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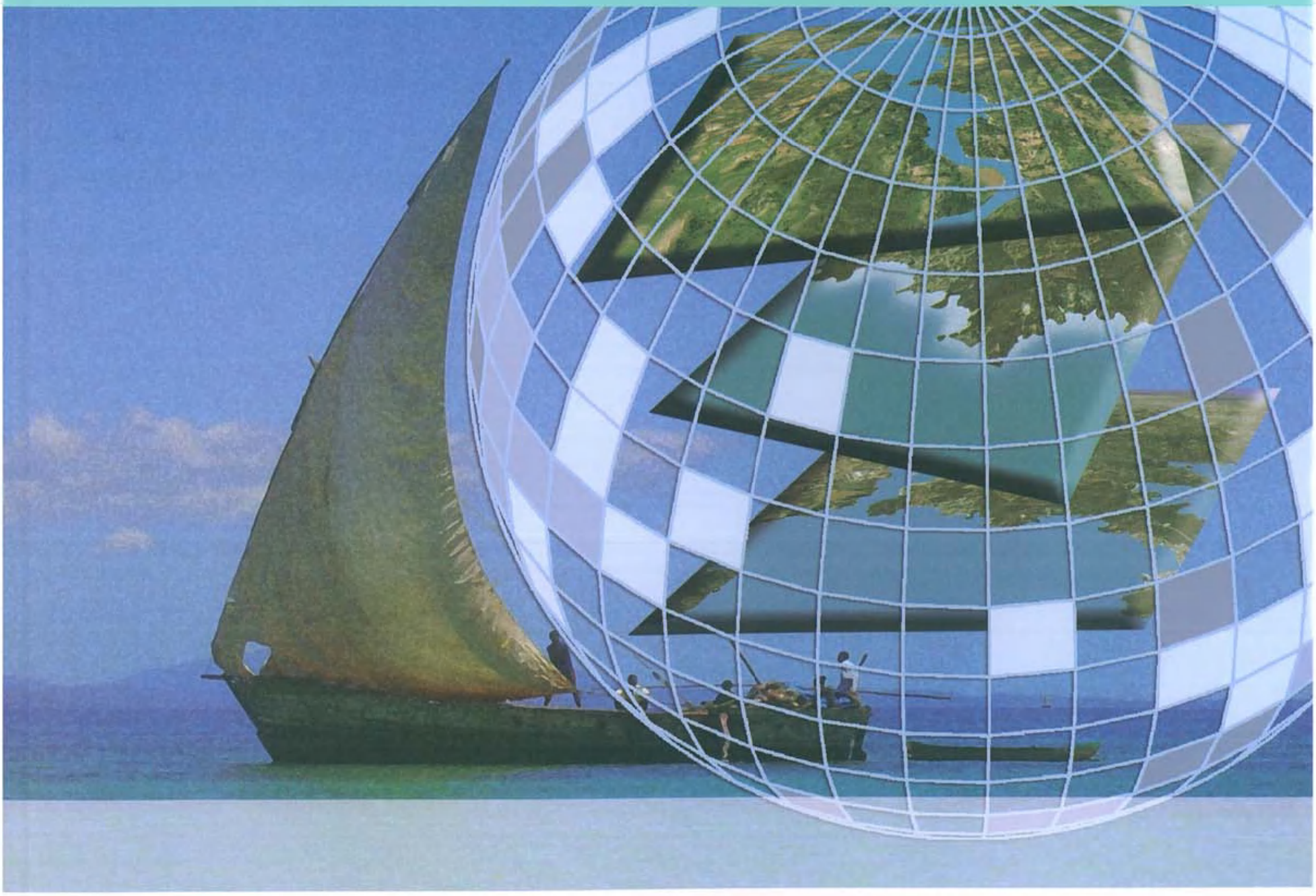
Geographic Information Systems to support the ecosystem approach to fisheries

Status, opportunities and challenges



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Preparation of this document

This technical paper has been prepared by the FAO Fisheries and Aquaculture Department and it is intended to provide background information and technical guidelines to promote the use of Geographic Information Systems (GIS) in marine fisheries in support of the implementation of the ecosystem approach to fisheries (EAF). It is based on information collected over a period of one year through a desktop study and from numerous contacts with fishery scientists and researchers. Reports of two workshops held in FAO late in 2008, "Development of GIS activities in the Nansen project" and "The use of spatial planning tools to support the implementation of the ecosystem approach to aquaculture" (Aguilar-Manjarrez *et al.*, and Kapetsky *et al.*, both reports in preparation) made an additional contribution with regard to definitions, principles and prospects on the use of GIS to support EAF.

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Abstract

The ecosystem approach to fisheries (EAF) has been developed during the last decade in response to perceived and actual deficiencies in previous methods of management. The EAF recognizes that fish are only one albeit important part of a much wider ecosystem incorporating an array of physical and biological components that humans interact with and exploit. Rather than managing single fish stocks, an EAF is concerned with the impacts of fisheries on the marine ecosystem, the interactions between different fisheries, of fisheries with the aquaculture sector, as well as with other human activities. The Geographic Information System (GIS) is considered an ideal platform upon which to perform necessary information management and decision-support analysis for the implementation of an EAF.

This technical paper is primarily intended to be a guide to methods that readers could adopt for their own use of GIS for an EAF and these methods are covered in some detail. The planning considerations for an appropriate GIS in terms of objectives, scope and geographical area are outlined. The practical considerations are discussed and include hardware architecture, various software possibilities, sources and types of data that will be needed, and the array of backup and support that is available.

More specifically, in Section 1 of this paper, the conceptual basis underlying EAF is discussed. In Section 2, a four-step participatory ecosystem management planning and implementation process consistent with EAF is recommended by the Food and Agriculture Organization of the United Nations (FAO) and includes: (i) scoping for issues, (ii) setting objectives, (iii) formulating rules and (iv) establishing a monitoring, assessment and review system. In Section 3, the use of GIS is examined beginning with a brief look at its history and development and then reviewing its current application and uses within marine fisheries. In Section 4, the potential use of GIS in a wide range of EAF-related projects is illustrated using examples that focus on mapping, modelling, management and communication. The degree to which GIS is currently being used for EAF implementation is illustrated by four case studies detailed in Section 5. Section 6 proposes a plan for implementation of an EAF using GIS and considers the challenges faced by developing countries in using GIS in fisheries management. Strategies to enhance the role of GIS in EAF are suggested. In conclusion, Section 7 makes recommendations for the adoption of GIS for EAF.

The adoption of GIS for an EAF is no easy task and a number of challenges must be faced but GIS for EAF is feasible even in relatively resource-poor situations. The authors hope this paper encourages fishery managers and researchers to explore the many benefits of GIS for managing fisheries in an ecosystem context.

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Acronyms and abbreviations

ASFA	Aquatic Sciences and Fisheries Abstracts
BCLME	Benguela Current Large Marine Ecosystem
BPI	Bathymetric position index
BTM	Benthic Terrain Modelling
CAD	Computer-aided design
CBD	Convention on Biological Diversity
CD-ROM	Compact disk – read only memory
CGFS	Channel Ground Fish Survey
CHARM	Channel Habitat Atlas for Marine Resource Management
COFI	Committee on Fisheries (FAO)
CPUE	Catch per unit of effort
DBMS	Database management system
EA	Ecosystem approach
EAA	Ecosystem approach to aquaculture
EAF	Ecosystem approach to fisheries
EBM	Ecosystem-based management
E-BMTN	Ecosystem-based Management Tools Network
EEZ	Exclusive economic zone
EFH	Essential fish habitats
ESSIM	Eastern Scotian Shelf Integrated Management (Plan)
EU	European Union
EwE	Ecopath with Ecosim
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information Systems
GLM	Generalized Linear Model
GPS	Global positioning system
ICES	International Council for Exploration of the Seas
IFREMER	Institut français de recherche pour l'exploitation de la mer (French Research Institute for the Exploitation of the Sea)
IT	Information technology
IUCN	International Union for the Conservation of Nature
LAN	Local Area Network
MCS	Monitoring, control and surveillance
MPA	Marine protected area
MSPP	Marine Spatial Planning Pilot

NGO	Non-governmental organization
NOAA	National Oceanographic and Atmospheric Administration
OGC	Open Geospatial Consortium
OSGeo	Open Source Geospatial Foundation
QGIS	Quantum GIS
ROI	Return on investment
SFS	Simple feature specification
TURF	Territorial use rights in fisheries
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
VMS	Vessel monitoring system
WAN	Wide Area Network
WSSD	World Summit on Sustainable Development
WWF	World Wildlife Fund

Executive summary

INTRODUCTION

Declines in fish stocks and degradation of the ecosystems where fishery resources occur have motivated the development of new approaches to fisheries management. The ecosystem approach to fisheries (EAF) results from the experience acquired in fishery management over the last decade and from the increased understanding of processes and dynamics of aquatic ecosystems and of the impacts of fisheries and other drivers on these ecosystems. EAF is now recognized as the reference framework for fishery management and as a holistic and integrated approach that takes into account the ecological, social, economic and governance aspects of fishery management. Successful application of the EAF requires careful planning and implementation. A good understanding of the spatial dimensions of the fishery system, for example knowledge of habitat and species distributions, spatial features of key physical and biological processes, distribution of human activities and degree of interaction among them, is fundamental to EAF planning and implementation. One means of operationalizing spatially related management factors that has shown considerable success in terrestrial applications is the Geographic Information System (GIS). This technical paper explains why this spatial mapping and analysis tool is important, indicates the audience for whom this paper in intended and identifies the aims and objectives that need to be addressed.

It is important to have a firm understanding of the concepts underlying EAF before examining GIS *per se*. A brief look at the history of EAF reveals the pivotal role that the Food and Agriculture Organization of the United Nations (FAO) has played in its emergence and shows how the concepts underpinning EAF have been formed from various FAO (and United Nations) earlier international instruments and initiatives. Compared with the conventional fishery management approach, EAF effectively entails an extension of many current practices but over a much wider ecosystem sphere and gives core consideration to sustainability, to stakeholder participation and to better prioritization in terms of risks and threats to the wider ecosystem. FAO recommends that the planning stage of an EAF includes four steps: (i) scoping to identify the broad issues to be addressed, (ii) setting objectives in terms of goals, indicators and overall performance, (iii) formulating actions and rules to ensure that EAF goals can best be achieved, and (iv) setting up a monitoring, assessment and review process to evaluate the effectiveness of what is being done and to serve as a feedback mechanism. The focus of the discussion in the main part of the paper is on GIS and the framework for EAF adoption.

GIS APPLICATIONS IN FISHERIES

For readers having a limited familiarity with GIS as it is used in the marine fisheries sphere, a brief overview of the broad functionality of GIS is provided. The development of GIS both in terms of fishery applications and its reliance on parallel technologies is noted. Fishery applications of GIS generally lag behind terrestrial applications because GIS technology is used less intensely in the marine sphere and because the 3D and 4D environment is not inclined to easy data collection or spatial analysis. Nevertheless, GIS now provides a broad spectrum of mapping and analytical functions, and these are exemplified in GIS applications for a range of fishery needs, e.g. habitat mapping, analysis of species distribution and abundance, fisheries oceanography, monitoring of fishers' activities and fisheries management. Case studies provide a brief insight into a varied cross-section of actual fisheries GIS work.

GIS IN SUPPORT OF AN ECOSYSTEM APPROACH TO FISHERIES

Because GIS is being used extensively in fisheries management and research, it has the potential to be readily adopted for EAF work. Indeed, it has been shown that GIS is, in many cases, an ideal platform for data storage, management and analysis to support decision-makers as they progress to implementation of an EAF. GIS for EAF is already being used in mapping, modelling, management and communications. With regard to each of these activities, a wide range of studies is exemplified and discussed for the purpose of providing the reader with the breadth and potential of GIS to support the many management and research needs of EAF.

In addition to providing examples that illustrate how aspects of EAF are addressed through the use of GIS, the authors present in detail three case studies that show how GIS might be applied in helping with EAF-based projects. The first case study concerns the main fisheries operating in the Benguela Current Large Marine Ecosystem off Southwest Africa. The focus of the study was to identify issues that concern the various stakeholders in the fisheries. The authors estimate that GIS can play a part in resolving about 45 percent of the more than 150 issues identified. Most of these "GIS-aided" issues relate to those aspects of EAF concerned with direct fishery matters rather than broader socio-economic matters. The second case study was based on the broader marine resource use of the seas to the southeast of Nova Scotia in eastern Canada. The aim of the Eastern Scotian Shelf Integrated Management (ESSIM) plan was to identify objectives that an EAF should seek to address in terms of optimizing the management of this potentially resource rich area. Again, the authors found that GIS can play a significant part in addressing these objectives. A final case study looked at another resource-stretched area, that of the eastern English Channel. The Channel Habitat Atlas for Resource Management (CHARM) project did not have deliberate EAF intentions in mind, though unlike the two other case studies, it was strong on the use of GIS. As several CHARM projects progressed, it became clear that the only way in which fishing in the English Channel ecosystem could become sustainable was through a deliberate attempt to draw in a much broader range of considerations and stakeholders.

IMPLEMENTING GIS FOR AN ECOSYSTEM APPROACH TO FISHERIES

Perhaps the core concern for readers of this paper is "How do I implement a GIS for an EAF?" Before this issue can be addressed, it is important to delimit a number of assumptions that are made about the levels of familiarity with GIS and EAF. In the context of this paper, the authors assume that readers have some background in GIS *per se* and, therefore, will not be starting to set up a GIS for EAF from scratch. Initially, in terms of the FAO framework for adoption of an EAF, the reasons for using GIS in the sense of identifying what the system can potentially do to enhance EAF and what the system's operational objectives might be are described. It is then possible to consult with main stakeholders and project workers to determine the desirable GIS outputs relative to the needs of a particular ecosystem's area. This is likely to include coverage of a broad range of fishery topics about which spatially related considerations are important.

Before adopting a GIS for an EAF, it is important to acquire familiarity with the practical aspects of GIS implementation and functioning, especially in capacity-building matters related to EAF work. It is likely that GIS work to address EAF objectives could initially be conducted using existing hardware configurations, though as work broadens to integrate a wider range of ecosystem considerations, the GIS architecture may need to be reviewed. Likewise, initially, existing software could be adequate but the GIS user may wish to experiment with the increasing array of often specialized or perhaps open-source software to perform specific operations or analyses. Data needs for EAF work are likely to rise exponentially. Much of the data will be specific to a particular project and are likely to be gathered by a project team or contractor but the general availability of marine-based, fisheries or wider ecosystem data is increasing at an accelerating rate and guidance is given on possible sources for such data. Additional support for GIS work in an EAF context is provided in the literature, on web sites and in the form of tools for modelling and portals for information.

To shift from working with a GIS for the traditional management of fisheries towards working with a GIS to cover the broader horizons associated with an EAF is not easy and presents many challenges. This paper describes these challenges in detail and offers advice on ways to overcome them, though for some challenges easy solutions are not available. For the success of an EAF, it is necessary to assemble an expert and dedicated GIS team, one that is prepared to share its efforts and create synergies with other groups working in fisheries. On the broader front, it is vital that all the EAF/GIS work presently being done in what are often fairly isolated and fragmented quarters be gathered together. If this can be achieved, much “reinventing of the wheel” will be eliminated to the advantage of everyone. Finally, this paper makes recommendations, which if vigorously followed, will better the chances that the fisheries ecosystem reverses its present direction towards demise.

1. Introduction

During the last decade, the concept of an ecosystem approach to fisheries (also referred to as ecosystem-based fisheries management) has increasingly been adopted in policy statements by fisheries management and environmental agencies, both governmental and non-governmental at the national and international levels. The application of an ecosystem approach to fisheries (EAF) represents the operationalization of sustainable development in fisheries, to be achieved through democratic and transparent practices that take account of diverse societal interests and use mechanisms that allow participation of stakeholders in the planning and decision-making processes. The ecosystem approach broadens the scope of fisheries management to also include the wider impacts of fishing on the marine ecosystem and to more explicitly consider environmental impacts on the marine ecosystem and its resources. The *FAO Technical Guidelines for Responsible Fisheries* on the ecosystem approach to fisheries (FAO, 2003) emphasizes the broad approach of EAF as one that "strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries". This definition clearly addresses both human and ecological well-being and merges two paradigms: protecting and conserving ecosystem structure and functioning, and managing fisheries with a focus on providing food, income and livelihoods for humans.

The FAO EAF guidelines together with other FAO guidelines (FAO, 2005 and 2008a) introduce methodologies for the practical application of an EAF and show how high-level policy goals can be translated into practical fisheries management actions. However, further knowledge and additional tools are needed at various steps of the fisheries management and planning processes in order to facilitate and promote its application. In particular, EAF meets the challenge of having to consider the multiple impacts of fisheries on the marine ecosystem, the interactions among different fisheries, and of fisheries on the aquaculture sector as well as on other human activities taking place at relevant time and space scales. In order to address these interactions, both science and management need to explicitly consider their spatial dimension. In this context, Geographic Information Systems (GIS) can prove to be one of the key tools in facilitating the application of the ecosystem approach as regards not only fisheries management but also development of new knowledge and understanding of the interactions between human activities and the ecosystem. "Ultimately, implementation of ecosystem-based management is an incremental and adaptive process" (Busch *et al.*, 2003: page 4). Although this statement applies to the implementation of EAF, this technical paper will show that the statement applies even more to the use of GIS for the implementation of EAF.

1.1 THE TARGET AUDIENCE FOR THE APPLICATION OF A SPATIAL DIMENSION IN EAF

Given that marine commercial and/or recreational fisheries are the most widely dispersed activity on the earth and given that they provide the principal economic livelihood for hundreds of millions of people, but above all, that the activity is in dire circumstances with respect to its sustainability, then the target groups for information on means by which fisheries circumstances can be improved will be widespread and varied. This is especially true because, for the most part, existing methods of managing the fishery activity have been unsuccessful and because the activity is carried out over large marine areas where there may be few enforceable rules or indeed means of enforcement. In addition, fishing takes place in a milieu where competition is often intense for the resource space and its economic rewards – partly because people now realize that fish provide a high quality protein diet.

This situation means that a very diverse group of agencies, institutions, organizations and other interested groups may need to know about managing fisheries within ecosystems. Box 1.1 provides categories of potential target groups. These groups will vary in their propensity to utilize GIS. For instance, groups that directly represent fishers are unlikely to be interested in having a GIS operational capacity but they are likely to be interested in a variety of GIS outputs. Indeed, decision-makers within all targeted groups will have an interest in outputs and it is likely that management organizations, conservation groups, non-governmental organizations (NGOs) and researchers will have an interest in operationalizing their own GIS for EAF purposes.

BOX 1.1

The main target groups potentially interested in GIS for EAF

Fisheries departments within government (at various levels). Most countries have governmental, legal oversight and responsibility over fishery activity and its sustainability.

Fishery research establishments. Though often under responsibility of and funded by governments, they usually have individual authority to pursue requisite research activities, many of which are now concentrated on EAF activities.

Fishery producer cooperatives. Fishery cooperatives are established to promote socio-economic advantages for their members. If they see how marine spatial planning can be to their advantage, they are likely to recommend its pursuance.

Other groups of fishers. These groups of fishers may be very diverse and perceive that their long-term interests will be served through adoption of a new and more comprehensive approach to fisheries management.

University departments – fishery science, ecosystem science and environmental science. With greater access to higher education worldwide and greater diversification of courses, there is increased interest in courses related to the environment and to sustainability.

Fishery managers. Fisheries are managed in diverse circumstances, e.g. from local control to wide-ranging control such as that exercised through the European Union's Common Fisheries Policy. It is likely that managers will increasingly move towards adopting EAF concepts.

International and national marine/fishery organizations. Each of these widely diverse organizations has an interest in promoting the continuing good health of marine and fishery environments.

Conservation groups. These groups might vary from regional to international in scale and have a remit (where relevant) to promote sustainability of fish and/or aquatic environments. EAF is increasingly being featured within their area of interest.

1.2 WHY LOCATION MATTERS IN EAF

Conventional fisheries management considers the spatial component of fisheries operations either explicitly, through time and area closures, or implicitly, through allocation of quota to regions or to fleet sectors with different distributions. Under an EAF management regime, consideration of the spatial component becomes increasingly critical as a broader set of ecosystem interactions needs to be taken into account. The requirement to also take into account the often conflicting and competing interests of a growing array of sectors and interests, ranging from resource users to conservation managers, also makes consideration of spatial aspects imperative.

The essential nature of spatial considerations in fisheries management was recognized as early as 1986 by Caddy and Garcia (1986) and in the FAO guidelines for integrated management of coastal zones (Clark, 1992). Recently, spatial considerations have become even more manifest in the decisions of many coastal countries to adopt Marine Spatial Planning as a means of creating organization with respect to the management of their marine resources and space (MSPP Consortium, 2006; Douvere, 2008). In this respect, the GIS has an increasingly important role to play in EAF implementation. Used by many as a research tool, the GIS is becoming increasingly embedded in fishery and wider ecosystem management processes, not least because of its ability to generate visual representations of complex ecosystem processes and in so doing facilitate communication with and among stakeholders.

Additional considerations now emerging in international communities regarding adaptation mechanisms in response to climate-induced changes affecting marine ecosystems and resources put a greater emphasis on the need to develop a spatial management and planning framework for which GIS is deemed to be an important supporting tool. Other emerging issues, such as demersal fisheries in the high seas (FAO, 2008b), call for more attention to the spatial dimension of fisheries management.

1.3 AIMS AND OBJECTIVES OF THIS PAPER

The aim of this technical paper is to provide the community of fishery scientists, stakeholders and managers with an up-to-date picture of the role of the GIS in conventional fisheries management and its role in EAF implementation. It is hoped that after having read and digested the content of this paper, the reader is in a position to understand and to make decisions concerning the theoretical (if not always the practical) use of the GIS as an aid to an EAF. It is important to note that, although this technical paper does not describe practical GIS methodologies *per se,* a large number of references to GIS sources for information about the practical aspects of GIS will be made throughout the text.

Section 2 of this paper considers the status of EAF development in terms of concepts, guidelines, definition and principles as set out by FAO. The role of an EAF is well-known within the scientific community, but the benefits of GIS still need to be more clearly articulated to fisheries managers and other stakeholders engaged in EAF implementation. Therefore, Sections 3 and 4 provide a brief overview of the history of the GIS in marine fisheries and discuss the role of GIS to support EAF implementation. Section 5 provides a number of case studies which illustrate the major role that GIS has played (or might play) in one or more aspects of EAF implementation in specific ecosystems. Finally, Section 6 proposes a plan for EAF implementation through the use of GIS tools by way of identifying a target audience and their basic requirements, providing sources for marine GIS data and training, and identifying opportunities for capacity building. This section also considers the specific challenges faced by developing countries and suggests strategies to increase capacity to enhance the sustainable and effective role of GIS in EAF. In conclusion, Section 7 makes recommendations for the adoption of GIS for EAF.

2. What is EAF?

2.1 BACKGROUND TO EAF

The adoption of the EAF resulted from an increased understanding of the interactions between human activities and ecosystems, a growing environmental awareness among the many different stakeholders, and lessons learned from fisheries management over the last 50 years. With an EAF, management systems are broader in scope in order to encompass the key interactions between fisheries, the resources they target and the wider ecosystems in which they operate. The broadening of scope is occurring in parallel with the recognition across all fields that natural resource management must be prudent, transparent and democratic.

The concepts underpinning EAF are reflected in a series of international instruments that were developed over several decades, such as the Law of the Sea (1982), the United Nations Conference on Environment and Development (UNCED), also referred to as the Earth Summit (1992), and the FAO Code of Conduct for Responsible Fisheries (FAO, 1995). The concept of "sustainable development" as an alternative approach to an approach simply based on economic growth, and which strives to "meet the needs of the present without compromising the ability of future generations to meet their own needs", permeates through all these instruments. The agreements that resulted from the Earth Summit, such as Agenda 21, and the legally binding Conventions, including the Convention on Biological Diversity (CBD), had an overarching significance for all human activities. Of direct interest for aquatic resources use is the 1995 Jakarta mandate on coastal and marine biodiversity because this mandate builds on the platform provided by the CBD by specifically linking issues of biodiversity and conservation to fishing activities.

The Code of Conduct for Responsible Fisheries represented a milestone within fisheries for better implementation of the principles of sustainable use and the establishment of improved principles and standards for the conservation, management and development of all fisheries. Given the difficulties experienced in the actual implementation of the code, new impetus was given to sustainable aquatic resources use at the 2001 FAO Conference on Responsible Fisheries in the Marine Ecosystem (FAO, 2002) through a renewed political commitment to a broader understanding of sustainable fisheries and the adoption of the EAF. Immediately thereafter, and ten years after the Earth Summit, a commitment was made at the World Summit on Sustainable Development (WSSD, 2002) to implement an ecosystem approach to fisheries by 2010.

In 2003, FAO published guidelines to facilitate EAF implementation (FAO, 2003). These guidelines were presented to the FAO Committee on Fisheries (COFI) in the same year. The FAO guidelines indicate the general process by which policies containing ecosystem conservation goals are turned into operational plans, activities, outputs and outcomes. Within this general conceptual framework, the specific purpose of an EAF is "to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems" (FAO, 2003).

2.2 CONVENTIONAL FISHERIES MANAGEMENT AND THE ECOSYSTEM APPROACH

The EAF as adopted by FAO is not considered a major departure from conventional fisheries management but rather an extension of it and with a greater emphasis on sustainability concepts as articulated in the Code of Conduct on Responsible Fisheries. Table 2.1 shows a comparison of key features of a management system using the conventional approach and a management system using an ecosystem approach, respectively.

TABLE 2.1
A comparison of conventional and ecosystem approaches to fisheries management

Conventional approach to fisheries	Ecosystem approach to fisheries
Has few fisheries management objectives.	Expands scope of fisheries management to explicitly address ecosystem and socio-economic considerations.
Focuses mainly on fishery sector issues, i.e. sectoral	Deals more explicitly with the interactions between the fishery sector and other sectors, e.g. petroleum industry, tourism, coastal development.
Deals mainly with single (target) species.	Responds to concerns about the broader impacts of fisheries on the marine ecosystem, including impacts on the habitat, vulnerable species and biodiversity.
Addresses fisheries management issues at the stock/fishery scale.	Addresses the key issues at the appropriate spatial and temporal scales. These issues are often nested (local, national, subregional, regional and global).
Is predictive, with decision-making mainly based on results from mathematical or statistical models that assess the outcomes of different management strategies.	Given the uncertainty associated with many of the issues to be dealt with, the limited data available and poor understanding of relevant processes, recognizes adaptive strategies as being more useful.
Considers scientific knowledge the only valid knowledge as a basis for decision-making.	Recognizes that it is not possible to obtain scientific knowledge on all the issues to be dealt with and that alternative knowledge (e.g. traditional knowledge) can be utilized as a basis for decision-making.
Operates through regulations and penalties for non-compliance.	Encourages compliance to regulations through incentives.
Uses a top-down (command and control) approach.	Uses a participatory approach, e.g. various forms of co-management are a key feature of the EAF.

