefited from IDRISI's capabilities. More recently, a project by Kam *et al.* (2008), mentioned in Section 7.3 above, on a GIS based study of fish farming in Bangladesh extends IDRISI's capabilities by developing a simple Excel-based batch-control program called the IDRISI™ Support Program (IdriSP) to automate the modelling process. The programs developed are packaged into a decision-support toolkit and offered as freeware in a DVD-ROM. They are particularly useful for use in developing countries where there are limitations to hardware capacities. For the convenience of target users, the project also developed the Suitability Analysis and Query for Aquaculture (SAQUA) software, which allows for GIS modelling of aquaculture suitability and for querying multiple map layers. The modelling features of SAQUA, enables the MCE technique to be used for mapping aquaculture suitability independently of any licensed, commercial GIS software.

TABLE 7.1
GIS software to support decision-making

Software/Extension	Decision support capability	Author	URL
ArcGIS	MCE, OWA	Environmental Systems Research Institute Inc	www.esri.com
AWRD (African Water Resource Database)	ArcView 3.x extension main thrust is on watersheds analysis	FAO-FIRA	www.fao.org/fishery/gisfish/id/2393
GisPlus, Mapitude, TransCA		Caliper Corporation	www.caliper.com
GRASS		GRASS Development Team	http://grass.itc.it/index.php
IDRISI	MCE, OWA, Fuzzy, Neuo-Fuzzy, Bayesian, Time series, etc	Clark University	www.clarklabs.org
IdriSP (IDRISI™ Support Program)	Excel-based batch-control program to automate the MCE modelling process	World Fish Center	www.worldfishcenter.org/rdproject www.fao.org/fishery/gisfish/id/4815
Manifold	Fuzzy Logic	Manifold Net Ltd	www.manifold.net/news/pr_bt2.html
MapInfo		MapInfo Corporation	http://mapinfo.com
MarGIS™		MarCon Computations International	www.marcon.ie/website/html/margis.htm
MARS	Designed to identify potential areas for sectoral development	The Crown Estate	www.thecrownestate.co.uk/mars
MCE-FLOWA	ArcGIS ArcScript	Combines MCE, OWA and includes linguistic qualifiers	http://arcscripts.esri.com/details.asp?dbid=14894
Modular GIS Environment (MGE), GeoMedia, GeoMedia Web Map		Intergraph Corporation	www.intergraph.com
NENle and BNSS	Bayesian network modelling	World Fish Center	www.worldfishcenter.org/rdproject

TABLE 7.1 Cont.

GIS software to support decision-making

Software/Extension	Decision support capability	Author	URL
Smallworld GIS		Smallworld Systems Inc.	www.worldfishcenter.org/rdproject www.fao.org/fishery/gisfish/id/4815
SAQUA (Suitability Analysis and Query for Aquaculture)	MCE and Bayesian network modelling	World Fish Center	www.worldfishcenter.org/rdproject www.fao.org/fishery/gisfish/id/4815
SPANS (Spatial Analysis System)		TYDAC Research Inc.	www.pcigeomatics.com

ArcGIS software

ESRI designs and develops the world's most widely used GIS technology. ESRI software is used by more than 300 000 organizations worldwide (www.esri.com). To increase the capabilities of ESRI products, optional software modules (or extensions) add specialized tools and functionality. ESRI's ArcGIS 9.3 desktop allows one to analyze data, examine relationships, test predictions, and ultimately make better decisions. It is a family of three products—ArcInfo, ArcEditor, and ArcView—that share the same core applications, user interface, and development environment. Each product provides additional GIS functionality whilst moving from ArcView to ArcEditor to ArcInfo (www.esri.com/software/arcgis/about/gis_for_me.html).

Specific to decision support, both the Analytical hierarchy process (AHP) and the Linguistic Quantifier Ordered Weighted averaging (OWA) procedures have been implemented individually in GIS environments. Eastman (1997) and Jiang and Eastman (2000) implemented OWA operators in GIS-IDRISI. Malczewski *et al.* (2003) implemented parameterized OWA procedures in ArcView 3.2 (i.e. a previous version of ArcGIS) environment as a GIS-OWA module. The AHP has been part of the IDRISI functionality for many years and it has also been implemented in the ArcGIS environment as a VBA macro (Marinoni, 2004).

A recent implementation of the AHP-OWA operators using fuzzy linguistic quantifiers has been developed by Boroushaki and Malczewski (2008) as an ArcScript extension (MCE-FLOWA). The AHP-OWA ArcScript brings the capabilities of the AHP and the OWA into ArcGIS environment for spatial decision-making problem solving.

MCE and OWA methods can be conducted manually, using map algebra in Excel and/or using a calculator or a model builder within a GIS software. However, the MCE-FLOWA ArcScript facilitates the process by providing a single tool thus making the entire MCE/OWA process easier and faster and improving ArcGIS functionalities.

The MCE technique was used by Vianna (2007) to improve the decision-making process for assessing the potential of marine aquaculture in the southern bay of Florianópolis, Brazil. A simplified version of this study using a small subset of factors and criteria has been drafted by L. Vianna and Philip Scott using the MCE-FLOWA ArcScript to conduct a few GIS training courses in Brazil (L. Vianna, personal communication, 2010). The use of MCE-FLOWA is interesting from a GIS viewpoint because it is perhaps the first application to use the ArcScript for aquaculture. The novelty behind this approach is that it deals with uncertainty of imprecise information and the final maps are presented in a continuous scale from zero to one to illustrate areas from low to high aquaculture potential.

ArcView 3.3

ArcView started as a graphical program for spatial data and maps made using ESRI's other software products. Over time more and more functionality was added to ArcView and it became a real GIS program capable of complex analysis and data management. Its simple GUI was preferred by many over the less user friendly, more powerful ARC/INFO. ArcView GIS 3.3 is still currently available, but as a retired product. Many users still use the older version, especially in developing countries because it is cheaper than ArcGIS and hardware requirements are less.

Jenness, *et al.* (2007a;b) created the "African Water Resource Database" (AWRD), a set of data and custom-designed tools, combined in a GIS analytical framework aimed at facilitating responsible inland aquatic resource management with a specific focus on inland fisheries and aquaculture (www.fao.org/fishery/gisfish/id/2389). The AWRD tool itself is an example of an ArcView 3.x extension to provide an assortment of new custom-designed applications and tools in addition to those provided by ArcView 3.x. The AWRD is valuable to EAA because it can be immediately applicable to assist in a wide variety of issues such as transboundary movements of aquatic species and increased participation of stakeholders in the decision-making process about watershed area uses. At present, two FAO Technical Cooperation projects in Cameroon and Mauritania are making use of the AWRD to support the development of master plans for the development of aquaculture in Cameroon, and aquaculture and inland fisheries in Mauritania. The AWRD also serves as an excellent tool for training.

MarGIS™

The objectives of the Understanding Irish Shellfish Culture Environments (UISCE) project were to: 1) develop a suite of computer models to facilitate the prediction of different aquaculture and water quality scenarios which could influence the nature and/or scale of shellfish aquaculture activity in a bay area; 2) to provide decision support system, based on the suite of computer models to the aquaculture industry with respect to the best locations and optimal size of shellfish aquaculture sites; 3) to provide an information base and liaison facility for industry (Dallaghan, 2009).

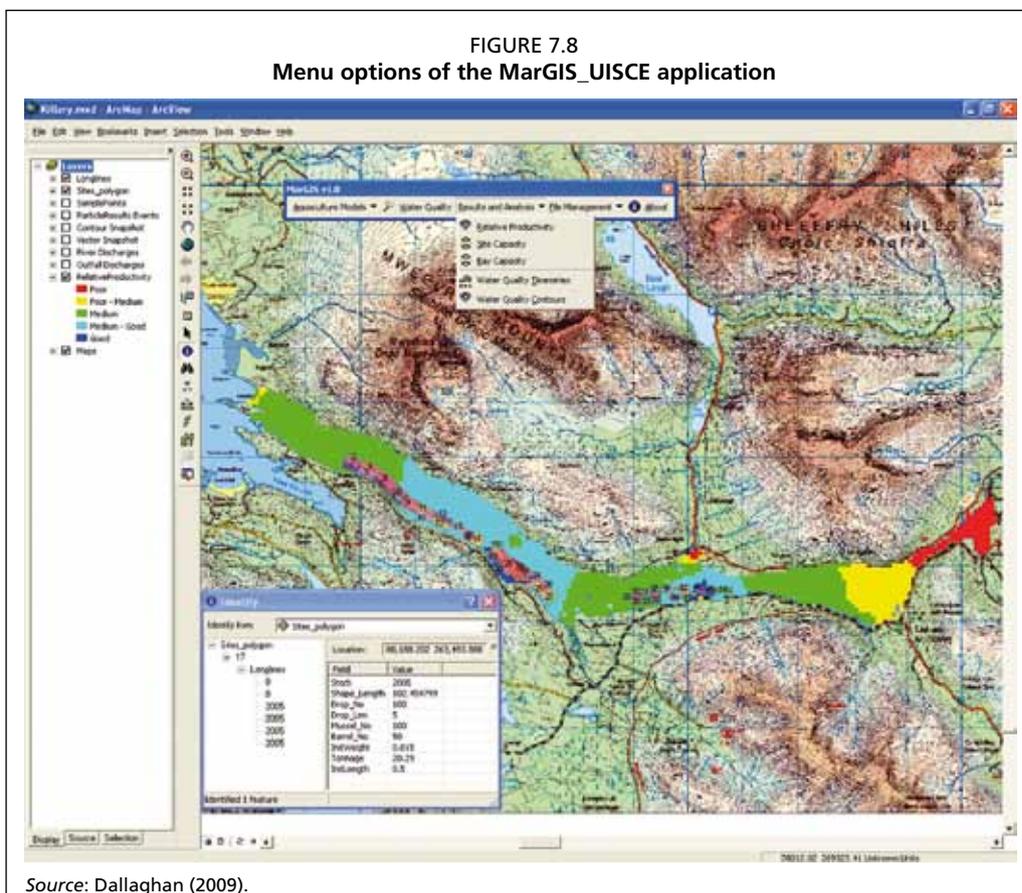
The decision support system titled MarGIS™ is a near real time interactive software application, tailored specifically for shellfish growers around the Irish coast, which will enable them to optimise their operations and production in a sustainable and environmentally sensitive manner. By using near real time current conditions, MarGIS™ will allow a farmer to quickly see what effect on his productivity would be expected if he were to make stocking density changes, for example, or to reposition one or all of his mussel lines, or introduce more mussel lines in the vicinity of the existing farm. By allowing the optimization of husbandry techniques such as this, the software encourages farmers and communities to work together (A. Berry, personal communication, 2010).

MarGIS™ has been developed within the ESRI ArcView environment to facilitate location specific predictions from the suite of computer models and allows for the modelling and reporting on issues surrounding the shellfish aquaculture industry from a 'macro' or bay scale level through to a 'micro' or individual animal level (Figure 7.8).

The primary deliverable from the UISCE project is not a 'once off' report. The resultant desktop application can be used repeatedly by growers and functionality added and refined as required. This system gives growers access to the best science that's out there and the knowledge, in software form, of international experts.

The system makes it easier to understand embayment from a food and flow perspective thus allowing growers to move away from ‘trial and error’ aquaculture. The data generated by this project forms an information base for industry and other state agencies. This data can be built upon and put to a variety of uses. An online demonstration of MarGIS™ can be seen at www.marcon.ie/website/html/margisdemo.htm.

FIGURE 7.8
Menu options of the MarGIS_UISCE application



Source: Dallaghan (2009).

MarGIS™ is especially relevant to EAA for a number of reasons; it can be used to infer near real time scenarios of environmental impacts of aquaculture at both farm and bay scales; the application encourages farmers and communities to work together thus ensures stakeholders inputs and participation; it centralizes the best science available in the fields of shellfish growth, aquaculture, water quality and ecological models and it places all this expertise under one roof. In fact, the integration of models with the GIS framework and the construction of a mechanism whereby models could communicate to each other was one of the project cornerstones.

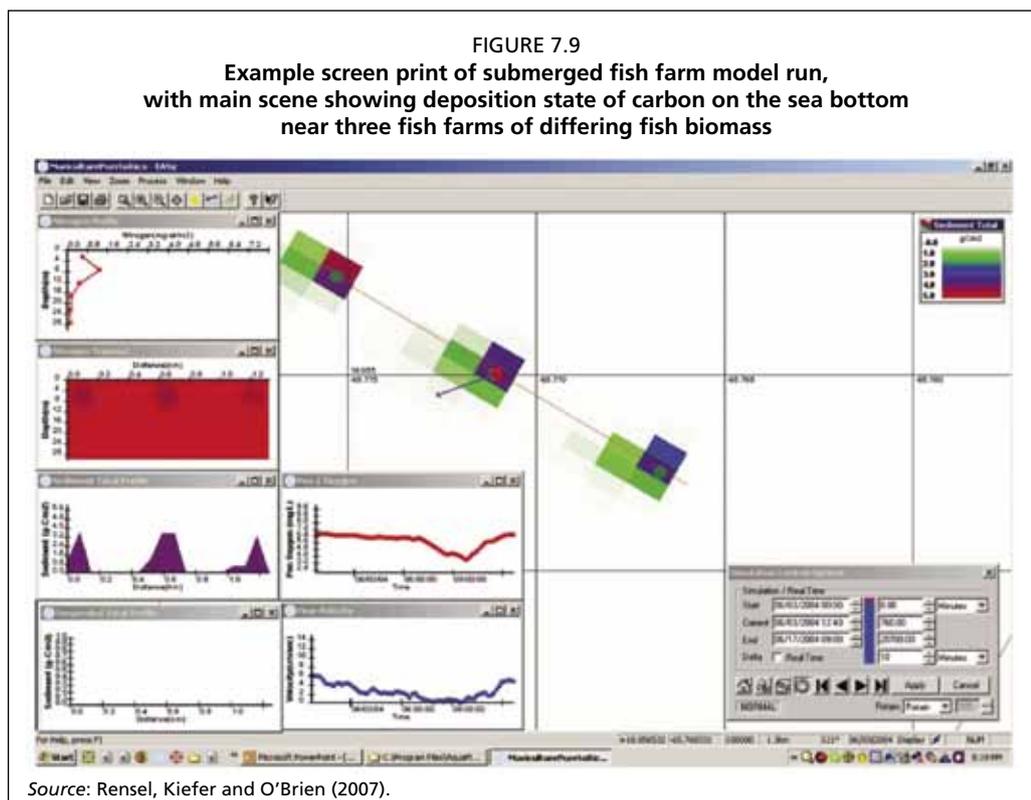
MaRS

The Crown Estate recognises that a strategic and proactive management approach will facilitate the equitable and sustainable use of the marine environment. MaRS (Marine Resource System) is being developed to increase expertise in the management of this key national asset and to ensure the multiple demands on this resource are managed in a responsible manner. MaRS is a decision-support tool using GIS technology to identify potential areas for sectoral development and has been successfully applied to wind farm development off shore (www.thecrownestate.co.uk/mars). The tool produces three key outputs: site suitability for potential business activity, the sustainability value of that activity and financial analysis of the potential revenue to the business which will enable long term informed decision-making for marine development.

AquaModel

AquaModel is an information system to assess the operations and impacts of fish farms in both water column and benthic environments, the first of its kind (www.aquamodel.org). AquaModel is a “plug-in” model that resides within the EASy Marine Geographic Information System which has been used on numerous studies and investigations involving fisheries and oceanographic topics. All environmental information from field measurements to satellite imagery is readily available for model development and use. AquaModel can be used to examine near and far field effects of individual or clusters of farms in the coastal shelf where nearshore or open-ocean aquaculture may develop. It is being adapted to deal with multiple, separate cages and multiple farm sites to meet this challenge. AquaModel is designed for: Administrators, who establish and enforce rules and extent of impact; Fish farmers, who wish to plan farms and obtain permits and; Investors, who wish to assess risks and opportunities (<http://netviewer.usc.edu/aquamodel/OverviewAquaculture.html>).

AquaModel runs on personal computers and describes benthic and water column effects concurrently. It has additional features not found in other models such as oxygen deficit plume modelling, sediment oxygen perturbation, phytoplankton stimulation, and zooplankton growth results from nutrient addition. A few options are shown in Figure 7.9.



Rensel, Kiefer and O'Brien (2007) describe a practical implementation of the AquaModel looking at “Modelling Water Column and Benthic Effects of Fish Mariculture of Cobia (*Rachycentron canadum*) in Puerto Rico: Cobia AquaModel.

Web-based tools

Rapid access to a broad spectrum of information and fast communication of ideas and data via the Internet are important stimuli to further development of GIS for aquaculture (examples are shown in Box 7.1).

BOX 7.1

Examples of Web based innovation projects in Aquaculture

Examples of work developed on Web-based applications for Aquaculture using GIS

- Brazil - The Special Secretariat for Aquaculture and Fisheries in Brazil (SEAP) created a National System for the Authorization of Aquaculture in Union Waters using GIS and Google Earth (http://200.198.202.145/seap/sinau_web/html2/google_earth.html).
- Canada
 - The Department of Agriculture and Aquaculture in New Brunswick maintains geographic information relating to the location of the province's marine aquaculture resources. MASM is a new GIS support tool which displays maps of all New Brunswick Crown Land marine aquaculture sites, as well as some site specific information, such as a site's size, the waterbody where it is located, and whether it is an approved site, a vacant site or a proposed site. Users of the tool will be able to view all marine aquaculture sites situated in tidal waters of New Brunswick (www.gnb.ca/0177/01770004-e.asp).
 - The Department of Fisheries and Oceans (DFO) is the leasing and licensing authority in the province of Prince Edward Island They have a mapping system that can be found at: www.glf.dfo-mpo.gc.ca/ao-bl/pei-ipe/leasing-baux/maps-cartes-e.php
 - Maps of aquaculture sites in British Columbia are available for download in GIS format at www.agf.gov.bc.ca/fisheries/finfish_main.htm under "Site Locations".
 - The Nova Scotia Department of Fisheries and Aquaculture have developed Aquaculture Site Mapping for the Nova Scotia Fisheries and Aquaculture, Aquaculture Division (www.gov.ns.ca/fish/aquaculture/aquamap.shtml).
- Chile - Chiles Industry Association for Salmon created a very interesting Web site that contains a section on "environmental monitoring" and "aquaculture zoning" for the industry (www.salmonchile.cl/frontend/seccion.asp?contid=473&secid=6&secoldid=6&subsecid=141&pag=1).
- Ecuador - An interesting example on the use of GIS, Remote Sensing and the Internet for assessing health management of shrimp aquaculture is an alert system to monitor shrimp health in the Gulf of Guayaquil, Ecuador (www.saema.espol.edu.ec/Jsp/index.jsp?NavBarId=gi1&idioma=1).
- Norway - The Directorate of Fisheries in Norway has created an interactive and very detailed map showing the locations of all the individual farms and their attributes; however, the site is in Norse. (<http://kart.fiskeridir.no/adaptive>).
- Peru - The Department of Aquaculture at the Ministry of Production in Peru has created an online mapping system to inventory and zone aquaculture (http://gis-dga.produce.gob.pe:8181/CATASTRO_ACUICOLA/mapviewer.jsf).
- South Africa - The Aquaculture Activities in the Western Cape Web site for South Africa has one of the largest sets of GIS the matic resources for that area. While it includes admin is tra tive areas, there are also data for estuaries, dams, rivers, marine coastal resources and even shellfish sites (http://gis.pgwc.gov.za/AISAMapping_v3_20100323/Default.aspx).
- Thailand - The Fishery Information Technology Center at the Department of Fisheries, Thailand develops and maintains computer networking, GIS, management information systems, and fisheries data collection and statistics reports for end users in Thailand. Current projects are: Inventories of aquaculture and fisheries structures; Fish cage identification and inventory; Vessel Monitoring systems; Fishing gear detection; and Flood management. Outputs from the GIS analysis are displayed on the Internet using ArcIMS technology and for internal use (<http://gis.fisheries.go.th/gis/WWW/index.jsp>).
- Global - The National Aquaculture Sector Overview (NASO) map collection consists of Google maps showing the location of aquaculture sites and their characteristics at an administrative level (state, province, district, etc) mainly, and at an individual farm level depending on the degree of aquaculture development, the resources available to complete a data collection form, and the level of clearance provided by the country experts. The NASO maps will be presented in the NASO Fact Sheets (www.fao.org/fishery/naso/search/en) and will be made available for about 20 countries in mid 2010.

