Review

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

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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.

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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.

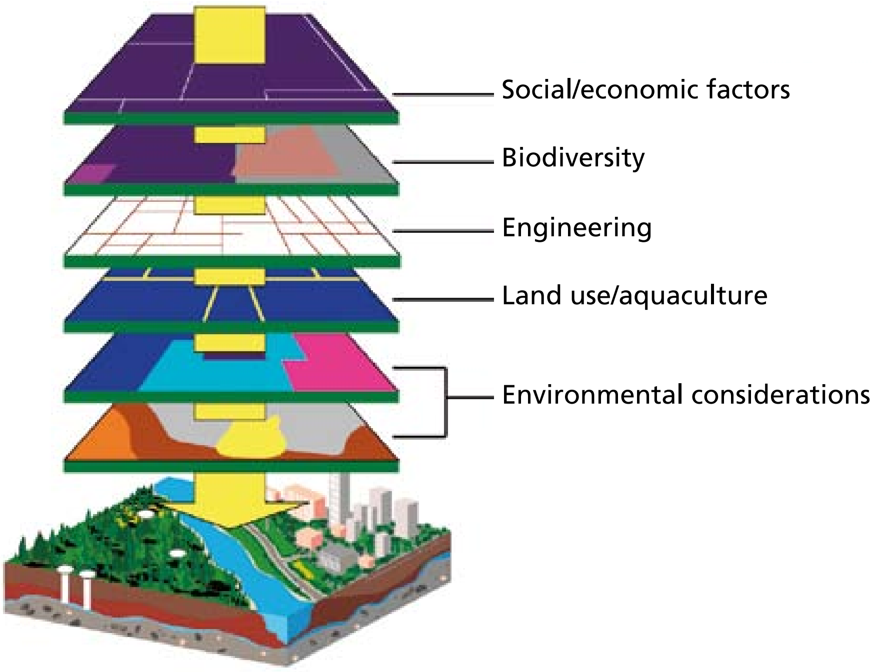
Geographic information systems (GIS) are an integrated collection of computer software and data used to view and manage information about geographic places, analyse spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information 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.

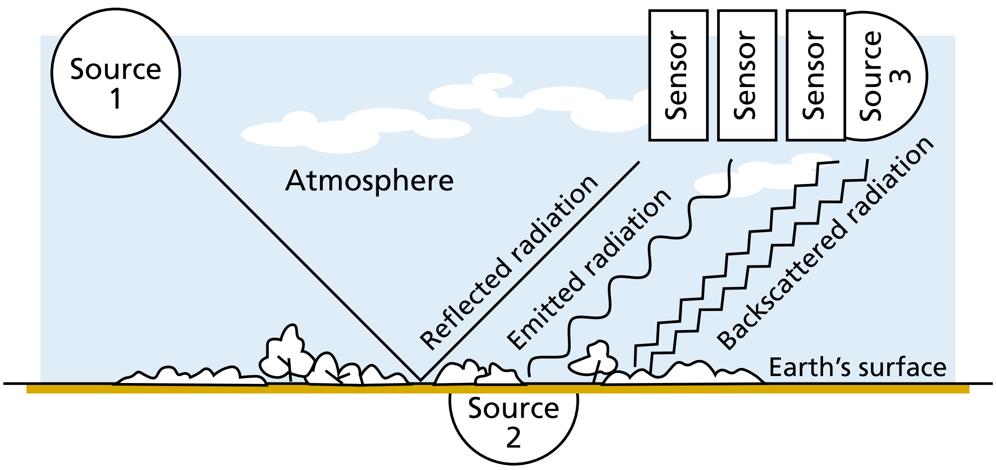
FIGURE 1.1
The overlay concept: the real world is portrayed by a series of layers in each of which one aspect of reality has been recorded



Source: Modified from Environmental Systems Research Institute, 2001.

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.

FIGURE 1.2
The key features of the remote sensing data collection process



Source: Curran (1985).

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 issues[1] 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 2007[2]:

"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.