Source: The authors.

Given the broader scope of EAF as compared with conventional fisheries management, and the often limited resources of fishery administrations and research institutes, the implementation of EAF will require a process of prioritization to identify the issues which need most attention or pose greater environmental risk, i.e. it is not just a question of adding new elements to conventional management.

2.3 APPLYING EAF, A PRAGMATIC APPROACH

The guidelines developed by FAO provide a framework for the comprehensive implementation of EAF principles[1]. Implementation of the approach entails going through a systematic and participatory assessment and planning process that leads to the formulation of fisheries management plans consistent with EAF. The plans also include mechanisms for assessing management performance on a regular basis. The sequence of steps in the process is illustrated in Figure 2.1 and can be briefly described as follows (FAO, 2003 and 2005).

STEP 1: Scoping

The spatial coverage of the management plan should be defined in such a way that it is most relevant to the fishery in terms of the area where the fishery takes place, the distribution area of the target resources, and the ecosystem where they occur, and that it allows identification of stakeholders having common or competing interests in relation to that resource or area. At this stage, relevant information on all aspects of

[1] A number of strategies have been suggested for EAF implementation (Busch *et al.,* 2003; Bianchi and Skjoldal, 2008; Fletcher *et al.,* 2002; Garcia *et al.*, 2003, and summarized in Garcia and Cochrane, 2005) but the authors chose to base their work on the approach adopted by FAO (2003).

FIGURE 2.1
Key steps in the EAF framework for developing fisheries management plans

Source: Modified from FAO, 2003.

the fishery or fisheries and the ecosystem, including people and livelihoods, should be compiled to serve as a basis for the following steps.

STEP 2: Setting operational objectives

Setting operational objectives entails a series of tasks, including determination of broad objectives and translation of these objectives into operational objectives and associated indicators and performance measures.

Set broad objectives

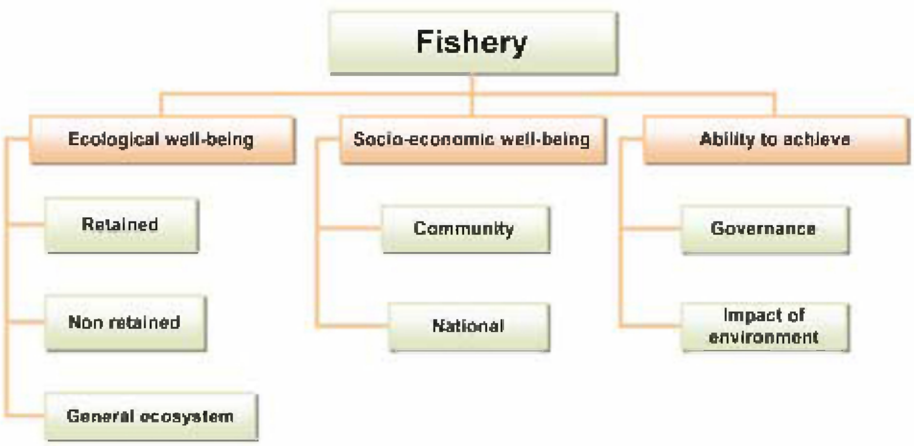
Management objectives consistent with EAF principles must be defined explicitly, with attention to ecosystem sustainability objectives as well as social and economic objectives, and should be consistent with high-level policy goals that are likely to be found in national legislation. These objectives will direct the identification of issues to be dealt with by management and the formulation of operational objectives.

Develop operational objectives from broad objectives

Specific operational objectives are needed to allow managers to implement specific measures and should, therefore, have a particular and practical meaning for the fishery being considered. The key tasks include:

- identification of detailed issues relevant to the fishery through participatory and structured methods, following key categories along the three main dimensions of a fishery system, i.e. ecological, socio-economic and governance, and including the influence of other drivers external to or beyond the control of the fishery (Figure 2.2);
- prioritization of issues through a formal process such as a risk assessment; and
- for each specific issue, formulation of an operational objective and associated indicators, reference points and performance measures.

FIGURE 2.2
A hierarchical tree used for systematically identifying key issues to be dealt with by management



Source: Modified from FAO, 2003.

Note: Each category can be further subdivided into subcategories, as appropriate. (Retained species = target and non-target species that are caught and retained; Non-retained species = discards; General ecosystem = other impacts of the fishery on the ecosystem, e.g. on the habitat, on ecosystem structure and functioning, on biodiversity; Community = social and economic issues at the community level; National = social and economic issues related to the given fishery at the national level; Governance = governance issues relevant to the given fishery; Impact of environment = factors affecting the given fishery beyond the control of the fishery administration, such as pollution, climate change, impacts from other human activities.)

STEP 3: Formulating actions and rules

An overall plan of action must be implemented. This plan is likely to contain a mix of measures that are perceived as being appropriate to the specific fisheries ecosystem. All management requires the setting of rules by which the activity must function and these rules should be based on best available knowledge. Suitable management measures are identified, such as catch controls, effort limitation, and closed areas or seasons, and for each of these measures there will be local by-laws or rules that may need continual adjustment in response to the ecosystem's change. This step is particularly challenging in tropical multispecies fisheries as consideration has to be given simultaneously to the impacts of fisheries on species with varying degrees of productivity.

STEP 4: Identifying monitoring, assessment and review mechanisms

Evaluate management

A monitoring and review process is needed to evaluate the extent to which management's measures are actually contributing to the broad and operational objectives, based on the selected indicators and agreed reference trends and directions. Usually the review process has a one-year cycle for tactical fisheries management and a longer (5 to 10 years) cycle for strategic planning and re-evaluation of the management plan.

Set up a monitoring, control and surveillance system

Successful fisheries management relies on a well-functioning monitoring and control system, particularly in the case of industrial fisheries. The introduction of a vessel monitoring system (VMS) opens the possibility for a more effective spatial management, which is particularly relevant to improve conventional fisheries management but also to address conservation concerns under an ecosystem approach.

Identification of the key stakeholders is fundamental to the successful development and implementation of the management plans. Although stakeholder identification can take place informally, more formal ways can be used (e.g. Renard, 2004; Vierros *et al.*, 2006). In addition to ensuring stronger legitimacy and transparency, a good process for stakeholder identification and analysis also provides the basic understanding of the social and institutional context relevant to the planning process.

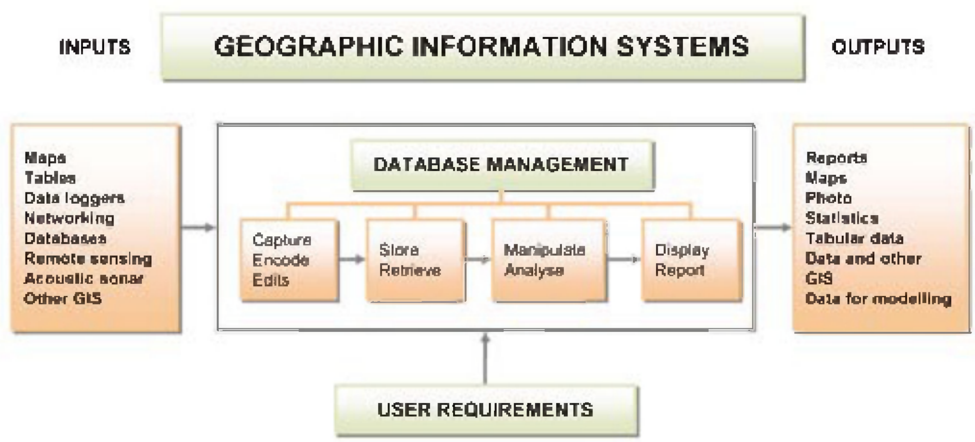
A number of the key steps in the ecosystems approach planning and implementation cycle (as described above) would benefit from more explicit consideration of spatial information about ecosystem components and properties. Furthermore, because of the participatory nature of EAF planning and implementation, visualization of important ecosystem properties would greatly facilitate stakeholder consultation and decision-making. Within the scientific process, spatial data visualized within a GIS environment can help improve understanding of the ecosystem in question and allow for more spatially resolved analyses and hypothesis testing. The following sections will consider in detail the current uses of GIS technology in marine fisheries, the role of GIS in support of EAF planning and implementation, case studies which integrate GIS into EAF, opportunities and challenges of GIS in support of the EAF (Section 6) with explicit reference to the EAF implementation framework outlined above and in Figure 2.1.

3. The current status of GIS in marine fisheries

3.1 GIS AS A TOOL

A GIS may be defined as a collection of computer hardware, software, data and personnel designed to collect, store, update, manipulate, analyse and display geographically referenced information (Rahel, 2004) (Figure 3.1). There is no single GIS; systems can be assembled in an infinite number of ways. Hardware can refer to desktop or laptop computers, plus other smaller mobile devices, and to technology designed to input or output data or information such as digitizers, scanners, printers and plotters. There are a many general commercial and free open-source GIS software packages and even more GIS applications that have been developed for specific purposes, such as for use by the military or utility companies. Data can be collected for specific projects in the field or can be obtained from commercial or governmental sources and data can be delivered via CD-ROMs, flash-drives or over the Internet or other such integrated server networks. Personnel are usually highly trained in both computer science and geographical analysis, though many specialists have moved from applied research areas to GIS when it has been advantageous.

FIGURE 3.1
A process diagram to conceptualize the functioning of GIS



Source: Modified from Rahel, 2004.

The importance of GIS is based on the fact that all earth processes and functions are inherently spatial. GIS are unique in their ability to conduct spatio-temporal analyses in order to understand complex earth processes. For any specific problem or area or time, data can be assembled and input to the system. GIS themselves are designed to perform a large array of spatio-temporal analyses and operations over multiple scales or resolutions. Output from a GIS is largely in the form of maps although it can also be in tabular, statistical or graphical form. The appeal and usefulness of a GIS lie in its capacity for problem solving in the spatial domain and for generating mapped representations of complex ecosystem interactions and processes in a way that managers can understand and make decisions from.

3.2 A BRIEF HISTORY OF GIS TECHNOLOGY AND DEVELOPMENTS

The history of the GIS began in the 1960s with the development of the Canada Geographic Information System. This first true GIS was designed to manage natural resources dispersed over a wide spatial area (Tomlinson *et al.*, 1976). At that time, a second impetus for computer generated mapping was provided by the Dual Independent Map Encoding project undertaken by the United States Bureau of the Census to produce spatially-based output from the 1970 United States census. The 1970s saw intensive work at universities such as Harvard, Minnesota, Edinburgh and the Royal College of Art in London to develop both vector- (line) and raster- (pixel) based mapping, so that by the end of the 1970s a large number of software packages for handling geographic information had been developed (Marble, 1980). Many of the early GIS were designed to meet specific needs and generally focused on improving basic mapping capability. Almost all the early work on GIS development was conducted by the public sector (government, universities and the military), mainly because very high costs were involved for acquiring and operating the requisite mainframe computers.

Following this innovative early period, the 1980s saw an era of commercialization (Longley *et al.*, 2001). This was made possible for a number of reasons, primarily the rapidly decreasing costs of computing, the development of cost-effective applications, the proliferation of data (largely through satellite remote sensing) and the emergence of smaller computing platforms (minicomputers and then personal computers), plus developments in parallel fields (see Box 3.1). The integration of these parallel technologies are extremely important for GIS because not only are many of them crucial to GIS but the existence of the GIS itself provides a rationale and spur for their own development. The 1980s saw the emergence of most of today's major software suppliers so that by the mid-1980s there were approximately 100 different commercial GIS packages available. Gradually the use of GIS spread into an increasing number of areas, though its major applications remained with the more traditional areas of land-use planning and resource management.

The 1990s saw continued though accelerating commercial development with expansion rates in the GIS sector as a whole of approximately 14 percent per annum (Payne, 1993; Frost & Sullivan, 1994). Along with the growth of GIS came the proliferation of associated activities such as the publication of dedicated books and journals, specialist conferences, the development of international standards through such organizations as the Open Geospatial Consortium (OGC), the establishment of GIS associations (e.g. the Association for Geographic Information in London) and a large expansion in GIS-oriented higher education. Towards the end of this period, some consolidation within the software development sector rationalized the number of commercial GIS packages available. It would be true to say that at the beginning of the 21st century we are now in an age of mass use and exploitation of GIS by a broad array of social, economic and environment sectors.

3.3 THE MAIN FUNCTIONALITIES OF GIS

The following is a brief overview of the main areas of functionality that GIS can provide.

- Data pre-processing and management. Before any GIS task can be performed, various editing or manipulation functions may be necessary to ensure that the data are in a suitable form and sufficiently accurate for subsequent analysis and representation. For example, data might need to be updated or corrected, or converted to an appropriate map projection. Scale changes might also be required.

BOX 3.1

Parallel technologies or disciplines that have assisted in the development of GIS

The Internet. It has allowed for information and data downloads and is now increasingly used for the development of interactive mapping engines.

Remote sensing. Satellite and aerial imagery are by far the largest source of data for GIS. Satellites also provide the basis for the global positioning system (GPS) and derived applications, e.g. vehicle navigation and VMS.

Environmental modelling. Outputs from models provide a source of data and modelling itself is often performed using a GIS environment.

Software developments. Not only are there many varied GIS packages but linkages between GIS and other specialized software are becoming increasingly common in many sectors.

Hardware. Hardware forms the computer-based platform for GIS operations and numerous other pieces of hardware may form part of a complete GIS, e.g. scanners, plotters, digitizers, data loggers, GPS and sonar.

Computer-aided design (CAD) and graphics. CAD represents a technology having similar input/output requisites to GIS and has thus contributed significantly to GIS development.

Digital cartography. While most cartography is not concerned with analysis *per se*, the output from digital cartography shares the exact requirements to those of GIS.

Geostatistics. Much of the output from a fisheries GIS depends upon the application of geostatistics to model various distributions or future projections.

Photogrammetry. It is a technique for measuring objects from photographs, electronic imagery, videos and satellite images, providing an important source of spatial information.

- Spatial and non-spatial data integration. Integration of geographic entities representing real location on the earth into non-spatial information is one of the strengths and prominent functionalities of a GIS. In this context, quantitative information (location, dimension, spatial relationships) can be combined with qualitative information (attributes, text, descriptions) to create a functional model of the real world.
- Measurement. This can be achieved in terms of not only distance, perimeter, volume and area but also in the sense of statistical measurements (sum, mean, mode, standard deviation).
- Distributions and relationships. Fundamental to geographic analyses are basic distributions and distributional patterns, e.g. do entities display clustered, random or uniform distributions? Are there spatial patterns showing contiguity, proximity or autocorrelation? What is the optimum location for any specific enterprise?
- Modelling. Models of geographic processes can be constructed to understand the world as it is now, as it has been in the past or how it might be in the future through "What if scenarios". They can range from relatively simple models, such as might be used by planners who seek optimum layouts for cities and their components, to more complex models that seek to discern optimum faunal habitats or to very complex models for processes such as climate change prediction.

- Network analyses. Networks can comprise extremely wide-scale geographic features such as transport routes, drainage networks, pipeline and cable networks, and other linear features. An array of cost and time analyses can be performed by GIS, including shortest path and optimum route analyses, time/cost efficiency routing and connectivity indices.
- Temporal analyses. An important area of interest is how natural and human processes change over time. GIS can, for example, be used to calculate rates of urban expansion, deforestation rates and crop-acreage changes over time. The long-term collection of remotely sensed data has greatly expedited time series analyses such as these changes.

To operationalize any of these functions, GIS applications are equipped with a range of functionalities which themselves are used in a programmed sequence in order to accomplish individual tasks. The commands must be directed towards spatially-referenced data to enable the GIS analyses to proceed. These data are held in files and databases that may be accessible locally or over a network and are held as individual files or as part of a wider data management system.

3.4 USE OF GIS IN MARINE FISHERIES

Although terrestrial applications of GIS had commenced by the late 1960s, it was another two decades before GIS was being applied in the marine environment. Meaden (2000) outlined a GIS Fisheries Task Conceptual Model that described why GIS was a complex task for early adoption by fishery researchers or scientists. In the mid-1980s, a seminal paper by Caddy and Garcia (1986) highlighted the importance of computer-based mapping and spatial analysis to fisheries. Around the same time, the GIS was being demonstrated as a valuable tool for aquaculture (FAO, 1985). Indeed the earliest applications of GIS to fish production were those applications utilized for locating sites for new marine aquaculture operations (e.g. Mooneyhan, 1985; Kapetsky *et al.*, 1987; FAO, 1989; Kam Suang Pheng, 1989).

These early examples of the application of GIS for location analysis were performed for the most part using remotely sensed imagery. Unlike the spatial complexities inherent in marine fisheries, aquaculture location deals with a nearshore static environment in simple 2D and costly surveys are not required to get a range of fisheries-related data. During the early phase of GIS adoption by fisheries, Simpson (1992) noted that remote sensing had the potential to generate much marine data of relevance to GIS applications, such as data for monitoring fishing effort, tracking pollutants, mapping bathymetry and sea-bed habitats, and providing measurements of physical and biological properties in the water column.

During the early 1990s, GIS slowly expanded its range of fishery applications (Meaden, 2001). One of the more popular uses of GIS was for constructing spatially-explicit models of fish-habitat suitability, particularly in inshore zones where, for instance, mangroves, estuaries, seagrass beds, bottom sediments and littoral environments could be mapped relatively easily. After the mid-1990s, the use of GIS for fishery-related work grew rapidly and by the time that the First International Symposium on GIS in Fisheries Science was held in 1999 (Nishida *et al.*, 2001), papers on GIS applications for marine fisheries were presented on various thematic areas (Table 3.1).

TABLE 3.1
Thematic areas of the papers on GIS marine fisheries presented at the First International Symposium on GIS in Fisheries Science in 1999

Thematic area	Number of papers
Fisheries oceanography/habitats	7
Fisheries resource analysis	5
Remote sensing and acoustics	3
Ecosystems/forecasting	2
Estuary and coastal management	2
General review	2
Concepts	1
Education	1
Research in progress	1
Software/database/computer systems	7

Source: The First International Symposium on GIS in Fisheries Science, 1999.

The accelerating rate and breadth of GIS-based, fisheries-related applications resulted from the same set of factors as outlined previously (decreasing costs of computing, better access to data). GIS technology has also been promoted through numerous publications, specialist conferences and workshops, and through the appearance of GIS-generated output in various fisheries journals and more general publications. For a more detailed description of the proliferation of fisheries GIS applications from the beginning of this century, see Meaden (2000), Meaden, (2001), Valavanis (2002) and Nishida *et al.* (2004). Despite this proliferation, it would be true to say that at the end of the last century the use of GIS for fisheries-related work was at an immature stage and this was a result of the very fragmented nature of the fisheries sector as a whole, i.e. much small-scale work was being pursued in isolated places, and because publications were mostly confined to the “grey” literature.

Fisher (2007) describes how applications of GIS to fisheries science and management came to be more sophisticated. Thus, in a survey of relevant publications issued before 2000, he found that a majority of the publications were concerned with qualitative studies that involved single parameters, a few publications reported multiple parameters and a very few publications contained studies that used quantitative (statistical and non-statistical) methods. However, when Fisher analysed recent fisheries publications, he found that the shift in publication content was markedly towards multiple parameter studies that embedded geostatistical techniques. The main thematic areas that presently utilize GIS with respect to fisheries can be categorized as follows.

- Habitat mapping. This is a process whereby sea-bed types are classified in terms of sediments, morphology, depth and benthos using data from various acoustic sonar devices and biological sampling equipment. Habitats can be portrayed in various means and categories, for example, by draping a map of sediment types or benthos over a 3D topographical image. Over the last decade, the importance of habitat mapping has increased markedly and in many ways habitat maps are now expected to form the basis upon which marine ecosystems are managed.
- Species distribution and abundance. The 2D mapping and modelling of the distribution and abundance of species of interest (resource analysis) has grown into a substantial area of research covering both terrestrial and marine domains. Marine species pose particular challenges as their populations are relatively dynamic in space and time. Mapping their distribution, therefore, presents a challenge to statisticians and ecological modellers.
- Fisheries oceanographic modelling. Research in this area is aimed at explaining the relationships between fish occurrence and oceanographic variables. This involves aggregating data from a wide variety of sources, with satellite remote sensing and fisheries surveys being of primary importance. Only a GIS has the functional capability of carrying out the necessary complex modelling.

- Fishers' activities. Knowledge of who is fishing where, who is catching what and by what means is a fundamental requirement for management to be effective. Many large-scale commercial fisheries are now subject to monitoring by satellite-based VMS. These systems are designed to augment existing logbook schemes and can potentially generate more accurate assessments of where fishing activities are taking place. Small-scale fisheries are required to submit logbook records of catch and effort, whereas subsistence fisheries are rarely subject to a formal reporting mechanism. Where spatially structured data for catch and effort exist, various GIS-based analyses are possible that seek relationships between fishing effort and marine ecosystem properties.
- Fisheries management. Managers have an overall responsibility to sustain fish stocks and to do this, they often work hand-in-hand with fishery scientists. Together they have access to a wide range of fisheries data. Use of GIS output allows better decisions to be made on factors such as closed areas, stock abundance, stock enhancement, marine reserve locations, fishing effort distribution and behaviour, and fish mortality rates. The capability for some management tasks will be greatly expedited with a move towards electronic fisheries logbooks.

It is interesting to note that Fisher (2007) does not include EAF as one of the thematic areas under which work in fisheries GIS might be classified. Despite this lack of explicit recognition, without a doubt much of the work now being carried out is moving in the direction of EAF, though perhaps this work is still taking a rather narrow view of what EAF implies. For overviews of recent GIS applications in fisheries management and research, the authors recommend Fisher and Rahel (2004), Nishida *et al.* (2004), Wright and Scholz (2005), Nishida *et al.* (2007) and Meaden (2009).

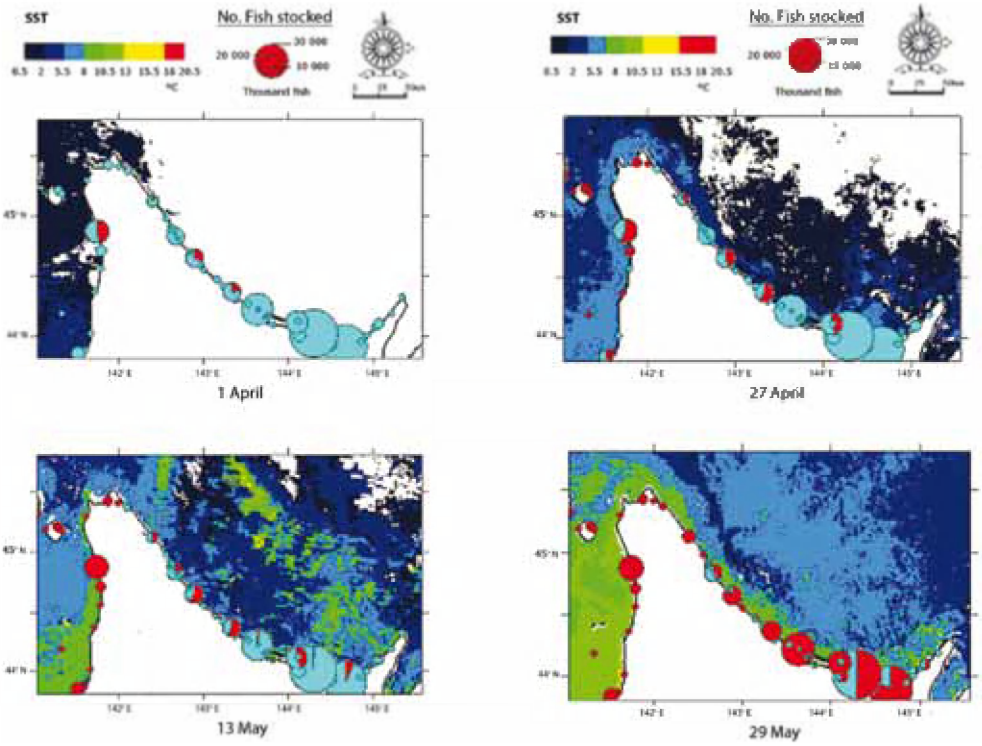
3.5 CASE STUDIES OF GIS APPLICATIONS TO FISHERY-BASED TOPICS

GIS applications in fisheries are increasing. The following four studies of some GIS applications were selected on the basis of the issues addressed, their ease of understanding, the variety of uses of GIS, the variety of data sources used in the study and the different geographic areas and spatial scales covered.

3.5.1 In search of the optimum time to release juvenile chum salmon into the coastal waters of northern Japan

With salmonid stocks rapidly declining worldwide and with salmon being an ideal species for large-scale hatchery rearing, the release of salmon directly into the coastal environment appears to be a sensible and economic strategy. In fact, this practice has long been followed in Japan. Miyakoshi *et al.* (2007) show how, for nearly a century, the quantitative release of chum salmon into the coastal waters around the northern Hokkaido region of Japan is closely mirrored by the return of chum salmon, especially since the 1970s when releases greatly increased. This is one of the most successful marine stock-enhancement programmes in the world. Nevertheless, the success rates could be greatly enhanced if an appropriate match could be made between a number of variables such as size of hatchlings, sea temperatures, food availability and stocking densities. Miyakoshi *et al.* used remote sensing data to establish sea-surface temperatures and this was related to the date of hatchling release and the release location for the period 1997 to 2001. Figure 3.2 shows the incremental buildup of chum salmon released during four time periods from the beginning of April to the end of May, 2000, with the red portion of the circles indicating the percentage of salmon released by the date shown. Also given are sea-surface temperatures. The GIS-based analyses showed that salmon production, as indicated by salmon returns, is more likely to be optimized where sea temperatures range from 8° C to 13° C, and when juveniles are > 5 cm in length. This information can potentially be used to maximize the benefits of future restocking operations.