Remote sensing

The scope of earth observation by satellite remote sensing, is very broad. It covers the physical system (e.g. surface temperature, winds, surface height, surface waves, ice cover and soon, surface salinity, land cover), as well as the ecosystem and water quality and surveillance. All of these are relevant to fisheries and aquaculture. Earth observation data have a very rich potential for both fisheries and aquaculture. Remotely-sensed data have been used in near-shore aquaculture site selection for more than 20 years (Kapetsky *et al.*, 1987; Meaden and Kapetsky, 1991; Kapetsky and Aguilar-Manjarrez, 2007).

Remote sensing is as an essential tool for the capture of data subsequently to be incorporated into a GIS and for real time monitoring of environmental conditions for operational management of aquaculture facilities. Remote sensing has been used to map the location of relevant land cover features in catchment areas, as well as the relevant aquaculture structures (Travaglia *et al.*, 2004; Ferreira, *et al.*, 2008). Remote sensing also has an important role to play in the early detection of Harmful Algal Blooms (HABs). For example, a team led by Hatfield Consultants Ltd. (Hatfield), under the ESA-funded Chilean Aquaculture Project (CAP), has implemented an early warning service based on Earth Observation (EO) data, which delivers forecasts of potential HABs to aquaculture companies via a customised Internet portal (Figure 7.10).

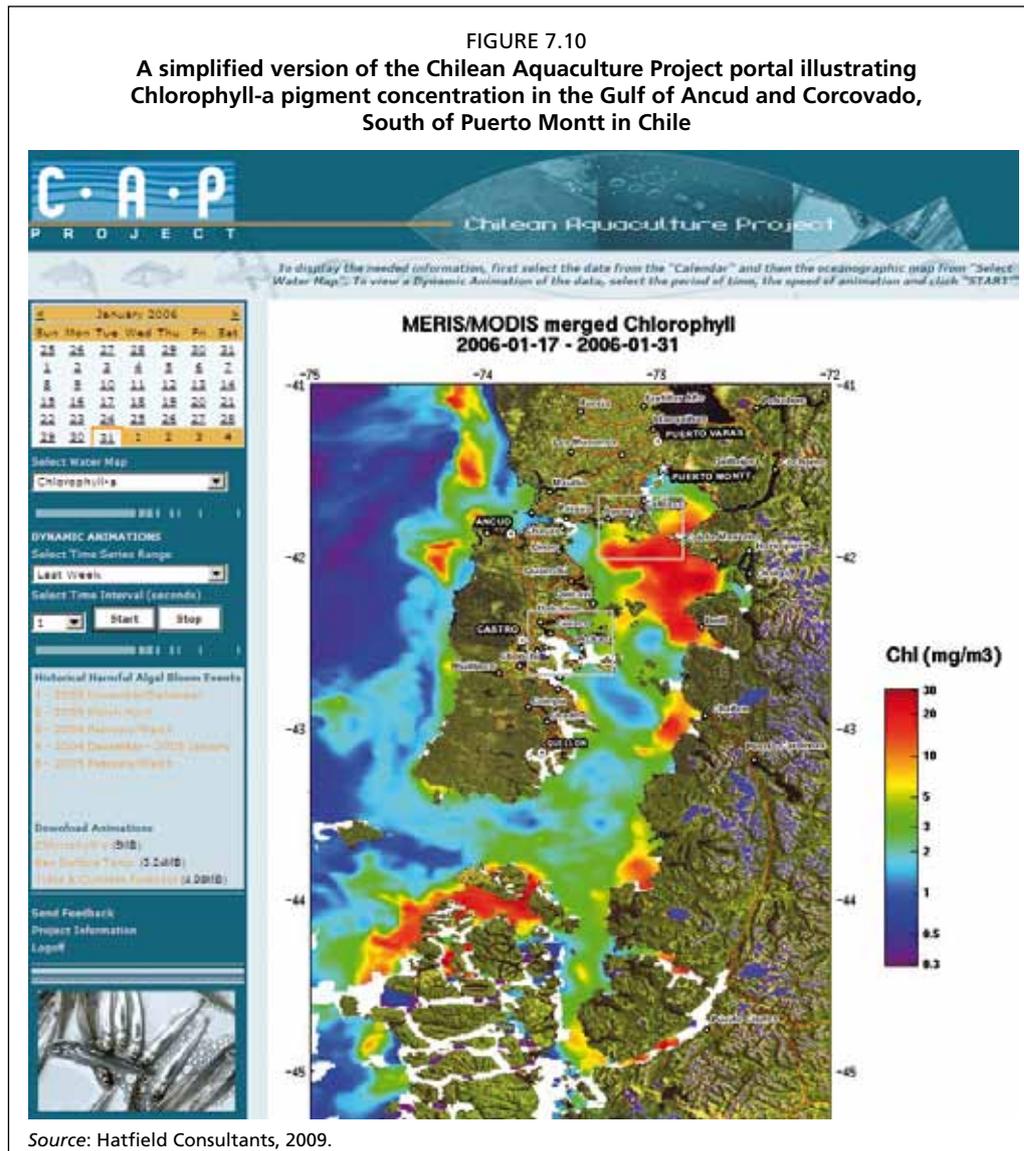
Through funding provided by the European Space Agency (ESA), Hatfield demonstrated an information framework for future Near Real Time (NRT) data integration of environmental and spatial data to improve management and monitoring of aquaculture facilities. The Chilean Aquaculture Project (CAP) project was designed for the rapidly expanding aquaculture industry, specifically monitoring programs of multinational companies, such as Mainstream Chile, as well as industrial associations (www.hatfieldgroup.com/sectors/aquaculture/cap.aspx). The products delivered under the project include daily composites of:

- Chlorophyll-a pigment concentration (Figure 7.10)
- Sea Surface Temperature (SST)
- Transparency (Secchi depth)
- Suspended Particulate Matter (SPM)

The International Ocean-Colour Coordinating Group (IOCCG, 2009) provides a recent and exhaustive report on Remote Sensing in Fisheries and Aquaculture with emphasis on marine related applications. The IOCCG report contains many examples of applications of remote sensing for the benefit of society, illustrating the advances that have been made. Similar rapid developments are expected in the future. This latter point is fundamental since remote sensing provides a global vision in an era of climate change and highly impacted and deteriorating marine ecosystems (Halpern *et al.*, 2008; Bundy *et al.*, 2009; Shin *et al.* 2009).

Google Earth

Google Earth is a virtual globe, map and geographic information program that was originally called Earth Viewer, and was created by Keyhole, Inc, a company acquired by Google in 2004 (<http://earth.google.com>). It maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and GIS 3D globe. The product, re-released as Google Earth in 2005, is currently available for free and for use on personal computers. Google Maps on the Web and Google Earth as a 3D interactive atlas software application are ideal tools for sharing geographical information in a simple way. GIS data can be incorporated as layers in Google Earth. This means that project data and/or outputs from spatial analysis can be better understood when overlaid on-top of Google Maps/Earth and these overlays can also facilitate communication and be used for wider dissemination and outreach.

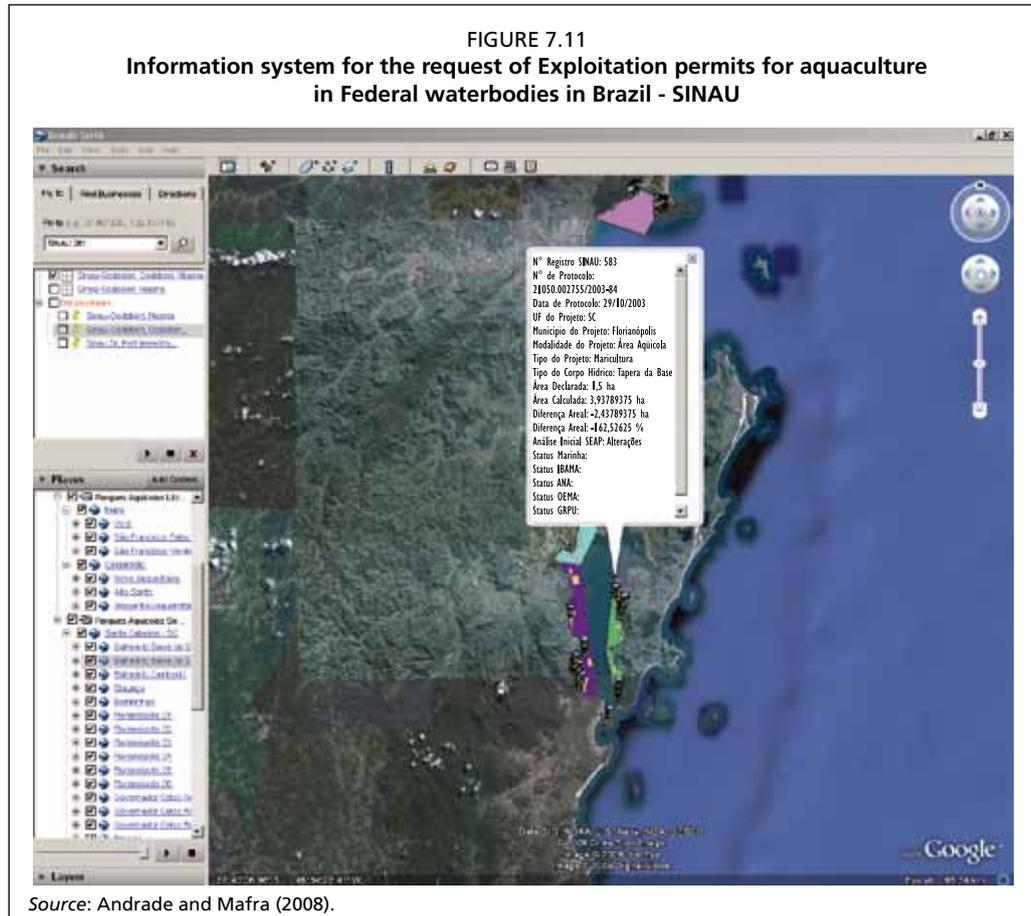


Ocean in Google Earth (<http://earth.google.com/ocean>), which launched February 2, 2009, will build on the popular 3-D mapping tool Google Earth by allowing users of Google Earth to dive beneath the water surface, explore 3D underwater terrain and browse ocean-related content contributed by leaders in ocean science and advocacy. Google is currently using Google Earth to map the world's oceans, complete with maps of seabeds and underwater imagery that can show the effects of climate change on seas. Its use for marine aquaculture is yet to be explored but the tools are very promising.

The Aquaculture Service (FIRA) of FAO is currently in the process of creating maps using "Google Maps and Google Earth" technology to assist member countries inventory and monitor aquaculture. These maps will become an integral part of National Aquaculture Sector Overviews (or NASO) – a series of fact sheet collections which have been posted in FAO's Aquaculture Gateway page (www.fao.org/fishery/naso/search/en). These maps will be of prime interest for the development and management of aquaculture from a EAA perspective because aquaculture needs to be mapped in order to place it into an ecological and administrative context.

A practical example of the use of Google Earth for aquaculture development has been reported in Brazil. Andrade and Mafra (2008) report that the Special Secretariat for Aquaculture and Fisheries in Brazil (SEAP) created a National System for the Authorization of Aquaculture in Union Waters (Sistema de Informação das

Autorização de Uso das Águas de Domínio da União para Aqüicultura - SINAU) using Google Earth for communication and outreach to manage the concession of aquaculture areas in federal waterbodies (see Figure 7.11 and http://200.198.202.145/seap/sinau_web/html2/google_earth.html).



Maps

A map is a graphic representation of the physical features (natural, artificial, or both) of a part or the whole of the Earth's surface, by means of signs and symbols or photographic imagery, at an established scale, on a specified projection, and with the means of orientation indicated (Crespi and Coche, 2008).

Maps are usually one of the outputs of a GIS, but can be effective tools for spatial communication in their own right. Mapping is the most straightforward way to visualize spatial relationships involved with the development and management of aquaculture and one of the easiest ways to communicate the two-dimensional needs of aquaculture for space among technical people and to the public in general.

There is a broad range of sophistication in mapping related to its purpose. Mapping for aquaculture development and management is considered in three categories: (1) Maps to delineate aquaculture sites and zones usually as accompaniments to technical reports, (2) Maps and varied attribute information accessed via the Internet that are aimed at a broad audience of government, commercial and private users involved with aquaculture development and management. (3) Interactive Internet mapping usually aimed at broad audiences that is accomplished by Internet map servers in which there is a choice of layers to view, layer attributes and descriptions and various functions such as zoom and pan. Kapetsky and Aguilar-Manjarrez (2007) provide some examples illustrating each mapping category for marine aquaculture.

La Tene Maps is an example of category one maps. It is a company based in Dublin, Ireland specialising in the research and production of maps, educational posters and associated data products. The company works mainly in areas which are constantly changing and particularly in the fields of Aquaculture, Fisheries, Oil and Gas Exploration, Renewable Energy, Energy/Power Generation, Marine Environment and Leisure Subjects. The company has a whole series of maps covering many parts of the world. La Tene Maps is worth mentioning and is relevant to EAA because they show the diversity of aquaculture activity in the area covered by the map by a set of specifically designed symbols to differentiate the species and type of activity carried out (www.latene.com/index.php/1/category/1/aquaculture).

In addition to the above, there are huge numbers of additional maps not described in this chapter that could be useful including all those from national mapping agencies and other specialized mapping agencies that are relevant to the EAA.

Marine fisheries GIS for EAA

Marine fisheries GIS is particularly relevant to EAA in that aquaculture and marine fisheries GIS have many issues in common (e.g. data, models, training, experience, etc), therefore, synergies between aquaculture and fisheries must be strengthened for development of ecosystem approach strategies.

A study by Kapestky and Aguilar-Manjarrez (2007) on “Geographic Information Systems, remote sensing and mapping for the development and management of marine aquaculture” addresses several synergies related to marine fisheries. These include the lessons that could be learnt from MPAs analysis to address marine aquaculture issues.

The MPA Center and the NOAA Coastal Services Center (www.mpa.gov) compiled an “Inventory of GIS-Based Decision-Support tools for MPAs (Pattison, dos Reis and Hamilton, 2004). The aim of this inventory is to make the MPA community aware of existing GIS-based decision-support tools that may aid them in a variety of MPA-related activities (siting, zoning, monitoring, etc).

Much of the data use in marine fisheries GIS is also relevant to marine aquaculture (bathymetry, temperature, currents, coastlines, territorial seas, economic exclusive zones, etc). A case study by Kapetsky and Aguilar-Manjarrez (2007) and Kapetsky and Aguilar-Manjarrez (in press) illustrate how freely downloadable data can be used to estimate open ocean aquaculture potential from national and global perspectives using many of these datasets.

The review by Carocci *et al.* (2009) on Geographic Information Systems to support the ecosystem approach to fisheries, describes a wealth of information, tools, models and data that are relevant to EAA.

A brief description of the various modelling approaches which have general relevance to the field of the ecosystem approach to fisheries (EAF) described by Plagányi (2007) is also a rich source of information from which synergies between EAA and EAF could be identified which utilise GIS.

EBM Tools Network

The EBM Tools Network (www.ebmtools.org) is an alliance of EBM tool developers, practitioners, and training providers dedicated to promoting EBM tools and support their use in EBM implementation in coastal and marine environments and the terrestrial environments that affect them (watersheds). The EBM Tools Network deals with any and all “software” tools that could be helpful for ecosystem-based management of coastal and marine environments including their watersheds. So they consider marine fisheries and aquaculture tools. Also, the Network deals with a wide range of tools in addition to marine fisheries and aquaculture, and one of their goals is to investigate how tools from different sectors can be brought together for planning. Since approximately half of ecosystem tools

have a spatial component (Robinson and Frid, 2003), GIS could be used in the future as the main operational platform.

The EBM Network tools analysis of tool functionality needed/tool categorization could be of immense value to FIMF's efforts/initiative on a toolbox for the ecosystem approach to fisheries (EAF). Likewise information about the EAF toolbox is very valuable to the EBM Network. The EBM has little aquaculture expertise in the Network and there are very few tools in the EBM that are dedicated to aquaculture, but they plan to include them, so EAA could also benefit from this EBM tools analysis/compilation once these plans materialise.

7.5 SUMMARY, DISCUSSION AND CONCLUSIONS

As fisheries and aquaculture are fundamentally spatially distributed, responsible management requires a solid understanding of the underlying spatial dimension. GIS and remote sensing provide the technologies for mapping and analyzing the distribution of aquatic resources, their environment, fishery management units, production systems, etc. which can support decision-making. Indeed, the ultimate aim of GIS is to support spatial decision-making. A GIS has the capacity to integrate information from a variety of sources into a spatial context and is well suited to support decision-making procedures. GIS can act as a tool in helping the decision-makers evaluate alternatives, visualise choices and explore certain alternatives, but it is the decision-maker who determines the criteria, the factors, the constraints, the individual weighting and the decision rules. There are a multitude of approaches to decision-making, and consequently, there is great room for bias in the decision-making process. GIS helps to provide objectivity to decision-making in the spatial realm.

Implementing GIS

Since decision-making is a sequential process, however, it is difficult to prescribe a standard methodology (e.g. for aquaculture site selection different sites have their own set of characteristics and an approach that works for one site may not work for another). Additionally, decision-making tools have broad applications in aquaculture of which site selection is an important one. In some cases, GIS may be a complex and time consuming process to implement fully, however even at its simplest level, GIS mapping and spatial analysis will enhance future implementation of the EAA.

Investment in GIS should be made with a clear understanding of what should be accomplished with such capabilities, and the decision support needs of the stakeholders that GIS can fulfil. In many cases, GIS capabilities are primarily used as tools for generating and displaying maps. However, the current state of spatial methods and technology, clearly indicates that GIS capabilities go beyond data management and visualization alone.

It may be difficult to properly assess the value of the information generated by a GIS project, and therefore its contribution towards decision support. Maguire, Kouyoumjian and Smith (2008) propose a new standardized Return on Investment (ROI) methodology for identifying, prioritizing, and calculating the business value of GIS technology for any organization. Given the increasing demands to improve accountability, efficiencies, competitive advantage, and resource utilization, the ROI method is an interesting way to help prioritize and target investment in GIS technology and address how and when that investment will deliver tangible benefits.

Modelling

It is difficult to prescribe the models to use because the choice of model depends entirely on the issue and research objectives. An ideal scenario for EAA is one in which a suite of models is developed and computed. It is also important to remember

that the better the background data, the more precise the output of the modelling will be. It is also worth considering the fact that many of the models developed have the utility of functioning outside or within a GIS platform (Figure 7.3a-d).

Decision support tools

All decision-making has a degree of uncertainty, ranging from a predictable (deterministic) situation to an uncertain situation (Malczewski, 1999). Consequently, particularly in uncertain situations, decision making involves the risk of making a “wrong” decision, because the information acquired is insufficient or the approach used is inappropriate. When uncertainty is part of the process, this uncertainty may in some cases be quantified and as such add another decision criterion to the evaluation process. Such tools are important for EAA and are likely to develop in the future. Key future improvements on decision support tools (DST) for aquaculture include: an increased use of socio-economic data, and the development of custom made tools and/or the use of DST used or created in other sectors to better address specific decision problems for marine aquaculture.

An important limitation to operational implementation of the EAA will be the sparse availability of information on the state of the wider ecosystem structure and processes. Implementation of the EAA requires a wide information-base for decision-making. Remote sensing from satellites has revolutionised our view of the surface of planet Earth, on land, in the atmosphere and in the sea. Remote sensing already provides real-time information of potential use to mariculture (e.g. sea surface temperature, chlorophyll, Harmful Algal Blooms). Also, archived remote sensing data can be used to analyze change spatially and temporally. Therefore, it would be of utmost value if remote sensing data could be made more readily available to non specialists for the EAA.

Future of models and GIS-based decision support tools as applied to aquaculture. Following the initial development of GIS in the 1960s, GIS has evolved from computer mapping and visualization to spatial database management to spatial analysis and modelling to web-based applications. Major opportunities for fisheries GIS scientists in the future are: (1) sharing data, information and applications through the Internet, (2) multidimensional GIS (i.e. 3 and 4 dimensional GIS, dynamic flow modelling), and (3) data acquisition through sensors and sensor networks (e.g. GPS-enabled mobile devices).

The Internet offer the possibilities for a new kind of distributed information and collaboration system. Such systems support the efficient working and collaboration process among the different involved experts of distributed projects. Web access to spatial data is becoming increasingly common, therefore standards are becoming increasingly important to GIS systems, as compliance with effective common standards is the only way disparate applications can access externally managed data and become interoperating components of a working GIS system. There is an increase in the use of Open Source (OS) GIS software, and, at least for now, this may offer some advantages for GIS users over more proprietary solutions.