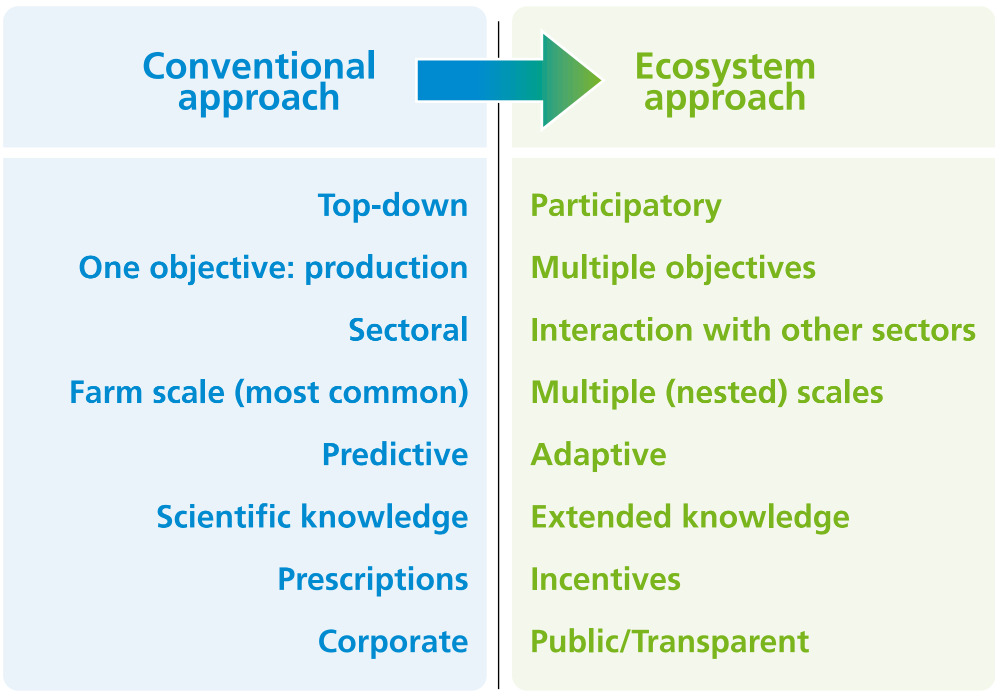
2.2 CONVENTIONAL AQUACULTURE MANAGEMENT AND THE ECOSYSTEM APPROACH

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.

FIGURE 2.1
The transition from a conventional approach to an ecosystem approach

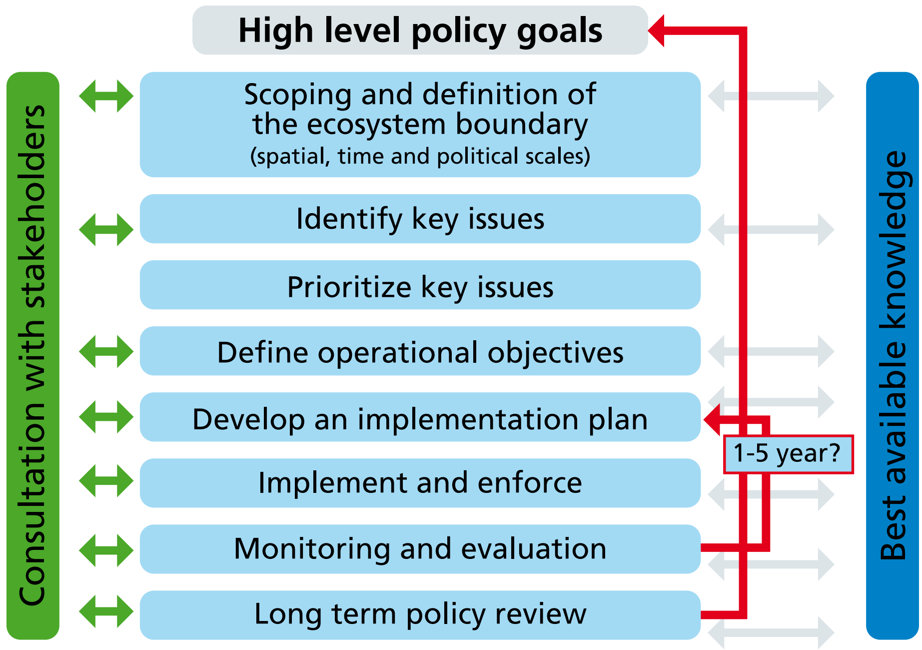


Source: FAO (2003).

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).

FIGURE 2.2
EAA Planning and implementation process



Source: AFPIC (2009).

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 it's 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.