FIGURE 3.2
The location of chum salmon release sites in the coastal waters of northern Hokkaido, Japan, 2000



Source: Reproduced with permission from Miyakoshi *et al.*, 2007.

Note: The red portions of the location circles indicate the proportion of total annual releases made by the date indicated.

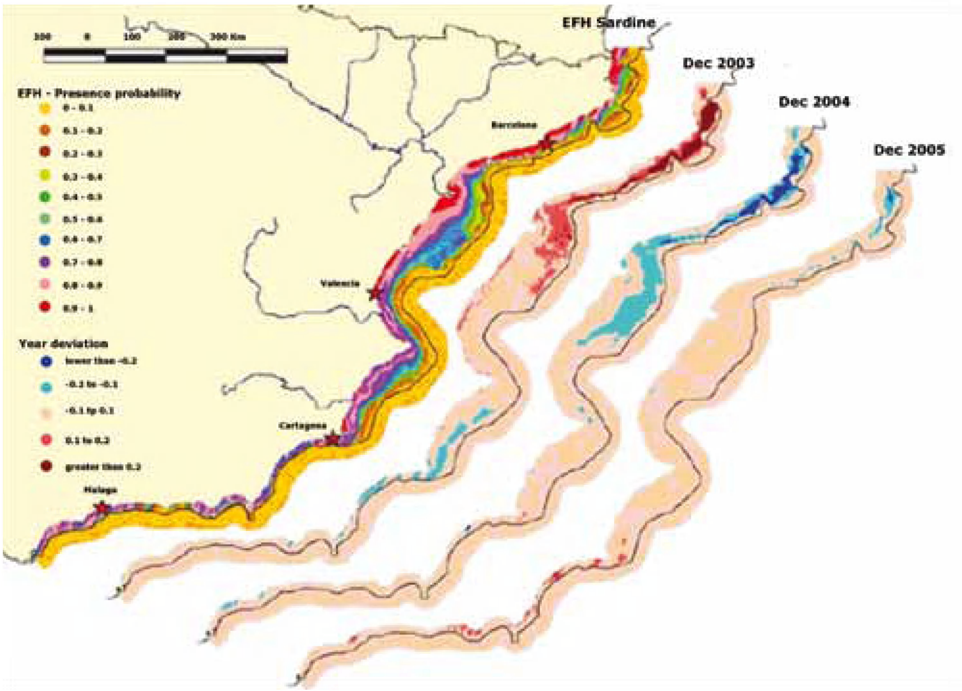
3.5.2 Identification of the essential fish habitat for small pelagic species in Spanish Mediterranean waters

Small pelagic fish such as sardines and anchovies provide an important fishery along Spain's Mediterranean coast. Spatial abundance data obtained from annual acoustic surveys were combined with environmental data in a GIS environment to generate a model that showed the likely optimum relationships between abundance and location for both anchovies and sardines. The model outcomes were then used to help define essential fish habitats (EFH) for these species. The statistical methods used to derive the EFH are described by Bellido *et al.* (2008). The environmental variables used were bathymetry, sea-surface chlorophyll-a and sea-surface temperatures. Bellido *et al.* noted substantial interannual variability in the distribution and quality of the EFH, particularly for anchovy, and they commented on the importance of assessing EFH for the management of the local marine resources. Figure 3.3 gives an example of the GIS output showing the EFH for sardines in the Spanish Mediterranean waters.

3.5.3 Development of a GIS for the marine resources of Rodrigues Island

Rodrigues Island, a small island in the Indian Ocean, is located about 600 km east of Mauritius, and like many similar islands in the tropics, it is under pressure from natural resource exploitation and increasing tourism. Until recently, there was a complete lack of structured information on marine resources and this hampered any attempts at management. Since 2000, a GIS (using MapInfo software) has been incrementally developed by the University of Wales with funding from various aid projects (Chapman and Turner, 2004). The intentions of the GIS were to integrate data on the distribution of biodiversity with environmental factors controlling distributions and with human

FIGURE 3.3
The essential fish habitat for sardines in the Spanish Mediterranean waters



Source: Reproduced with permission from Bellido *et al.,* 2008.

activities such as fishing and conservation planning measures. Biotope mapping based on satellite imagery and ground truthing was carried out for the entire lagoon area surrounding the island, which at 240 km^2 is the largest lagoon in the Indian Ocean. As a result of the mapping effort, 42 separate biotopes within four main habitat groups were described, i.e. coral, consolidated limestone, lagoon mud, and sand and rubble. Figure 3.4 shows a satellite image of the island and the distribution of main habitat types in the lagoon. The GIS is linked to a relational database to store and display site-based data, including biotope descriptions, photographs, species lists, illustrations and environmental data. A rich variety of GIS outputs was derived and the analysis of some of this output has helped to improve the designation of marine protected areas and other conservation measures. This GIS comes complete with a detailed user's guide plus a companion document that describes the GIS in detail, including the processes involved in developing the system and the research projects behind the data.

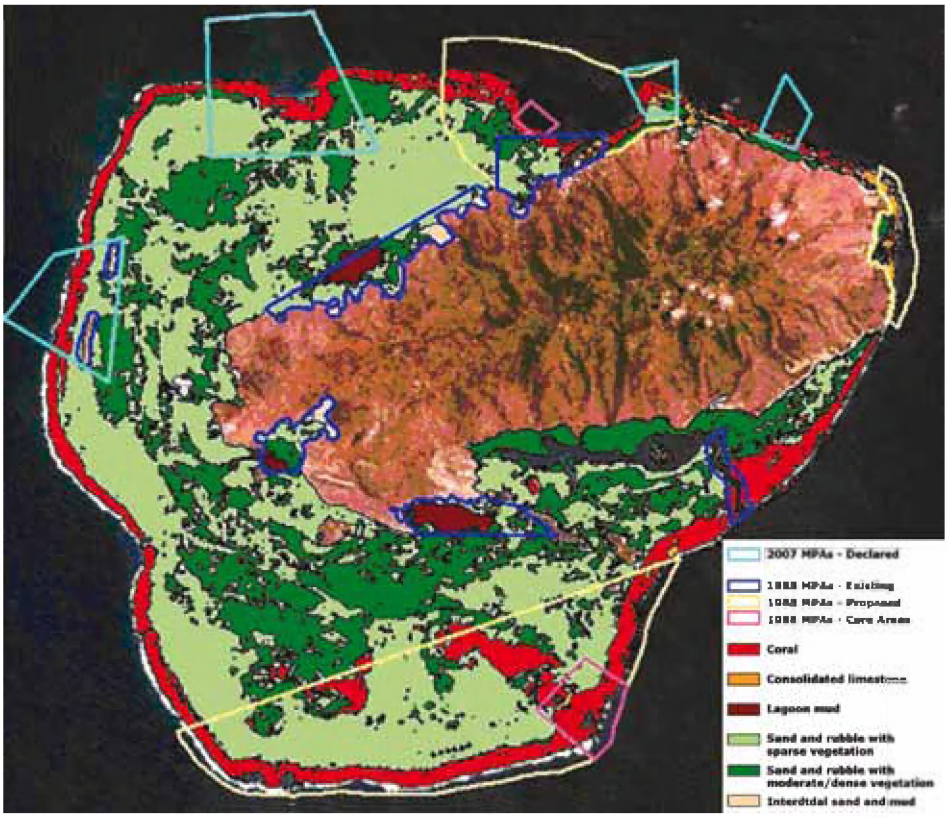
3.5.4 The influence of closed areas on fishing effort in the Gulf of Maine

It has long been suggested that problems likely to be associated with establishing closed areas to fishing are the so-called "boundary" and "displaced effort" effects. The boundary effect refers to the likely increase in fishing effort around the boundary of the closed area in response to the greater likelihood of catching fish that spill over from the closed area. The displaced effort effect refers to a natural concentration of fishing effort in the smaller available marine space, to the likely detriment of benthic habitats[2].

The Gulf of Maine is a large gulf of the Atlantic Ocean off the coasts of Maine, New Hampshire and Massachusetts in the United States of America. By comparing fishing effort distribution data for 1990–1993 (pre-area closure) with effort distribution data for 2003 (post-area closure), Murawski *et al.* (2005) found that, indeed, in 2003 effort

[2] For a more detailed account of the influences of areas that are closed to fishing see Hilborn *et al.* (2004).

FIGURE 3.4
A map of Rodrigues Island and lagoon showing combined habitat classes



Source: Reproduced with permission from Chapman and Turner, 2004.

Note: Shown on the map is an overlay of the reserve areas as identified in Pearson (1988) and of the northern reserve areas as proclaimed by the Rodrigues Regional Assembly in April 2007.

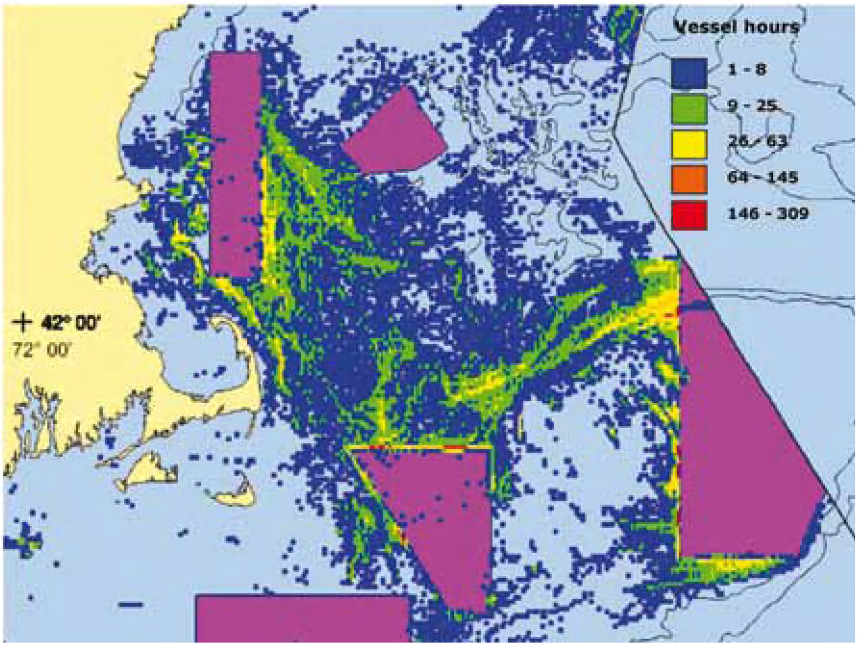
had been concentrated and nearly 10 percent of total effort was deployed within 1 km of the closed area boundaries. As is shown in Figure 3.5, this effort concentration varies significantly between the five closed areas, obviously reflecting different fish densities that relate to habitat suitability. An analysis of catch quantities and fishing location revealed that for some species some of the closed areas were having a positive effect and that the average revenue per hour trawled was about twice as high within 4 kms of a closed area than the revenue generated in more distant locations. Revenue generation was, however, highly variable among closed areas and along boundaries, reflecting overfishing in some areas and seasonal variations in fish distributions. It should be noted that the information demands to produce this type of GIS output are very high and VMS location data has contributed a large portion of the needed information. A major data problem for many fisheries and management authorities is the accuracy of catch locations, as is the case in most northern European fisheries where catches are only assigned to so-called ICES rectangles, which measure 1 degree longitude by 0.5 degrees latitude[3].

3.6 CONCLUSIONS

In the two decades since GIS was first used for spatial analyses or mapping of fisheries related themes, significant progress has been made. However, it is likely that progress has not been as significant as progress achieved in many terrestrial GIS applications because of the many challenges that face workers who try to apply mapping

[3] Approximately 5 000 km^2 in mid-latitudes.

FIGURE 3.5
Hours of fishing effort by otter trawls in the Gulf of Maine, 2003



Source: Reproduced with permission from Murawski *et al.*, 2005.

Note: Closed areas are shaded in purple.

technologies to an environment that functions in three dimensions, and where almost everything that can be mapped is constantly moving (see Section 6.4). Despite these and other challenges, the enthusiasm shown for GIS use by many fishery researchers, managers and organizations will ensure that GIS has a vibrant future. This future will be enhanced by the fact that fisheries are entering an era when the ecosystem approach to fisheries has come to the fore and the following section will illustrate how this is being achieved.

4. The role of GIS in support of EAF implementation

4.1 INTRODUCTION

The previous sections outlined the underlying principles and foundations of EAF and described the important role of GIS and spatially structured data for understanding and managing marine fisheries. The aim of this section is to connect the two – EAF and GIS – in order to consider the role of GIS in support of the practical implementation of EAF. GIS will undoubtedly play an important role in improving our understanding of the interactions both within and between biophysical and socio-economic components of marine ecosystems (Babcock *et al.*, 2005; Cury, 2004). Access to better information and a heightened understanding of ecosystem interactions will allow managers to make more informed decisions when introducing EAF principles to new fisheries and consolidating implementation efforts for established fisheries.

A 2008 survey of scientists and managers at the Coastal Services Center of the United States National Oceanic and Atmospheric Administration (NOAA) provided insights into the role of GIS in implementing ecosystem-based management (EBM), within which EAF is a subset (NOAA Coastal Services Center, 2008). When asked to describe the types of decision support software used for EBM, the survey respondents ranked custom GIS applications as most useful. The survey also found that lack of data resources describing ecosystem processes and components was the second most common barrier to EBM implementation. While there is no doubt that EAF has the potential to be a data-hungry process, a lack of data should not be a barrier to progress and EAF should proceed based on the best available information (FAO, 2003).

GIS will have an important role to play in providing the necessary information, as well as in deciding an appropriate geographic scale or set of nested scales for the development of EAF implementation frameworks and management plans. While setting objectives and goals should not depend on GIS and the availability of spatial ecosystem data (O'Boyle *et al.*, 2005a), the ability to visualize and understand ecosystem properties and processes, and interactions between these and human activities, can potentially facilitate the process of identifying and selecting appropriate objectives. The design of spatial management frameworks, such as marine protected areas and zoning schemes, for delivering key operational objectives will increasingly make use of GIS as a core platform. How management frameworks bring about changes in human behaviour and patterns of exploitation and lead to knock-on effects on target and non-target ecosystem components can also be better understood if management interventions are placed in their proper geographic context within a GIS environment.

GIS can interact with the implementation of EAF processes in four ways by providing a platform for mapping, modelling, management and communication. Each of these interactions is discussed in Section 6.

4.2 MAPPING IN EAF WITH GIS

Our understanding of ecosystem properties, pressures, processes, and threats is based in part on our ability to place these components in their true geographic context. In order words, we need a map. Currently, our ability to generate maps of ecosystem components is primarily limited by a lack of access to necessary data resources and this can act as a barrier to EAF implementation. As mentioned above, implementation should not be hindered by a lack of data, but certainly a basic level of data will be required in order to make progress. Interestingly, it seems that countries that are fortunate enough to have access to relatively comprehensive (space-time-ecosystem) data resources are not necessarily moving ahead with EAF-based work as quickly as might be expected (Barnes and McFadden, 2008). Having the data, or even not having the data but an idea of what data needs to be collected, is not necessarily a precursor to rapid progress. While access to data resources can be perceived as a major barrier to EAF implementation, it is likely that many other barriers exist.

Regardless of the amount of data resources available, tools are needed to help visualize, analyse and make sense of the ecosystem components that the data represent and this is where GIS plays a considerable role at a basic but very fundamental level. The following discussion focuses on some of the major themes regarding data that are needed for EAF implementation and the role of GIS as a tool to help understand and visualize the ecosystem components that the data represent.

4.2.1 Ecoregions

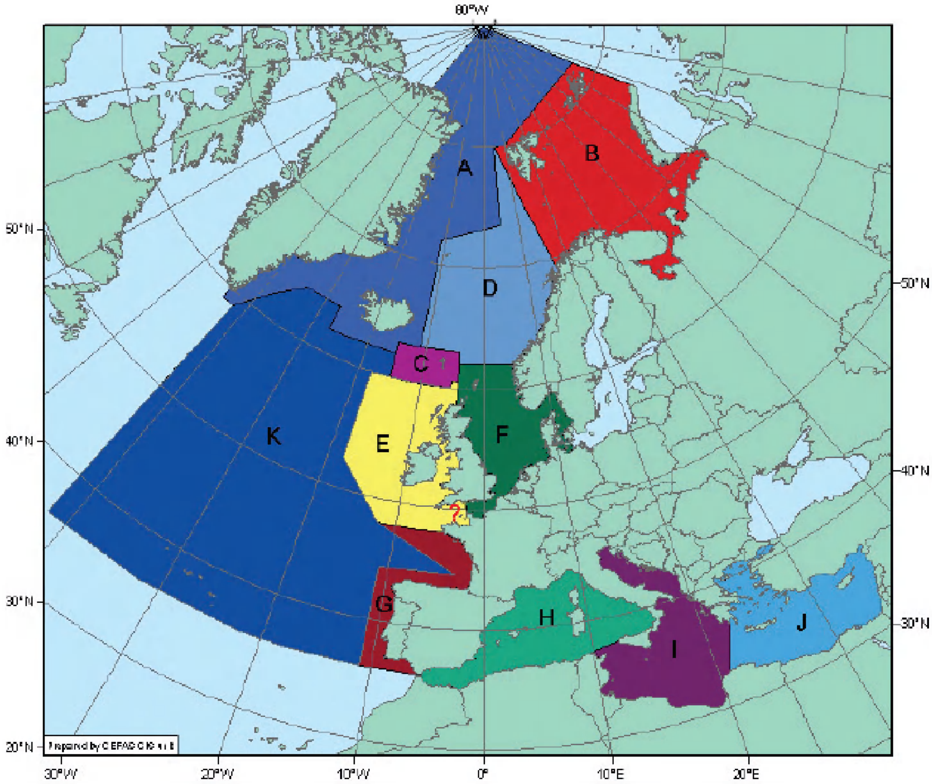
As described in Section 2.3, a first step towards EAF implementation consists in a scoping exercise, during which a decision is made on an appropriate geographic area within which EAF management plans can be developed. The area will typically comprise a relatively discrete ecosystem or "ecoregion", the scale of which depends on the fishery/fisheries for which management plans are to be developed. Where sufficient information exists, defining ecoregion boundaries should be based on an understanding of the distribution of biogeographic and oceanographic processes both within the ecoregion and across a wider area and should where possible take account of existing political, social, economic and management divisions (ICES, 2005). By definition, an ecoregion comprises sites whose biogeographic and oceanographic characteristics are greatly similar. Variability in the key parameters of interest among sites within an ecoregion would, therefore, be expected to be smaller than variability in those same key parameters among ecoregions.

A number of global-scale ecosystem classifications exist and can be used as a broad framework for regional ecoregion characterizations, notably those of Longhurst (1998) and Hempel and Sherman (2003), and more recently those of Spalding *et al.* (2007). Characterizations for smaller sea regions are also underway or have been completed in recent years (ICES, 2005; O'Boyle and Jamieson, 2006; Day *et al.*, 2008). Ecoregions recently proposed at the European scale are shown in Figure 4.1. In all instances, a central requirement for defining ecosystem boundaries is access to spatial information on ecosystem components. Understanding ecosystem processes and their spatio-temporal variability, and defining boundaries between ecoregions can be greatly facilitated if ecosystems are visualized in their proper geographic context, preferably within a GIS environment.

4.2.2 Species

Once an ecoregion or a subset thereof has been defined for the development of an EAF management plan, descriptions are needed of the species – both target and non-target – that occur within its boundaries. Descriptions should preferably be accompanied by maps showing the spatial distribution and, where possible, the abundance of adults and areas of critical life stages, such as spawning areas and nursery grounds. If important species are found to occupy only a proportion of the ecoregion or are found to migrate across the ecoregion's boundaries, some spatial redefinition of the ecoregion might be required, either by modifying the boundaries or by generating smaller subunits (Babcock *et al.*, 2005).

FIGURE 4.1
Proposed ecoregions for the implementation of EAF in European waters



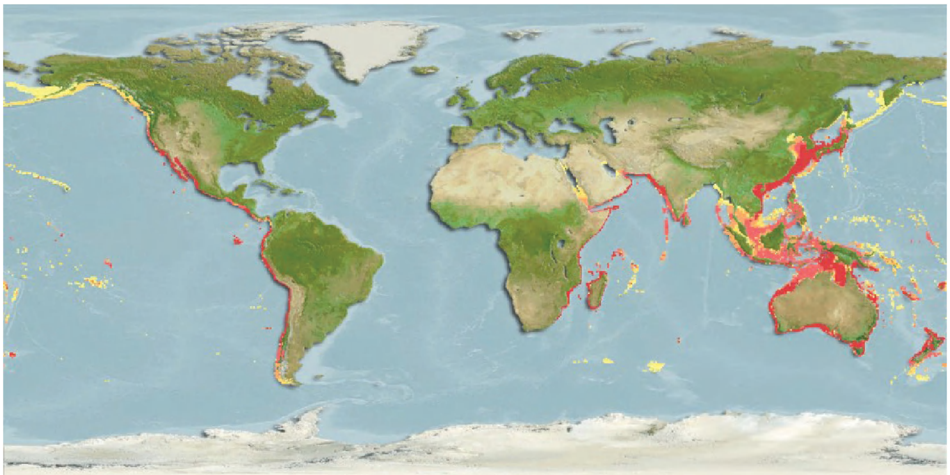
Source: CES, 2005.

Species distributions can be mapped within a GIS environment using fisheries independent survey data and can be depicted as presence only, presence-absence or relative abundance, depending on the type of catch data and the efficiency with which the gear captures the particular species life-history stage. There are probably only a few ecoregions in the world where marine species distributions can be represented with any real confidence using direct observations from fisheries independent surveys. Most areas will suffer from a severe lack of independent data and thus may need to rely more heavily on fisheries dependent data (commercial or artisanal), despite their inherent biases and often poor relationship to actual patterns of distribution and abundance that are known to exist (Maunder and Punt, 2004).

As an alternative, species distributions can be predicted using one or more of the many numerical methods designed to estimate the presence or abundance of a species at locations where no observations have been made. This relatively mature area of research can be overwhelming for the uninitiated (for a relatively concise, comprehensive and recent review see Austin, 2007). Fortunately, a number of online and offline, semi-automated GIS-based tools are becoming available that simplify some of the decision-making processes. For example, the recent launch of the online AquaMaps[4] global system of species distribution prediction modelling from presence data represents a significant step forward, having automated a number of key routines while providing users with full control where needed of parameters affecting the potential distribution of one species (Kaschner *et al.*, 2007) (Figure 4.2). These and similar systems have the potential to provide coarse resolution distribution maps to managers and scientists who need to make progress with EAF implementation but who lack species data, particularly for non-target species.

[4] Available at www.aquamaps.org

FIGURE 4.2
A predicted distribution of chub mackerel (*Scomber japonicus*)



Source: From the AquaMaps server (www.aquamaps.org) based on occurrence data from FishBase (www.fishbase.org). The map is reproduced with permission from R. Froese, Leibniz Institute of Marine Sciences, Germany.

Note: The map has not undergone expert review so it may contain errors.

In the absence of data, or if there is reluctance to use complex model algorithms to predict distributions, expert judgement can be used. Despite technological advances and new research outcomes, expert-derived maps of species distributions can often prove just as reliable, or even more so, than mathematical predictions (Yamada *et al.*, 2003).

An example of the use of expert knowledge combined with species habitat preferences is the collection of aquatic fishery resource distribution maps available from the FAO Web site[5]. While the maps only represent a snapshot of the distribution of a species (Figure 4.3), averaged across several years of observations, expert knowledge maps such as these have been used successfully in defining hotspot zones of biological richness and vulnerable habitats (Carpenter and Springer, 2005).

FIGURE 4.3
The distribution of chub mackerel (*Scomber japonicus*)

Source: From the FAO Fisheries and Aquaculture Department species distribution maps based on expert knowledge and habitat preferences.

[5] Available at www.fao.org/fishery/collection/fish_dist_map/en

4.2.3 Habitats

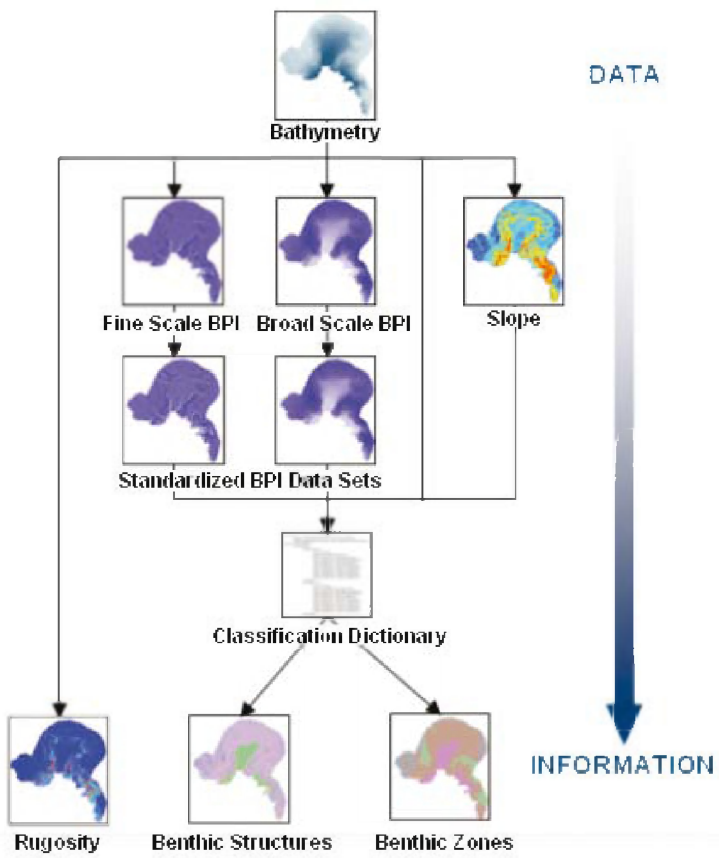
Knowing where critical or sensitive habitats occur is key to successful EAF implementation. A suite of instruments, methods and processes are available for constructing maps of sea-bed physical and biological features over different spatial scales and resolutions (Green *et al.*, 2000; Kenny *et al.*, 2003). The choice of instrument and platform to use will depend upon the type of environment, the optical penetration of the water, the resolution required and, probably most importantly, the level of financial resources available. Habitat mapping can be a very expensive process and many countries, including those countries that are relatively wealthy, do not have sufficient resources to generate comprehensive descriptions of their sea-floor environments using direct observation techniques at a resolution suitable for management. Habitat maps as well as maps of species distributions can be generated using prediction methods that rely on numerical methods or expert judgement or a combination of the two (e.g. Eastwood *et al.*, 2006).