Remote sensing data have a very rich potential in fisheries and aquaculture. The information and software will become more widely available, user friendly, and accessible to managers rather than just to specialist remote-sensing scientists.

The main theme of the Fourth International Symposium on GIS/Spatial Analyses (www.esl.co.jp/Sympo/index.htm) was the move towards EAA and EAF, and this is likely to become increasingly dominant over the next decade. The EAA and EAF have many issues in common (e.g. data, models, training, experience, etc) therefore synergies between aquaculture and fisheries must be strengthened for development of EA strategies.

There is still very little attention given to economic or social factors relating to

spatial aspects of fisheries or aquaculture, so they merit further analysis to be able to fully support EAA. With EAA and EAF now looming large it is expected that more attention will be given to these important factors.

There are a mixture of methods and applications which involve management to different degrees. One of the main challenges identified is the need for dynamic information to be made more readily available to decisions-makers and stakeholders on a real-time basis and that more research be conducted on how to best teach decision-makers to utilize spatial information.

8. Case studies of GIS, remote sensing and mapping applications in aquaculture in relation to EAA implementation

This chapter has two objectives. The first is to show the relevance of GIS capabilities in aquaculture to EAA principles in a general way. This sets the stage for the second objective that is to illustrate by actual application examples the ways in which GIS, remote sensing and mapping can contribute to the implementation of the EAA through case studies and a variety of other applications in aquaculture.

8.1 THE RELEVANCE OF GIS CAPABILITIES TO EAA PRINCIPLES

Underlying the implementation of the EAA is the fundamental need to define ecosystems spatially and by their attributes. GIS can be used for this purpose, but experts from many disciplines have to be involved to assist with the definition of each component of the ecosystem (e.g. ecologists for the natural components, sociologists and economists for the human components).

1. the natural environment as modified by man including the atmosphere, land and water;
2. the human environment with its major elements all of which have an economic underpinning including the physical realm and infrastructure, the chemical realm with inputs to, and outputs from atmosphere, terrestrial and aquatic environments, and finally; and
3. the biological environment one part of which is subject to extractive activities such as agriculture, forestry, and fisheries.

The strength of GIS is in its capability to spatially integrate and analyze the natural and human environments. Natural environments are defined spatially by natural physical features, basically land and water boundaries. Human boundaries are defined administratively with a combination of natural features (rivers, mountains) and artificial geographic boundaries established by a coordinate system. GIS can be used to integrate spatial natural environments with human spatially defined areas (e.g. administrative) at a range of scales.

8.2 THE RELATIONSHIP OF SPATIAL ANALYSES TO SUPPORT EAA PRINCIPLES

There are three EAA principles. This section illustrates how spatial analyses relate to each principle.

EAA principle 1 – Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society

Ecosystem functions from the human viewpoint provide; good quality air, water, arable land and healthy crops as well as renewable resources such as fish and wood products.

Ecosystem functions from the aquaculture viewpoint provide an environment for rapid growth and high survival rates for cultured products and a safe environment

for culture structures and support installations. This Principle corresponds to spatial analysis of the natural environment.

The main application in aquaculture in relation to the EAA is defining the boundaries of natural ecosystems so that, in turn, the ecosystem functions and services within those boundaries can be defined and examined in relation to aquaculture. Other applications include: predicting the effects of variability in the environment on aquaculture for:

1. estimates of potential, zoning and siting;
2. real-time management of aquaculture operations;
3. estimating carrying capacity; and
4. estimating ecosystem resilience

Integrated Multitrophic Aquaculture also comes under this principle as a kind of mitigation of aquaculture impacts

EAA Principle 2 – Aquaculture should improve human well-being and equity for all relevant stakeholders

The general application in aquaculture for EAA is the state of well-being measured in socio-economic terms within spatial boundaries such as gross domestic product, poverty, livelihoods and markets.

The aquaculture applications are:

1. spatial distribution and spatial analyses of aquaculture and of other stakeholder activities (production facilities, transportation and marketing chains, technical support installations, plant and animal health and tracing/tracking); and
2. spatial distribution and spatial analyses of aquaculture and of its status (livelihoods, poverty, etc).

EAA Principle 3 – Aquaculture should be developed in the context of other sectors, policies and goals

This corresponds to spatial analyses of the natural environment together with the human environment. Most of the aquaculture issues fall within this principle. The main application in aquaculture is minimizing or eliminating competing and conflicting uses while also identifying complementary uses through spatial analyses.

8.3 CASE STUDIES OF GIS, REMOTE SENSING AND MAPPING APPLICATIONS IN AQUACULTURE IN RELATION TO EAA PRINCIPLES AND SCALES

Because the EAA is a new more holistic strategy, there are no case studies specifically so targeted. However, there are numerous examples of spatial planning applications in aquaculture that have an EAA orientation. Expanding on Chapter 6, the underlying purpose is to further demonstrate that spatial analyses can be easily designed to meet a variety of EAA needs with respect to scales and principles.

The case studies listed in Tables 8.1 and 8.2 below have two characteristics:

- They call attention to a wide variety of applications that have contributed to solving important issues that affect the sustainability of aquaculture;
- They also provide information usually lacking from scientific papers and reports, namely, in what ways, and with what commitments of time and specialized personnel the work has been completed.

Thus, these case studies are aimed at two kinds of audience: (1) Those with limited knowledge of the benefits and constraints of spatial tools applied to aquaculture who can best appreciate how spatial tools can be of use by associating their own experiences and issues with descriptions of applications, and (2) those with GIS technical skills who can benefit from new methodological approaches revealed by these case studies.

Table 8.1 lists featured case studies selected on the basis of quality which are also illustrative of innovative ways to address issues in aquaculture with GIS. As a measure of economy, the full case studies are not repeated here. Rather, their main attributes with respect to the EAA are tabulated in Table 8.1. They can be accessed in full from the GISFish (www.fao.org/fishery/gisfish) by searching on the GISFish ID provided. Amongst the applications listed in Table 8.1, six were selected to describe the use of GIS-based models and spatial decision support of relevance to EAA principles and scales (Table 8.2).

The case studies and EAA-relevant examples are tabulated according to the EAA principles, the EAA scale, the issues associated with each EAA principle, the environment and/or ecosystem targeted, and the scale of the GIS application. A brief comment on the relevance of the example application to the EAA is also included.

TABLE 8.1
Case studies from GISFish and their relevance to EAA principles and scales

Author, Year, Title, *GISFish ID	Country	Environment	EAA principle	EAA scale	GIS scale	Main issue	Sub-issue	Relevance to the EAA
EAA Principle 1 – Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society								
Populus et al. (2003) Geomatics for the management of oyster culture leases and production id/gf241	France	Brackishwater	1	Waterbody	Bay	Practice and management	Inventory and monitoring of aquaculture and the environment	Combines environment with intra-specific interactions and effects on growth and survival
Populus et al. (2003) GIS in support to data analysis for enhanced sustainability of shrimp farming in the Mekong Delta, Viet Nam id/1946	Viet Nam	Brackishwater	1	Watershed	State/Province	Practice and management	Inventory and monitoring of aquaculture and the environment	Aquaculture in relation to the environment and ecosystems
Bacher et al. (2003) Modelling the effect of food depletion on scallop growth in Sanggou Bay (China) id/1240	China	Brackishwater	1	Waterbody	Bay	Development	Suitability of site and zoning	Carrying capacity
Bayot et al. (2002) Sistema de alerta epidemiológico y de manejo para la acuicultura del camarón en Ecuador id/1291	Ecuador	Marine and brackishwater	1	Waterbody	Gulf	Development	Anticipating the consequences of aquaculture	Early warning system
Pérez (2002) Use of a GIS-based particulate waste distribution model as a tool to aid marine fish cage site selection id/1236	All coastal countries	Marine	1	Farm	Open ocean	Practice and management	Environmental Impacts of aquaculture	One of the few farm-scale applications
Bushek et al. (1998) Land-use patterns, hydrodynamics and the spatial pattern of Dermo disease in two South Carolina estuaries id/gf40	United States of America	Brackishwater	1	Watershed Waterbody	Estuary	Practice and management	Inventory of aquaculture and the environment	One of few examples dealing with diseases related to the environment
Ferreira et al. (2008) SPEAR Sustainable options for People, catchment and Aquatic Resources id/5380	China	Marine	1 (3)	Waterbody	Bay	GIS for aquaculture practice and management	Environmental Impacts of aquaculture	This project is valuable to EAA because it is a holistic assessment of aquaculture on the basis of people, planet and profit

* Note: To locate the publication stored in GISFish simply add the id to the end of the GISFish URL (e.g. www.fao.org/fishery/gisfish/id/1284)

TABLE 8.1 Cont.
Case studies from GISFish and their relevance to EAA principles and scales

Author, Year, Title, *GISFish ID	Country	Environment	EAA principle	EAA scale	GIS scale	Main issue	Sub-issue	Relevance to the EAA
Hunter (2009); Hunter <i>et al.</i> (2007; 2006) A GIS-based decision support tool for optimisation of marine cage siting for aquaculture: A case study for the Western Isles, Scotland id/4056; id/4059	United Kingdom	Marine	1(3)	Waterbody	Off-the-coast and offshore	GIS for aquaculture practice and management	Environmental Impacts of aquaculture	The thesis addresses key issues for Environmental Impact Analysis and proposes novel methodologies to enhance current EIA practices/methods of relevance to EAA principle 1.
Suvanachai (1999) GIS and Coastal Aquaculture Planning in Thailand id/4387	Thailand	Marine	1(3)	Waterbody	Off-the-coast	GIS aimed at development of aquaculture	Strategic planning for development	An inventory of aquaculture structures and their characteristics have already been produced and is regularly updated. The inventory is available on the Internet at http://gis.fisheries.go.th/WWW/index.jsp
Funge-Smith and Aguilar-Manjarrez (2009) Aquaculture Information Management and Traceability System in Thailand id/5537	Thailand	All environments	1(3)	Farm Watershed/ Aquaculture zone	All scales	GIS for aquaculture practice and management	Environmental Impacts of aquaculture	This case study is noteworthy for EAA because it is relatively generic, applicable in other countries with significant aquaculture production systems, and provides an opportunity for utilising an operational GIS
EAA Principle 2 - Aquaculture should improve human well-being and equity for all relevant stakeholders								
Scott, Vianna, and de Campos Mathias (2002) A GIS supported diagnostic of Rio de Janeiro aquaculture production chain and its implications for development id/1284	Brazil	Inland and Brackishwater	2	Watershed	State/Province	Development	Strategic planning for development	Economics related to potential production of several species in two environments
Arnold <i>et al.</i> (2000) Hard clam (<i>Mercenaria spp.</i>) aquaculture in Florida, USA: Geographic information system applications to lease selection id/gf127	United States of America	Brackishwater	2	Waterbody	Bay	Development	Suitability of site and zoning	Also resolution of competition between fisheries and aquaculture

TABLE 8.1 Cont.
Case studies from GISFish and their relevance to EAA principles and scales

Author, Year, Title, *GISFish ID	Country	Environment	EAA principle	EAA scale	GIS scale	Main issue	Sub-issue	Relevance to the EAA
van Brakel and Ross (2008) Integrating socio-economic data into a spatial framework for aquaculture development id/4955	Thailand and Cambodia	Inland	2	Watershed	Local and State/Province	Aquaculture practice and management	Economics	Linked socio-economic and administrative datasets from various sources integrated into a spatial framework for aquaculture development
Wetlands Management Department, Ministry of Water and Environment, Uganda; Uganda Bureau of Statistics; International Livestock Research Institute; and World Resources Institute (2009) Mapping A Better Future. How Spatial Analysis Can Benefit Wetlands and Reduce Poverty In Uganda id/5291	Uganda	Inland	2	Waterbody	National	Multisectoral development and management	Planning for aquaculture among other uses of land and water	Emphasis placed on poverty and livelihoods linked to an aquatic ecosystem management context
Kam et al. (2008) Determination of High-Potential Aquaculture Development Areas and Impact in Africa and Asia id/4815	Cameroon, Malawi, Bangladesh and China	Inland	2(3)	Aquaculture zone	Regions	Development	Strategic planning for development	Ensured equity for all relevant stakeholders. Included sociological analysis of qualitative socio-institutional factors
EAA Principle 3 - Aquaculture should be developed in the context of other sectors, policies and goals								
Kapetsky and Nath (1997) A strategic assessment of the potential for freshwater fish farming in Latin America id/gf10	Latin America	Inland	3	Market	Continental	Development	Strategic planning for development	Economic surrogate for access to markets
Travaglia, Kapetsky and Profeti (1999) Inventory and monitoring of shrimp farms in Sri Lanka by ERS-SAR data id/1244	Sri Lanka	Brackishwater	3	Watershed	Region in country	Practice and management	Inventory and monitoring of aquaculture and the environment	Inexpensive, comprehensive, potentially multi-temporal monitoring
Travaglia et al. (2004) Mapping coastal aquaculture and fisheries structures by satellite imaging radar. case study of the Lingayen Gulf, the Philippines id/1368	Philippines	Brackishwater and marine	3	Waterbody	Gulf	Practice and management	Inventory and monitoring of aquaculture and the environment	Also resolution of competition between fisheries and aquaculture
White (2009) EIA and monitoring for clusters of small-scale cage farms in Bolinao Bay: a case study. id/4840	Philippines	Marine, Brackishwater and Inland	3	Aquaculture zone	Lake, estuary and bay	Development	Suitability of site and zoning	Multi-faceted study including carrying capacity and environmental impact assessment for siting and zoning

TABLE 8.1 Cont.
Case studies from GISFish and their relevance to EAA principles and scales

Author, Year, Title, *GISFish ID	Country	Environment	EAA principle	EAA scale	GIS scale	Main issue	Sub-issue	Relevance to the EAA
Kapetsky and Aguilar-Manjarrez (in press) Spatial perspectives on open ocean aquaculture potential in the US eastern Exclusive Economic Zones *In press	United States of America	Marine	3	Aquaculture zone	Region in country/open ocean	Development	Strategic planning for development	Unique in estimating potential for open ocean aquaculture including integrated multi-trophic aquaculture
Aguilar-Manjarrez (1996) Development and evaluation of GIS-based models for planning and management of coastal aquaculture: A case study in Sinaloa, Mexico id/gf211	Mexico	Brackishwater	3	Watershed	State/Province	Development	Strategic planning for development	Excellent example of model integration and multiple criteria decision-making
Andrade and Mafra (2008) Information system for the request of exploitation permits for aquaculture in federal water bodies in Brazil-SINAU id/4998	Brazil	Marine, brackishwater and inland	3	Waterbody/ Watershed	Country	Practice and management	Web-based aquaculture information system	Practical system for permitting but with potential for incorporating multiple uses including EAA
Dolmer and Geitner (2004) Integrated Coastal Zone Management of cultures and fishery of mussels in Limfjorden, Denmark id/1934	Denmark	Marine and brackishwater	3	Waterbody	Estuary	Multisectoral development and management	Management of aquaculture and fisheries	Takes into account culture and capture of one species and competition for space with another in CZM context
Hershner and Woods (1999) Shallow water resource use conflicts: clam aquaculture and submerged aquatic vegetation id/gf120 and id/1261	United States of America	Brackishwater	3 (1)	Waterbody	Bay	Multisectoral development and management	Management of aquaculture together with fisheries	Also anticipating the consequences of aquaculture on the environment
Handisye et al. (2006) The effects of climate change on world aquaculture: a global perspective id/4522	World	Inland, marine and brackishwater	3 (1)	Global	Global	Practice and management	Inventory and monitoring of aquaculture and the environment	Includes social and economic considerations with climate change a fundamental issue
Rensel, Kiefer and O'Brien (2007) AquaModel: Comprehensive Aquaculture Modelling Software id/4775	United States of America	Marine	3 (1)	Waterbody	Local/ waterbody	Development	Anticipating the consequences of aquaculture	Practical example of pre-modelling aquaculture impacts on the environment - water column and bottom
Grant et al. (2007) Remote sensing of particle depletion by coastal suspension-feeders id/4625	Canada	Brackishwater	3 (1)	Waterbody	Local/ waterbody	Practice and management	Environmental Impacts of aquaculture	Unique for demonstrating ecosystem scale impact of aquaculture on the environment

TABLE 8.1 Cont.
Case studies from GISFish and their relevance to EAA principles and scales

Author, Year, Title, *GISFish ID	Country	Environment	EAA principle	EAA scale	GIS scale	Main issue	Sub-issue	Relevance to the EAA
Ross and Salam (1999) GIS modelling for aquaculture in South-western Bangladesh: Comparative production scenarios for brackish and freshwater shrimp and fish id/gf102	Bangladesh	Inland and Brackishwater	3 (1)	Watershed/ Waterbody	Region in country/open ocean	Development	Suitability of the site and zoning	Multiple species in two environments
Pemsl et al. (2006) Determining high potential aquaculture production areas - analysis of key socio-economic adoption factors id/4255	Bangladesh and Malawi	Inland	3 (1)	Watershed	Country	Development	Economics	Blends environment and socio-economics
Greenhawk, Jordan and Smith (1995) Maryland oyster geographical information system: Management and scientific applications id/gf54	United States of America	Brackishwater	3 (1)	Waterbody	Bay	Practice and management	Restoration of habitat	Habitat assessment and planning for restoration
Kapetsky and Aguilar-Manjarrez (2008) The potential of open ocean aquaculture in Exclusive Economic Zones from global and national perspectives id/4974	World	Marine	3 (1)	Global	Offshore/EEZ	Development	Strategic planning for development	Estimates area loss to offshore aquaculture of foregoing development in ecologically sensitive zones
van Brakel, Nguyen-Khoa1 and Ross (2008) An agro-ecosystems approach to aquaculture and inland fisheries: fish out of the water? id/4968	Cambodia	Inland	3(1)	Watershed	District and Province	GIS for multisectoral development and management that includes aquaculture	Management of aquaculture together with fisheries	Proposed a method to operationalize ecosystems approaches to fisheries and aquaculture by delineating resource boundaries. They derived such 'boundaries' from environmental data in order to characterize agro-ecosystems as distinct social-ecological resource governance units, of which aquaculture and fisheries are inseparable components.
Pérez, Telfer and Ross (2003) Use of GIS-based models for integrating and developing marine fish cages within the tourism industry in Tenerife (Canary Islands) id/1792	Spain	Marine	3 (2)	Waterbody	Seacoast	Multisectoral development and management	Planning for aquaculture among other uses of land and water	Specifically takes into account human elements and their economy in CZM

8.4 CASE STUDIES FOR SPATIAL DECISION SUPPORT

The selected cases listed in section 8.3 represent a broad sampling across geographic scales ranging from local areas (i.e. a small bay), to sub-national regions (i.e. individual states: provinces), to national and continental regions. They also vary with regard to types of species and culture systems and to the degree to which GIS outcomes have been used for practical decision-making. Further, the case studies demonstrate the thematic extent of GIS applications that are possible in aquaculture including: site selection for targeted species, environmental impact assessment and monitoring, conflicts and trade-offs among alternate uses of natural resources, and consideration of the potential for aquaculture from the perspectives of technical assistance and alleviation of food security. The cases also vary significantly with regard to complexity of the analytical methods used (i.e. ranging from simple overlays to weighted combinations to use of relatively sophisticated models). Finally, the case studies are indicative of the diversity of GIS software that is available. In this section, we examine six cases in some detail from the perspective of their applications for spatial decision support for the EAA (Table 8.2). These case studies represent practical examples and the current state-of-the-art in GIS applications in aquaculture. Each of them is presented in the following format:

- *Objectives*
- *Target decision support audience*
- *Geographic area and scale of analysis*
- *Analytical framework and results*
- *Relevance to EAA*

This chapter can provide only a limited range of case studies. Additional case studies and examples of applications pertinent to the EAA are listed in Table 8.1 and guidance is given as to where the original material can be obtained as well as indicating the general purposes for which GIS can be beneficial for EAA purposes.