The methods used to generate ecoregion maps follow similar principles in that a certain level of prediction is needed to assess ecosystem variability across a range of different spatial scales and to use this information to define boundaries between ecoregions.

With reference to methods that produce habitat maps using prediction methods, one striking example is the Benthic Terrain Modelling (BTM) system created by the Department of Geosciences at Oregon State University and NOAA's Coastal Services Center. As described in Iampietro and Kvitek (2002) and Rinehart *et al.* (2004), the benthic terrain classification process (Figure 4.4) developed for the BTM builds upon several processes of existing methods used within the terrestrial and sea-floor mapping communities (Wright *et al.*, 2005). A central theme of the process is the creation of bathymetric position index (BPI) data sets through a neighbourhood analysis function. Positive, negative or near-zero values of BPI can reveal ridges, depressions or flat area occurrences, providing BTM users with a useful parameter for terrain classification. Additional outputs created by the BTM include slope, rugosity,and standardized, classified benthic terrain data sets.

In tropical waters, satellite and aircraft-mounted optical sensors

FIGURE 4.4
A graphical depiction of the process utilized by the Benthic Terrain Modelling system



Source: From www.csc.noaa.gov/products/btm/. Used with permission from Wright *et al.*, 2005.

can generate synoptic maps of nearshore and shallow water marine habitats without extensive and expensive *in situ* sampling. Although of relatively low resolution, imagery from the Landsat programme is now being made available free of charge[6] and can be put to many uses in relation to EAF implementation. For instance, Landsat images coupled with spatial analysis and underwater sight surveys have been used to estimate reef habitat area of Humphead wrasse (*Cheilinus undulatus*) in Indonesia, Malaysia and Papua New Guinea in order to evaluate the non-detrimental volumes of species catches, and in turn the amount of exports. (Oddone *et al.*, in preparation). Higher resolution imagery, while more expensive, is still relatively cheap compared with the high cost associated with ship and aircraft surveys and, through cooperative efforts, is in some cases being released free of charge to non-profit and public sector organizations (Kark *et al.*, 2008).

To produce a habitat map from a satellite image, the data contained in the image need processing to generate a set of habitat descriptions. The global-coverage coral reef maps and descriptions generated from Landsat imagery by Andréfouët *et al.* (2006) could potentially be input directly to EAF management plans by countries that might otherwise not have the means or ability to generate maps of their own. Similar initiatives at the regional or global scale for other important marine habitats such as seagrass beds, seamounts and cold-water corals, would also be of value to EAF practitioners (Kitchingman and Lai, 2004; Wabnitz *et al.*, 2007; Tittensor *et al.*, 2009).

While there is still no universally agreed system of classifying habitats, it is arguably more important to classify habitats using a scheme that is understandable to the people involved in the EAF process. This is probably most important when rural communities are the principal stakeholders, as non-vernacular descriptions will have little meaning. Habitat maps generated in partnership with local knowledge of the marine environment have the potential to be more readily accepted by the people who interact with and rely on the resources described by the maps (Lauer and Aswani, 2008). A participatory approach using community-based knowledge is critical to implementation success.

4.2.4 Human activities

Patterns of exploitation by commercial, artisanal and to some extent subsistence fisheries need to be better understood to allow assessments of impacts on target and non-target species and habitats and to set appropriate objectives for management within an EAF framework. The movements of the large commercial vessels are increasingly being monitored by way of automated systems of regular satellite positioning known collectively as VMS. Various fishery-specific rules have been developed to discriminate vessel behaviour, principally between fishing and non-fishing activity, and to separate satellite-derived locations into these two groups so as to identify fished locations (Deng *et al.*, 2005; Mills *et al.*, 2007).

The majority of fishing vessels in the world are not, however, monitored using sophisticated VMS. For these vessels, patterns of fishing activity will need to be mapped using alternative techniques, either based on numerical rules, fishers' knowledge or a combination of the two (Caddy and Carocci, 1999; Close and Brent Hall, 2006). Patterns of fishing activity can be mapped from logbook data, although the spatial resolution used by many official logbook schemes is often considerably lower than might be suitable for EAF management (Jennings *et al.*, 1999; Bellman *et al.*, 2005). In the absence of logbooks and VMS data, understanding where fishers fish can only be achieved through the use of fishers' knowledge. Regardless of the source of data used to develop maps of fishing grounds and patterns of activity, the involvement of fishers in the process is critical and very much in keeping with an underlying principle of EAF, which is to promote active engagement among key stakeholders.

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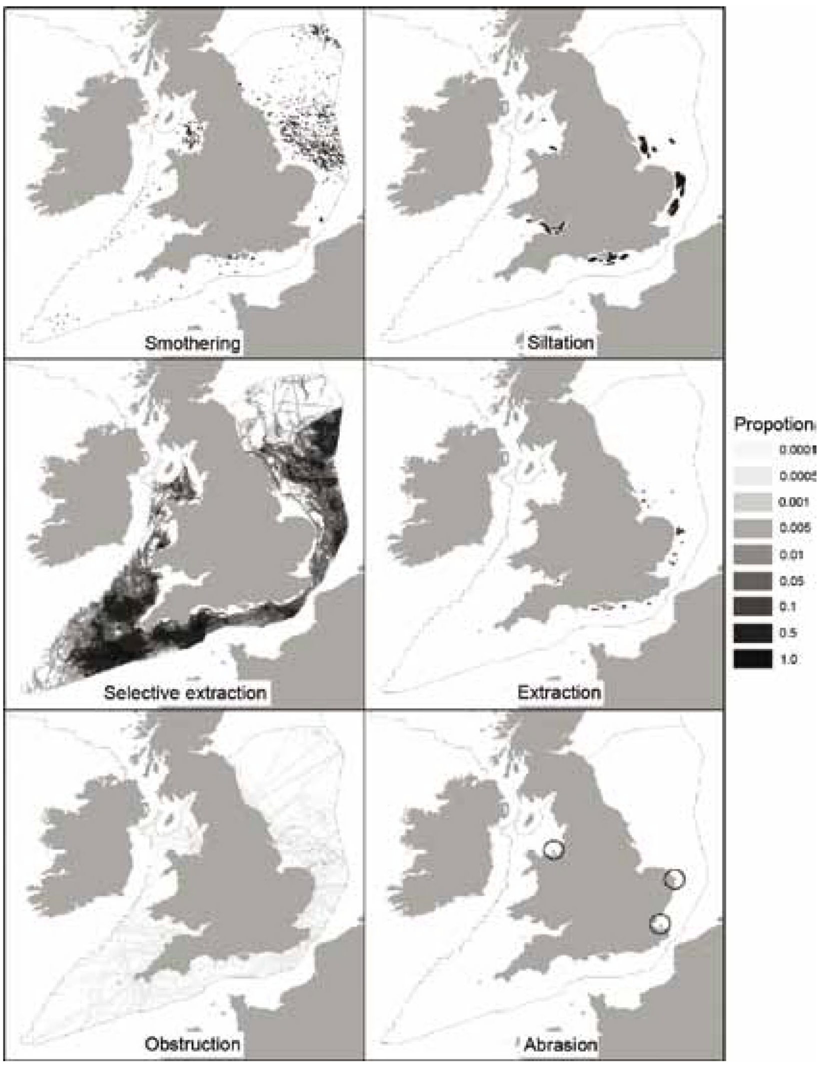
[6] Available at http://landsat.usgs.gov/

Fishing is not the only source of pressure on the marine environment. Mineral extraction, shipping, renewable energy facilities, pollution from land-based sources and many other sources exert different pressures at different levels. All activities that create pressures and impacts within the region where EAF is being implemented need to be visualized and quantified in some way. A number of studies have demonstrated how assessments of pressure from the majority of key marine sectors can be generated within a GIS environment at both global and regional scales (Eastwood *et al.*, 2007; Ban and Alder, 2008; Halpern *et al.*, 2008a) (Figure 4.5). To allow comparative assessments of the levels of pressure caused by different human activities, common metrics need to be developed based on the types of pressure that are caused rather than the activities that cause them. Evaluation frameworks can then be used to rank the relative importance of different pressures on different habitats (Chuenpagdee *et al.*, 2003; Halpern *et al.*, 2007).

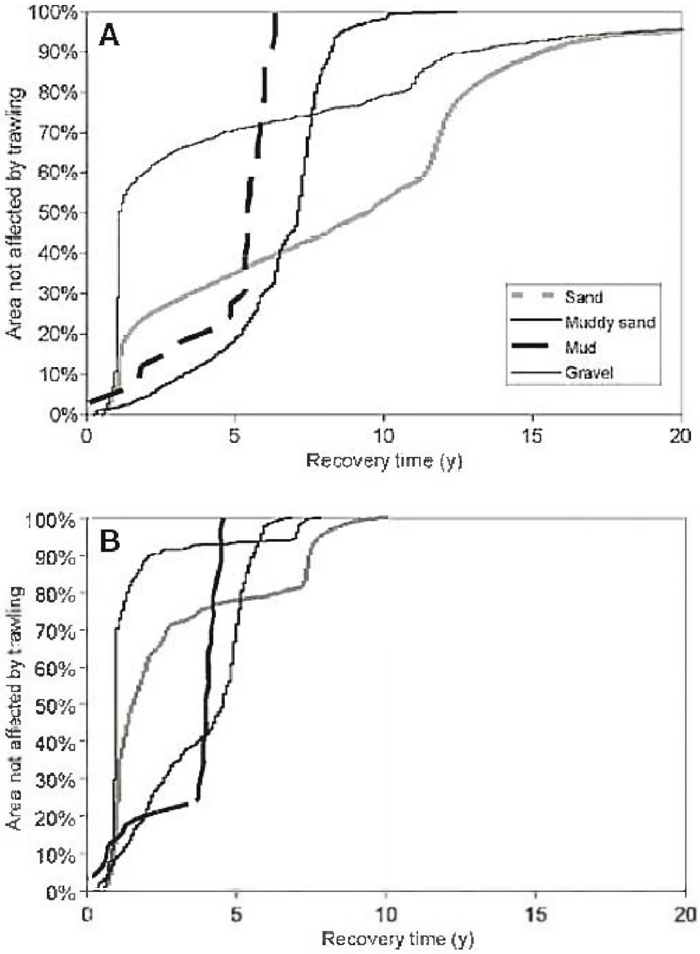
FIGURE 4.5
Maps of the waters around England and Wales showing the overall spatial extent of major pressure types, 2004



Source: Reproduced from Eastwood *et al.*, 2007. © Crown copyright.

Note: Maps show the overall spatial extent of each of six major pressure types in terms of the proportion of sea bed affected within grid cells of 2x2 nautical mile resolution. Circles have been drawn on the map of abrasion to draw attention to the three small areas where this pressure occurred in 2004.

FIGURE 4.6
State indicators of an ecosystem in the North Sea



Source: Reproduced from Hiddink *et al.*, 2006b.

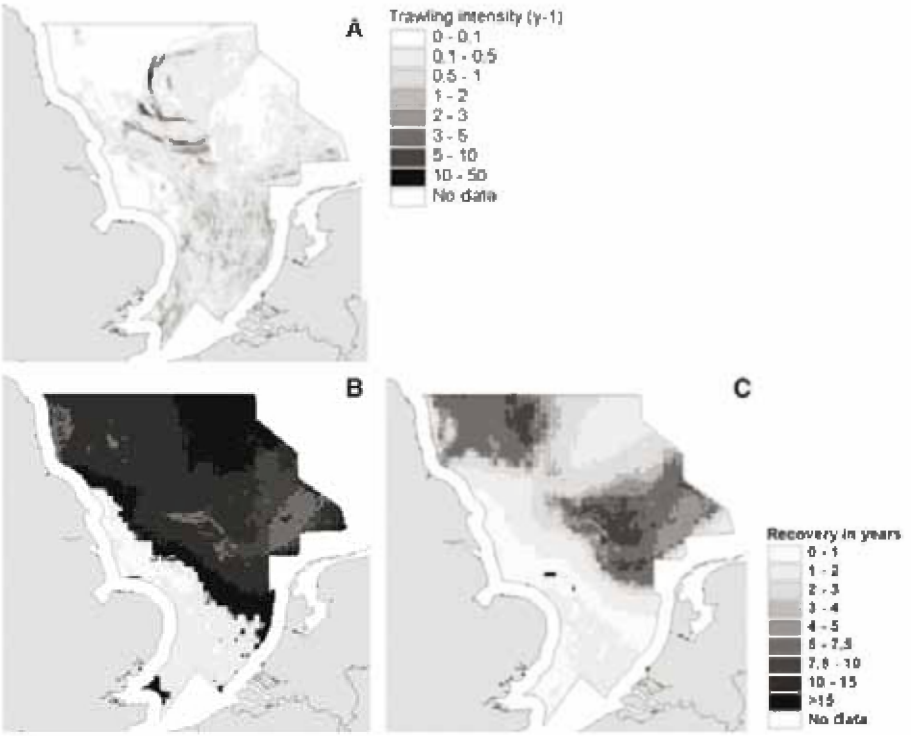
Note: Indicators were developed after a single trawl pass for (A) benthic biomass and (B) benthic production.

4.2.5 Indicators

The use of indicators to monitor progress against objectives is central to EAF implementation. In general, indicators are spatially aggregated metrics that track trends in one or more ecosystem components, whether ecological, social or economic. In this way, indicators can be used to assess the effectiveness of management towards agreed objectives and to communicate information in relatively simple terms to stakeholders in the ecosystem (Jennings, 2005). Communication in simple terms is critical, as a lack of understanding by the many stakeholders will reduce the efficacy of the indicator as a means to trigger management action (Degnbol, 2005).

A large body of research literature exists on indicators and covers their development, evaluation, optimal properties and guidance for their selection from a suite of possibilities (Jennings, 2005). As indicators are typically spatially aggregated metrics, they are not necessarily considered to have explicit spatial properties. The construction of indicators does, however, in many cases rely on spatial data regardless of whether the final metric has a spatial component. Relatively few indicators have been constructed and represented in a spatially disaggregated form with the assistance of GIS functionality (see Fréon *et al.*, 2005, and Hiddink *et al.*, 2006b), probably because of the relatively high data requirements and model complexity involved in their estimation. Indicators that can be mapped have the advantage that they can be visualized in their true geographic context. This might increase the likelihood that the indicator is understood by non-specialist stakeholders and so might be associated with a higher degree of acceptability. For example, compare Figure 4.6 with Figure 4.7 (Section 4.3.2), both of which were generated by the same study of Hiddink *et al.* (2006b) but where the graphed output in Figure 4.6 was created by spatially aggregating the information used to generate the mapped output in Figure 4.7. Both outputs can be interpreted relatively easily. However, it could be argued that the information in Figure 4.7 could more easily feed into decision-making due in part to the higher degree of spatial disaggregation and its mapped representation, allowing comparisons with the human activities to be managed, in this case fishing with sea-bed trawl gear. Developing indicators that can be mapped at a resolution suitable for management decisions should be a future goal for the research community.

FIGURE 4.7
An example of the integration of GIS into a model of the North Sea benthic community



Source: Modified from Hiddink *et al.*, 2006b.

Note: (A) Trawling intensity calculated from VMS records in the Dutch and United Kingdom sectors of the North Sea. (B) Recovery time of benthic community biomass after a single trawl. (C) Recovery time of benthic community production after a single trawl.

The cost of collecting the data needed to generate the majority of indicators of the state of an ecosystem is relatively high. In resource poor situations, relatively simple pressure indicators can be used, such as fleet size, fishing mortality and effort, or catch and discard rates (Piet *et al.*, 2007). Simple indicators such as the percentage of mature fish, fish of optimum length or highly fecund fish in the catch could also be used (Froese, 2004). GIS may have a more limited role to play in these situations because, to have any meaning in tracking trends at the level of the fish population, the indicator might need to be constructed by aggregating spatial data across a wide geographic area. However, GIS can still be used to help understand spatial patterns and variability in the data prior to spatial aggregation and in so doing may help to interpret any trends in the population that might be suggested by the indicator.

4.2.6 Management regulations

If modern systems of fisheries management relied on GIS (which they rarely if ever do), one of the most important requirements would be to secure up-to-date and accurate geographic representations of management regulations. Almost all fisheries regulations apply to defined geographic areas and act to restrict operations in some way. Regulations can apply to the entire marine management area though some, such as local by-laws or community agreements, cover much smaller spatial areas. The only difference between such regulations, aside from the fishing operations they target, is the spatial scales over which they apply.

One might wonder why so many countries and regions with long histories of fisheries exploitation and relatively mature systems of fishery research and management have generally not invested in the time and resources needed to visualize the entirety of their management regulations on a map, preferably a digital one. Such is the case of Europe, in whose waters some of the world's most highly regulated fisheries operate. The inability to visualize the full set of management regulations and the complexity of the management system in general means that few people can fully understand it. If the people directly involved in the fisheries are unable to see the full picture of the rules and regulations under which they operate, one of the most fundamental principles of EAF has been broken, namely that systems of governance should ensure both human and ecosystem well-being and equity (FAO, 2003). Equity is difficult to achieve when the system of governance is too complex for fishers, let alone other marine stakeholders, to understand.

GIS is now so widely accessible that there is no reason why this situation could not be improved, regardless of the size or complexity of the fisheries under management control. Management may not necessarily improve substantially if regulations were held within a spatial database but at least an opportunity would be created for a wider range of stakeholders to be informed, engage, and provide inputs to new and potentially simplified regulatory systems.

4.3 MODELLING IN EAF WITH GIS

By far the most common use of GIS in fisheries is to generate maps from fisheries survey data to understand distributions of effort, target species, bycatch and discards in relation to one another and to environmental features. However, GIS can also be used as a tool for the construction of models designed to accommodate the spatial structure of the input data and generate geographically referenced model outputs. Below some of the interactions between GIS and modelling applications of relevance to EAF implementation are outlined.

4.3.1 Spatial stock assessments

Traditional forms of fisheries management, albeit under new guiding principles, will remain a core component of EAF in many parts of the world and for many years to come. In that sense, the expected paradigm shift from single-species assessments to more holistic ecosystem considerations will be an evolutionary process for the vast majority of fisheries (Francis *et al.*, 2007). Ecosystem-based fishery management will require us to take a more spatially disaggregated view and make decisions at a higher spatial resolution, whereas traditional fisheries assessment methods are typically based on a higher spatial aggregation. Single-species stock assessment methods, the cornerstone of modern systems of fisheries management, operating at "stock level", tend to disregard the well-known spatial heterogeneity within the area of distribution of the stock. The basic assumption in conventional fishery science is that the relations used are acceptable as long as the stock or the fishery (or both) are randomly distributed (Ricker, 1975). As a consequence, assessments are conducted as if the fishery, environmental and biological processes within the presupposed geographic boundaries of the stock were spatially homogenous. Population variables (growth, age/size frequencies) and the environmental conditions they are associated with as well as fisheries parameters (e.g. catchability) are, therefore, pooled spatially. GIS combined with spatial statistics are now able to deal more explicitly with the spatial heterogeneity inherent in population dynamics and environmental conditions, allowing for population models to be constructed at a greater level of spatio-temporal disaggregation and for the spatial variability of environmental parameters to be incorporated. A shift to a more detailed spatial resolution in traditional fisheries assessment methods will facilitate EAF implementation.

Estimating stock size is central to the current system of allocating catch quotas and will likely remain central in formulating management options under an EAF in many regions. Methods designed to improve estimates of stock abundance by taking spatial structure into account more explicitly can be separated into two general categories: statistical methods that are spatially explicit and methods based on non-spatial statistics.

Spatially explicit methods generally centre on a branch of statistics known as geostatistics, which at a basic level attempt to account for any spatial structure in the process being estimated. Geostatistical techniques have been particularly successful in improving estimates of fish population abundance from acoustic data (Rivoirard *et al.*, 2000). A variety of geostatistical techniques are now available within standard GIS software, increasing the opportunity to make use of advances in these methods within stock assessment frameworks.

The use of non-spatial statistical methods for improving estimates of abundance is relatively mature (Venables and Dichmont, 2004). The application of these methods is often aimed at standardizing catch and effort data for the purpose of generating indices of abundance and not specifically aimed at accounting for spatial variability (Maunder and Punt, 2004). These and other methods designed to uncouple spatial processes from environment-driven patterns in distribution have the potential to provide more realistic assessments of the error associated with abundance estimates (Nishida and Chen, 2004), which helps make clear where the causes of uncertainty lie. They may also offer greater insights into the factors causing changes in the geographic distribution and environmental preferences of marine fish (Booth, 2004), which is becoming very topical in relation to climate change and its impacts on aquatic ecosystems. Dealing more effectively with uncertainty and understanding the environmental drivers of change in fish populations will provide direct benefits when formulating management options under an EAF.

4.3.2 Ecosystem interactions

Ecosystems are complex. Understanding interactions between ecosystem components, especially those with which humans interact, is essential to EAF implementation. There are a growing number of models designed to help make sense of ecosystem complexity and to understand the effects of human interactions (Plagányi, 2007; Travers *et al.*, 2007). While some of these models can accommodate spatial data and in turn generate mapped outputs, none of them are able to interact or make explicit use of data and tools available in a GIS. It could be argued, therefore, that GIS will have a limited role to play in the development and operation of ecosystem models. However, the current lack of integration into GIS is probably more a reflection of a separation in development pathways: ecosystem models are generated through scientific research and are designed to meet highly specific needs, whereas advances in GIS functionality are more general in scope and designed to meet common requirements across a broader and somewhat divergent set of user needs.

Convergence between GIS and ecosystem models might greatly contribute to EAF implementation in areas that are highly regulated and comprise mature fisheries. To this end, spatial considerations are playing an increasingly important role in the development of ecosystem modelling approaches (Plagányi, 2007). One area towards which efforts could initially be directed is the level of interoperability between the various software applications designed to operate ecosystem models and GIS software, in particular with the exchange between the two of georeferenced data. This would provide ecosystem modellers with access to the growing volumes of physical, chemical, biological and socio-economic data held in common spatial data formats, data which are readable by GIS but are not interoperable with ecosystem models. It would also allow model outputs to feed into broader ecosystem visualizations within GIS environments and by doing so facilitate communication with non-specialists.

One of the most popular ecosystem models worldwide is Ecopath with Ecosim (EwE), with the Ecospace model providing the spatial component (Pauly *et al.*, 2000).

Currently, Ecospace operates within its own spatial environment and is generally unable to interact with GIS and standard georeferenced data but in the near future, it is expected that Ecospace and GIS will be able to interact (V. Christensen, University of British Columbia, personnel communication). Integration into GIS is happening elsewhere. For example, Hiddink *et al.* (2006b) demonstrate how a size-based model of the North Sea benthic community could integrate into GIS to estimate the effects of fishing on production and biomass at a relatively high degree of spatial resolution (Figure 4.7). It is likely that interaction between ecosystem models and GIS will increase over time, allowing model outputs to be viewed alongside a broader set of ecosystem components, both human and environmental.

4.3.3 MPA placement and design

Marine protected areas (MPAs) are increasingly advocated as an important tool for fisheries management. While debate continues over the efficacy of MPAs compared with traditional forms of management (Kaiser, 2005; Jones, 2007), there is little doubt that MPAs of some description will form a central component of EAF management.

GIS can facilitate the design and placement of MPAs in support of EAF in a number of different ways. At the most basic level, GIS can help many stakeholders to visualize and better understand the spatial interrelationships between ecosystem components and the MPA designed to preserve or protect them. As discussed earlier, GIS can also help to map and model the distribution of many of the ecosystem components, both human and biological, needed to design and locate MPAs.

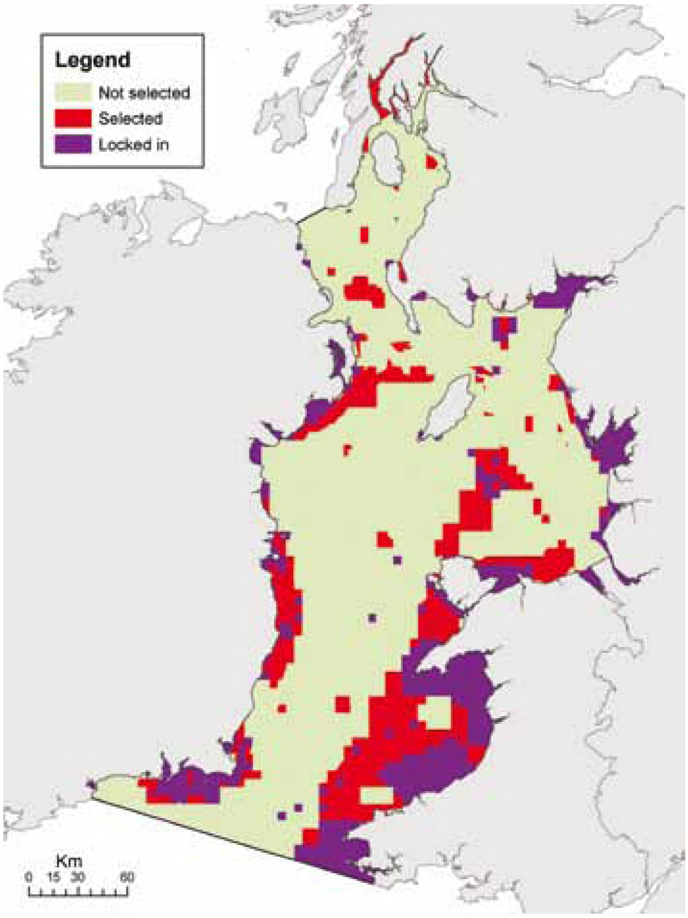
GIS can also provide a mechanism to visualize MPA placement scenarios constructed using specialist models and algorithms. The Ecospace module of Ecopath with Ecosim is designed to assess the wider ecosystem implications of MPA placement by predicting changing patterns of biomass within an ecosystem resulting from different patterns of exploitation caused by MPAs. The reserve selection software Marxan (Ball and Possingham, 2000) is another popular tool used for MPA design and placement but it operates under a very different set of principles to Ecospace. With Marxan, near-optimal MPA configurations are selected algorithmically in order to meet a predefined set of nature conservation targets, such as the proportion of a population that needs to be conserved within a particular ecoregion (Figure 4.8). The outcomes of MPA placement cannot be assessed via Marxan, its main function being to select MPAs from a set of possibilities. Although the development of Marxan was stimulated in part by those people seeking solutions to MPA placement for nature conservation objectives as opposed to meeting fisheries targets, Marxan can generate MPA scenarios that take account of fishing opportunities and whether these opportunities might be lost or gained by particular design configurations (Lynch, 2006; Richardson *et al.*, 2006).