TABLE 8.2
GIS applications in aquaculture according to the models and decision support used

No.	Authors	Year	Country	System	Species	Software	GIS Integration and Models	Decision support	EAA principle
1	Palerud et al. (2008); Legovic et al. (2008); White (2009). id/4840	2008 2009	Philippines	Cages Stakes	Milkfish (<i>Chanos chanos</i>) Oysters (<i>Crassostrea iredalei</i>)	ArcGIS 9.1	Loose coupling TROPOMOD, MERAMOD and DEPOMOD	NO MCE per se was used.	1(3)
2	Ferreira et al. id/5380	2008	China	Cages, Longlines, Ponds	Macroalgae: <i>Laminaria japonica</i> and <i>Porphyra haitanensis</i> ; Four species of bivalve: the Pacific oyster <i>Crassostrea gigas</i> , Asian-Pacific oyster <i>Ostrea plicatula</i> , razor clam <i>Sinonvacula constricta</i> and ark shell <i>Tegillarca granosa</i> ; Two species of finfish: the Japanese seabass <i>Lateolabrax japonicus</i> and the large yellow croaker <i>Larimichthys crocea</i>	ArcGIS 9.1	Loose coupling Fifteen models were used: ASSETS, CoBEX-ECO, Delft3D- FLOW, Delft3D-WAQ/ECO, EcoWin2000,FARM, MARKET, MOM, Saas, ShellSIM, SWAT, TGC, Winshell, and LMPrawn	NO MCE per se was used.	1(3)
3	Hunter, Telfer and Ross Hunter id/4056; id/4059	2006; 2007 2009	Scotland	Cages	Atlantic Salmon, <i>Salmo salar</i> Species addressed in Biodiversity sub-model: The Western Isles has a relative abundance of unique and rare species from sea birds to sea mammals	Idrisi Andes	Embedding GIS in spatial analysis and modelling. Multi-criteria evaluation models	Desk-study MCE with a small group of experts using discrete thresholds.	1(3)

TABLE 8.2 Cont.
GIS applications in aquaculture according to the models and decision support used

No.	Authors	Year	Country	System	Species	Software	GIS Integration and Models	Decision support	EAA principle
4	Andrade and Maffra id/4998	2008	Brazil	All culture systems	All species	ArcGIS 9.1	Embedding GIS in spatial analysis and modelling. Multi-criteria evaluation models	Practical use of MCE with a large number of stakeholders using fuzzy thresholds	3
5	Kam <i>et al.</i> id/4815	2008	Cameroon, Malawi, Bangladesh and China	Ponds	Freshwater (e.g. Tilapia).	SAQUA; Idrisp; GeNle and BNSS; IDRISI; ArcView, ArcGIS; AGRAUA.	Options for Embedding GIS in spatial analysis and modelling and also for Loose coupling. Bayesian network; Agro-ecological (Thermal growth period; pond water availability; fish yields)	MCE using discrete and fuzzy thresholds.	2(3)
6	Funge-Smith and Aguilar-Manjarrez id/5537	2009	Thailand	All culture systems	All species	ArcGIS 9.3	Modelling has yet to be developed	MCE will be one of the decision-making tools to use.	1(3)

Case Study 1:**Development of programmatic EIAs and monitoring programmes for clusters of small scale cage farmers (Source: Palerud *et al.* (2008); Legovic *et al.* (2008); and White (2009).**

The work was undertaken by the NORAD funded EMMA project (Environmental Monitoring and Modelling of Aquaculture impact in risk areas of the Philippines) and the EU FP6 funded PHILMINAQ project (Mitigating impact from aquaculture in the Philippines (www.philminaq.eu)).

Objective

The purpose of the project was to increase the organisation and representation of farmers so that “clusters” of farms could be effectively monitored and managed, thus avoiding the classic boom and bust cycle of small scale aquaculture avoided.

Target decision support audience

Government aquaculture planners and managers

Geographic area and scale of analysis

The study was centred on three areas in the Philippines, Bolinao Bay (marine), Dagupan estuary (brackish) and Taal Lake (freshwater). This case study describes the methodology used in Bolinao Bay.

Analytical framework and results

Palerud *et al.* (2008) and Legovic *et al.* (2008) developed a methodology for the estimation of safe aquaculture carrying capacity, optimal site selection, and zoning of aquaculture parks for sustainable aquaculture development for small scale farmers in Bolinao Bay in the Philippines.

In Taal lake there were found to be 9 500 cages generating 120 000 tonnes of fish per annum. In Bolinao bay there were 460 fish cages of which 322 were operational (70 percent) and 138 were not operational (30 percent) with an annual production of 8 844 tonnes from cage culture, 13 755 tonnes from pen culture and 3 289 tonnes from mussel culture. In both areas there was found to be little planning, management and control of aquaculture development.

The project involved a range of activities including GIS and assessment of carrying capacity, zoning and development of zone committees, cluster level environmental assessment and monitoring, training/awareness, capacity building and institutional strengthening.

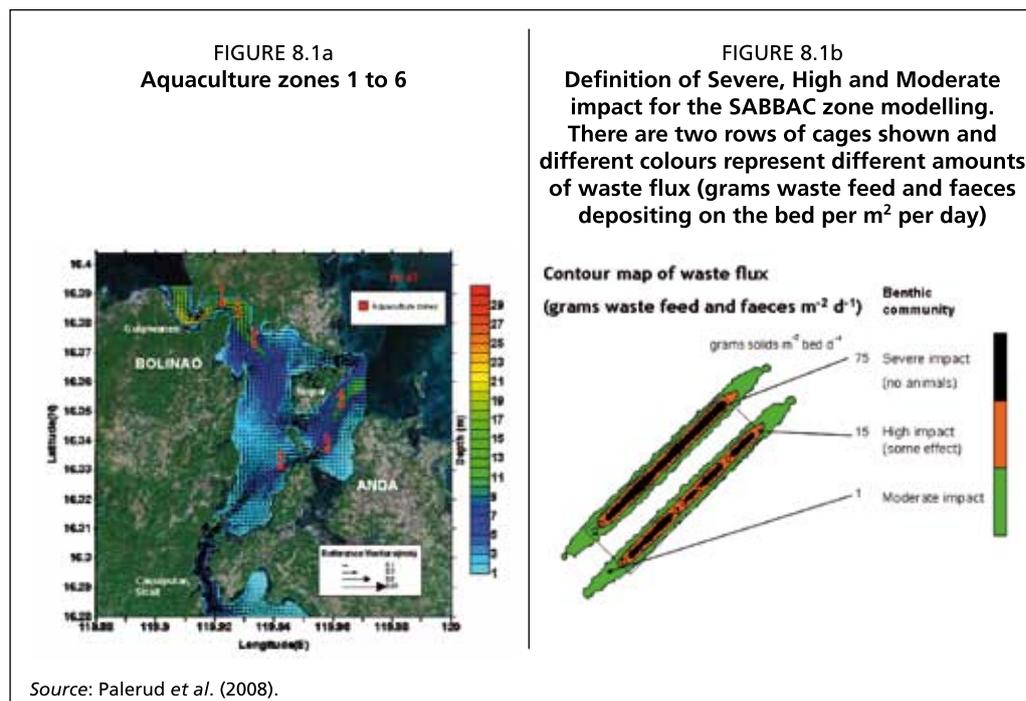
Using a depositional model TROPOMOD¹, three rows of cages were tested for each aquaculture zone (Figure 8.1a). The area of high and severe impact was found to occupy the majority of the zone area and little area was available between rows for remediation of impact (Figure 8.1b). Thus, in all aquaculture zones except Zone 4, two rows of 18 cages were found to be optimum. As larger cages were present in Zone 4, two rows of 12 cages were recommended.

Relevance to EAA

Many studies have noted the inadequacy of Environmental Impact Assessment (EIA) to address the cumulative impacts of large numbers of small scale development, typical of much aquaculture production worldwide (FAO, 2009; GESAMP, 2001). Therefore this study is particularly valuable to EIA and hence to EAA because it illustrates an example of a strategic environmental assessment, or environmental assessment applied to clusters of farms, coupled with analysis

¹ TROPOMOD is a particle tracking model used for predicting output, movement and deposition of particulate waste material (with resuspension) and associated benthic impact of fish farms.

of environmental capacity issues and it addresses the importance of ecosystem-based co-management of a shared waterbodies (White *et al.*, 2008; White and San Diego-McGlone, 2008). Moreover, a large number of countries have referred to the lack of monitoring systems or capacity for field evaluations and checking EIA effectiveness (FAO, 2009) therefore this study is also particularly valuable to EIA and EAA because it addresses this issue by proposing three types of survey for monitoring the impact of aquaculture. These ranged from low cost through intermediate to fully scientific surveys and differ in terms of cost, complexity and accuracy but all give a good indication of the level of aquaculture impact. A field manual of methodology for the three categories of monitoring survey can be downloaded from www.philminaq.eu.



From a GIS viewpoint this study is useful because it shows how a number of models can be coupled with GIS to identify zones, estimate the maximum number of cages in a zone, estimate the minimum distance between zones and undertake scenario testing to identify management options for minimising impact.

Case study 2:

Sustainable Options for People, Catchment and Aquatic Resources (source: Ferreira *et al.*, 2008)

This SPEAR project (2004–2007) was financed by the European Union INCO-DEV programme (www.biaoqiang.org). It was a follow-up to the experiences gained in the Sustainable Mariculture in Northern Irish Loughs Ecosystems (SMILE) project (2004–2006) for determining environmentally sustainable carrying capacity for shellfish aquaculture for Irish loughs (Ferreira *et al.*, 2007).

Objectives

The general objective of SPEAR was to develop and test an integrated framework for management of the coastal zone, using two test cases where communities depend primarily upon marine resources.

Target decision support audience

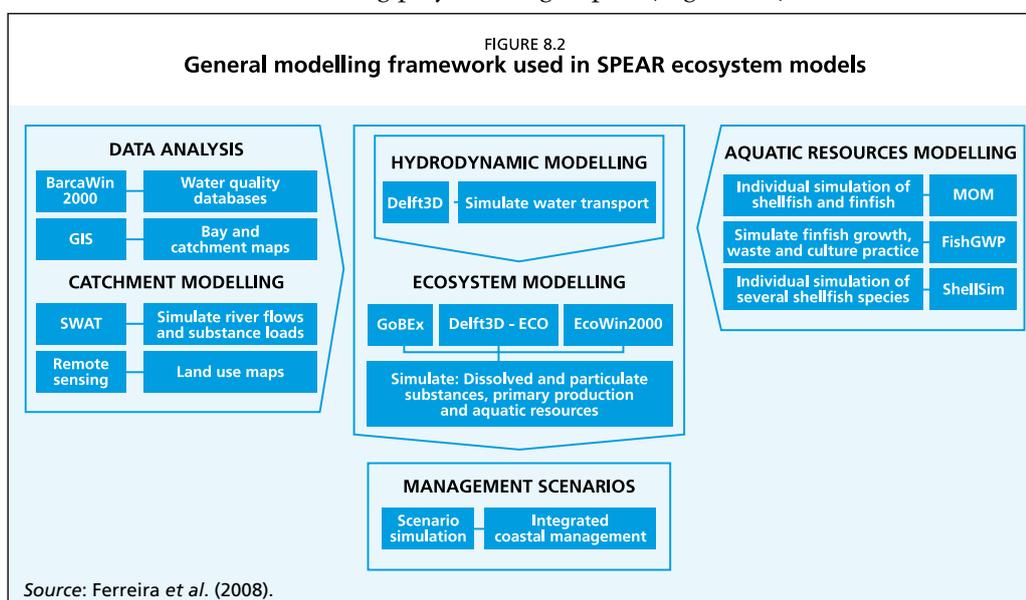
Coastal zone planners and managers.

Geographic area and scale of analysis

Two contrasting coastal systems in China were used as study areas. Sanggou Bay is in a rural area in the North, and Huangdun Bay is an industrialized area south of Shanghai, that is subject to substantial human pressure at both local and regional levels.

Analytical methods and results

The overall SPEAR framework accounted for watershed interactions, ecological structure and human activities. The interdisciplinary approach used combined natural and social sciences, and addressed the complex scaling issues inherent in integrated management. The main objectives of model development at the ecosystem scale were to: Simulate the ecosystem processes on a multi-year scale for each bay; simulate the aquatic resources produced in the bays; develop the socio-economic components to dynamically integrate this framework; and to calibrate and validate the research model suite. A key feature of the general modelling approach used in SPEAR was to integrate the various models in order to develop a robust ecosystem modelling framework where GIS and Remote Sensing play an integral part (Figure 8.2).



From a technical standpoint, outputs from the SPEAR project represent the state-of-the-art in coastal management, featuring web-based models, hybrid ecological-economic approaches, and management tools to be used at a variety of scales. Technological developments will mean that the tools themselves will evolve fairly rapidly, but the underlying scientific paradigms are expected to change more slowly.

Relevance to EAA

This project is valuable to EAA because it is a holistic assessment of aquaculture on the basis of people, planet and profit. The challenge of bringing the various components of the People-Planet-Profit equation together as a holistic indicator of sustainable carrying capacity in coastal areas appears both achievable and appropriate for integrated coastal management.

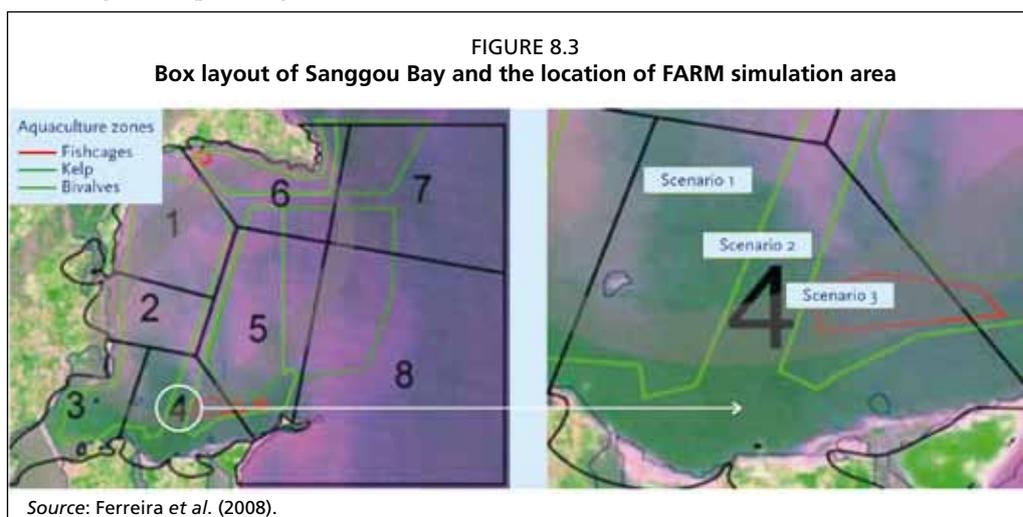
From a GIS viewpoint this project is noteworthy in a number of ways: First, it represents a good example of integration of spatial data across different scientific disciplines; secondly, it is novel because it combines models running at widely different time and space scales for different ecosystem components as a requirement for scaling and as co-validators of each other, lending confidence to the outcomes and thirdly a socio-economic viewpoint was included using the MARKET model. Also valuable are the set of management scenarios proposed by the project team and stakeholders that clearly illustrate the role and value of GIS (Table 3).

TABLE 8.3
Development scenarios for Huangdum Bay and Sanggou Bay

System	Scenario description	Tools
Huangdum Bay	Assess impact of change to fish cage numbers and sizes. Assess impact of nutrient discharge reduction from waste water treatment plants Combination of the two scenarios above	GIS, EcoWin2000 SWAT, Delft3D, EcoWin2000 As above
Sanggou Bay	Reduce culture densities for shellfish alone by 50% (achieved by increasing distance between longlines and/or droppers, to assess consequences for total production value. Alter species composition: currently there are 450 Mu* of fish cages, 50 000 Mu of Laminaria, 40 000 Mu of shellfish, proposed change to a 70:20:10 (kelp:filter:finfish) Replace oyster culture (1500 Mu) with abalone culture (1000 Mu) and fish cages (400 Mu)	GIS, EcoWin2000 MOM, FARM

* Mu is the Chinese Unit of area. In aquaculture, the culture Mu is used for licensing, and although nominally rated as 1/15 of one hectare, its size is variable according to the productivity of the system, i.e. a less productive system has a larger Mu. Typical values range from 1000-5000 m².

Figure 8.3 illustrates one of the management scenarios from the project. The farm selected as a demonstration site is located in Box 4 of Sanggou Bay, where Pacific oyster (*Crassostrea gigas*) raft culture, Japanese Flounder (*Paralichthys olivaceus*) and Puffer fish (*Fugu rubripes*) cage culture coexist.



In summary, GIS was used throughout the project in several key roles:

- In decision support as the geographic component of key variables. This helped in the decision-making process and interpretation of results;
- In modelling, by providing input values relevant for parameterization and calibration, by serving as a platform for communication between different models and by allowing a first approach at 2D validation processes, allowing the use of spatialized assessment of model results by applying relevant indexes (e.g. index of agreement); and
- In visualisation at several stages of the project by allowing the spatialization of relevant inputs and results, and by performing spatial analysis of model results.

However, most models used in this project were not fully integrated within a GIS software. This was done in a follow-up project, Understanding Irish Shellfish Culture Environments (UISCE), on carrying capacity in Ireland, where an application in ArcGIS was used to run the various models (J.G. Ferreira, personal communication, 2009).

It may be difficult to properly assess the value of the information generated by

SPEAR, and therefore its contribution towards decision support. However, a number of follow-up actions have taken place and give a positive indication of their impact. No specific management measures are reported in China as a direct result of SPEAR, although indirectly there was an increase in management awareness both of

- i. the options available to address some of the problems, such as high mortality of young fish in Huangdun Bay, or over-exploitation of aquaculture in Sanggou Bay;
- ii. the tools which can be used to look at the outcome of different management approaches.

As a follow-up to SMILE and SPEAR, the Institute of Marine Research (IMAR) has been working with others on individual shellfish modelling over the past two years. In particular IMAR has developed a new model called AquaShell, which aims to include the minimum set of equations required to successfully simulate bivalve growth, and has implemented it for the Pacific oyster and applied it to oyster cultivation in Chile. IMAR has a proposal (in review) led by Mr. Cedric Bacher (IFREMER) which aims to further develop efforts by SMILE and SPEAR, to interface GIS, individual-, farm-, and ecosystem-scale models (J. G. Ferreira, personal communication, 2009).

Case study 3:

A GIS-based decision-support tool for optimisation of marine cage siting for aquaculture: A case study for the Western Isles, Scotland (source: Hunter, Telfer, and Ross (2006); Hunter, Telfer and Ross (2007); Hunter (2009).

This project focuses on GIS models developed by the Institute of Aquaculture, at the University of Stirling (www.aqua.stir.ac.uk/GISAP/gis-group/donna.php).

Objectives

The main objective of the study was to develop a holistic management tool for sustainable coastal marine aquaculture through the development of a multi-faceted model that allows consideration of sensitive environments.

Target decision support audience

As the Scottish government promotes better collaboration and integration of all involved in coastal zone governance (Baxter *et al.*, 2008) this study illustrates the benefits to be gained from harmonized management of information in a GIS.

Geographic area and scale of analysis

The chosen study area for this research was the Western Isles also known as the Outer Hebrides, off the North West coast of Scotland at a latitude 58 00° N and a longitude of 7 00° W in the north Atlantic Ocean.

Analytical framework and results

To date, GIS models for aquaculture management have usually had a single focus based on selection of fish farm sites, prediction of wastes, etc. This project seeks to integrate and develop existing approaches and to develop and integrate novel tools for considering all available environmental information in conjunction with the distribution of waste, other aquatic stakeholder uses, anthropogenic and natural inputs, land resources and effects on the marine environment, river systems, visual impacts of the development and area designation (i.e. conservation areas and their overlaps with existing area management). All of these factors need to be taken into account when implementing environmental management and investigating carrying capacity. In addition, implementation of the EU Water Framework Directive (WFD) will require a combined, multi-site approach in consideration of environmental data. Models that enable the integration of all this information will be

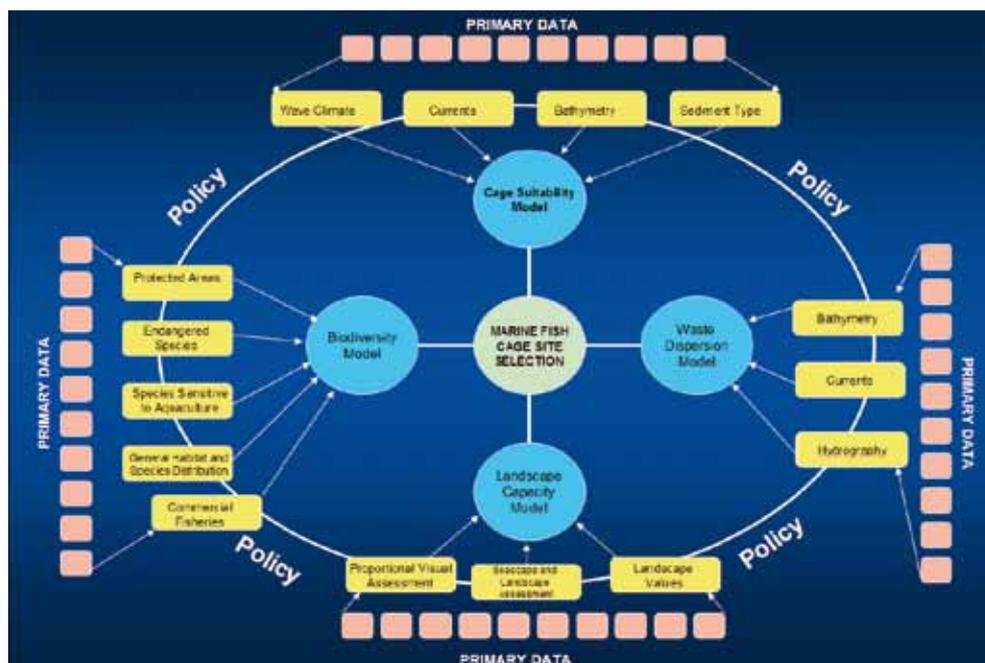
extremely useful for coastal management and will form a “second generation” environmental management tool for modelling and regulation of fish farming in Europe.

This project builds on further development of models developed by the Institute of Aquaculture, at the University of Stirling, using the extensive modelling tools and geographic information capabilities within GIS to construct a completely integrated coastal environmental management package. This can then be used for both environmental regulation of whole coast systems in which fish farming occurs and for environmental management of multiple farm systems, taking into account all inputs to the coastal environment which impinge on its carrying capacity.

The GIS support tools evaluated and integrated by Hunter, Telfer and Ross (2006); Hunter, Telfer and Ross (2007) and Hunter (2009) were based on four main sub-models. These were: Cage site suitability; Particulate waste dispersal, Biodiversity sensitivity indicators and Visual landscape capacity. Each of these sub-models may contain other important sub-models, such as significant wave height and period, and all can either operate as stand-alone decision-making tools or be combined into a holistic model which incorporates a flexible method of trade-off management. The main thrust of combining these sub-models was to link complex databases of environmental (including requirements of Environmental Impact Assessment and monitoring), socio-economic, farm level production information and governmental policy information.

Figure 8.4 shows a conceptual model framework providing holistic decision support for marine aquaculture in the Western Isles, Scotland. The schematic shows a range of primary data sources feeding into four principal sub-models, each of which has a number of sub-model components. All sub-models may be operated as stand-alone tools, or the outcomes may be combined into an overall decision support system. The decision rules at different levels of the model are set by “Policy” which covers environmental limits, engineering tolerances, national policy and regulatory drivers. Figures 8.5a-d illustrate some of the resulting outputs from each of the sub-models.

FIGURE 8.4
Conceptual model framework providing decision support for marine aquaculture in the Western Isles, Scotland.
 Decision rules at different levels of the model are set by environmental limits, engineering tolerances, national policy and regulatory drivers



Source: Hunter (2009).

Figure 8.5d shows the overall sensitivity of biodiversity to aquaculture and is based on a combination of layers including relative biodiversity. The superposition of current aquaculture sites indicates that aquaculture is located in areas of high biodiversity and hence high sensitivity. All sites have been active for some time so this also begs several questions such as: “Is Biodiversity affected by aquaculture? Is aquaculture enrichment good for biodiversity?, and Are sheltered locations like these good for biodiversity and aquaculture? The present case study revealed that there are no prior data to judge whether biodiversity was affected by aquaculture, that it is equally possible that aquaculture enrichment is good for biodiversity, and that sheltered areas can be expected to be good for both aquaculture and biodiversity.

Relevance to EAA

This system would allow developers to isolate sites for the development of aquaculture on the basis of all of these criteria and again pre-model much of the criteria for development. In some cases, this may be a complex and time consuming process to implement fully, however even at its simplest level, GIS can enhance future implementation of the EIA and environmental regulatory process, through data storage, manipulation and acquisition.

Important for the EAA is that the tools developed demonstrate their value to support the objective management of the increasing demands on the coastal zone and can facilitate decision-making amongst stakeholders, multiple agencies and governing bodies that are responsible for management and use of the coastal zone. Many of the criteria that are required for EIA processes are still based on considering fish farms in isolation (Telfer, Atkin and Corner, 2009) therefore this study is also important for EAA in that the models developed demonstrate their use for multi-site aquaculture planning and management within a coastal zone management plan. Parts of the work were commissioned by the Scottish Aquaculture Research Forum, an industry body, and several aspects are now being developed as part of area management agreements in other parts of the country.

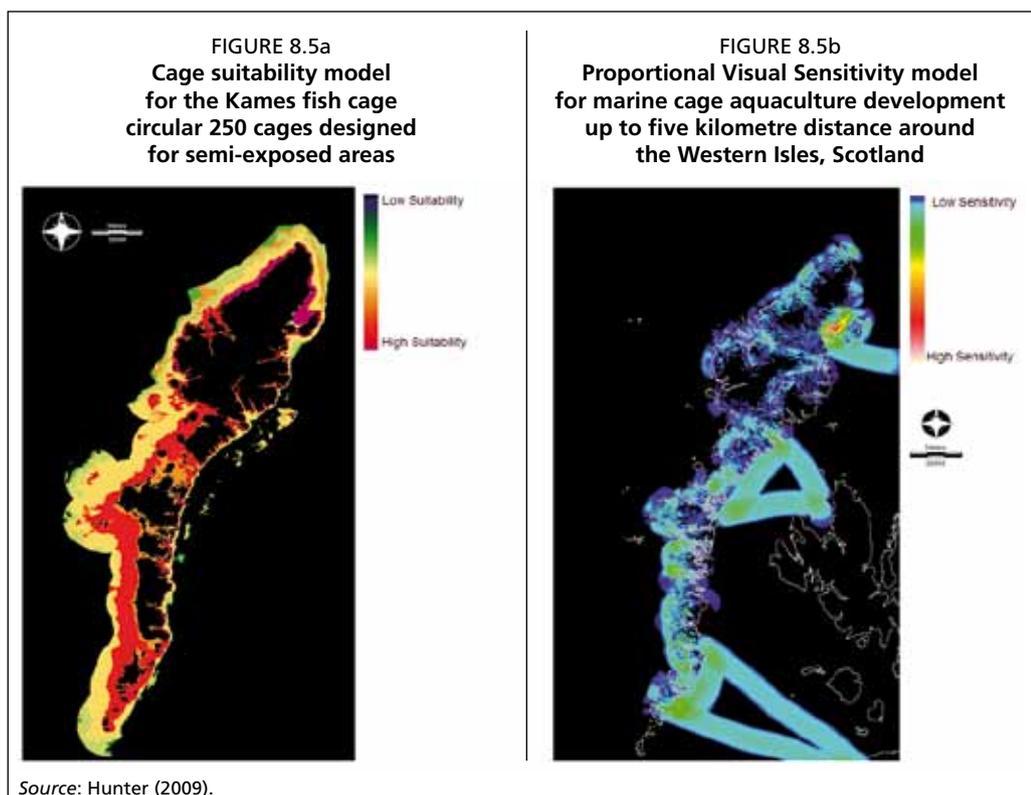
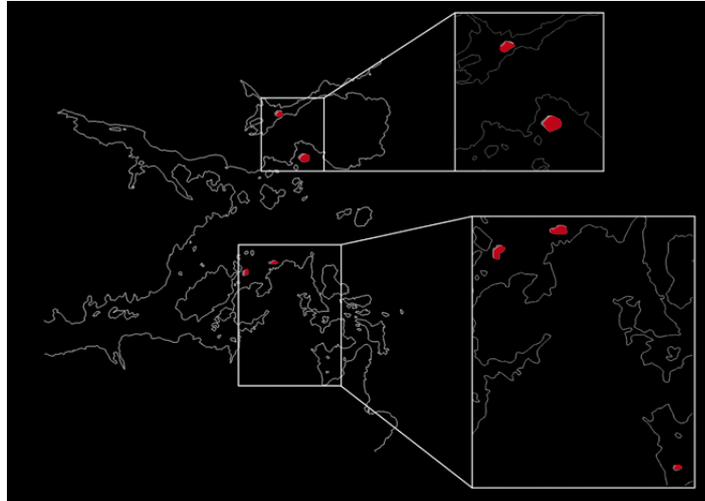
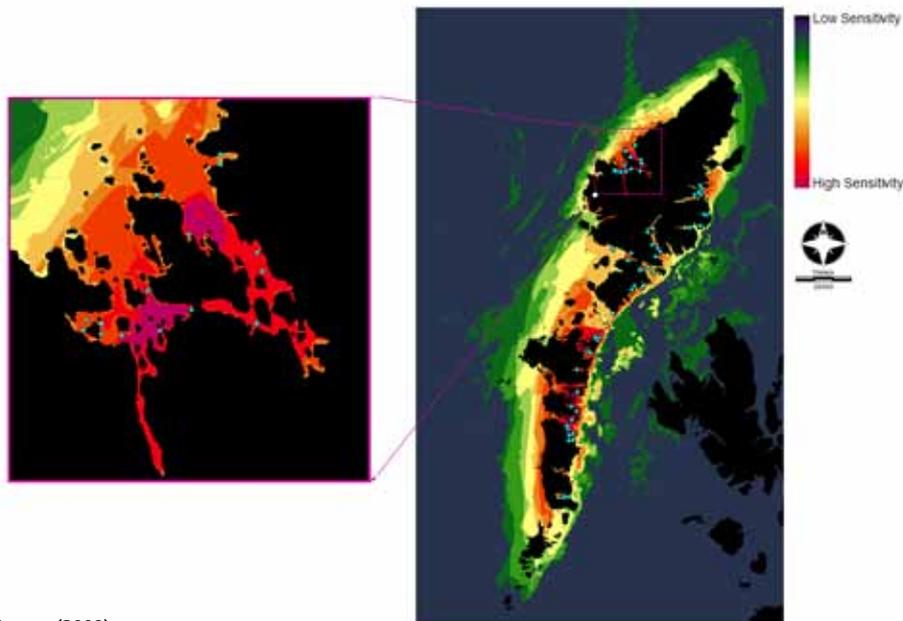


FIGURE 8.5c
 GIS based particulate dispersion model for Loch Erisort and Loch Leurbost Fjord systems using maximum surface current speed as the forcing image and with a resolution of one metre.



Source: Hunter (2009).

FIGURE 8.5d
 Current active fish farm locations in the Western Isles (indicated as cyan dots) overlaid on the overall model of Biodiversity sensitivity to aquaculture for the Western Isles



Source: Hunter (2009).

Case study 4:

Local Plans for Marine Aquaculture Development in Brazil (source: Andrade and Mafra, 2008)

There are specific regulations to guide the development of planning applications to demarcate marine aquaculture parks in Brazil. Normative Instruction No. 17/2005 sets the criteria and procedures for the elaboration and approval of Local Plans for Marine Aquaculture Development (Planos Locais de Desenvolvimento da Maricultura – PLDM), in order to delimit coastal aquaculture parks and preferred areas for traditional communities.

Normative Instruction No. 11/2008 provides some improvement on the guidelines for the PLDM elaboration, with more guidance on GIS products that must be developed as part of the plan, and procedures to select suitable areas for the aquaculture parks (<http://tuna.seap.gov.br/seap/html/aquicultura/index.htm>).

Objectives

The primary objective of this work was the development of guidelines to demarcate marine aquaculture parks in Brazil.

Target decision support audience

Environmental agencies, navy, universities, fishermen and aquaculture organizations, extension agencies and NGOs.

Geographic area and scale of analysis

Marine and inland aquaculture in Brazil

Analytical methods and results

The PLDM process begins with a strategic environmental analysis at the local level, with the identification and localization of environmental reserves, review of users of coastal resources (navigation, leisure, tourism and fishery grounds), detailed environmental characterization of selected marine areas and surrounding land activities that might negatively impact aquaculture development, logistic considerations and the biological requirements of target aquaculture species. Once elaborated, draft versions of the PLDM are discussed at state and local committees with participants from the environmental agencies, navy, universities, fishermen and aquaculture organizations, extension agencies and NGOs.

A similar approach is used in the demarcation of inland aquaculture parks, although there is no specific regulation as for the PLDM for marine areas. For inland aquaculture, the main hydroelectric reservoirs have been the object of studies to demarcate aquaculture parks. These studies include carrying capacity analysis according to the method proposed by Dillon and Rigler (1974) adapted by Beveridge (1987). The method requires information about phosphorous content effects in feed and fishes, food conversion ratios, sedimentation rates and residence time in order to calculate the sustainable stocking density of each reservoir. The planning process also includes the development of a GIS for the selection of suitable areas and demarcation of aquaculture parks. An example of GIS developed for one major hydroelectric reservoir can be viewed at

http://ecologia.icb.ufmg.br/~rpcoelho/Parques_Aquicolas/website/ or

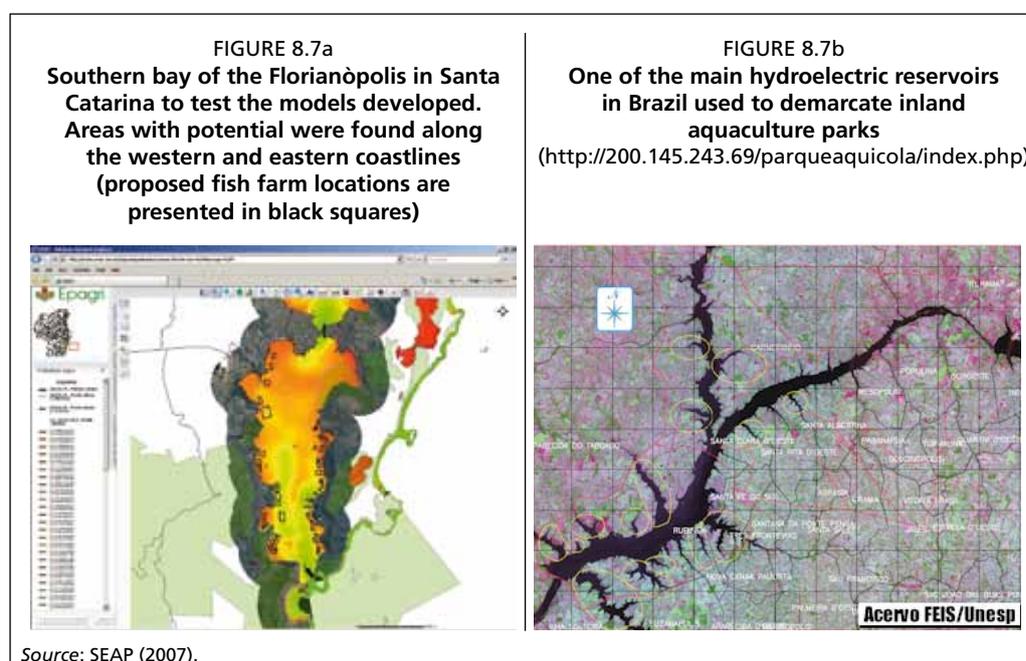
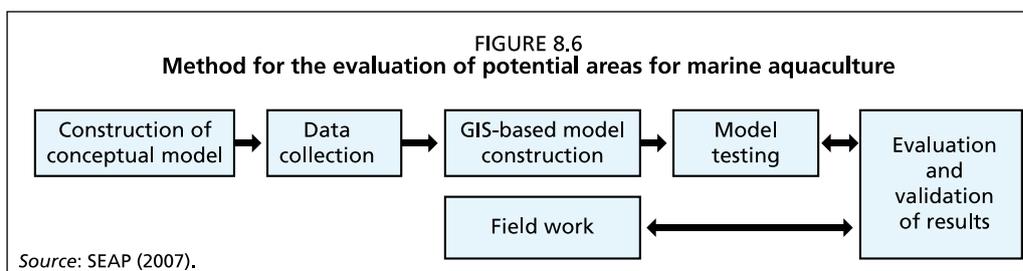
<http://200.145.243.69/parqueaquicola/index.php>

For coastal aquaculture, the planning and management process through the PLDM is under development in 11 states and 77 municipalities along the Brazilian coastline. The first PLDM approved, at Santa Catarina state, demarcated 36 000 ha of marine aquaculture parks with 2 420 ha of production areas for bivalves and seaweeds (SEAP, 2007). These parks will regularize 800 aquaculture farmers already in operation and also plan the allocation of further production areas for 2 585 new farmers. Estimated direct and indirect employment generated with this action is 7 740 and 31 000 respectively. The GIS developed for the PLDM in Santa Catarina can be viewed at

<http://arcims.ciram.com.br/sigeo/mapadinamico/viewer.htm?service=PLDM&ovmap=PLDM>

The southern bay of Florianópolis in Santa Catarina was chosen as a pilot study to test the methodology developed (Figure 8.6). Thirty-five site selection factors identified by a group of 18 experts including oceanographers, geographers, cartographers, administrative personnel including extension agents, mariculture

technicians, and mussel and oyster farmers were used. The factors were grouped into eight sub-models. They were: hydrodynamic, physical, pollution, Socio-economic, infrastructure, markets, production and bio-ecological and the MCE applied to derive a final suitability map. Figure 8.7a illustrates potential areas for marine aquaculture in the southern bay of the Florianópolis and Figure 8.7b illustrates one of the main hydroelectric reservoirs in Brazil to demarcate inland aquaculture parks.



Relevance to EAA and GIS

The PLDM process is particularly important for the EAA because it includes a strategic environmental analysis at local level and because once elaborated, the PLDMs are discussed amongst a broad range of relevant stakeholders and consensus is reached. From a GIS viewpoint this study is noteworthy because it illustrates the use of a simple analytical framework and it is a good example of a fully fledged practical application of the MCE method using the Analytical Hierarchy Process (AHP) to support decision-making for marine and inland aquaculture development.

Case study 5:

Determination of High-Potential Aquaculture Development Areas and Impact in Africa and Asia (source: Kam *et al.*, 2008).

A three-year research project, titled “Determination of High-Potential Aquaculture Development Areas and Impact in Africa and Asia”, was carried out to develop and supply the tools for integrative analysis to support informed decision-making on promoting and scaling out target technologies for pond aquaculture (www.worldfishcenter.org/rdproject).

Objectives

The main project objective was to determine recommendation domains for promoting the development of freshwater pond aquaculture aimed at improving household food security and the livelihoods of smallholder farmers. Recommendation domains are places and sets of conditions for which a particular target aquaculture technology is considered feasible and therefore good to promote.

Target decision support audience

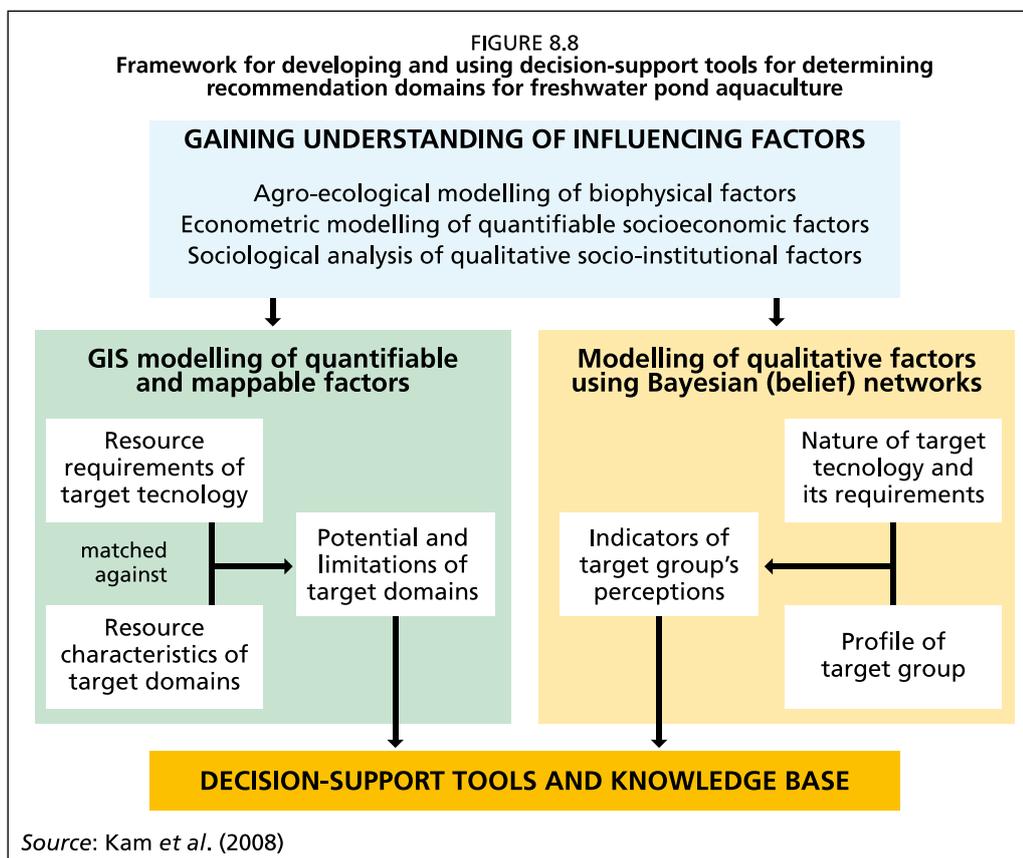
The project results will be useful for policy planners and decision-makers in national, regional and local governments and development funding agencies, aquaculture extension workers in regional and local governments, and researchers in aquaculture systems and rural livelihoods.