One of the strengths of both Ecospace and Marxan is that they allow a range of MPA network scenarios to be explored and visualized so that the stakeholders may consider a variety of options. Within an EAF framework, strong engagement by stakeholders is critical to facilitating common agreement and finding workable solutions that are broadly acceptable to society. The interaction between GIS and MPA modelling tools also allows non-specialists to better understand the quality of the input data describing conservation features and human use of the sea, and where gaps in information exist. MPAs designed with broad agreement on the quality and coverage of data being used as input to Marxan and other MPA modelling tools potentially stand a much better chance of achieving broad acceptability (Smith *et al.*, 2009).

4.3.4 Fishing vessel movement and behaviour

To maintain or increase catch rates and respond to changing patterns of fish abundance, fishers adopt a variety of different strategies, such as exploiting alternate fishing grounds, modifying or switching their gear, or deploying their gear in a different way. Fishing behaviour is also influenced by the prevailing management regulations. When new regulations are introduced, fishing behaviour changes in an attempt to maintain high catch rates. One of the primary arguments against MPAs, which are designed to protect species within their boundaries by excluding certain fishing methods, usually bottom trawling, is that fishers will be forced to switch to alternative grounds (Hilborn *et al.*, 2004). Shifting fishing effort to new areas may assist recovery inside the MPA but it could also lead to a net degradation of the wider ecosystem if the newly exploited grounds were previously unexploited or only lightly exploited prior to the MPA's introduction. Understanding patterns of exploitation, fishing behaviour and the way behaviour is modified through the introduction of new fisheries management regulations is, therefore, critical to EAF implementation (Kaiser, 2005).

FIGURE 4.8
A map of the Irish Sea showing existing MPAs and new areas selected by Marxan software to meet nature conservation targets



Source: Reproduced with permission from Lieberknecht *et al.*, 2004.

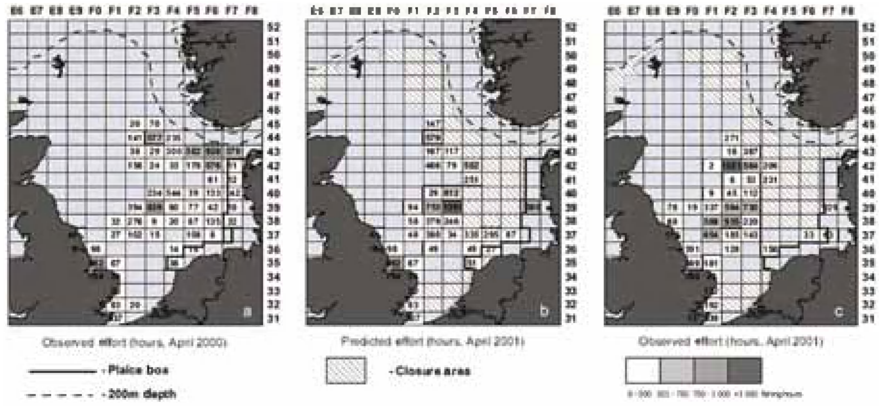
Note: MPAs are marked as "Locked in" on the map.

Understanding fishing vessel movement and behaviour and how these are modified as a result of newly introduced management actions, such as the creation of MPAs, lends itself to investigation within a GIS environment. At the simplest level, data from logbooks or VMS can be mapped and summarized both before and after the imposition of the regulation to observe whether exploitation patterns have been modified (e.g. Murawski *et al.*, 2005). This information can then be used to infer the behavioural changes that might occur if similar management measures were introduced elsewhere. If fishing is considered analogous to predator foraging, observed fishing patterns can also be compared alongside theoretical models of foraging behaviour to assess the degree of conformity. This might help to improve understanding of the processes driving fishers' behaviour and fishing location choice (e.g. Bertrand *et al.*, 2005).

Empirical models that summarize the economic imperatives of the fishery (i.e. maintain or increase catch rates) can also be instructive in explaining and predicting behavioural patterns (e.g. Hutton *et al.*, 2004; Figure 4.9). The real power of these models comes from their ability to predict the effects of management scenarios such as closed areas on ecosystem components other than the target stock. Hiddink *et al.* (2006a) provide an example of how this can be achieved by coupling an economic choice model describing the behaviour of beam trawlers to a model of the North Sea benthic community, one based on organism size.

FIGURE 4.9

An example of an empirical model that predicts change in a fleet's fishing effort as a result of area closure



Source: Reproduced with permission from Hutton *et al.*, 2004. © Crown copyright.

Note: (a) Distribution of fishing effort of English beam trawlers in the North Sea in April 2000. (b) Predicted distribution of effort in April 2001 as a result of the imposition of an areas closure and based on a model designed to estimate fleet dynamics. (c) Observed distribution of fishing effort for the same fleet in April 2001.

The Ecopath suite similarly allows exploration of management scenarios on fleet behaviour and subsequent effects on ecosystem components (Pauly *et al.*, 2000). Improving the spatial resolution of ecosystem models and integrating them into fishing movement and behaviour models, preferably within a GIS environment or at least capable of GIS integration, will be an important area for future model development.

4.4 MANAGEMENT IN EAF WITH GIS

Although fish populations and the fisheries that exploit them operate within geographical space, fisheries management information technology systems rarely make comprehensive use of GIS. This is unfortunate given the power of GIS to improve our understanding of spatial processes and interactions. The process of fisheries management does, however, make use of GIS albeit in a piecemeal way. All the issues highlighted above, from mapping fish distributions to modelling the effects of new management measures on ecosystem attributes, require the use of GIS or could benefit from them and can individually and collectively feed into EAF forms of management. GIS is unlikely to be used to perform stock assessments or as an environment to run ecosystem models, at least not in the short term. The outcomes of such models can nevertheless be more easily interpreted and, therefore, better understood by managers and non-scientists if viewed within a GIS environment alongside a more complete range of ecosystem attributes such as benthic biodiversity, water column productivity and pressures from human activities.

Multiple, competing uses for marine ecosystems and their services, and the impact of changing environmental drivers, require that ecosystem-based management and related spatial management measures be responsive and adaptive. Innovative GIS technologies and mapping are then required to address the a) status and variability of ecosystems, b) the spatial distribution of ecosystem services, c) the ecosystem vulnerability to environmental drivers and human use, and d) changes in human activities, and socio-economic and social features.

There are two areas where GIS will undoubtedly play an increasingly pivotal role: integrated marine management and planning, and fisheries monitoring and enforcement.

4.4.1 Integrated marine management and planning

Fisheries management systems in areas with a long history of commercial fishing can often be highly complex. Spatial regulations govern who can fish where, what gear can be used, what fish can be landed in what size range, what has to be thrown back and what other marine sectors (oil, gas, recreation, shipping) are also permitted to exploit in the same sea space. The spatial scales over which management regulations operate largely reflect jurisdictional boundaries and to a lesser extent reflect the scales over which the target resources are thought to occur. For implementation of EAF, management boundaries may need to be redefined, as matching the scale of management to the scale of the ecosystem components to be managed will be an important goal (FAO, 2003). Thus, while revised systems of fisheries management will continue to operate over multiple spatial scales, boundaries need to be more compatible with the ecosystem being managed. In a multiple-scale EAF framework, objectives will also need to be nested and compatible across scales (O'Boyle *et al.*, 2005a), and be matched by cross-scale linkages in fisheries governance (Degnbol and Wilson, 2008).

Reconciling these scale issues will require a greater emphasis on integrated marine management and planning, more so than there has been in the past. In many ways, EAF can be considered a subset of integrated management by dealing specifically with fisheries issues but being mindful of the wider need for full integration into the management of other sectors. Mature systems of fisheries management are already complex structures; integrated management will potentially make matters more complex. It is here that GIS can provide some benefits by helping to visualize, understand and reconcile scale issues. GIS cannot provide the answers, but being able to visualize a complex web of management boundaries, and the ecosystem components they are directed towards, can encourage dialogue and facilitate wider stakeholder participation in the planning process.

GIS can also bring benefits to proposed systems of integrated marine management based on zoning and spatial allocation. Under a zoning scheme, access to each zone would be actively managed in order to prohibit some activities while allowing other activities in such a way as to ensure that objectives for the entire zoned area were met (Halpern *et al.*, 2008b). For example, zones could be specified as extraction free, e.g. no-take for fisheries, aggregates, minerals, or could permit one or more of these activities if the impacts to the ecosystem components found within the zone were deemed acceptable and did not compromise objectives for the zone itself or for the wider zoned area. Within zones, extractive activities such as fishing could be further regulated based on the finer scale distribution of ecosystem components with specific sensitivities to different fishing gears (Jennings and Revill, 2007). In this type of scheme, a zone allocated for extractive use could be further subdivided into blocks, with access to individual or groups of blocks being regulated based on the habitat it contained and the degree of sensitivity to the various extractive methods it might be subject to.

Allocation of access rights to blocks within zones based on assessments of levels of impact has been the norm for the majority of offshore extractive industries (e.g. oil, gas and aggregates) for many years. The one exception is fishing[7]. Reconciling this management dichotomy will be critical to the success of EAF and is an area where GIS can bring real benefits. Only with the use of GIS can zone-block scenarios be visualized alongside the full range of human activities and ecosystem components that fall within the management scheme. Developing and testing zoning scenarios might be performed using more specialized software but the outputs visualized in GIS will encourage dialogue and discussion among a broader range of stakeholders on the acceptability of any proposed scheme.

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[7] In a limited number of countries or regions Territorial Use Rights in Fisheries (TURFs) are allocated among coastal fishers (Christy, 1982).

In order to develop a zoning plan, new information will be needed, and much of it will be spatially-structured. Key information requirements have already been highlighted in earlier sections. A source of information that will be particularly critical for EAF in the context of integrated management will be maps showing the distribution of current and past fishing activities, together with maps of fishing grounds considered to be important from the perspective of the operators. The location and distribution of fished areas and important grounds can be estimated using VMS but the estimation procedure is at best based on intelligent guesswork. In addition, locations are rarely associated with catch data and many fishing vessels are not subject to VMS monitoring. Fishers, therefore, need to engage more fully in the process of defining the importance of fished areas to ensure that they are on a more even footing with other extractive industries and conservation interests. In the absence of this information, fishers' interests could easily be compromised when attempting to resolve spatial conflict issues with other marine users (Degnbol and Wilson, 2008).

4.4.2 Monitoring and enforcement

Spatial fisheries regulations will need to be properly monitored and enforced to ensure that they become more than just paper exercises. Accurate monitoring will become even more critical if regulations impose tight restrictions on fishing practices, such as those regulations in the scenarios for integrated marine planning outlined in the subsection 4.4.1 above. Monitoring and enforcement could potentially benefit from greater use of GIS functionality if the monitoring system in place depends upon a rigorous programme of data collection.

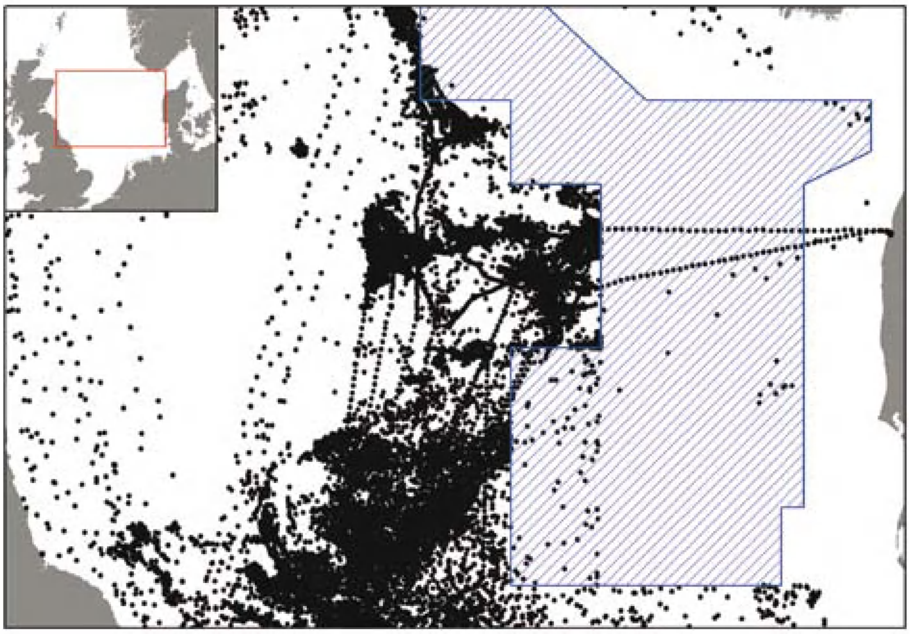
There are essentially three approaches to fisheries monitoring. The first approach relies on visual sightings via onboard observers on vessels or spotter planes. Sightings from both vessels and planes are a very expensive option, especially if good coverage of a wide sea region is needed, but efficiency can be improved through collaborative efforts with fishers as demonstrated in West Africa through the Sustainable Fisheries Livelihood programme launched by FAO in 1999[8].

The second approach is to use automatic position tracking via VMS (Figure 4.10). VMS are relatively expensive to install but cheap to operate and provide management authorities with the means to track movements relative to spatial regulations without the need for visual observations. There are, however, a number of inherent limitations to VMS, such as the trade-off between position frequency and cost (the more frequent the positions, the greater the cost), and lack of discrimination between fishing and non-fishing locations. For satellite-based fisheries enforcement to be effective, vessels would need to transmit their position at increasingly shorter time intervals as they approach boundaries and also relay shoot and haul positions via an electronic logbook (Kemp and Meaden, 2002). Sophisticated and semi-intelligent fisheries monitoring systems such as this seem unlikely in the short to medium term for a host of reasons (high costs, lack of compliance, misuse of systems), though they may be a necessity for fisheries enforcement under a tightly regulated zoning scheme.

The third approach is to encourage self-monitoring and enforcement by participants in the fishery, a lofty goal and one rarely practiced but nevertheless possibly the only solution to achieving effective fisheries monitoring and enforcement for many of the world's fisheries. Building trust and generating greater ownership are critical to success. For a system of self-regulation to be effective, fishers would probably benefit from the use of GIS as a mechanism to improve communication regarding the distribution of ecosystem features with which fishers would need to be concerned.

[8] For more details see http://www.fao.org/fishery/topic/14837/en

FIGURE 4.10
Satellite positions of United Kingdom trawlers in the North Sea during the 2001 cod box closure



Source: Reproduced from Eastwood *et al.*, 2008. © Crown copyright.

Note: Vessel activity is unknown, causing difficulties for enforcement of the closed area.

4.5 COMMUNICATION IN EAF WITH GIS

Fisheries operating under EAF principles will benefit from the use of GIS in at least one way: communication. Regardless of the amount of data available about the ecosystem and the fisheries operating within it, GIS can help improve understanding of ecosystem components and interactions among stakeholders by generating overviews that are relatively easy to comprehend. Maps convey more information than would be possible with other forms of data communication and complex information can also become more accessible to non-experts through the use of maps. In the increasingly sophisticated world of fisheries and marine ecosystem science, maps can help bridge the gap between science and management and bring about a greater understanding of marine ecosystems, processes and interactions.

EAF management in the developed world will be a data-hungry process. In advanced operating environments, GIS can bring benefits through the use of interconnected remote servers sharing geospatial data through open standards and transfer protocols, allowing marine and fisheries data suppliers to share their spatial data more easily both across and between organizations and with the public. As we move towards managing fisheries as part of wider ecosystems and develop operational systems of integrated marine planning and management, access to spatial data and an ability to visualize, run models and make decisions based on a complex array of multi-parameter information will be critical. GIS can play a central role in the production of digital maps developed from disparate data sources and in doing so will play a central role in communicating to stakeholders and building a shared understanding of the ecosystem and the issues that EAF will need to reconcile.

4.6 CONCLUSIONS

GIS can bring benefits to many aspects of EAF implementation, not least of which is improving the flow of information and levels of communications among diverse stakeholders. As a technology, GIS has attained a level of maturity and accessibility that places it within the reach of fisheries managers and scientists, even in relatively resource poor settings. The benefits that GIS can bring to EAF management processes, from simple mapping to sophisticated ecosystem modelling, suggest that the question should not be whether GIS has potential to aid with EAF but how it can best bring about benefits in country-, region- or fisheries-specific locations. Indeed, for seas bordering highly industrialized nations, it is highly unlikely that EAF implementation would proceed without the use of GIS technologies in one form or another.

This section has highlighted thematic areas in which GIS can interact with the EAF process by supporting efforts to map, model, manage and communicate relevant information on ecosystem properties and processes. These areas are not distinct partitions but in many ways are highly interrelated, as will be seen in Section 5, which shows via case studies that GIS is becoming central to the implementation of EAF. These studies tend to be focused in areas of well-established and highly commercialized and regulated fisheries. Therefore, in Section 6 the authors consider the steps that are needed to ensure that GIS reaches a much broader section of the global fisheries community and realizes its full potential.

5. Case studies to illustrate ways to integrate GIS into EAF

5.1 INTRODUCTION

It is impossible to state precisely when GIS was first used explicitly as a tool in EAF management or research. This is because the GIS, by its very nature, is a tool that is frequently employed for aggregating and analysing related data sets concerning a topic that must be spatially-referenced. This bringing together of data usually implies that various facets of the ecosystem are under investigation and, of course, the wider the variety of parameters that are being integrated, the closer the project will be to a holistic EAF study. It is likely that few specific applications of GIS for EAF implementation were undertaken prior to 2000 and, indeed, St. Martin (2004) charts the rise of EAF itself as occurring only during the mid- to late- 1990s. St. Martin also presents a strong rationale for GIS being the obvious platform on which to house any EAF study, certainly in view of the essential spatio-temporal variations, intervariations and intravariations that characterize different ecosystems.

In this section, the authors examine three case studies, each of which takes a different approach to the implementation of EAF. The case studies cover marine areas that are different in terms of their scale, their resource base and their range of economic activities. In combination, the case studies have documented some useful experience of the challenges of EAF implementation and can, therefore, be used to formulate sound advice for EAF practitioners. The case studies were selected because they describe in detail many of the numerous considerations of EAF, thereby making it possible to formulate recommendations on how GIS might aid the EAF process as well as offering a range of potential EAF implementation strategies.

5.2 ECOSYSTEM-BASED FISHERIES MANAGEMENT IN THE BENGUELA CURRENT LARGE MARINE ECOSYSTEM OF SOUTHERN AFRICA

The Benguela current along the coast of southwest Africa is linked to an intensive upwelling area where high nutrient flow ensures high marine productivity. Many fisheries operate along this coast and these fisheries, plus oil extraction, ensure that social and economic factors are of high value and significance. If resource extraction is to be sustained, then high productivity can only be achieved with careful ecosystems management. The importance of this has long been recognized and a sophisticated ecosystem-based science research programme has been in operation in the Benguela waters since the 1980s (Payne *et al.*, 1987). Since 1996, a programme of strong cooperation among the three national governments (Angola, Namibia and South Africa) seeks to improve the fisheries as well as to look at traditional facets of the fishery ecosystem, i.e. factors concerning direct marine productivity.

During the last decade, a programme led by FAO addressed the transboundary human impacts on the ecosystems, with a focus mainly on the fishery sector[9]. The FAO-coordinated work, reported in Cochrane *et al.* (2007), essentially "investigates the feasibility of using an ecosystems approach to fisheries management in the Benguela Current Large Marine Ecosystem (BCLME) region through examining the existing

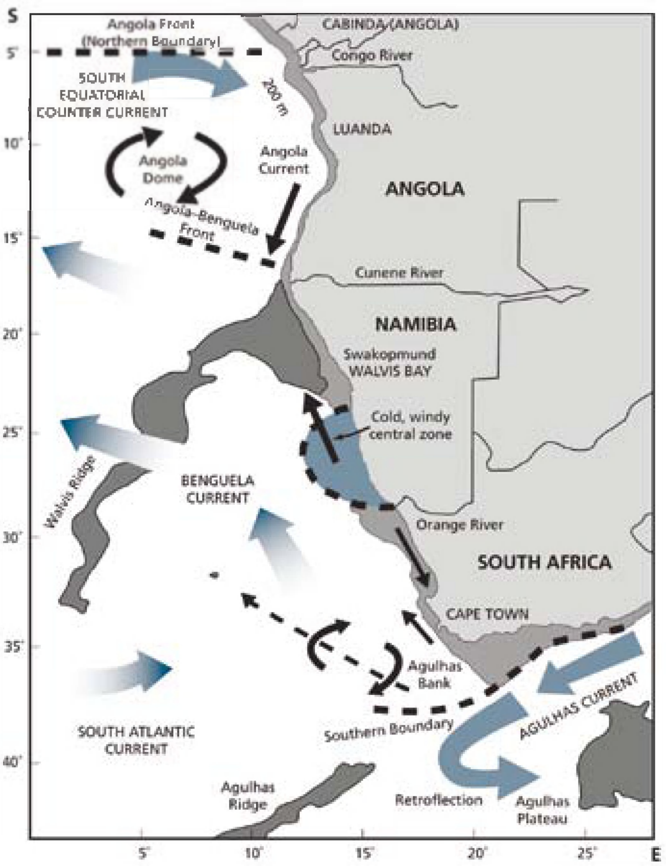
[9] Additional information available at www.bclme.org

issues, problems and needs related to EAF, and considering different management options to achieve sustainable management of the resources at an ecosystems level". The project, which was managed by various fisheries agencies with assistance from FAO, covered marine areas of South Africa, Namibia and Angola (see Figure 5.1) and took place from January 2004 to December 2006. Ten major fisheries in the three countries were examined. The project used a structured and participatory approach designed to engage the various stakeholders in identifying and prioritizing gaps in the existing approach to fisheries management and to generate potential management actions needed to address these gaps. The project also used cost-benefit analyses to evaluate the importance of each of the potential objectives and actions identified to improve the management of each fishery. There is no need here to detail all of the methods and approaches used in this lengthy study – this information can be obtained from Cochrane *et al.* (2007) and from Fletcher *et al.* (2002), whose work provided the basis for the current study. In this section, the authors intend only to identify thematic areas in which GIS could be used as part of the EAF process and they briefly describe the EAF process followed. It should also be acknowledged that the project as designed and implemented by FAO had no intention to explicitly utilize GIS to secure its aims.

At the outset, the project team agreed to adopt the FAO (2003) definition of the purpose of EAF (see Section 2.1) but noted that this definition was just one of several. They then noted that ideally an EAF should start from a holistic viewpoint in the sense that it should be implemented across all fisheries within an area. Because this would be a major and somewhat unrealistic task, an early decision was taken that EAF should be "implemented incrementally according to opportunities and crises". Hence, the major fisheries in the three countries were selected rather than all fisheries and included artisanal and subsistence fisheries.

Because the EAF being adopted was to take a "human" inputs viewpoint, the starting point for the EAF was for the stakeholders of the ten fisheries to identify perceived issues and problems in the various fisheries. Therefore, a series of workshops were held in each of the three countries. They were attended by stakeholders who included managers, decision-makers, fishing industry members, conservationists and scientists. The workshop participants generated a list of issues for each country and for each fishery. Between 150 and 200 issues were identified, although many of the issues were duplicated for different countries or fisheries. For each issue a "risk score"

FIGURE 5.1
The main physical features associated with the Benguela current system



Source: Reproduced with permission from Cochrane *et al.*, 2007.

(denoting perceived importance) was then derived by multiplying a "consequence" by a "likelihood", whereby consequence equates to the severity should the issue not be resolved and likelihood equates to the likelihood of the issue occurring. It is in the resolving and managing of these issues that GIS can best form an invaluable input to the EAF process.

Table 5.1 ranks 50 of the most important issues in which GIS could play an analytical part either directly or indirectly. Note that the "risk scores" shown are indicative only because of the variability in risk assigned to the different fisheries in the different countries. How each issue with regard to the EAF may be addressed by GIS in terms of mapping, modelling and/or managing is indicated. For some of the issues, the participants were not able to assign only one exact use for GIS, so for those issues more than one category is indicated. For many of the issues GIS would be of limited use in the absence of suitable data-gathering systems. In addition to the issues listed in Table 5.1, there were many issues that may have relevance but are beyond a more immediate EAF-GIS concern. These included economic, well-being and social issues concerning the fishery and its wider structure, plus a number of management and governance issues.

TABLE 5.1
The major EAF issues identified by stakeholders in ten different southern African fisheries that may be addressed by GIS

Issue	Indicative "risk" score	GIS mapping	GIS modelling	GIS managing
Impact of small-scale fisheries on inshore stocks	30	X	X	X
Stock status (variability and uncertainty of)	30	X	X	X
Size composition of the stock (average size of fish caught is declining)	30		X	X
Need to redevelop infrastructure (roads, bridges, etc.)	25	X	X	X
Fishing activity taking place in nearshore areas (impact on stocks and environment)	24			X
Utilization of high-value species for fishmeal	24	X		X
Impact of bottom trawl fishery on species abundance	24	X		X
Allocation of fishing rights (often seen as unfair)	24	X	X	X
Inadequacy of monitoring and control systems	24	X		X
The negative impact the hake fishery may be exerting on the sustainable use of monkfish	24	X	X	X
Decreased food availability for fish predators	24	X	X	X
Affect of short-term climatic anomalies, e.g. El Niño events	24		X	
Poor understanding of decadal-scale fluctuations in abundance of primary species	24		X	
Dependence of a large number of the families on small-scale or semi-industrial fisheries	20		X	
Lack of management plans for all species	20			X
Open access in small-scale fisheries (attracts too many entrants)	20			X
Improvement of communication among scientists, managers and industry representatives	20			X
The barrier represented by oil exploitation areas to the distribution of sardinella	20	X	X	X
Climate anomalies affecting recruitment (uncertainties surround this)	20		X	

TABLE 5.1 (cont)

Issue	Indicative "risk" score	GIS mapping	GIS modelling	GIS managing
Climate anomalies affecting fish availability (uncertainties surround this)	20	X	X	
Seasonal migrations, particularly of shared stocks	20	X	X	X
Impact of bottom trawling on bottom substrate	20	X	X	X
Lack of models and indicators for multispecies assessments	20		X	
Open-access nature of a small-scale fishery	20	X		X
Pollution resulting from oil exploitation activities	20	X	X	X
Variability in resource availability that makes planning difficult	18	X	X	X
Fishery statistics – variable status of data gathered	18	X	X	X
Removal of grazers, which leads to accumulation of plankton biomass and possibly to sulphur eruptions and low-oxygen events	16	X	X	X
Shared resource – could be between countries or fishing groups	16	X		X
The conflict between increasing oil exploitation and the development of industrial fisheries	16	X		X
Lack of distribution networks – transport and markets	16	X		X
Impact of the small-scale fishery on the horse mackerel fishery	15	X		X
Impact of the artisanal fishery on the sardinella fishery	15	X	X	X
Current high fishing mortality	15		X	X
Poor understanding of the knowledge of life history	15	X	X	
Low selectivity of the trawl fishery is affecting natural-size structure	15	X		X
Removal of biomass (especially top predators), which may alter the trophic structure and functioning of the ecosystem	15		X	X
The longline fishery is affecting natural-size structure by catching larger fish	12	X		X
Reduction or changes in geographical distribution of the species due to fishing activity	12	X	X	X
Lack of processing plants and job opportunities	12	X	X	X
Pressure on coastal ecosystems, e.g. destruction of mangroves	12	X	X	X
Lack of knowledge about round herring, gobies and chub mackerel	12		X	X
Amount of bycatch being taken (uncertainty surrounds this)	12		X	X
Overexploitation of demersal resources with a further decline expected if no management measures are taken	9		X	X
Conflicts between the small-scale and the industrial fisheries	9	X		X
Preference of inland communities for small, pelagic fish	8		X	
Changes in community structure (could refer to fish or human community)	8		X	
Biomass estimation methods are variable among countries and stocks	6	X	X	X
Licence allocation to purse seiners (not always seen as fair)	6	X		X
Impacts of factory and other effluents	5	X	X	

Source: Adapted from Cochrane *et. al*, 2007.