Geographic area and scale of analysis

The project was piloted in four countries: Cameroon and Malawi in Africa, and Bangladesh and China (focusing on Henan Province) in Asia. These countries occupy various stages along the spectrum of aquaculture development, thereby allowing researchers to test the applicability and usefulness of the decision-support tools under differing sets of circumstances.

Analytical framework and results

The project adopted a framework, depicted in Figure 8.8, that integrates the various multidisciplinary components into a knowledge-based analytical and decision-support system to provide an informed basis for recommending particular aquaculture practices and technologies. An important first step in the research was to gain an understanding of the main factors influencing the potential for successfully adopting the target aquaculture technology. This then served as the basis for using the GIS and Bayesian network



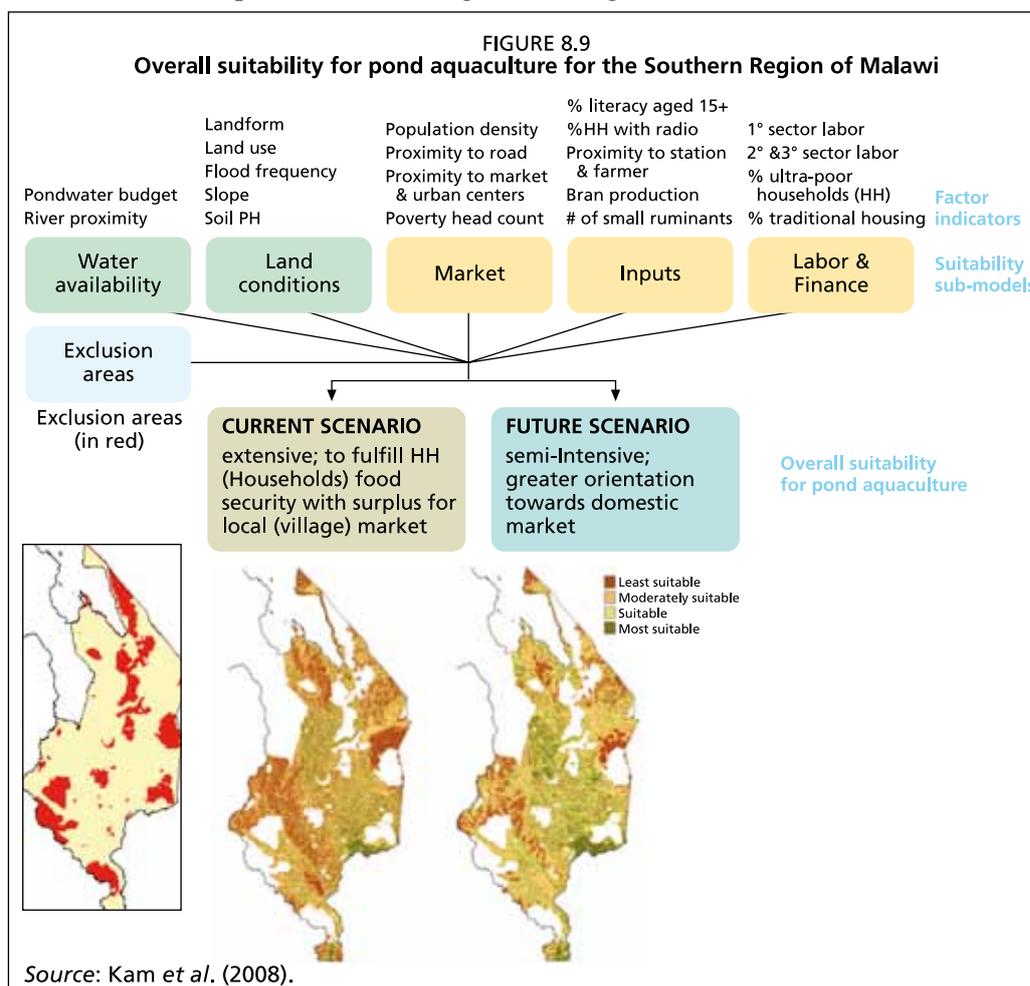
modelling techniques developed by the project to analyze the data collected on these influencing factors. The resulting decision-support toolkit can help various target users identify both the locations and the conditions suitable for smallholder freshwater pond aquaculture, as well as the aquaculture systems and technologies suited to these locations.

The main outputs of the project were: (1) an integrated knowledge base of freshwater pond aquaculture systems and practices, as well as the driving factors for their adoption and continued development; and (2) an analysis and decision-support package that can be used to (a) identify places and situations in which freshwater aquaculture is feasible; and (b) elucidate the nature of constraints requiring appropriate interventions to realize the potential of the target areas.

Relevance to EAA

This project is noteworthy to EAA for a number of reasons:

- The project developed a comprehensive framework that was able to integrate modelling of both quantifiable and qualitative factors using Bayesian (belief) networks. The outcome of the Bayesian modelling was a reading of the probability of farmers' positive versus negative perception of the target technology, which indicates the likelihood that they will adopt it.
- The combination of the GIS and Bayesian network tools identify places and sets of conditions for which a particular target aquaculture technology is considered feasible and therefore good to promote and also identify the nature of constraints to aquaculture development and thereby shed light on appropriate interventions to realize the potential of the target areas (Figure 8.9).



Terminology: HH (Households).

- Also included in the decision support toolkit are software programs developed to estimate and map (a) the thermal growth period, which is the duration when water temperature is conducive for fish growth; (b) the duration of pond water availability for fish culture, based on water balance modelling and taking into account agro-ecological and hydrological conditions of the target area; and (c) fish growth and yield based on the von Bertalanffy growth model and the optimum growth period estimated using (a) and (b).
- Participation of national partners in the model development process was always encouraged and played an important part of the project
- These decision-support tools were matched to target user's roles, knowledge and skills to ensure the sustained use of such decision-support tools so that the required skill sets and expertise are either available, acquired or outsourced.

Case study 6:

Aquaculture information management and traceability system in Thailand (source: Funge-Smith and Aguilar-Manjarrez, 2009)

Aquaculture development in Thailand has grown consistently for the past 25 years. Sectoral development policies of successive governments have been directed towards intensification and expansion of the sector, as clearly evidenced by shrimp aquaculture development in coastal and, subsequently, inland areas. With expansion and growth, problems relating to environmental degradation and losses due to animal health emerged. An FAO Technical Cooperation Project Facility (TCP-F), requested by the Department of Fisheries, Thailand, (DoF Thailand), addressed these issues through creation of decentralized capacity for the DoF Thailand to better manage the environment, aquatic animal health and traceability of aquatic products through a comprehensive aquaculture management information system (AMIS). A TCP-F mission was conducted in February 2008, and the follow-on to this mission is a full-scale project that will become operational in 2011.

Objectives

The project is aimed at improving sustainability and livelihood security of aquaculture stakeholders, improving quality and traceability of aquaculture products, and sustaining or expanding trade in aquaculture products. These goals correspond with a stated vision of DoF Thailand for sustainable aquaculture development.

Target decision support audience

The stakeholders include the provincial and district offices of the DoF as well as DoF central offices and research centres, other ministries and departments that have mandates for lands, waters and the environment as well as the entire aquaculture sector. The target beneficiaries are the aquaculture producers, harvesters, transporters, marketers, processors and exporters as well as the government agencies who take decisions on the allocation of lands and waters for aquaculture and other uses. Ultimately, the target beneficiaries are the consumers of Thai aquaculture products on international and national markets.

Geographic area and scale of analysis

Thailand's total area, including areas under inland waterbodies and some coastal waterways, is 513 115 km²

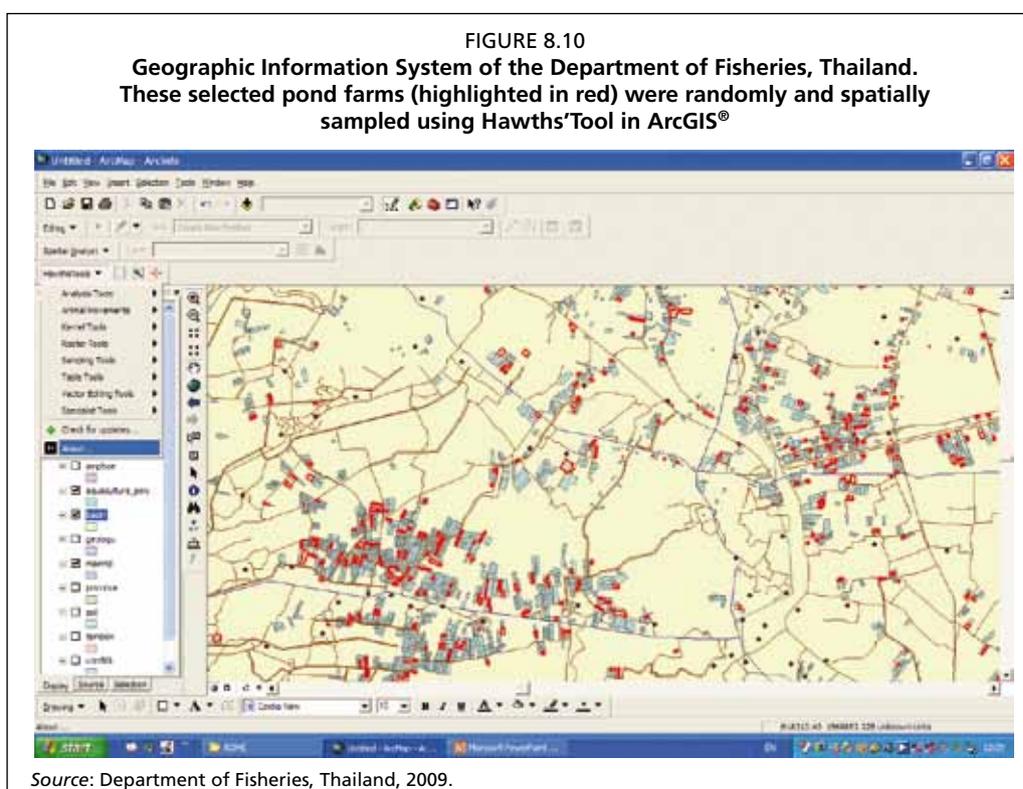
Analytical framework and results

An Aquaculture Management Information System would be operated mainly by provincial and district DoF personnel and research centres, with wider application and participation by personnel at all levels the fisheries department as well as other

departments, ministries and NGOs. The system will support the development of tools for increased traceability and improved management of aquaculture information in Thailand.

Top-level management support, GIS awareness, technical capacity, and the scope and quantities of data for aquaculture zoning and planning in Thailand are already largely in place. Therefore, the main constraints appear to be a lack of data sharing, shortage of awareness of the analytical/modelling capabilities that GIS can provide, lack of access to experience concerning how GIS can be deployed. Thus, this FAO project aims to improve/enhance cooperation amongst Divisions at the DoF and existing institutions/ministries having expertise in GIS, and Remote Sensing for collaborative work and data sharing.

The Fishery Information Technology Centre at the DoF is responsible for developing and maintaining computer networking, GIS, information management systems, and fisheries data collection and statistical reports for end users in Thailand. Current projects on GIS at the Centre are: Inventories of aquaculture and fisheries structures; Fish cage identification and inventory; Vessel Monitoring Systems development; Fishing gear detection; Exclusive Economic Zone for Aquaculture management and Flood monitoring. Outputs from the GIS analysis are displayed on the Internet using ArcIMS® technology and for both internal and external use (<http://gis.fisheries.go.th>). An example of the type of information already in existence at the DoF is illustrated in Figure 8.10. This figure shows how GIS tools can be used to randomly select farm ponds in Thailand. Of relevance to the EAA is the capacity of these tools to be able to inventory aquaculture structures, monitor aquaculture performance and predict production.



Note: Hawth's tools have now been replaced by the Geospatial Modelling environment (L.G. Ross, personal communication, 2010).

Relevance to EAA

The project is noteworthy because it has the elements to guarantee its sustained use.

Importantly, the project was requested by the Department of Fisheries, Thailand (DoF), themselves and there is a strong interest within the Department of Fisheries, Thailand at both central and local levels to find ways to improve the management of information and traceability. This strong interest will ensure the commitment of DoF. The technical support given under the project will build on the existing capacities within the DoF to ensure a continued implementation of the overall objective after the end of the project.

This case study is noteworthy for EAA because it is relatively generic, applicable in other countries with significant aquaculture production systems, and provides an opportunity for utilising an operational GIS to support a comprehensive Aquaculture Management Information System. This is a timely initiative as DoF Thailand is committed to secure/sustain the use of GIS for fisheries and aquaculture at all administrative levels. The Fishery Information Technology Centre, well equipped with skilled manpower and data, could provide strong support to the project. Successful implementation of this full-scale project would lead to improved operational decision-making on aquaculture management and development and enhanced aquaculture planning and policy capabilities.

8.5 SUMMARY AND CONCLUSIONS

This chapter had two objectives. The first was to relate GIS applications in aquaculture to EAA principles in a general way and to illustrate the strength of GIS through its capability to spatially integrate and analyze the natural and human environments. In this way each of the three EAA principles can be viewed in terms of the relevance of various kinds of spatial tools and analyses that can be applied to attaining the objectives, both explicit and implicit, of each principle.

The second objective was to illustrate ways in which GIS, remote sensing and mapping can contribute to the implementation of the EAA through case studies and other examples. Twenty-one case studies spanning all of the EAA principles and scales have been selected and summarized in tabular format, and further access to these is provided via the FAO GISFish gateway. From these case studies, six were selected to be described from a decision-making and modelling viewpoint. These case studies clearly demonstrate that spatial analyses can be easily designed to meet a variety of EAA needs with respect to scales and principles, and are indicative of the state of the art, allowing readers to make their own assessment of the benefits and limitations of use of these tools in their own disciplines. The complete original studies are accessible via GISFish.

An approach for incorporating much of the information needed for the Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) processes through a single modelling and data collation process involves the use of GIS. Models such as those developed by Hunter (2009) could be widely adopted to integrate this process. These models are still under development but they clearly illustrate that GIS already has the capability to take environmental impact modelling forward, and can provide a clear foundation for creating more powerful and robust tools that are easy to replicate, are rapidly updatable and that can be policy-driven in their application.

Although most models developed in SMILE and SPEAR were not implemented or fully integrated within a GIS software, the progress which was made in both projects illustrate the role of GIS to support the implementation of a national programme for sustainable aquaculture, drawing upon excellent collaboration among science, management and industry, and harmonizing the concerns of fishers and environmental decision-makers, the aquaculture industry and conservation agencies.

9. Capacities to implement the ecosystem approach to aquaculture

9.1 INTRODUCTION

Chapter 5 on potential impacts of aquaculture on the environment and environmental impacts on aquaculture helps to gauge needs for spatial analyses to support the EAA at the country level. Complementary to that, the objective of this chapter is call attention to the need to identify, qualify and quantify capacities to carry out spatial analysis that could be brought to bear at country level in support of the EAA. The underlying requirement is to match training and technical support to the capacity to absorb them in relation to needs for spatial analyses in the EAA.

Capacity-building describes those programs designed to strengthen the knowledge, abilities, relationships, and values that enable organizations, groups, and individuals to reach their goals, in this case for the sustainable use of resources. It includes strengthening the institutions, processes, systems, and rules that influence collective and individual behaviour and performance in all related endeavours. Capacity-building also enhances people's ability to make informed choices and fosters their willingness to play new developmental roles and adapt to new challenges. Capacity is about more than potential; it harnesses potential through robust programs to make progress in addressing societal needs and is fundamental to fostering environmental stewardship and improving the management of areas and resources¹.

Carocci *et al.* (2009) indicate that an effective implementation of GIS to support the ecosystem approach to fisheries (EAF) largely depends on:

- The availability of an enabling environment, either at local, national or at international level or within a specific institution, including the availability of skills and competencies amongst personnel who have a clear understanding of its advantages and disadvantages.
- The availability of proper hardware, and adequate technological infrastructures and software are also important aspects of the capacity of an institution to deal with the complexity of collating, storing and analyzing spatial components of an ecosystem.
- Training opportunities and access to adequate support to promote the building of national capacities.
- The accessibility to suitable data. Data accessibility here will include practical cost considerations, data requirements, potential data sources, plus knowledge of data collection, storage and upkeep methods.

Carocci *et al.* (2009) also state that it is the above range of factors that collectively will build the capacity for GIS work. The same holds true for the EAA as does other material in their section on capacity building (Carocci *et al.*, 2009, Section 6.3).

This includes data (already covered herein in Chapters 3 and 4), technical support (covered in GISFish in terms of opportunities for formal and self-training including distance learning), software (covered in several ways in GISFish including freeware) and GIS configuration that, for reasons of economy will not be repeated here.

¹ Definition adapted from Committee on International Capacity-Building for the Protection and Sustainable Use of Oceans and Coasts, National Research Council, 2008.

Rather, the emphasis in this review is on defining in which countries and in which environments capacity building will be of the highest priorities.

Capacity to implement GIS, remote sensing and mapping in support of the EAA will depend on many factors, in various institutions at the national level:

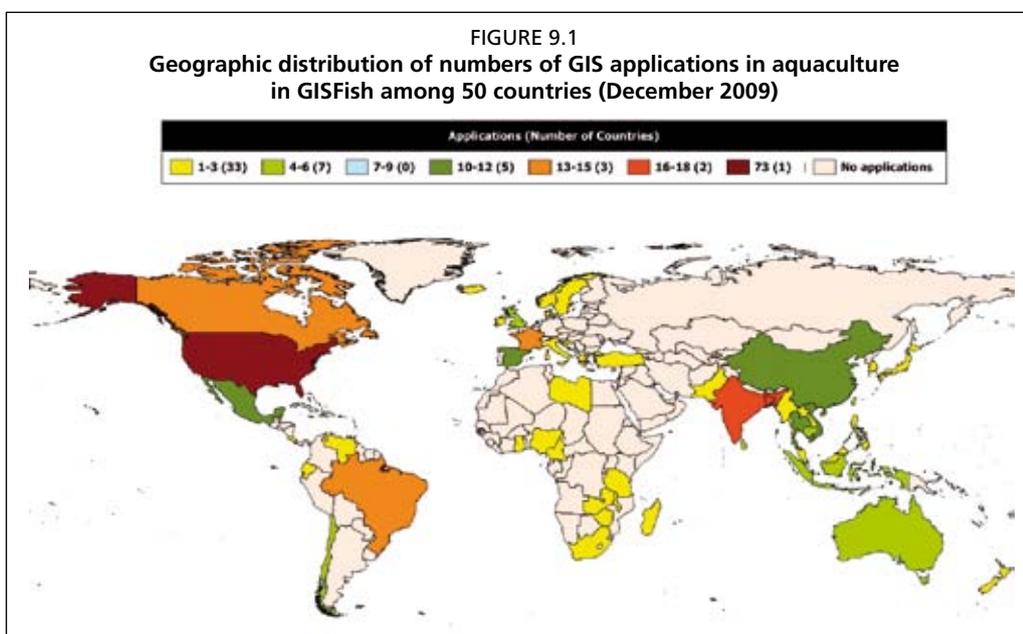
- *Government policy on the EAA*
- *Awareness of the benefits of spatial analysis*
- *Finances and commitment for personnel, equipment and operations*
- *Experience in spatial analysis*
- *Internet access and speed*

Of these, the first three are beyond the boundaries of this review. However, two of them, experience in spatial analysis as indicated by numbers of GISFish records per country and Internet access and speed, are the focus of the following sections.

9.2 AQUACULTURE GIS APPLICATIONS BY COUNTRY

In allocating effort to spatial analyses in support of the EAA it is important to know the level of experience in GIS in each country so that technical assistance and training, if required, can be allocated according to needs and capacities. One such indicative measure is the count of the number of applications by country in the GISFish aquaculture database. This is an indicative measure because some studies in targeted countries may have been carried out by expatriates or consultants without full involvement of nationals.