As can be noted from the table, many issues of relevance to EAF, such as dealing with shared stocks and improving fisheries data and statistics, and information on bycatch, should already have been addressed under a conventional fisheries management framework. Thus, theoretically, they should have received low risk scores, indicating they were of little concern, but as the table shows, in some cases they were considered important issues. Furthermore, this southern African study very clearly showed considerable concern for wider ecosystem issues such as interactions between fish species, disturbance of trophic structures, pollution and impacts of fishing on the other ecosystem components.

Another important finding showed the relationship between the state of the stocks and type of issue mentioned. Thus, the fisheries that were overexploited had concerns (issues) that were overwhelmingly related to social, economic, management and governance matters, and it is with these matters that arguably GIS is the least able to be of help. The implication of this is that the lack of a well-managed fishery is likely to shift the balance of concern from the fishery itself towards more general societal issues. Overall, approximately 45 percent of all issues raised by the ten fisheries examined would lend themselves to analyses by GIS, these issues for the most part being more directly fishery-related. Given the implication that a poor fishery leads to strong socio-economic concerns, a good case can be made for adopting GIS within an EAF as a means of initially preventing problems from arising in the fishery industry.

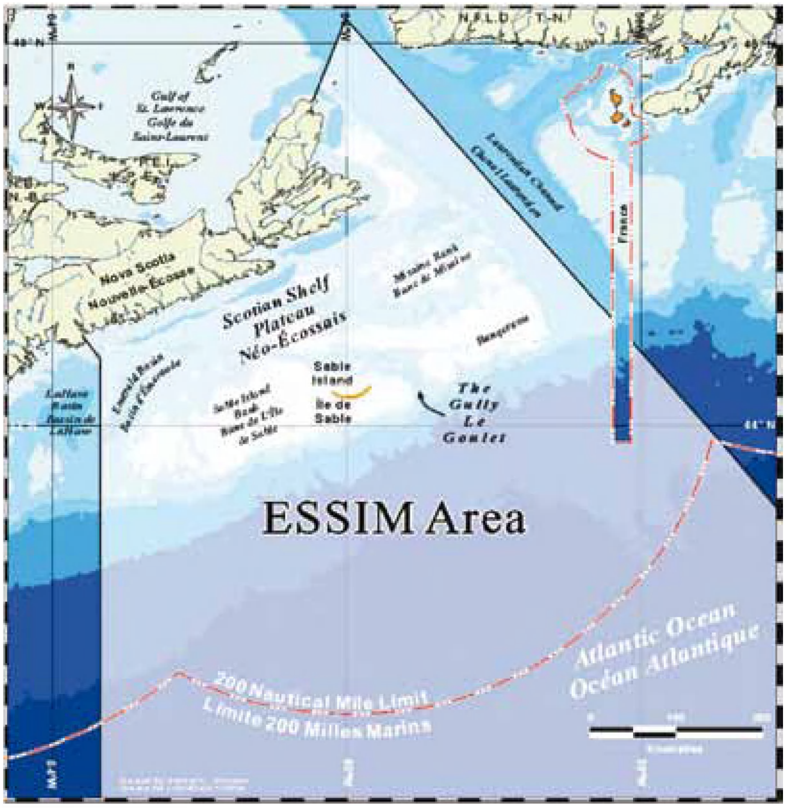
The activities that concluded this EAF study were as follows. Workshop participants prepared a "Performance Report" that contained the issues that the participants had ranked as high priority on the basis of the risk scores together with the potential management responses (measures) designed to reduce the high risks. Because the workshops had been so important in identifying issues, establishing risks and agreeing management responses, as articulated in the performance report, Cochrane *et al.* (2007) stressed the importance of good stakeholder representation as the basis for fisheries management under EAF.

Once the management responses had been agreed for each fishery, a benefit-cost analysis was undertaken during a separate workshop to establish the relative advantage of each management measure identified in the performance report. Scores were allocated on a scale of 0–4 to each management measure. Scores could be positive or negative according to the broad objectives of the fishery and two sets of scores were obtained, i.e. one for short-term objectives and one for long-term objectives. The benefit-cost results for all of the ten southern African fisheries studied are contained in the report of Cochrane *et al.* (2007). Interestingly, the report noted that many of the short-term benefit-cost ratios were negative to the extent that if the management measures were to be implemented, socio-economic hardships to the fishery community would result. In contrast, the long-term benefit-cost ratios were overwhelmingly positive. The short-term negativity would create a substantial problem for policy or decision-makers and strategies will need to be developed to mitigate any undesirable consequences. The report also stressed that all fisheries should be included in the benefit-cost analyses (and indeed the whole EAF procedure) and that all issues should be considered, not just the high priority ones dealt with at the workshop. Overall, it noted that "the benefit-cost analysis process was found to be very informative and an important step in the implementation of EAF" and that the EAF "is far preferable to the fragmented and reactive approach to addressing problems that typifies fisheries management decisions around the world at present".

5.3 THE EASTERN SCOTIAN SHELF INTEGRATED OCEAN MANAGEMENT PLAN IN CANADIAN ATLANTIC WATERS

The Eastern Scotian Shelf Integrated Ocean Management Plan (ESSIM) is a recent initiative of the Canadian federal government and is designed to generate a multiyear, strategic-level plan to provide long-term direction and commitment for integrated, ecosystem-based and adaptive management of all marine activities in or affecting

FIGURE 5.2
The Eastern Scotian Shelf management area



Source: Reproduced from O'Boyle, Sinclair, *et al.*, 2005.

the waters of the Eastern Scotian Shelf (ESSIM, 2005). The ESSIM area, covering 325 000 km^2, lies in a broad arc to the south and east of the northern part of Nova Scotia (Figure 5.2). The management area stretches seawards to the limit of the Canadian exclusive economic zone (EEZ). Because this plan is very much a first for Canada and because management problems faced in the offshore area are very different from the problems of the inshore zone, at present the ESSIM project is concentrated almost exclusively on offshore waters beyond the 12 mile territorial sea limit. At a later stage, complementary plans for the inshore zone will be developed in conjunction with the province of Nova Scotia and other interests. The ESSIM (2005) document outlines the characteristics of the marine environment and of the human uses for this area and much useful documentation regarding this eastern Scotian shelf management scheme[10] is available on the Internet.

The ESSIM Plan focuses on the management needs and priorities related to multiple ocean use, ecosystem management, and conservation and collaborative planning. These issues are broader than the issues relating to fisheries management alone but the same principles apply. Thus, EAF can be considered a subset of the ecosystem-approach (EA) for multiple-use marine planning, as encapsulated by ESSIM. For example, with regards to stakeholder engagement, "the [ESSIM] Plan is being developed through a collaborative and inclusive planning process involving all interested and affected government departments, sector groups and individuals", the goal being to develop a plan that is accepted by all interested parties. The EAF has similar goals. In the case of ESSIM, interested parties comprise the following institutional components: (a) an ESSIM Forum; (b) a stakeholder roundtable; (c) a government sector structure; and (d) a planning office. The whole ESSIM Plan is enshrined in a vision statement and guiding principles. It provides an objectives-based approach to ocean management, setting out long-term, overarching ecosystem and human-use objectives to support agreed outcomes for environmental, social, economic and institutional sustainability in the ESSIM area.

The overarching objectives are:

- to integrate the management of all measures and activities in or affecting the planning area;

[10] See www.dfo-mpo.gc.ca/Library/286215.pdf

- to manage for conservation, sustainability and responsible use of ocean space and marine resources;
- to restore and/or maintain natural biological diversity and productivity; and
- to contribute to social, cultural and economic well-being of stakeholders and coastal communities.

A recent study (Charles *et al.,* 2009) provides invaluable background to the problems in the ESSIM area and concentrates particularly on the social and economic factors involved, offering indicators that can and should be monitored and applied on a regular basis to evaluate the well-being and sustainability of fisheries and the marine environment.[11]

High-level objectives are supported by operational objectives for which specific indicators and targets can be set. The plan also provides an area-based approach whereby planning, management and decision-making for multiple human use and ecosystems conservation can be undertaken at appropriate spatial scales. The whole plan has to be carefully integrated into existing management plans, jurisdictions, responsibilities and objectives, and the plan itself is embedded in recently enacted federal legislation, i.e. the Oceans Act, 1996. A series of Action Plans will be developed for two- to three-year periods as part of the implementation process. As the planning process evolves, monitoring and performance measuring mechanisms will be established to enable regular evaluation and reporting on the plan's objectives. It should be mentioned here that, as with the case study reported in Section 5.2 above, this plan contains no specific reference to the use of GIS.

The authors use the plan objectives as the basis for illustrating where GIS can fit into an EA to management. Table 5.2 lists the objectives, and again they are categorized as relative to mapping, modelling or management in the GIS context. As with the Benguela EAF programme, it can be seen with ESSIM that there is a far greater potential to use GIS to meet objectives relating to more direct fishery ecosystem issues and that GIS is of particular relevance to matters relating to basic mapping and modelling.

The ESSIM Plan specifically mentions that GIS has already been used to create an atlas showing the extent and location of the major human activities in the area, including various management zones (ESSIM, 2005). The atlas will soon be extended to cover the mapping of ecological components. Data sets contributing to the atlas will form the basis of a spatio-temporal framework to assess risks associated with human activities, including ecosystem impacts and sector activity interactions. Figure 5.3 illustrates the type of detailed mapping data that is available for this location (from O'Boyle *et al.*, 2005b). It is important to note that the ESSIM Plan discusses the types of marine planning work that will be possible and describes the tools that will be available to pursue the project objectives. The ESSIM Plan concludes with a consideration of the various management strategies and potential actions available, allocating lead authorities and time lines for this as well as looking at project implementation and review procedures.

5.4 CHANNEL HABITAT ATLAS FOR RESOURCE MANAGEMENT (CHARM) IN THE EASTERN ENGLISH CHANNEL

The English Channel, the stretch of water separating France from England, is one of the world's busiest shipping lanes. The waters of the channel also support locally important fisheries, are an important source of aggregates, provide numerous leisure and tourist facilities, and are crossed daily by numerous passenger ferries. Because of the potential for resource conflict, efforts began in the late 1990s to consider options for resource utilization in a limited transboundary geographic zone. Following the success of this project, in 2003 the European Union agreed to fund a similar but larger project called CHARM, covering the eastern quarter of the English Channel (Figure 5.4).

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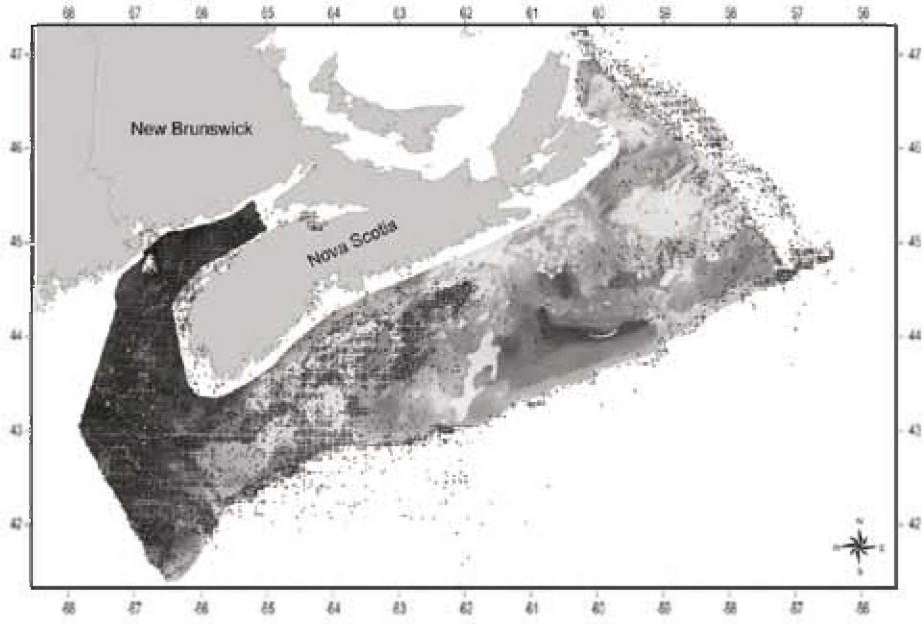
[11] See www.gpiatlantic.org/pdf/fisheries/fisheries_2008.pdf for the Charles *et al.* (2009) study.

TABLE 5.2
Objectives to which an EA might aspire for the eastern Scotian Shelf area and which have the potential for GIS-based mapping or analyses

Issue	Objective	GIS mapping	GIS modelling	GIS management
Important benthic communities	Identify and protect important benthic communities, e.g. unique, diverse or productive	X	X	X
Sensitive benthic communities	Identify and protect coral and other sensitive communities	X	X	X
Important pelagic communities	Identify and protect important pelagic communities	X	X	X
Sensitive pelagic communities	Identify and protect sensitive pelagic communities	X	X	X
Conservation of communities	Maintain/restore identified pelagic, benthic and demersal communities or assemblages	X	X	X
Conservation of communities	Maintain/restore identified seabird communities or assemblages	X	X	X
Commercially harvested species	Maintain/restore species, populations and productivity	X	X	X
Endangered species	Protect and rebuild species stocks	X	X	X
Ecosystem structure and function	Maintain/restore bycatch of non-target species within acceptable limits		X	X
Invasive species	Limit and monitor invasive species	X		X
Ecosystem resilience	Maintain/restore genetic diversity		X	
Ecosystem structure and function	Monitor the base of the food chain to detect changes that may affect other ecosystem components	X	X	
Ecosystem structure and function	Monitor environmental conditions that may influence productivity at the base of the food chain	X	X	
Trophic structure	Preserve trophic structure, including forage species for higher-level predators		X	X
Trophic structure	Preserve traditional role of top predators		X	X
Diversity of habitats	Identify and protect rare habitats	X	X	X
Bottom habitat	Maintain/restore physical characteristics of sediments that are conducive to resident biological populations	X	X	X
Processes in sediments	Maintain/restore geochemical conditions necessary for functioning of resident community	X	X	
Toxic chemical contamination	Maintain concentrations of toxic chemicals below levels harmful to local biota	X	X	
Eutrophication	Maintain/restore oxygen levels sufficient for productive biota growth	X	X	
Water column	Maintain/restore the chemical quality of the waterbody	X	X	
Non-biodegradable debris	Maintain amounts of solid wastes within acceptable limits	X		X
Health of resident biota	Maintain/restore marine environmental quality conducive to healthy biota	X	X	
Contaminant levels in fish	Prevent chemical or biological contamination of species for human consumption	X		
Community well-being	Ensure access by local people to sustainable livelihood opportunities derived from the sea	X		X
Community well-being	Enhance ocean-related services and infrastructure	X	X	
Economic well-being	Generate wealth from the ocean by fostering new opportunities and enhancing existing opportunities	X	X	
Economic well-being	Ensure efficiency of resource use and open space		X	
Industrial capacity and assets	Balance multisectoral use on the Scotian Shelf and reduce resource use conflict	X	X	X
Industrial capacity and assets	Promote stewardship and best practices		X	
Integrated management processes	Ensure policies, plans, programmes and measures are applicable to ocean users	X		X
Integrated management processes	Promote adaptive management in response to change			X

Source: Adapted from ESSIM, 2005.

FIGURE 5.3
An example of the type of mapping data available to the ESSIM Plan



Source: O'Boyle, Sinclair, *et al.*, 2005.

Note: Dots indicate location of bottom trawling during 1999–2003. Base map shows benthic community sensitivity where white equals most sensitive and black equals least sensitive.

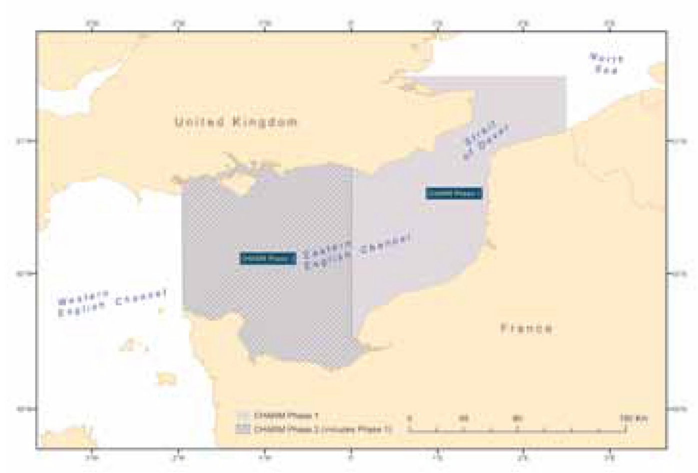
This project resulted in the production of a hardcopy resource atlas of the area (Carpentier *et al.*, 2005). The project involved small teams of researchers from seven institutions (academic and research) located on both sides of the English Channel. Although fisheries were at the core of the project, the study included numerous other important ecosystem properties, both physical and biological, within the water column and the sea bed. In so doing, the project moved towards some core facets of EAF and GIS was used extensively for mapping and modelling[12].

Following Phase 1 of CHARM, Phase 2 was initiated in 2006 and completed in September 2008. This phase had a similar partnership but substantially increased funding, allowing a broader range of work to be accomplished, and the project itself looked at the whole of the eastern English Channel (Figure 5.4). The objectives of CHARM Phase 2 were to develop an integrated system of marine management for the evaluation of living resources and to identify important species habitats in the eastern English Channel. Figure 5.5 provides an illustration from Charm Phase 2 and shows how the surveyed distribution of a species (executed by the IFREMER Channel Ground Fish Survey [CGFS]) compares with outputs from predictive habitat modelling for that same species. Information from CHARM Phase 1 was integrated into additional Charm Phase 2 data so as to create ecosystem and conservation planning models for the wider area. In the Charm Phase 2 project, a wider variety of species were examined and many more stakeholders were involved.

To assess the project in the context of EAF, it is valuable to highlight the specific actions that were undertaken – these are listed in Box 5.1. It can be seen that the CHARM Phase 2 project is less wide ranging than the previous two case studies in that it maintains a focus on fish and their habitats and tends to ignore wider social and economic

[12] Additional information available at http://charm.canterbury.ac.uk and at www.ifremer.fr/charm

FIGURE 5.4
The areas covered by Phase 1 and Phase 2 of the CHARM project

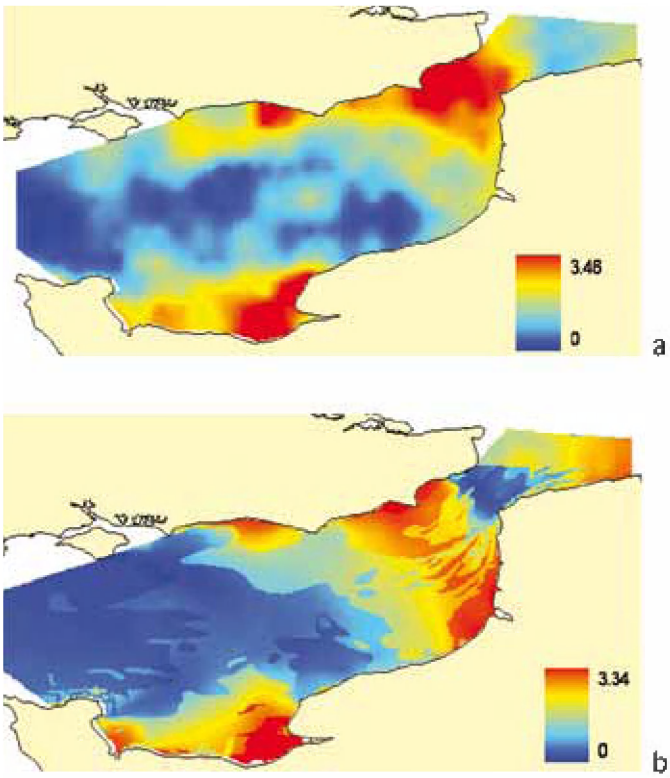


Source: Carpentier *et al.*, 2005.

considerations. However, unlike the other case studies, the CHARM project had a definite intention to utilize GIS as the platform for all of its mapping and for most of the modelling[13].

The CHARM project benefited from access to both substantial bodies of data for the study area and to a strong team of specialists in habitat modelling, spatial geostatistics, conservation modelling, and web development. However, the approach adopted by the CHARM team was not

FIGURE 5.5
A comparison of survey data and habitat modelling output for the Callionymidae family in the eastern English Channel from the CHARM Phase 2 project



Source: The IFREMER Channel Ground Fish Survey (CGFS).

Note: (a) Mean spatial distribution (number per km2) of fish, 1988 to 2006 (October, CGFS). (b) Preferred habitats (modelled using Generalized Linear Models (GLMs)) for fish, e.g. reticulate dragonet, 1988 to 2006 (October, CGFS). Significant predicators: bed shear stress, salinity, temperature, sea-bed sediment type.

[13] Examples of the GIS output can be seen at http://charm.canterbury.ac.uk and www.ifremer.fr/charm

BOX 5.1

The main actions undertaken as part of the CHARM Phase 2 project

- Develop fish species distribution maps for input to ecosystem modelling and management planning (under actions 5 and 6).
- Develop a sea bed habitat map using the best available data.
- Gather primary data from local fishing communities to be used as inputs to models developed under actions 5 and 6.
- Complete a bilingual comparison of French and United Kingdom policies in the context of marine resource management.
- Develop a model of the eastern English Channel ecosystem functioning using mass-balance food-web models (Ecopath with Ecosim) and habitat models developed under action 1 (Ecospace) in order to evaluate management scenarios driven by inputs from stakeholders.
- Develop a conservation planning system for the eastern English Channel based on the Marxan spatial planning software.
- Use the outputs from the atlas and modelled scenarios in Ecopath and Marxan to develop a draft management strategy that can be reviewed by stakeholders.
- Deliver all outputs through an interactive atlas on the project's Web site.
- Produce the final report.

without problems or challenges. The problems can be basically summarized as the following:

- Data was not available for all ecosystem components and collection of needed data would have been beyond the funding possibilities of the project.
- Most of the biological resource data represented only a snapshot in time – this would give it very poor statistical validity under most testing regimes.
- Allied to the above, it was sometimes difficult to establish an optimum resolution at which to work.
- Different aspects of the ecosystem function at different spatial and temporal scales greatly influenced data collection and analysis strategies.
- The approach adopted by the project team could be considered as top down. Thus, although stakeholders were involved, their participation was minimal. Most decisions and actions were based on the project team's perceptions of what might be desirable aims for an optimum functioning marine ecosystem in the English Channel area.
- It was difficult to establish the most appropriate thematic areas (and boundaries to these areas) to be covered. All research projects are resource and time limited so inevitably some important aspects of the total ecosystems cannot be included.

Based on the experience gained from CHARM Phase 2, a Phase 3 will commence in late 2009. It is intended that this phase will take the project further towards a full EAF implementation. It is also clear that opportunities are many for the integration of GIS into most facets of EAF work. Box 5.2 sets out the main objectives for this new phase of the project.

5.5 CONCLUSIONS

The three case studies provide an assessment of potential uses of GIS in the EAF adoption process. Undoubtedly, had the authors looked at further studies, other uses for GIS would have been found. Both Boxes 5.1 and 5.2, and more especially the actual texts of Cochrane *et al.* (2007) and ESSIM (2005), show that ecological issues are predominant in the EAF analysis and planning in these case studies. However, there

BOX 5.2
The main tasks and objectives for a proposed Phase 3 of the CHARM project

- Include also the western English Channel (doubles the project area).
- Carry out a detailed data review and inventory.
- Incorporate plankton to space/time mapping and modelling.
- Better identify fish spawning areas.
- Better identify the role of benthic organisms in the English Channel.
- Classify marine habitats using European Union habitat directives.
- Set up a "fisheries exploitation" database.
- Identify the "fisheries culture" (the place and impact of fishing in coastal areas).
- Carry out further habitat and trophic network modelling (for the whole of the English Channel area).
- Analyse socio-economic changes in the fishery scene.
- Reinforce collaboration between fishery ecologists and economists to advance development of an EAF.
- Explore the prospects for the diversification of marine activities.
- Explore the impacts of climate change on the English Channel.
- Provide necessary inputs to conservation planning.
- Develop GIS interface tools for better geospatial modelling.

is reason to believe that this is not a general characteristic of EAF and that in other situations (e.g. small-scale fisheries) the human dimensions of the fishery system and relative issues may be predominant. GIS is expected to be of use in both situations.

As a contribution towards the process of linking GIS with EAF, FAO compiled two databases, which will eventually form part of the GISFish Internet site[14]. The first database provides a list of papers which address spatial aspects of EAF and the second database provides a list of Web sites containing information on the uses of GIS and spatial analyses in the EAF. In Table 5.3 below, the papers are categorized by the EAF application area addressed, e.g. biodiversity, and by the main GIS role discussed, i.e. "mapping", "modelling", "management" and "communications" (refer Section 4).

The table shows that the various categories of publications devoted to the use of GIS for EAF are remarkably well distributed among mapping, modelling, management and communication, indicating that within the context of these roles a broad range of issues are currently being addressed. The 52 papers in the "Communications" category convey in a more general sense the linkage between EAF and GIS. This area is very well represented in the literature. However, many important areas such as "Mapping the impact of fisheries", "Mapping catch and effort distributions" and "Modelling of spatial stock assessment" are receiving very little attention. As mentioned earlier in this section, GIS applications for EAF are rarely shown to address wider social and economic issues but this may be a reflection on the process used to select the 214 papers for inclusion in the FAO database. For instance, the search for these papers was conducted using the Aquatic Sciences and Fisheries Abstracts (ASFA)[15] bibliographic database and perhaps this database itself is not being furnished with a wide enough array of papers to account for the holistic EAF approach as perceived by Cochrane *et al.* (2007).

[14] See www.fao.org/fishery/gisfish/index.jsp
[15] See www.fao.org/fishery/asfa for additional information.

TABLE 5.3
Categories of GIS publications relating to EAF

Main GIS role	Main EAF application area addressed	No. of papers
Mapping	Impact of fisheries	2
Mapping	Catch and effort distributions	1
Mapping	Ecosystems or ecoregions	19
Mapping	Biodiversity	4
Mapping	Habitats	6
Mapping	Species distributions	7
Mapping	Management regulations	1
Mapping	Multispecies analysis	9
Mapping	Social and/or economic impact studies	1
Mapping	Indicators	13
Modelling	MPA (design, implementation, monitoring)	21
Modelling	Ecosystem modelling	26
Modelling	Spatial stock assessment	4
Management	Integrated marine management and planning	32
Management	Fisheries management systems	15
Management	Fisheries development	1
Communications	Principles, practices, case studies and issues which constitute the foundation for EAF	52
Total papers		**214**

Source: www.fao.org/fishery/gisfish/index.jsp)

6. Implementing GIS for EAF

6.1 INTRODUCTION AND UNDERLYING ASSUMPTIONS

The previous sections have provided information on EAF principles for implementation (Section 2), the history and use of GIS in marine fisheries (Section 3), the opportunities for GIS to support EAF implementation (Section 4), and case studies describing the practical use of GIS for EAF (Section 5). In this section, the authors outline some of the underlying assumptions regarding GIS implementation. They then refer back to the EAF implementation framework recommended by FAO as set out in Section 2 and consider the degree to which GIS can provide explicit input to the process. In doing so, they highlight the areas where GIS can presently provide support and information to fill gaps that exist. They provide detailed suggestions for building GIS capacity as it relates to EAF and finally discuss the challenges to the use of GIS to support EAF implementation.

In many ways the considerations required for implementation of a GIS to aid EAF will not be different from considerations required for the implementation of any GIS. There is plenty of literature and web-based information to advise on the latter (e.g. Lo and Yeung, 2002; Longley *et al.*, 2005; Wright *et al.*, 2007, Yeung and Brent Hall, 2007)[16]. In this section, the authors are concerned not with GIS implementation *per se*, i.e. the practical considerations and procedures for physically acquiring the system, but with the general concepts pertaining to GIS and to its links with EAF. They assume that the reader is familiar with at least some of the basic functioning of GIS for EAF. Their assumptions about the readers' familiarity with GIS appear in Box 6.1.

It is important to highlight the above because the implementation of a GIS is not easily carried out and requires preliminary preparation. A GIS can be a very complex system, one that involves many technologies and working skills and can be capital intensive. Having said this, it would still be possible to implement a GIS specifically for EAF work without prior basic preparation but the learning curve would be long and there may be added preliminary considerations concerning the system's requirements and feasibility. However, the output from the system may be extremely significant in terms of perpetuating fisheries, ecosystems and biodiversity, and, of course, maintaining a socio-economic milieu that is dependent upon the resources being exploited. All of the preparations listed in Box 6.1 are vital to the success of GIS implementation. Further discussion on this point is outside the scope of this paper.

6.2 THE SCOPE OF GIS AND USER REQUIREMENTS

In this section, discussion is concerned with elements of the "S" in GIS. A GIS will only function well if the system is fit for its purpose so it is imperative that careful consideration be given to what the system will actually do and how the whole system will be established. For instance, an individual or small organization can undertake GIS projects using a single desktop IT system. Undoubtedly, much fisheries GIS work has been very successfully performed at this operating scale or at a slightly larger scale,

[16] See also Web sites at www.gis.com/implementing_gis/index.html and www.innovativegis.com/basis/primer/implissues.html

BOX 6.1

The assumptions underlying the discussion on implementation of GIS for EAF

- There exists an appreciation of the need for EAF and its processes, including scoping and identification of objectives.
- There exists an appropriate group or institution in charge of the implementation of GIS for EAF. Thus, it is important that one organization have the capacity to deal with the complexity of collating, storing and analysing data on the spatial components of an ecosystem.
- There is some familiarity with the basic purpose and functioning of a GIS.
- The operational and management environment, and the system's procurement procedures have been dealt with.
- A GIS will function in an IT work environment equipped with the requisite skills, where innovation thrives and where the system's operating requirements and its limitations are recognized and appreciated.
- Fisheries lie at the core of the GIS for EAF, even when the GIS is interoperable with, for instance, a GIS developed as part of "an ecosystems approach to shipping" or a GIS being used by an aggregate company to monitor its environmental impact.
- There is recognition that the benefits gained through the use of GIS are likely to outweigh the costs involved.
- Some aspects of the GIS design such as user identification, networking arrangements and hardware requirements may already have been determined.
- Procedures are in place for maintaining, upgrading and servicing the data and the GIS-based system itself.
- The various stakeholders (those having common or competing interests) may for the most part have been identified.

whereby numerous computers may be integrated into a Local Area Network (LAN). However, in this era of EAF, working entirely at a local scale is unlikely to be sufficient or successful. Furthermore, because EAF will often entail collaboration at the cross-sectoral level, consideration should be given to developing the GIS as a utility to be shared among the relevant institutions or departments. In this section, the authors highlight some of the main considerations required for operating GIS in both the much broader functional IT environment and the wider environmental, social, economic and political spheres that the EAF will demand.

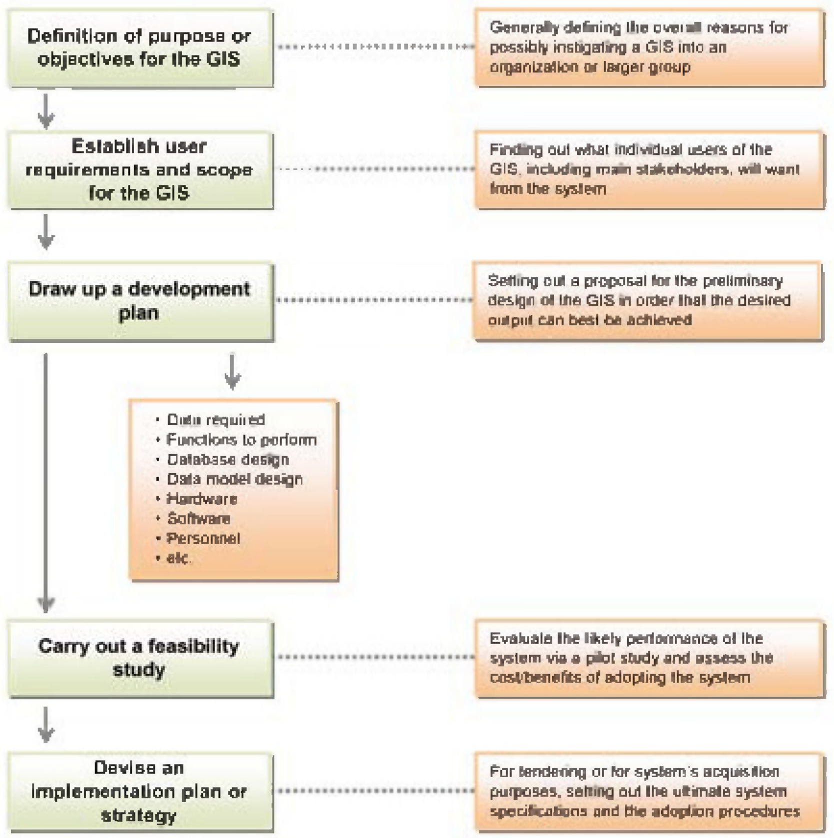
Figure 6.1 shows the steps in the design of a typical GIS. In the literature, there are many variations on this system development model. Further details of system design are given in Tomlinson (2007) and Peters (2008)[17]. The first two steps of the system development process are examined in this section. Detailed information on the third step of the process, i.e. drawing up a development plan, including important capacity-building activities, is contained in the following section (Section 6.3).

6.2.1 The objectives and scope of GIS in support of the EAF implementation framework

The combined first two steps in GIS development, i.e. defining objectives of the GIS and establishing the scope for the GIS, are discussed in relation to the four steps in the

[17] For users who are interested in a more detailed and holistic approach to determining ways to successfully apply GIS to solve problems or create new opportunities and services in an organization, the Return on Investment (ROI) methodology provides an achievable, fact-based and benefits-focused approach to quantifying return on investment. The methodology enables potential GIS users to gain backing and build consensus among organization stakeholders, while educating and preparing them for change. For additional information see http://roi.esri.com/index.cfm.

FIGURE 6.1
Steps in the development of a typical GIS and GIS implementation strategy



Source: The authors.

EAF implementation framework as set out in Section 2 (refer Figure 2.1), namely:

- scoping
- setting operation objectives
- formulating actions and rules
- establishing a monitoring, assessment and review system

Each step of the EAF framework in turn is considered in terms of the ability of GIS ability to provide support for each step of the EAF implementation framewave is considered, drawing on information provided in section 3 to 5. Table 6.1 provides a summary of the linkages between specific indicators and operational objectives in the EAF implementation framework and the role of GIS.

EAF implementation framework Step 1: Scoping

Mapping ecosystem components and interactions

The initial step in the implementation framework involves the definition of a management area based on the geographic scope of the fisheries, the ecosystem within which they reside and all key interactions with stakeholders and resource users. Understanding the extent of all these elements and how they interact will require access to much geographic information, provision of which a GIS has an obvious role. As described in earlier sections, a GIS is well suited to mapping a range of ecosystem properties and human interactions including: existing management regulations; target and non-target resources, both living and non-living; sea-bed habitats and features of conservation value, and other ecosystem properties of value; and human pressures and activities. Identifying the features to be mapped will require dialogue among the various stakeholders. Feature identification will likely be an iterative process, with an initial set of maps being generated on the basis of stakeholder input, followed by further refinement or enhancement on the basis of follow-up discussions.

Modelling to predict ecosystem components and interactions
Direct observations will rarely be possible for all features of interest, such as the distribution of target and non-target resources, so some features will need to be inferred through modelling and prediction. For many developing countries, access to data will be further reduced and models may be unsuitable for accurate prediction. In these cases, expert judgement could be used. Indeed, expert judgement will be essential in the mapping of ecosystem features and properties, regardless of the level and quality of available data and model predictions.

Mapping management regulations
Management regulations, where they exist, will almost certainly contain sufficient geographic information to allow them to be mapped. Generation of digital maps of all the management regulations currently in operation is an activity in which all countries can in principle engage, regardless of their current developmental status.

GIS support to EAF implementation framework Step 1: Scoping
Key areas where GIS could presently support Step 1 (scoping) of the EAF implementation framework can be summarized as follows:

- through online services, improving access to existing information and data on ecosystem properties, both human and ecological, and the ways they interact;
- generating digital maps of target and non-target resources, key ecosystem properties and features of conservation interest, and human pressures and activities, using direct observations, model predictions or expert knowledge;
- generating digital maps of all management regulations operating within the ecosystem;
- visualizing ecosystem regulations and properties in order to stimulate discussion with stakeholders over the scope and definition of the management area; and
- managing spatially-structured data of relevance to the EAF management area.

The role for GIS in support of Step 1 will be played largely through its capability to generate mapping output as an aid to decision-making, with maps perhaps being derived from integrated data emanating from disparate sources.

EAF implementation framework Step 2: Setting operational objectives

Mapping to visualize ecosystem components and interactions being addressed by objectives and to measure rates of change in ecosystem features being managed
Setting broad and specific objectives for fisheries falling within the scope of the management plan will not necessarily require the explicit use of GIS aside from the obvious benefits that digitally created maps bring to the understanding of ecosystem properties and the way they interact. Objectives will need to be developed from the best available information and have practical relevance to the fisheries they are designed to manage. They must, therefore, be expressed in a way that managers and stakeholders can understand, and here GIS may be able to offer support by generating visual descriptions of the properties that the objectives are trying to address. For example, the Eastern Scotian Shelf Integrated Ocean Management Plan (ESSIM) described in Section 5.3 included objectives relating to the preservation of sensitive habitats. The next step is to develop a quantifiable and measurable set of indicators, such as the spatial extent of the feature to be conserved. In this example, digital spatial data will be needed to

monitor rates of change in the extent of the feature within the given management area and when mapped can be used to understand interactions with human pressures and how these change following management interventions. Management rules can, therefore, be adjusted in an adaptive manner as new information is generated.

Mapping and modelling to construct indicators
The role of GIS in constructing indicators and, in particular, in establishing the link between pressure and state indicators is currently very much a research activity. As the volumes of ecosystem data grow and models of ecosystem processes become more spatially explicit, indicators are expected to become more spatially resolved. Given the expense of collecting the necessary data for indicators of ecosystem state, it is likely that in the short- to medium-term, managers will have to rely more heavily on human pressure indicators as these can be measured more easily and cheaply. GIS can help in the construction of human pressure indicators by using a range of mapping and modelling techniques and can also help to better understand the ways in which human pressures interact by estimating cumulative pressures from multiple sources as described in Section 4.2.

Using an example presented in the FAO guidelines (2003), which compares potential objectives with example indicators and data requirements (Table 6.1), the authors consider how the analysis of spatial components and the effective use of GIS can play a role in improving our knowledge of the underlying processes within the ecosystem and can assist in the decision-making process for the implementation of an EAF.

GIS support to EAF implementation framework Step 2: Scoping
Key areas where GIS could presently support Step 2 of the EAF implementation framework can be summarized as follows:

- visualizing ecosystem properties to improve understanding by managers and non-technical stakeholders in order to facilitate discussions over the development of realistic and practical objectives and supporting indictors;
- constructing and visualizing spatially explicit indicators; and
- visualizing the outcomes of spatially explicit models that describe interactions between pressure and state indicators in order to allow management scenarios to be explored and assessed.

EAF implementation framework Step 3: Formulating actions and rules

Mapping ecosystem components and interactions to guide management rule formulation
Once objectives have been set for the fisheries and other ecosystem properties, management rules designed to influence human activities will need to be formulated and may include catch limits, gear restrictions, closed areas or seasons and technological modifications to fishing gear. GIS can help to better understand the current set of spatio-temporal interactions between resources and the human activities that exploit them and in so doing help guide where management rules will be most effective. For example, maps showing where levels of bycatch are highest and where sensitive habitats are located will prove critical to managers seeking to reduce the effects of fishing on non-target ecosystem components.

Modelling ecosystem interactions to visualize effects of management interventions
When combined with appropriate model algorithms, GIS can also prove effective in locating MPAs designed to meet nature conservation objectives while taking into consideration objectives for fisheries and other ecosystem components, as demonstrated in Section 4.3.

GIS can also help visualize modelled interactions between pressure and state indicators, and similarly fleet movements and behaviour in response to management. Model outputs visualized within geographic space have the potential to help managers assess potential outcomes of management options through their effects on pressure and state, allowing selection of interventions that seem most likely to achieve progress with the relevant objectives.

TABLE 6.1
The role of GIS in linking indicators and operational objectives

Objective	Example indicator	Data requirements	GIS role
Fishery resources (target species)			
Reduce fishing effort	Fishing effort of different fleets	Vessels, time fished and gear type per fleet	Analysis of the spatial distribution of fishing effort through VMS, logbook data, spatial modelling
Increase/maintain fish landings of commercially valuable species by area	Fish landings by major species by area	Total landings by major species per fleet per year	Analysis of the spatial distribution and variability in catch data, and vessel and gear types for landing sites
Increase/maintain spawning stock biomass of key retained species above a predefined limit	Spawning stock biomass of the key retained species (or suitable proxy such as the standardized catch per unit of effort (CPUE)	Length and/or age composition of major retained species	Identification of spawning areas through analysis of scientific survey data using geostatistical methods for identification of area preferences
Other ecological concerns			
Reduce number of deaths of vulnerable and/or protected species to a predefined level	Number of deaths of vulnerable and/or protected species	Catch of vulnerable and/or protected species and catch of non-fishery material (critical habitat)	Identification of critical habitats and essential fish habitats
Decrease/maintain the same area of the fishery impacted by gear	Area of the fishery impacted by gear	Area fished by each fleet	Identification of areas of fishing activities through analysis of VMS data, logbook data and spatial modelling
Increase the amount of habitat protected by MPAs to a predefined level	Amount of habitat protected by MPAs	Area under MPAs by habitats	MPA modelling, MPA location, identification of critical habitats
Increase ratio of large fish in the community	Size spectrum of the fish community	Length of fish in a representative sample of the community	Identification of spatial distribution of species at different life stages through the analysis of scientific surveys
Minimize the impact of other activities on fish resources and habitats	Area of fish nursery habitat degraded	Area of habitat, e.g. seagrass beds, mangroves and coral reefs	Assessment and mapping of other activities, identification of critical habitats, identification of nursery areas, location of MPA
Economic			
Increase exports	Export value	Destination of landings from each fleet	Analysis of landings by landing sites and in connection with economic infrastructures
Social			
Maintain or improve cultural values	Cultural value	Cultural sites and values	Mapping of the cultural sites to be preserved
Management activity			
Have well-developed management plans, including indicators and reference points, and ensure an evaluation procedure is in place for all fisheries	Number of fisheries with well-developed management plans, including indicators and reference points	Number of fisheries with well-developed management plans, including operational objectives, indicators and reference points	Mapping of fisheries operating areas, analysis of conflicts, jurisdictional spatial framework

Source: Adapted from FAO, 2003.

GIS support to EAF implementation framework Step 3: Formulating actions and rules
Key areas where GIS could presently support Step 3 of the EAF implementation framework can be summarized as follows:

- visualizing interactions between resources and human activities, whether these interactions are represented by direct observations or model predictions, to help guide the formulation of management rules;
- assessing the efficacy of management scenarios in meeting ecosystem objectives when coupled with models of ecosystem interactions, in particular models that describe links between pressure and state indicators;
- generating options for locating MPAs designed to meet nature conservation objectives while taking other ecosystem properties into consideration; and
- generating options for adaptive spatial management plans and management in response to climate change and other environmental pressures.

EAF implementation framework Step 4: Establishing a monitoring, assessment and review system

Mapping and modelling to measure progress against management objectives
Many of the uses of GIS to support Steps 1–3 of the EAF implementation framework will have relevance to Step 4. For example, the collection and visualization of new data and their translation into indicators and input to ecosystem models will allow progress against management objectives to be monitored. GIS will also have an explicit role to play in monitoring, control and surveillance of fisheries and other resource users through VMS or their equivalents and electronic logbooks.

GIS support to EAF implementation framework Step 4: monitoring, review and assessment
Key areas where GIS could presently support Step 4 of the EAF implementation framework can be summarized as follows:

- visualizing new data and updated model runs describing ecosystem components and interactions – typically expressed in the form of indicators – to allow progress against management objectives to be assessed; and
- providing the framework for monitoring, control, and surveillance systems designed for the operational management of fisheries and other human activities.

6.2.2 Strengthening the use of GIS for EAF implementation

To summarize the previous section, the strongest role GIS will play in EAF implementation will be in generating visualizations of ecosystem components and interactions, whether from direct observations or model predictions, and similarly visualizations of management regulations designed to protect and conserve both target and non-target components. GIS will also provide an effective framework for the management and distribution of geospatial data through online services and act as the platform or interface for operational systems designed to manage fishers and other resource users. For GIS to become fully effective in these areas, a number of developments will be needed to strengthen and enhance existing GIS capabilities. These developments are summarized in Table 6.2 below.

Fisheries management under EAF should be aimed at achieving the agreed objectives (FAO, 2005), and the authors have shown how this should be achieved via a careful review of the EAF framework. What spatial information is needed to feed into the decision-making process will become clear once the operational objectives and indicators have been identified. The authors envisage that the setting of objectives and/or indicators might involve a complex series of discussions among diverse stakeholders who may not necessarily represent a single region, area or country. Once again, it is important to stress that the effective implementation of an EAF does not necessarily require a full knowledge of all ecosystems components. In most cases, the lack of data or time or capacity within the governing institution suggests a more pragmatic approach in which fewer objectives may be initially achievable. Nevertheless, the authors believe that GIS can contribute to filling in some of the gaps relating to our knowledge of the ecosystems, especially the gaps relating to the spatial behaviour and distribution of ecosystem biotic and abiotic components.

TABLE 6.2
Developments needed for the strengthening and enhancing of existing GIS capabilities

GIS capability	Strengthening mechanism/activity
Generation of visualizations of ecosystem components and interactions, and management regulations	• Compiling observations on ecosystem components (human and biological) and translating these observations into indicators using common standards • Further enhancing of predictive modelling of ecosystem components to provide information when direct observations are not possible • Constructing spatially-resolved predictive models capable of describing the causal link between pressure and state indicators • Strengthening links between ecosystem models and GIS to allow greater options for visualizing model outcomes alongside a wide array of ecosystem components • Developing standards for visualizing ecosystem components described using expert knowledge alone for areas where predictive models are unavailable and observations are not possible • Representing all management regulations in digital form and developing systems of interpretation to allow complex management rules to be more easily understood by non-specialists
Management and distribution of geospatial data	• Developing data repositories (archive centres) for ecosystem components • Strengthening the links among and to archive centres via the Internet to allow greater access to data by the public and the stakeholders
Platform/interface for operational management systems targeting fisheries and other human activities	• Further expanding existing fisheries surveillance systems, such as VMS, to all large-scale commercial and industrial fisheries • Improving access to activity data generated by expanded fisheries surveillance systems to allow routine assessments of pressure from resource users by scientists and managers • Introducing electronic logbook schemes within a GIS framework to allow management actions to be more responsive • Developing operational systems of integrated marine management within which system EAF would form a subcomponent

Source: The authors.

6.3 CAPACITY BUILDING TO ENABLE GIS USE

The success of an effective implementation of GIS to support EAF largely depends on:

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

It is the above factors that collectively will build the capacity for GIS work. A look in more detail at capacity-building measures is presented in the subsections below. However, given the scope of this technical paper, which is to deal with concepts rather than practicalities, it is assumed that readers have some background in GIS *per se* and, therefore, will not be setting up a system from scratch. The underlying assumptions made regarding GIS implementation for EAF were mentioned in Section 6.1.

The application of GIS for an EAF will likely necessitate many more GIS-related considerations than are presently being taken into account. Readers may not be familiar with some of the more recent trends and developments in GIS applications. It is to these matters that the discussion now turns.

6.3.1 GIS configuration and system architecture

Our concern in this subsection is with the overall system design (or architecture) of the GIS mainly in terms of its hardware and software, i.e. based on the operational and system needs of the GIS users. Thus, it will be important to have the whole GIS functioning in an optimum way in terms of costs, efficiency and quality of output. The main questions to ask are "Will the demands of GIS for EAF be likely to affect the system's architecture?" and "What might be the main configuration features of a GIS for EAF?" It should be pointed out that determining the system requirements is not an "exact" science due to the dynamic nature and number of variables that must be considered, matters that are compounded by the rapid evolution of GIS software and associated technology.

The present use of GIS for fisheries-based work (research or management) is likely to be characterized by:

- small scale, a single seat or several seats on a limited LAN usually situated within a single institution;
- pressure to perform a variety of ad hoc mapping, modelling or management tasks;
- very little work contact with outside (external) GIS users;
- development of in-house ways of working, often quite successfully;
- limited internal support within the institution; and
- performance of a wide range of tasks, all of which require learning and frequent training upgrades.

The physical GIS operational systems for achieving present output goals will vary greatly from one establishment to another depending on factors such as the size of the institution, funding availability, goals for the GIS work and the ingenuity of the GIS operatives. Systems will typically be confined to a few workstations, either independent or perhaps connected to a central server, and various peripheral hardware for data input purposes and for hardcopy output. It is likely that input devices such as digitizers and scanners will not be used, having given way to CD-ROMS and to Web-delivered software, images or data.

As pointed out in Sections 2, 4 and 5 above, in order to adopt an ecosystem approach to fisheries, the GIS system will need to broaden its functionality, i.e. it will need to greatly expand its information and participation network. This will necessitate the establishment of contacts, lines of communication and good working relationships with numerous other individuals, groups and institutions – those people who are involved in the complete fisheries ecosystem environment.

From a practical GIS working perspective, various decisions will need to be taken, primarily based on the results of the scoping exercises described in Section 6.2. These decisions concern the physical nature of the IT environment, including the system architecture that can best achieve the overall objectives of the EAF. The types of questions that need to be addressed are shown in Box 6.2. Answers to these questions should be derived in meetings and workshops specifically set up in order to get the wider functioning GIS efficiently operational.

It is beyond the scope of this paper to specifically advise on all of the various aspects of a suitable GIS system for EAF work. A multitude of possible computer configurations are possible. Computer processing capacity itself needs to be the highest affordable within budgetary constraints, and indeed FAO (2008a) notes: “There can be considerable computing requirements for some of the moderate to more complex ecosystem models. This is particularly the case if there is high spatial, temporal or taxonomic resolution”. However, most GIS work for fisheries management can be carried out on high specification, standard desktop computers and it is likely that existing computer hardware and software will suffice until the GIS/EAF work is well underway.

The three main alternative system configurations relevant for GIS work are the “stand-alone”, the centralized and the distributed configurations, each of which can be adjusted in many ways to suit individual circumstances and needs. Figure 6.2 illustrates the basic hardware components of a stand-alone configuration: a personal computer, a CD-ROM drive, a scanner, an Internet connection and a printer. Data input to the personal computer can be from the CD-ROM drive (which may be internal or external to the computer), the scanner and Internet sources. Data output from the personal computer is commonly to an ink-jet or laser printer, though it can be to a larger plotter. This basic configuration allows one user to perform GIS work. With a relatively high specification computer, sophisticated GIS work can be performed. Figure 6.3 illustrates the main features of a centralized computing environment. In this configuration, one central server supports GIS file and database transactions, with the server being linked to a local area network (LAN) and/or a wide area network (WAN) to accommodate many users simultaneously. Remote users on the WAN who require data from the central server would link to the central server via a terminal server. Remote browsers who require data from the central server would link to the central server via either a map server or a web server. The benefits of a centralized configuration to a small or medium-sized operation/user consist in reduced hardware needs and administration costs, improved data access and security, and reduced network traffic.