In, December, 2009, the GISFish database held 373 publications records pertaining to spatial analyses applied to aquaculture. Even though the content is biased towards publications in English, and there are no doubt many more examples of applications that have appeared in national languages, this compilation does indicate a strong background of experience with which to support the implementation of the EAA, but not one that is geographically homogeneous (Figure 9.1).



Among the 373 applications there are a number such as reviews and manuals that did not geographically pertain to individual countries. Among the remaining applications some pertained to two or more countries and those were re-allocated to each individual country. Finally, there were 298 GIS applications in aquaculture that could be associated with a total of 51 countries (Figure 9.1).

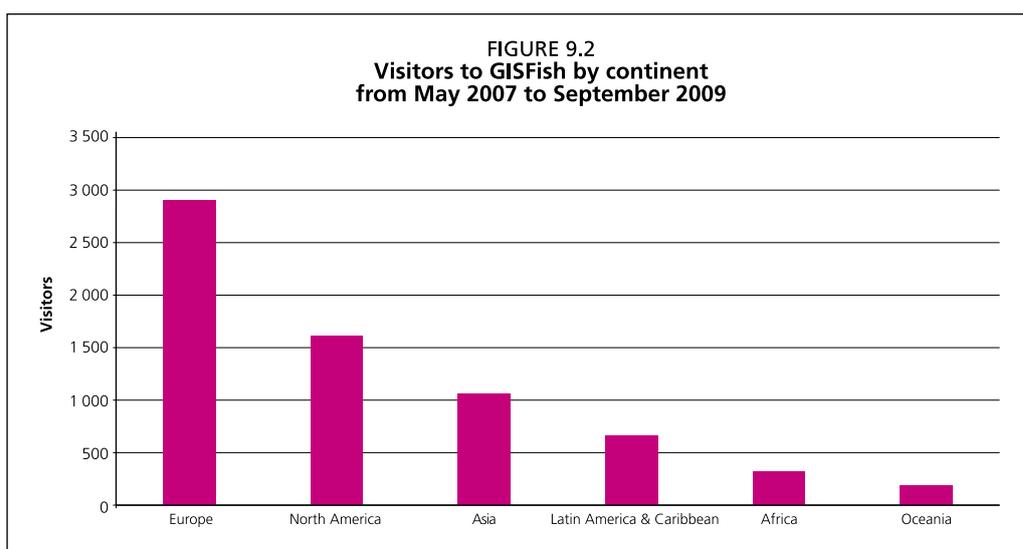
The United States of America accounted for 73 (24 percent) of the total, followed by India with 18 (6 percent), Bangladesh with 17 (5 percent) and, Brazil, Canada France

each with 15 (5 per cent each), Thailand with 12 (4 per cent) and China, Mexico Spain, and Viet Nam each with 10 (3 per cent each).

Regarding the number of applications per country it is striking that there are many countries for which there are no aquaculture GIS applications at all. In summary, there were 298 applications among only 51 countries. In comparison, there were 163 countries having recorded aquaculture production in 2005 (FAO, 2007). The number of spatial analysis applications per country is underestimated for a number of reasons to do with language, how GIS applications are treated in publications and technical reports. Nevertheless, even though GIS has been applied to fisheries and aquaculture since the early 1980's, GIS applications in aquaculture cannot yet be said to be numerous and widespread. This poor geographic distribution of GIS usage indicates that training is likely to be a top priority for the implementation of GIS in support of the EAA. Further, in order to encourage a more widespread use of spatial tools applied to aquaculture and especially to the EAA it will first be necessary to promote GIS among administrators and decision-makers.

It is of concern that of those countries that practice aquaculture most intensively (Chapter 5), about half apparently are not represented in the GISFish Aquaculture Database. In contrast the numbers of visits to GISFish is encouraging in showing a widespread interest in GIS applications in aquaculture and inland fisheries (Figure 9.2).

The average number of visits to GISFish per country per month is 375, and the

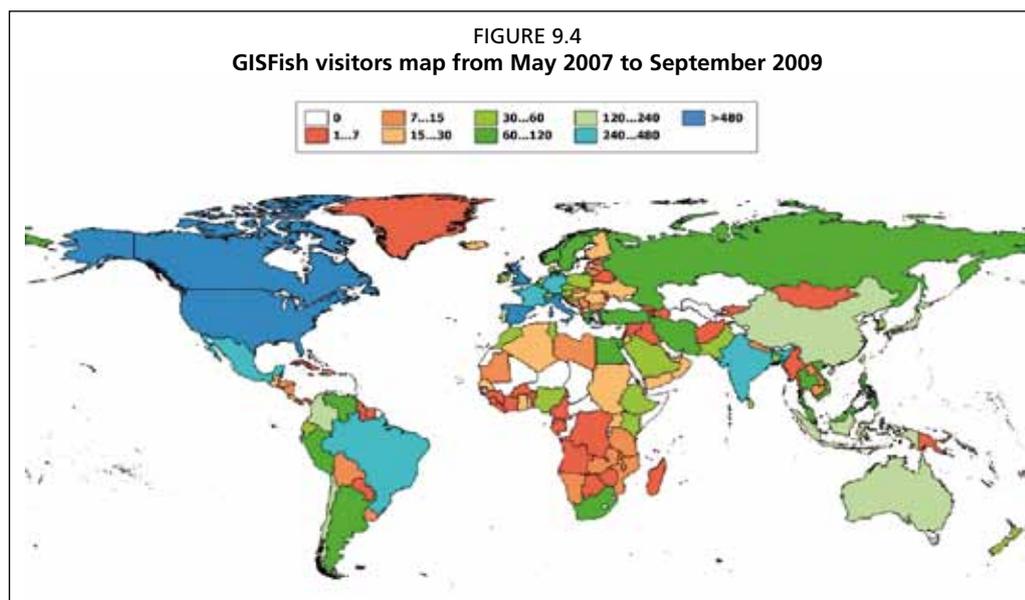
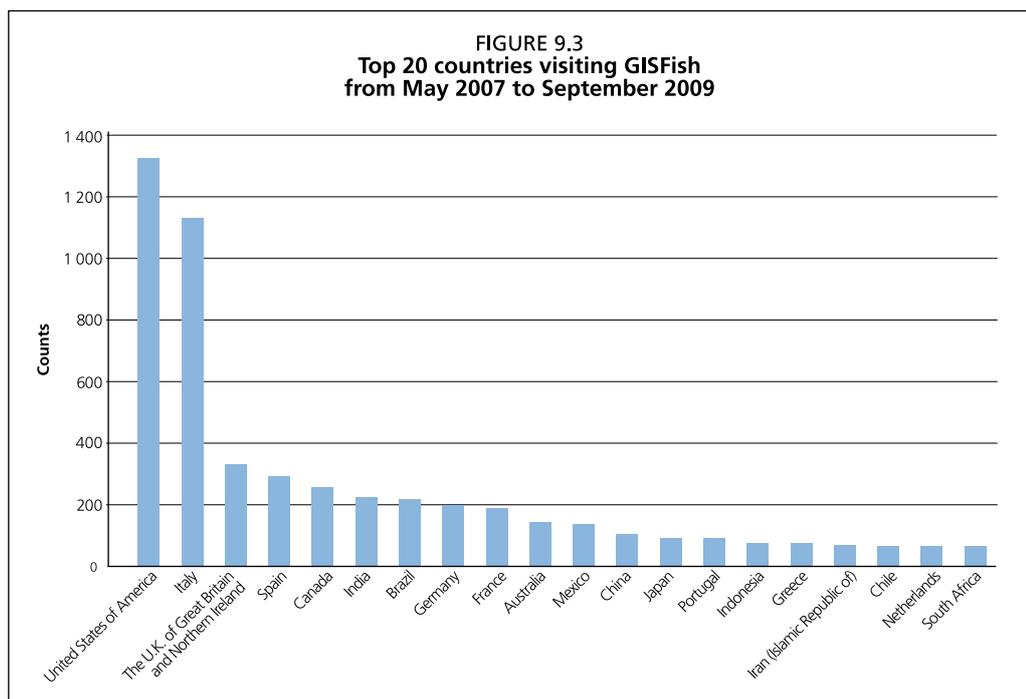


average number of countries visiting GISFish per month is 66. The top 20 countries that visited GISFish during the period of May 2007 to August 2009 inclusive, is presented in Figure 9.3. Clearly, Italy and the United States of America stand out as being the main visitors, however, there are many other countries that visit as shown in Figure 9.3 and 9.4.

9.3 ACCESS TO THE INTERNET AS A MEASURE OF CAPACITY FOR SPATIAL ANALYSES IN SUPPORT OF THE EAA

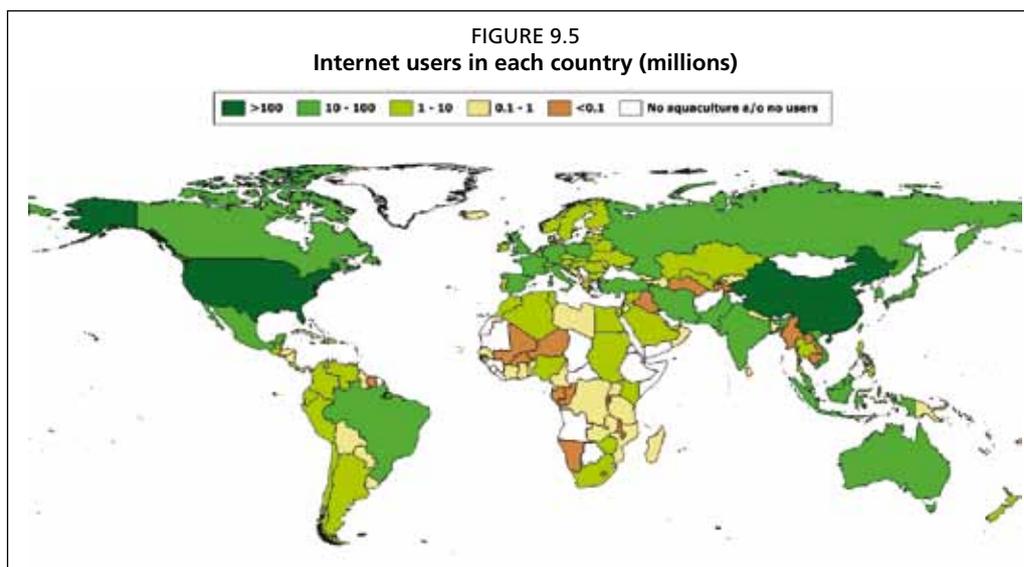
Access to the Internet and speed of access are extraordinarily important measures for gauging capacities to implement spatial tools in support of the EAA and for realizing that support. The Internet is a pipeline for communications and a data download pathway, as well as a backbone for training and technical support. In these regards the Internet is an essential element in providing the support required.

The number of Internet users within 220 countries and territories is tabulated in the World Fact Book (available at www.cia.gov/library/publications/the-world-factbook/rankorder/2153rank.html). Statistics vary but are mainly from 2007 and 2008



and may include users who access the Internet at least several times a week to those who access it only once within a period of several months. About 35 percent of the countries have one million or more users. The United States of America and China, Japan, India and Brazil rank first to fifth, respectively (Histogram: Statistics/Internet/InternetUsers&CIACC.xls).

Of the 163 countries recording some aquaculture production, there are data on the numbers of Internet users for 154 countries and territories (Figure 9.5). Numbers of Internet users vary greatly among countries spanning a range of less than one hundred thousand to more than 100 million. The only significant aquaculture producer not included is the Peoples Democratic Republic of Korea. Aquaculture producing countries with the least Internet users occur mainly in Africa. The number of Internet users in a country is not a guarantee that fisheries and aquaculture administrations are so equipped, yet this is an indicative means of evaluating training and equipment needs and for gauging the probability of success of technical interventions.



9.4 SYNERGIES BETWEEN THE ECOSYSTEM APPROACH TO AQUACULTURE AND THE ECOSYSTEM APPROACH TO FISHERIES, AND WITH OTHER SECTORS

One of the main outcomes from this review is the recognition that there are many issues, data requirements and analytical and decision-making developments that are common for both aquaculture and fisheries. More broadly, the same can be said for many other users of lands and waters. This is true not only in qualitative terms but also applies to all levels of organization and scale from global to sub-national. Taking advantage of these commonalities makes possible economic efficiencies (i.e. reduced costs) in data collection, data processing, spatial analyses and training. Moreover, the contacts and cooperation that result from a common or shared approach, or shared needs, pay additional benefits.

The following are some of the possible activities in which synergies could be sought between aquaculture and fisheries with regard to the implementation of the ecosystem approach to aquaculture (EAA) and the ecosystem approach to fisheries (EAF).

Activities with spatial components common to aquaculture in the EAA and to fisheries in the EAF in which synergies could be sought:

- Spatially and/or operationally defining ecosystem boundaries;
- Minimizing impacts on ecosystems (including societal impacts);
- Anticipating environmental and man-made impacts on aquaculture and fisheries;
- Facilitating integration of environmental, social and economic and administrative realms of aquaculture; and
- Anticipating and/or analyzing competing, conflicting and complementary uses of land and water.

Synergies should be sought and encouraged at all levels of the implementation of spatial planning tools for the EAA. Because training and technical assistance are going to be the major tasks, they are areas on which to concentrate searches for commonalities and competences. In practical terms, other specialized agencies of the UN family with strong training components (e.g. UNESCO) and well-developed capacities in spatial analyses (e.g. UNEP) as well as global NGOs (e.g. IUCN, WWF) with the same qualifications would appear to present good prospects for mutually beneficial cooperation.

9.5 SUMMARY AND CONCLUSIONS

Capacity-building describes programs designed to strengthen the knowledge, abilities, relationships, and values that enable organizations, groups, and individuals to reach their goals for the sustainable use of resources. The objective of this chapter was to call attention to the need to identify, qualify and quantify spatial analysis capacities that

could be brought to bear at country level in support of the EAA. Prior information on capacity is vital in order to match training and technical support to the capacity to absorb them.

Several measures were employed to estimate capacities at the country level. These showed that the geographic distribution of the numbers of GIS-based applications in aquaculture did not cover all aquaculture countries and did not correspond with the intensity of aquaculture production. Because the Internet will have to serve as the backbone and pipeline for data, training and technical assistance in support of the EAA, Internet availability and access are essential. Many countries were shown to have limited numbers of Internet users.

This chapter also shows that information on which to gauge national capacity to undertake GIS, remote sensing and mapping in support of the EAA is generally difficult to come by and to evaluate remotely. Indeed, our experience shows that, even by concentrating on one country, searching the literature and the Internet for applications and for government and commercial entities, employing short-term national consultants and making site visits may give an incomplete picture, especially if the language of the country is not that of the investigators. This experience suggests that that small multidisciplinary teams of nationals of each country should evaluate their spatial analysis capacities as an essential step in planning for GIS in support of the EAA.

GIS support to the EAA depends on the general level of implementation of spatial tools in the country and more specifically on the interest of the fisheries and aquaculture administration, its finances, and the capacity and interest of staff. As regards GIS capacity and for efficiency in support of the EAA, direct contact should be made with the aquaculture administration in each country in order to make evaluations of the capacities of each to implement spatial tools and in order to be able to tailor technical assistance to the needs of the technical staff.

10. Advancing the use of spatial planning tools to support the EAA

10.1 INTRODUCTION

For brevity, the detailed conclusions synthesized from those set out at the end of each chapter of this review are assembled in the report of the workshop (pp 1-11) and not repeated here. Rather, the purpose of this chapter is to lay out several salient conclusions and to recommend activities to advance the use of spatial planning tools to support the EAA.

This review has established that there is an ample resource of technically broad spatial planning experience that can be tapped to support the implementation of the EAA through the use of GIS, remote sensing and mapping along with decision-making and modelling. This conclusion is based on an assessment of the availability of spatial data, and experience in addressing general issues in aquaculture at a broad range of scales and in a great variety of ecosystems that are relevant to the EAA, and in spatial decision-making and modelling. Specifically, the review has demonstrated that spatial planning tools easily encompass the three principles of the EAA and comprehensively cover the scales relevant to the EAA. The review has also shown that the experience is not homogeneously distributed globally as is the likely case with capacities to realize the benefits of applying spatial analyses to the EAA. Therefore, a major conclusion of this review is that the main tasks in support of the EAA are going to have to be promotion, training and technical assistance of GIS, remote sensing and mapping to ensure the timely and effective use of these tools.

The review has also employed methodologies to identify the countries which potentially make the most intensive use of freshwater, brackish- and marine environments for aquaculture as well as those in which the potential environmental impacts of other activities on aquaculture may be greatest. Some of those countries will be those most in need of awareness building of benefits, training and technical assistance.

With these challenges in mind, the remainder of this chapter is devoted to recommendations that are made mainly from the viewpoint of FAO Aquaculture Service (FIRA) that would be guiding the spatial planning initiatives in relation to overall EAA implementation at the global level. However, it is clear that spatial planning in support of the EAA will proceed best when it is tightly integrated temporally and geographically with the broader EAA effort.

10.2 FUTURE ACTIVITIES TO IMPLEMENT SPATIAL PLANNING TOOLS IN SUPPORT OF THE EAA

Filling gaps to lay a solid foundation for spatial planning tools in support of the EAA

Future activities in support of the EAA can be viewed as several major but related initiatives: (1) technical guidance for the development of innovative applications of spatial planning tools that can serve as core training materials that, in turn, can be deployed to EAA hotspots as needed, (2) capacity building that goes forward at all levels from global to sub-national, and (3) promotion of spatial planning tools at decision-making and technical levels. Of these, the first and third are expected to be closely managed by the FAO Aquaculture Service (FIRA) while opportunities for cooperative activities on capacity building should be explored with external organizations.

Development of spatial planning tools in-house and with external organizations

Implementation of the EAA can be viewed as somewhat akin to the development of the Code of Conduct for Responsible Fisheries. That is, implementation of the EAA will be a long, step-wise process that will include policy and technical guidelines as well as global, regional and national-level project activities. Therefore, a second important conclusion of this review is that, in order to ensure that planning for the use of spatial tools and analyses in support of the EAA is well founded, more specific and more detailed preparatory work will have to follow this review.

Innovative applications of spatial tools in the past have included strategic assessments of aquaculture potential at country, regional and continental levels. Presently new applications are aimed at mariculture with particular attention to off-the-coast and offshore aquaculture. Additionally, the development of the Africa Water Resources Database (AWRD) has opened up an opportunity for spatial analysis of waterbody ecosystems within larger terrestrial ecosystems. Analytical tools and comprehensive data are already at hand in the AWRD (Jenness *et al.*, 2007a; 2007b) that could be deployed for developing and testing EAA concepts and for implementing both the EAA and the EAF. Nevertheless, a number of topics should be pursued in order to address the gaps identified in this review. The topics are:

- Incorporating GIS-based social and economic analyses in aquaculture for the development of the EAA; what is needed are lessons learned from aquaculture, fisheries and other disciplines;
- Further exploration, documentation and synthesis of GIS-based decision support and risk analysis relevant to the EAA and catalogues of their respective tool boxes to follow the detailed survey already available herein as Chapters 7 and 8;
- Integrating spatial planning tools in the EAA via promotion, technical assistance and training: here are needed innovative ways to identify needs and capacities at all levels of administration; and
- Increasing capacities for training in spatial analyses via the Internet in the context of the EAA; and needed here are lessons learned from other disciplines and institutions that have been successful in reaching large audiences with low cost, effective solutions via the Internet.

Special attention is drawn to gaps in applications in aquaculture that deal with economics and social matters because of their close relationship with the EAA principles. A fundamental problem is that ecological and economic-social data are usually collected using political rather than geographic or ecosystem-based boundaries although, technically to a greater extent this can be overcome by GIS. A related and underlying problem lies in the basic education given to fisheries and aquaculture professionals, i.e. the lack of requirements for a solid foundation in economics and social sciences to accompany the natural sciences. There are several solutions to this, each with differing time horizons. The most rapid is to include economists and sociologists in spatial analyses, if no aquaculture specialists in these disciplines are available. Another, more medium term solution is to provide training on economic and social issues for technical staff with biological and ecological orientations. Finally, curricula preparing graduates for careers in aquaculture development and management need to be broadened to include not only natural sciences but also economics and sociology along with spatial awareness as required courses, or indeed graduates in ecosystem courses could have their courses broadened to include socio-economic elements as necessary. Aquaculture is very interdisciplinary and a good training programme will include aspects for all of the above components – and more.

Another gap is the lack of involvement of aquaculture with multisectoral planning. GIS, as is well known, can help to overcome this issue, but administrators and practitioners alike have to realize that they must go outside of their own disciplines

to utilize the available expertise and to better understand competing and conflicting uses. This comes down to promotion through raising awareness of benefits and the inclusion of this solution in technical guidelines. One avenue in which to cover these topics is via expert reviews and case studies and eventually the preparation of technical guidelines that serve as core training materials. Another avenue is through workshops for managers and administrators to raise awareness about the capabilities of the tools and to formulate project proposals to implement them.

Cooperative training activities focused on the EAA

Training and post-training support of technical staff in fisheries and aquaculture departments, as well as departments and organizations involved in regulation or licensing will be required to implement spatial planning tools at the scales most pertinent to the EAA.

There is need to reach a large, globally dispersed audience. Accordingly, a broad strategy is required that takes advantage of common interests in the EAA principles and objectives and synergies that are shared by other organizations. Some of these could become potential partners and include:

- Universities (e.g. Stirling University in Scotland; The University of British Columbia in Canada, etc).
- The UN family of specialized agencies
- International and national NGOs involved with ecosystems and the environment
- International and national aquaculture associations and trade groups
- International and national aquaculture industries

Because spatial data is one of the principal shared needs among organizations, data collection and sharing could be one of the building blocks of cooperation that could eventually extend to joint projects.

Looking inward at FAO, there is a considerable body of organization-wide GIS experience and spatial data within the organization to implement spatial tools in support of the EAA. Other FAO-resident relevant experience already gained, readily available and highly pertinent is from the FAO Fisheries and Aquaculture Department EAF initiative. Additionally, there is untapped experience resident in the inland fisheries part of GISFish. While the resident experience is impressive in FAO, looking outside could also be fruitful. Common interests and skills reside in university programs and professors specialized in GIS for aquaculture and fisheries (e.g. Stirling University in Scotland) as well as in international NGOs with interests and competences in ecoregions and ecosystems and their conservation and management (e.g. World Resources Institute). The sources of ecosystem and other data listed in Chapters 3 and 4 provide an entrée to identify the latter organizations.

Gauging capacities to implement spatial tools in support of the EAA among countries

The countries likely to be most intensively impacting the coastal and inland environments through aquaculture activities have already been identified (Chapter 5), but their capacities to embrace the expert use of spatial planning tools are not generally known. Gauging capacities to implement spatial tools in support of the EAA is an essential step in providing the assistance required. At the country level this is very difficult and quite uncertain when done remotely. For example, the number of Internet users in a country is not a guarantee that fisheries and aquaculture administrations are well connected (Figure 9.3), yet this is an essential part of evaluating training and equipment needs and for gauging the probability of success of technical interventions. A well organized effort is required to gauge capacities. As a starting point, and in order to acquire this information quickly and inexpensively, the fisheries and aquaculture

departments of FAO member countries should be emailed a brief questionnaire in order to identify the individuals and units using GIS and to request a summary of GIS activities and computer and Internet capabilities. The benefits of making such contacts are many and go beyond basic information collection itself. They include the opportunity for a dialogue that could reveal problems, potentials strengths and weaknesses that could eventually lead to improved and more efficient prescriptions for technical assistance. For example, opportunities for neighbouring countries to assist one another through networking or more formally through training and exchanges could result. Regional aquaculture networks such as the Network of Aquaculture Centres in Asia-Pacific (NACA); Network of Aquaculture Centers in Central and Eastern Europe (NACEE); Aquaculture Network of the Americas (RAA) and Aquaculture Network for Africa (ANAF) are important for the coordination of research, training and information exchange to promote aquaculture development on a regional basis, especially emphasizing the sharing of available resources (Aguilar-Manjarrez, 2008). It would be of utmost value if such centres were also able to provide operational information on GIS useful to support the EAA

Promotion

The EAA is holistic and therefore promotion of spatial awareness has to be not only at the ecosystem level but also all administrative levels. Additionally, promotion has to reach an audience much broader than practitioners of spatial planning tools for aquaculture alone. There are several potential audiences each with a need for a somewhat different approach in order to raise awareness of the need and benefits of applying spatial tools to the EAA. These include:

- aquaculture administrators;
- environmental regulators;
- coastal zone planners: decision makers with responsibilities broader than for aquaculture alone,
- aquaculture industry leaders and managers, including farmers, trade organizations, and financing institutions; and
- university professors in the fields of natural resource management, sociology and economics to orientate training and research; and
- private industry including farmers, trade organizations, and financing institutions; and
- NGOs with interests in conservation of natural resources.

The salient question is how to most effectively reach this varied audience. This is recommended as one of the future activities above on “Filling gaps to lay a solid foundation for spatial planning tools in support of the EAA.”

An important aspect of promotion is raising awareness of the benefits and constraints of spatial tools as applied to the EAA. The GISFish portal already provides an avenue to this kind of information, but it is mainly aimed at those who are already somewhat familiar with GIS and who may be actual practitioners. If spatial tools for the EAA are to attain their potential, then administrators and decision-makers at the national level have to be made aware of the alternatives (e.g. contracted investigations vs. developing in-house capabilities) for their implementation. Facts pertaining to their benefits and costs in terms of capital investments, personnel and operating costs need to be disseminated. A new FAO Technical manual on “Geographic information systems and remote sensing in fisheries and aquaculture” is currently in preparation. This manual aims to address this need using selected case studies from different regions, environments, species and culture systems to illustrate the range of uses of spatial planning tools to support EAA and EAF implementation. Along the same lines, one of the follow-ups to the present review, especially Chapter 7 on decision-

making modelling, will serve as one of the key background documents to assist a multidisciplinary team of 12 experts to prepare a much broader review entitled “Progressing aquaculture through virtual technology and decision-making tools for novel management” (Ferreira *et al.*, 2010). This will be presented at the Global Conference on Aquaculture 2010 (www.aqua-conference2010.org/). This review will broaden and enrich the present review. As a complement to this, advantage can be taken of the GISFish portal which contains many applications and case studies. The case studies presented in GISFish can be viewed as potential models for gauging the benefits accruing from future investigations as well as the time and personnel required in order to achieve results.

Technical assistance

Technical assistance for spatial planning tools in support of the EAA can take many forms such as missions and regional and in-country projects, as well as manuals and reviews and the GISFish Web portal. Access to the Internet particularly with country level client EAA practitioners is going to be essential for Email communications, as a spatial data and tools pipeline, and for delivering promotion and training. Relatively inexpensive initiatives could yield great benefits such as the activity on inventory of aquaculture outlined below.

Spatial inventory of aquaculture

As mentioned in Chapter 5, much of the implementation of the EAA will depend on defining aquaculture’s impact on the environment and environmental impacts on aquaculture. Fundamental to defining these potential impacts are two kinds of information: (1) the boundaries of ecosystems and, (2) the locations of aquaculture and its characteristics. For the implementation of the EAA and for the use of spatial tools in support of the EAA, there is no substitute for a spatial inventory of aquaculture with follow up monitoring in order to detect changes in distribution and attributes. In short, the locations of various kinds of aquaculture installations including production sites, storage, transport and marketing facilities, along with their attributes, are indispensable for two purposes: (1) placing the aquaculture industry locationally within an ecosystem context, and (2) establishing administrative responsibilities for management and development in geographic terms. Fully developed spatial inventory should become a priority and for a relatively inexpensive initiative, the benefits can be great, delivering essential data for spatial analyses in support of the EAA. Thailand already provides one example of such an implementation (Suvanachai, 1999). Satellite remote sensing has already been shown by FAO and others to be efficient for aquaculture inventory and examples are included as GISFish case studies (www.fao.org/fishery/gisfish/id/1014).

The FAO Aquaculture Service (FIRA) is in the process of mapping aquaculture as part of the National Aquaculture Sectors Overviews (www.fao.org/fishery/naso/search/en). There is ample justification for amplifying and accelerating this activity due to its fundamental importance to the EAA as well as side benefits including the improvement of aquaculture statistics. An amplification of the NASO effort should include the preparation of a simple manual aimed at national level aquaculture departments on the methods to inventory and attribute aquaculture using image processing and GIS freeware. Remotely sensed data can be obtained from freely downloadable sites such as TerraLook and satellite images for base maps and other layers from earth browsers such as Google Earth and Microsoft Virtual Earth as indicated in Chapter 4. A part of this manual could include methods for field verification carried out by local personnel with inexpensive GPS units to collect the attribute data and to provide the spatial verifications. The GIS would then become the information backbone of the inventory by containing the spatial data, by placing the

inventory in other spatial contexts and by holding the attribute data. To this end, there will be a need to create and/or strengthen information systems to keep the national aquaculture inventories up-to-date that will require more sophisticated training. Work already carried out in Thailand provides a template for further refinement (Suvanachai, 1999). FIRA can assist by perfecting and disseminating the methodology as appropriate for various levels of aquaculture development. Dissemination can be through manuals and training courses that can be direct or online. For the latter, GISFish should be further developed to serve as a training materials pipeline.

Practical implementation

Practical guidelines for GIS to support the EAA need to be developed. The present review and the FAO Technical manual on “Geographic information systems and remote sensing in fisheries and aquaculture” (in preparation) should be used as a base or starting point. GISFish is a portal to many additional resources upon which to build the manual, these include, literature, internet training opportunities, freeware, and data, a first step is to filter these resources for their usefulness.

Figure 7.1 in Chapter 7 illustrates a schematic representation of the phases in a GIS project which is still useful in a generic sense to any GIS project. However, a more specific example of GIS implementation to support the EAA is UNESCO's initiative on marine spatial planning (MSP) because the MSP process and tools could be adapted to, or adopted by the EAA.

Many steps in the MSP process (Ehler and Douvère, 2009) require or are facilitated by the use of software tools or other well-defined spatially-explicit methodologies (collectively referred to as “tools”). The present review aims to promote awareness, use, and development of GIS-based tools that can help implement the EAA. The review also provides a knowledge base of tools for EAA. As MSP is a means of implementing EAA, virtually all of the GIS-based tools presented in this review are relevant to MSP.

The purpose of the UNESCO initiative on MSP is to help countries operationalize ecosystem-based management by finding space for biodiversity conservation and sustainable economic development in their marine environments. One way to do this is through marine spatial planning. UNESCO's work focuses on moving marine spatial planning beyond the conceptual level by:

- Developing a step-by-step approach for implementing marine spatial planning;
- Documenting marine spatial planning initiatives around the world;
- Analyzing good practices of marine spatial planning;
- Collecting references and literature on marine spatial planning;
- Enhancing understanding about marine spatial planning through publications;
- Developing capacity and training for marine spatial planning.

Most of the 10 steps for MSP are relevant to GIS for EAA and are listed here:

- Step 1 Defining need and establishing authority
- Step 2 Obtaining financial support
- Step 3 Organizing the process (pre-planning)
- Step 4 Organizing stakeholder participation
- Step 5 Defining and analyzing existing conditions
- Step 6 Defining and analyzing future conditions
- Step 7 Developing and approving the spatial management plan
- Step 8 Implementing and enforcing the spatial management plan
- Step 9 Monitoring and evaluating performance
- Step 10 Adapting the marine spatial management process

A modified version of these MSP steps as required for GIS to support EAA implementation (also see Figure 2.1 in Chapter 2) could be:

- Step 1 Defining ecosystem boundaries
- Step 2 Identifying issues and potential stakeholders
- Step 3 Organizing stakeholder participation
- Step 4 Defining operational objectives
- Step 5 Developing and approving the spatial management plan
- Step 6 Obtaining financial support
- Step 7 Defining legal issues and their spatial context
- Step 8 Implementing and enforcing the spatial management plan
- Step 9 Monitoring and evaluating performance
- Step 10 Adapting the marine spatial management process

Finally, it is important to note that the ecosystem approach to aquaculture (like the ecosystem approach to fisheries) is about people. It is in their interest to develop aquaculture in an environmentally and people-friendly way and it is people who will be implementing the EAA (C. Brugère, personal communication, 2010). Likewise, it is entirely up to aquaculture decision-makers and spatial analysts as potential EAA implementers to make sure that GIS tools are used responsibly, and it is the creative use that they make use of these tools which will make them effective.

11. Glossary

GIS-RELATED TERMINOLOGY

Cell. The smallest unit of information in raster data, usually square in shape. In a map or GIS dataset, each cell represents a portion of the earth, such as a square meter or square mile, and usually has an attribute value associated with it, such as soil type or vegetation class.^a

Fuzzy classification. Any method for classifying data that allows attributes to apply to objects by membership values, so that an object may be considered a partial member of a class. Class membership is usually defined on a continuous scale from zero to one, where zero is nonmembership and one is full membership. Fuzzy classification may also be applied to geographic objects themselves, so that an object's boundary is treated as a gradated area rather than an exact line. In GIS, fuzzy classification has been used in the analysis of soil, vegetation, and other phenomena that tend to change gradually in their physical composition and for which attributes are often partly qualitative in nature.^a

Geographic Information System (GIS). An integrated collection of computer software and data used to view and manage information about geographic places, analyse spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analysed.^a

Geodatabase. A database or file structure used primarily to store, query, and manipulate spatial data. Geodatabases store geometry, a spatial reference system, attributes, and behavioral rules for data. Various types of geographic datasets can be collected within a geodatabase, including feature classes, attribute tables, raster datasets, network datasets, topologies, and many others. Geodatabases can be stored in IBM DB2, IBM Informix, Oracle, Microsoft Access, Microsoft SQL Server, and PostgreSQL relational database management systems, or in a system of files, such as a file geodatabase.^a

Global Positioning System (GPS). A system of radio-emitting and -receiving satellites used for determining positions on the earth. The orbiting satellites transmit signals that allow a GPS receiver anywhere on earth to calculate its own location through trilateration. Developed and operated by the U.S. Department of Defense, the system is used in navigation, mapping, surveying, and other applications in which precise positioning is necessary.^a

Keyhole. Markup Language. XML grammar and file format for modelling and storing geographic features such as points, lines, images, polygons, and models for display in Google Earth. A KML file is processed by Google Earth in a similar way that HTML and XML files are processed by web browsers. Like HTML, KML has a tag-based structure with names and attributes used for specific display purposes. Thus, Google Earth acts as a browser of KML files.^b

Landsat. A series of US polar orbiting satellites, first launched in 1972 by NASA (National Aeronautics and Space Administration), which carry both the multispectral scanner and thematic mapper sensors.^d

Maps. Graphic representation of the physical features (natural, artificial, or both) of a part or the whole of the Earth's surface, by means of signs and symbols or photographic imagery, at an established scale, on a specified projection, and with the means of orientation indicated.^f

Map Projection. A method by which the curved surface of the earth is portrayed on a flat surface. This generally requires a systematic mathematical transformation of the earth's graticule of lines of longitude and latitude onto a plane. Every map projection distorts distance, area, shape, direction, or some combination thereof.^a

Metadata. Information that describes the content, quality, condition, origin, and other characteristics of data or other pieces of information. Metadata for spatial data may describe and document its subject matter; how, when, where, and by whom the data was collected; availability and distribution information; its projection, scale, resolution, and accuracy; and its reliability with regard to some standard. Metadata consists of properties and documentation. Properties are derived from the data source (for example, the coordinate system and projection of the data), while documentation is entered by a person (for example, keywords used to describe the data).^a

Modelling. The representation of a system by a mathematical analogue, obeying certain specified conditions, whose behaviour is used to simulate and interpret a physical or biological system.^f

Multi-Criteria Evaluation (MCE). Decision support tool for Multi-Criteria Evaluation. A decision is a choice between alternatives (such as alternative actions, land allocations, etc.). The basis for a decision is known as a criterion. In a Multi-Criteria Evaluation, an attempt is made to combine a set of criteria to achieve a single composite basis for a decision according to a specific objective. For example, a decision may need to be made about what areas are the most suitable for industrial development. Criteria might include proximity to roads, slope gradient, exclusion of reserved lands, and so on. Through a Multi-Criteria Evaluation, these criteria images representing suitability may be combined to form a single suitability map from which the final choice will be made.^c

Raster. A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. Groups of cells that share the same value represent the same type of geographic feature.^a

Remote sensing. Collecting and interpreting information about the environment and the surface of the earth from a distance, primarily by sensing radiation that is naturally emitted or reflected by the earth's surface or from the atmosphere, or by sensing signals transmitted from a device and reflected back to it. Examples of remote-sensing methods include aerial photography, radar, and satellite imaging.^{a,e}

Resolution. The detail with which a map depicts the location and shape of geographic features. The larger the map scale, the higher the possible resolution. As scale decreases, resolution diminishes. The dimensions represented by each cell or pixel in a raster.^a

Scale. The ratio or relationship between a distance or area on a map and the corresponding distance or area on the ground, commonly expressed as a fraction or

ratio. A map scale of 1/100 000 or 1:100 000 means that one unit of measure on the map equals 100 000 of the same unit on the earth.^a

Shapefile. A vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class.^a

Vector. A coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each vector feature, as opposed to a raster data model, which associates attributes with grid cells.^a

FISHERIES AND AQUACULTURE TERMINOLOGY

Code of Conduct for Responsible Fisheries. FAO-formulated code, which sets out principles and international standards of behaviour for responsible aquaculture and fisheries practices with a view to ensuring the effective conservation, management and development of living aquatic resources, with due respect for the ecosystem and biodiversity.¹

DEPOMOD. A particle tracking model used for predicting the sinking and resuspension flux of particulate waste material (and special components such as medicines) from fish farms and the benthic community impact of that flux.^g

Ecosystem. An organizational unit consisting of an aggregation of plants, animals (including humans) and micro-organisms, along with the non-living components of the environment.¹

Ecosystem Approach to Aquaculture. The ecosystem approach to aquaculture is a strategic approach to development and management of the sector aiming to integrate aquaculture within the wider ecosystem such that it promotes sustainability of interlinked social-ecological systems. This is essentially applying an ecosystem based management as proposed by CBD (UNEP/CBD/COP/5/23/ decision V/6, 103-106) to aquaculture and also following Code of Conduct for Responsible Fisheries (CCRF) indications.¹

Large Marine Ecosystem. Large area of ocean space of approximately 200 000 km² or greater, adjacent to the continents in coastal waters, that has distinct bathymetry, hydrography, productivity and tropically dependent populations.^k

Mariculture. Cultivation, management and harvesting of marine organisms in their natural habitat or in specially constructed rearing units, e.g. ponds, cages, pens, enclosures or tanks. For the purpose of FAO statistics, mariculture refers to cultivation of the end product in seawater even though earlier stages in the life cycle of the concerned aquatic organisms may be cultured in brackish water or freshwater.^f

Marine protected area (MPA). A protected marine intertidal or subtidal area, within territorial waters, EEZs or in the high seas, set aside by law or other effective means, together with the overlying water and associated flora, fauna, historical and cultural features. It provides degrees of preservation and protection for important marine biodiversity and resources; a particular habitat (e.g. a mangrove or a reef) or species, or sub-population (e.g. spawners or juveniles) depending on the degree of use permitted. The use of MPAs for scientific, educational, recreational, extractive and other purposes including fishing is strictly regulated and could be prohibited.¹

Marine Spatial Planning (MSP). A process of analysing and allocating parts of three-dimensional marine spaces to specific uses, to achieve ecological, economic, and social objectives that are usually specified through the political process; the MSP process usually results in a comprehensive plan or vision for a marine region. MSP is an element of sea use management.^h

Stakeholder. Any person or group with a legitimate interest in the conservation and management of the resources being managed. Generally speaking, the categories of interested parties will often be the same for many fisheries, and should include contrasting interests: commercial/recreational, conservation/exploitation, artisanal/industrial, fisher/buyer-processor-trader as well as governments (local/state/national). The public, the consumers and the scientists could also be considered as interested parties in some circumstances.^j

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The potential of spatial planning tools to support the ecosystem approach to aquaculture

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Attention is presently turning to the processes, methods and tools that allow practical implementation of the ecosystem approach to aquaculture (EAA). This will require the use of various tools and methodologies, including environmental impact assessments and risk analysis. Ecosystem-based management involves a transition from traditional sector-by-sector planning and decision-making to the more holistic approach of integrated natural resource management at different scales and for ecosystems that cross administrative boundaries. An essential element for the implementation of the EAA will be the use of spatial planning tools including Geographic Information Systems, remote sensing and mapping for data management, analysis, modelling and decision-making. These proceedings focus on the status and process of implementing these tools which, in turn, necessitate the development of capacity building, training and promotion of spatial planning among decision-makers and technical staff. The document is organized in two parts. The first, the workshop report, deals with the background of the EAA effort and the genesis of the workshop. Most importantly, it captures the salient contributions of participants from their formal presentations and general discussions. The main conclusions of a review of the status and potential of spatial planning tools, decision-making and modelling in implementing the EAA are also included. The review itself, along with an abstract, forms the second part.

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