BOX 6.2

Examples of questions that need to be addressed regarding the system architecture of GIS for EAF

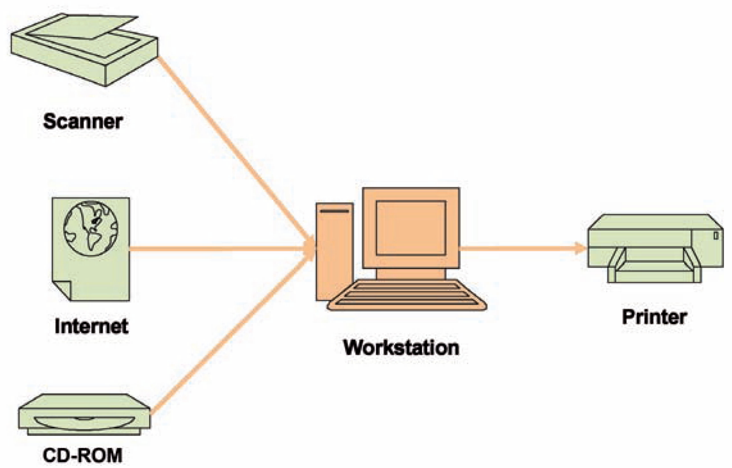
- Who are the main partners likely to initially participate in the broader GIS work?
- Who will be taking the lead role in GIS work or decision-making?
- What is the current range and state of the computing facilities?
- What type and range of GIS output needs to be produced?
- What are the main options for the system’s configuration?
- Would a new, dedicated EAF computing system be desirable?
- In the broadest sense, does each participating partner have adequate computing/GIS capacity?
- Is there a data inventory? Where will the data be stored? How will data be maintained and distributed? Who will have access to what data?
- Will some work need to be carried out externally rather than internally by the main partners?
- What tasks should individual workers perform, i.e. should the aim be for each worker to specialize or to acquire broad, general knowledge?
- How will workflow patterns be decided?
- Are there implementation procedures ready for adoption if the GIS system needs expanding?
- Will the GIS be able to function compatibly with the system operating in a neighbouring ecosystem area?

Figure 6.4 illustrates a typical distributed GIS architecture. In the distributed configuration, multiple groups of "clients", with perhaps each client being a group of individuals using a LAN within one building or organization, are supported by departmental file/database servers, which in turn are supported by one or many distributed file/database servers, each of which may be located in different parts of a WAN. Each distributed file/database source might be represented by each of the main participants in the EAF. Compared with the centralized computing environment, distributed architecture is more expensive to operate since large amounts of data replication may ensue and hardware costs would be higher. Although the diversity and complexity within an ecosystem management area will determine the configuration to be used, it is likely that the distributed model of computing will eventually evolve as the norm for GIS in EAF work. This is largely a reflection of the fact that when a full EAF is operational, it will certainly need to interact with very diverse groups and organizations. However, under various circumstances, a centralized system could be employed and when this is possible, and as long as the data requirements are manageable, this system is probably easier from a management and operations viewpoint. It is likely that most initial EAF work will deploy this system.

Regardless of the general form of system architecture selected, in response to the need for increased collaboration, the GIS working environment will likely undergo a number of changes requiring a "stricter" or more disciplined and integrated approach. The types of system-related tasks or procedures that are likely to be agreed upon and regularized include:

- **Standards**. Keeping to agreed and strict standards helps to ensure that geospatial information will be compatible and interchangeable among all participants in the EAF group. There are nationally and internationally agreed standards to be observed with respect to various aspects of computing. In this regard, FAO developed the GeoNetwork opensource to connect spatial information communities and their data. The GeoNetwork is based on International and Open Standards for services and protocols (i.e. ISO/TC211[18] and OGC[19]). A detailed discussion of standards is beyond the scope of this paper. Kresse and Fadaie (2004) provide detailed coverage of GIS standards.

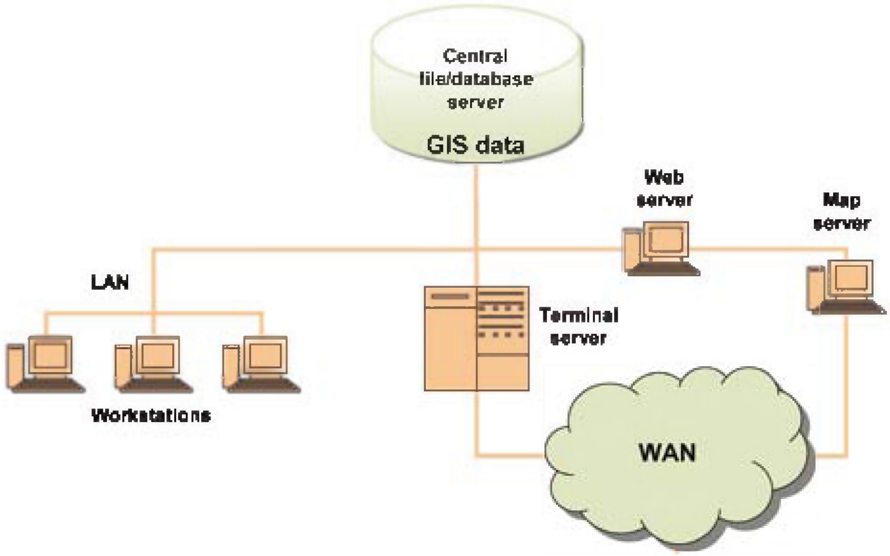
FIGURE 6.2
A minimal stand-alone computing configuration for GIS work



Source: The authors.

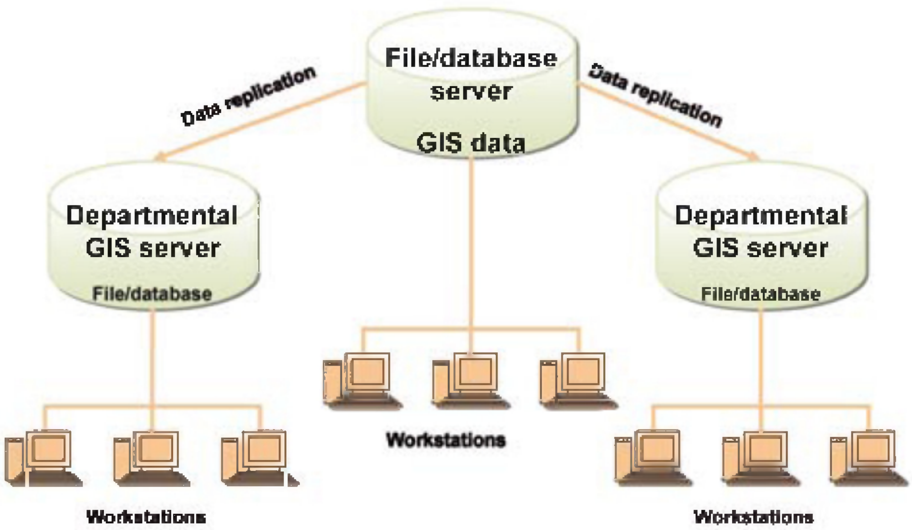
[18] For further details see www.isotc211.org
[19] For further details see www.opengeospatial.org

FIGURE 6.3
A typical centralized computing environment



Source: The authors.

FIGURE 6.4
A typical distributed computing environment



Source: The authors.

- **Workflow and allocation**. To ensure a productive work environment, systems need to be structured to avoid anticipated bottlenecks. This may affect both computing equipment needs and staffing needs.
- **Staff training**. Working within a wider IT environment will create pressure to understand more of the total GIS process relative to wider fisheries' needs.
- **Data updating and editing**. If it is to have value, work in the complex marine ecosystem areas requires constant attention to data quality. Section 6.3.3 below gives more details on data needs and sources for GIS.

- **Metadata upkeep and data archiving**. Requirements to handle a large number of data sets can only be satisfied with extremely good data management, record keeping and archiving systems (see also Section 6.3.3).
- **Security**. A wider IT environment will require decisions on access and security of access.
- **System maintenance**. A main task of the person who oversees the GIS work will be to ensure that IT systems are operationally functioning for the maximum time. This is only achieved if maintenance (in its widest sense) is adequately addressed.

If required and available, "system analysts" can be employed to give advice on system architecture. Many large organizations that might be moving to adopt GIS for EAF work are likely to have in-house IT personnel who can also offer help. A number of system architecture and design reports can provide the reader with practical examples of system analysis and implementation strategies, e.g. Parsons Brinkerhoff Quade and Douglas (2004)[20], Clough Harbour & Associates LLP (undated)[21] and GeoNorth LLC (2007)[22].

6.3.2 GIS software

Once the scope, objectives and system architecture for an EAF have been identified, consideration should be given to the selection of GIS software applications taking into account critical success factors and mandates, costs, technical risks, availability and type of data, and level of user support (Huxhold and Levinsohn, 1995). Most groups working with a fisheries GIS probably chose and presumably familiarized themselves with a core GIS. Given the length of time taken to acquire this familiarity, they in most cases will continue using the chosen GIS for EAF work and indeed their use of existing GIS software will generate an immediate return in terms of expediting analysis and modelling outputs.

For those persons who are starting GIS work in an environment with limited financial resources, it is useful to know that adequate and sophisticated open-source/free, as well as low-price commercial GIS products, such as Quantum GIS[23], uDig[24], Manifold[25] and IDRISI[26], are available for EAF work.

A useful comparison of GIS main functions between two popular GIS software systems, ArcGIS 8.3 and Manifold 6.0, was made at Cornell University (Lembo, 2004). Functions were broken into five separate categories: user interface, database management, database creation, data manipulation and analysis, and data display and presentation. The study can be used as a supplementary checklist for competitive benchmarks of GIS software.

Dependency on known software can deprive users of the flexibility to adopt an open-minded approach to the problems encountered during the implementation phase of an EAF. In response to the users' need for greater flexibility, an increasing number of ad hoc GIS applications and spatial information systems are being designed to collate, manage and visualize spatial information related to marine ecosystems. These applications are mainly based on open-source software and are often categorized as "freeware". The following web sites provide a detailed listing of GIS freeware and open-source software[27]:

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[20] Available at www.dbw.ca.gov/csmw/PDF/SysArchPlan.pdf

[21] Available at http://www.co.wayne.ny.us/Departments/planningdept/Adopted%20Wayne_County_Conceptual_System_Design_Dec_18_07.pdf

[22] Available at www.tigard-or.gov/online_services/gis/docs/sys_arch_app_design.pdf

[23] See www.qgis.org for further details.

[24] See http://udig.refractions.net for further details.

[25] See www.manifold.net/index.shtml for further details.

[26] See www.clarklabs.org for further details.

[27] The Dutch group ITC developed a well-known GIS, used primarily in developing countries, called ILWIS. ILWIS is now available free of charge as open-source software. See www.itc.nl/ilwis/

- http://osdir.com/ml/gis.freegis/
- www.gossrc.org/geographical
- http://dusk2.geo.orst.edu/djl/samoa/tools.html
- http://en.wikipedia.org/wiki/Category:Free_GIS_software
- http://software.geocomm.com

These types of software, as well as providing access to free or very inexpensive GIS capability, frequently come with a source code that can be modified and then passed on to other users. It may have simplified licensing arrangements and the user is not tied to the sometimes restrictive demands of the major GIS software suppliers.

One example of open-source software is Quantum GIS (QGIS), a user friendly GIS licensed under the GNU General Public License and the official project of the Open Source Geospatial Foundation (OSGeo). QGIS provides a continuously growing number of capabilities via its core functions and plug-ins to visualize, manage, edit, analyse data and compose printable maps. A second example of open-source software is Open OceanMap[28], specifically designed for EAF work. This product, developed by Ecotrust, is a participatory tool to gather spatially explicit data to inform socio-economic considerations and assessments (e.g. fishing grounds, cost/earning). This software has been rigorously tested and Steinback *et al.* (2009) note: "The application of Open OceanMap has demonstrated that the inclusion of socio-economic considerations of fisheries, fishermen, and coastal communities can be fully realized and integrated in marine ecosystem-based management". In light of what was said in Section 5 about the great difficulty of integrating socio-economic data into a GIS for EAF work, Open OceanMap should prove to be a good starting point for this task.

Moves are now underway by the International Cartographic Association to develop professional and technical operating standards for the development of free and open-source geospatial software[29]. At the same time, many scientific institutions, trying to facilitate the exchange of information among the community of researchers and managers, may need to retain existing "conformist" GIS software. The balance between the conflicting demands of experimentation and conformity may need careful consideration relative to factors such as funding availability, agreement among other stakeholders within the EAF consortium, ease of maintenance and availability of training, computing and applications expertise, and the availability of software to suit individual area/group needs. There are a few specialist "marine fisheries" GIS-based software packages that may fulfil most functionality required for at least the "fishery" aspects of an EAF, e.g. "Marine Explorer" described in *Environmental Simulation Laboratory Inc.* (2007) and *Marine Analyst,* which is distributed by Mappamondo GIS[30].

An additional consideration with regards to GIS software is the so-called software-based "tools" for EAF, some of which are connected in various ways with GIS functionality. Useful sources of information on this subject are the EcoGIS project web site[31] and the Proceedings of the Twenty-Sixth Annual Environmental Systems Research Institute (ESRI) User Conference, 2006[32]. The EcoGIS project was launched in 2004 and is a collaborative effort between the NOAA National Ocean Service, the National Marine Fisheries Service and four fisheries management councils. This project developed a set of GIS tools to better enable both fishery scientists and managers to adopt EAF. Both the EcoGIS and ESRI web sites explain the main functional areas within EAF for which the tools have been designed, i.e. fishing effort analysis, area characterization, bycatch analysis and habitat interactions, and other relevant

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[28] A short summary about this product is available at www.csc.noaa.gov/geotools/documents/2009_preceedings.pdf
[29] See details at http://ica-opensource.scg.ulaval.ca/index.php?page=home
[30] This can be viewed at www.mappamondogis.it/fisheryanalyst_en.htm
[31] See details at www.st.nmfs.noaa.gov/ecogis/index.html
[32] Available at http://proceedings.esri.com/library/userconf/proc06/index.html

information. Additional information on EcoGIS can also be found in DFO 2008)[33] and in Nelson *et al.* (2007).

6.3.3 Data for GIS

Data needs

With the expansion of traditional fisheries GIS work to cover the demands of an EAF, it is clear that the scope of GIS work will significantly expand. The initial EAF scoping process should identify the main mapping, modelling and management themes. Once these themes are established, data needs can be determined, based upon the perceived data inputs for successfully fulfilling each GIS task. Data volume will increase greatly, eventually probably being at least an order of magnitude greater than would now be required for most fisheries management or research work. Because the authors recommend that EAF work be built up incrementally, there may be no immediate need to make extra system provisions for this increase in data volume. However, this anticipated increase as well as the prioritization of the additional themes promoted to fulfil EAF need to be considered in forward planning. For those people who were accustomed to working in fisheries management or marine ecology, it should be noted that the nature of the data pertaining to the wider EAF may be very different from the data with which they are used to working in that much of it might refer to the terrestrial environment, e.g. factors relating to processing plant locations, or to indices of wealth, well-being or protein availability relative to populations either living in fishery hinterlands or depending on fish markets for their livelihoods. In addition, some of the data may be qualitative, perhaps based on fishers' perceptions of where they fish or fished or what fishing was like in the past in terms of the species caught or the methods used. Details on the less direct aspects of fisheries ecosystems can be found in De Young *et al.* (2008).

Data sources and acquisition

The greater the amount of data required inevitably means the more diverse the data sources, many of which may be unfamiliar to those people who work predominantly in fisheries GIS. Indeed, the amount of data and the number of data sources needed for the EAF could be very large and the authors provide below only a brief introduction to possible sources. This is justified for the following reasons.

- The data themselves may cover a variety of thematic areas – fisheries, oceanography, marine ecosystems and/or environments and species.
- There are countless data sets each of which might be categorized under several headings.
- The amount of potential data is likely to accrue at an exponential rate.
- Data searching systems are becoming more widespread and sophisticated.
- Much data will refer to individual areas or projects and is quite likely not to be located via search engines.
- Separating sites that provide statistics or information from sites that provide data useful to GIS is difficult.

In this subsection, the authors provide the reader with a hint of available data sources, most of which are on the Internet. Annex 2 provides a starting point for data searches. It lists data providers under two headings: (i) Fisheries Data and Databases and (ii) Marine Data and Databases. Much of the information is based on a revision and update of the work originally published in Valavanis (2002). In addition to the specific web sites listed in Annex 2, there are a number of specialized, web-based search facilities such as FAO's Aquatic Sciences and Fisheries Abstracts (ASFA) database[34] and

[33] Available at www.dfo-mpo.gc.ca/csas/csas/publications/pro-cr/2008/2008_007_b.pdf

[34] See www.fao.org/fishery/asfa

Fish & Fisheries Worldwide on BiblioLine[35]. Also, a number of databases are available on CD-ROMs, although this form of data delivery is becoming less important.

Having access to Web sites that may deliver data sets or databases is important but in an era of EAF, having access to data of the increasing number of marine projects worldwide, many of which are willing to share their data, is also important and it is likely that access to such data will increase at an exponential rate. There is now easy access to primary, remotely-sensed data covering surface characteristics of the oceans (e.g. sea-surface temperature, salinity, chlorophyll content, shallow water bathymetry, wave height and direction) and derived products (e.g. primary production of the oceans). Data on sea-bed composition and morphology, acquired either through direct interpolated measurement or derived integrated measurement (e.g. through the analysis of gravimetric anomalies), is also becoming increasing available and most government departments have data pertaining to bathymetry. Many scientific institutions have started to make three dimensional (water column) data available for a variety of measurements.

As far as biological data is concerned, information is still very scattered and not easily accessible. National and regional initiatives in many parts of the world make accessible information on the distribution of aquatic species collected through direct observations (e.g. tagged species) or as output of biodynamic modelling based on the habitat preferences of marine species. Data sets are gradually accruing, usually in advanced economies or in marine areas where resources are heavily exploited, and provide information on benthos distributions or biological information from regular or specific sampling surveys.

Information regarding fishing activities is still infrequent, though there are a few examples of the use of VMS as a way to track the location and behaviour of fishing vessels in order to assess their potential impact on the fishery resources and the habitats and as a means to better manage their distribution (see Sections 3.5.4 and 4.4). Some nations have now implemented fisheries logbooks as a means of establishing fish catches by time and location, and the number of such systems (mostly electronic) is likely to rapidly increase. It must be hoped that access to this potentially sensitive data can be shared with the scientific and management communities, though the need for confidentiality may be a barrier to sharing.

In many instances, the data needed for the successful use of GIS for EAF will simply not be found or indeed does not exist. In these cases, it may be necessary to collect the data using primary data collection methods (including interviews of fishers). This paper is not concerned with data collection methodology, but it is worth cautioning on a few important points as regards this matter.

- Careful attention must be given to sampling frequency and resolution. All spatio-temporal distributions or processes operate at different scales, and their occurrence or location may vary from regular to random. This will have a major effect on sampling space/time frequency (resolution). The general principle must be the more sampling the better but experience should indicate a sensible sampling strategy. The authors point this out because under an EAF regime, it is likely that each single data set could be used in scenarios of widely varying scales.
- When collecting marine or fisheries data for GIS use, it is important that all data be subject to 4D[36] georeferencing. It is also useful when carrying out fish surveys to ensure that physical water parameter data is collected at the same time/place as the fish sample is collected.

[35] See www.nisc.co.za/databases?id=12

[36] Most GIS applications are currently considered as 2D. The third dimension may also exist in the system, either as part of the coordinates of a specific object (the Z value) or as an attribute of that object, i.e. the depth value. 4D concerns the temporal dimension, in this case the time when the data was collected.

- Readers might wish to familiarize themselves with newly emerging marine data models that offer the possibility of 4D mapping and modelling (Polloni and Dwyer, 2007). Much of the GIS work discussed in this paper is totally reliant on 4D data.

Data organization and storage

Once data is acquired, it is important that considerable attention be given to the organization and storage of the data. In general, it is likely that the different partners who are involved in any specific EAF "consortium" will, by agreement, carry on with much of their existing GIS work and will wish to continue to cater to their own needs for data storage and organization. But, with the implementing of EAF comes the need for increased sharing of data and appropriate arrangements should be made for doing so. It is likely that most data sharing among partners will be transacted using web servers linked to a WAN. It is also likely that one partner will take the lead role for GIS work and it is important that this partner pays special attention to maintaining the data in a secure place and in good condition. The GIS/computing areas that take on increased importance are:

- Data organization. With the increase in the amount of data being handled, it is advisable to give consideration to how databases are organized. As with most filing systems, it is likely that a hierarchical database filing structure should be established and the database management system used should be able to establish links both horizontally and vertically across the hierarchy (most proprietary GIS systems will have this functionality).
- Data dictionary. It is important to know the exact meaning of the file names ascribed to files, data sets or databases. The files are likely to be accessible to many people who may not easily be able to interpret definitions without a data dictionary.
- Data formats. A GIS needs to support a variety of data file formats to increase the interoperability and integration with other systems such as relational database management systems, statistical packages and ecosystem modelling software[37].
- Data standards. In order to make the environment of the computing world more user friendly and improve the interoperability, standards are being formulated. More than 25 organizations are involved in the standardization of various aspects of geographic data and geoprocessing. Further details can be found on the International Standards Organization web site[38] or on the Open Geospatial Consortium (OGC) Web site[39].
- Metadata. Metadata contains useful information about how and when a GIS data layer was created, its intended purpose, its scale and projection, and whether any restrictions apply to it. Metadata is essential to any GIS implementation or data development effort. It allows subsequent users to review information about how the data sets were prepared and what their appropriate use should be.

As implied above, data considerations will come increasingly to the fore as GIS is applied to EAF. Therefore, it cannot be stressed strongly enough that the acquisition and management of data receives a very high priority. An additional EAF-related data factor for consideration is that of overlapping or "flexible" ecosystem areas. Marine ecosystems cannot be simply divided into a series of abutting or contiguous fixed spatial areas. All designated ecosystem areas should have spatial overlaps with neighbouring areas. This means that data sharing should occur between neighbours and it is advisable that very close GIS working relationships be established.

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[37] See www.safe.com for details on most format conversion packages.
[38] See www.iso.org
[39] See www.opengis.org

6.3.4. Support for the use of GIS

Using GIS in an EAF is not different from using other applications of GIS in decision-making. Support for the use of GIS is conceived in terms of access to GIS practical computing advice, availability of additional training, access to and availability of published information in journals or books, information over the Internet and the possibility of attending conferences. In addition to the many publications and web addresses already provided in this paper, the following projects or support sources are worthy of mention.

1. FAO is conducting a project entitled "Scientific Basis for Ecosystem-based Management in the Lesser Antilles, including Interactions with Marine Mammals and Other Top Predators"[40]. A component of the project involves capacity building through the use of GIS and other methods as part of an overall ecosystem management plan.
2. A UNEP publication entitled "In-depth Review of the Application of the Ecosystem Approach: Activities of organizations in the application of the ecosystem approach"[41] reviews support activities underway within a variety of organizations.
3. The International Union for the Conservation of Nature (IUCN) is among a number of organizations that now offer courses on marine-based ecosystem management, many of which have a GIS component[42].
4. The World Wildlife Fund (WWF) identified 12 critical steps to implementing ecosystem-based management in marine capture fisheries and these steps are illustrated with reference to the most highly exploited fishery areas[43].
5. The Ecosystem-Based Management Tools Network (E-BMTN) is a group that promotes awareness about and development and effective use of tools for ecosystem-based management in coastal and marine environments. Because approximately half of the ecosystem tools have a spatial component (Robinson and Frid, 2003), GIS could be used as the main operational platform. Box 6.3 defines the main categories of tools available via the E-BMTN web site[44].
6. Vance *et al.* (2008) describe the development of "GeoFish", a tool which allows for the integration of GIS into oceanographic and fishery models for display and analysis purposes. With GeoFish, scientists and managers are able to use a graphical interface to display data sets, select the data to be used in a scenario, set the weights for factors in a model and execute the model within the GIS environment[45].
7. A new and interesting development is "TerraLib" (Camara *et al.*, 2008)[46]. TerraLib, a GIS classes and functions library available on the Internet as open source, allows a collaborative environment for the development of multiple GIS tools. Its main aim is to enable the development of a new generation of GIS applications based on the technological advances on spatial databases. Box 6.4 describes the functions and support that TerraLib offers.
8. As a means of disseminating information on GIS as it applies to EAF, FAO is developing the GISFish portal[47]. Initially the aim of the portal was to be a "one stop" site to provide the global experience with GIS, remote sensing and mapping as they apply to aquaculture and inland fisheries. It is intended that the aim of the portal be to disseminate information for the marine fisheries domain with a special emphasis on the use of GIS to aid EAF. The new portal is to be launched in 2009.

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[40] Preliminary details can be found at www.fao.org/fishery/eaf-lape/en
[41] Available at www.cbd.int/doc/meetings/sbstta/sbstta-12/information/sbstta-12-inf-02-en.doc
[42] See www.iucn.org/what/ecosystems/marine/index.cfm?uNewsID=429
[43] See http://assets.panda.org/downloads/wwf_ebm_toolkit_2007.pdf
[44] Available at www.ebmtools.org/
[45] See details at www.pmel.noaa.gov/foci/publications/2007/vanc0632.pdf
[46] See further details at www.dpi.inpe.br/terralib/
[47] Available at www.fao.org/fishery/gisfish/index.jsp

6.4 CHALLENGES TO THE USE OF GIS IN MARINE ECOSYSTEMS

This section has drawn from a recent publication by Meaden (2004), which outlines the main challenges to using GIS in fisheries and aquatic environments. From both a theoretical and practical viewpoint, demand for the effective use of GIS in marine fisheries is growing. From the theoretical point of view, an issue of concern is the lack of dedicated applications and a conceptual framework for GIS as applied to marine fisheries, and by implication to EAF. Historically, GIS was developed mainly to provide answers to land-based issues (e.g. agriculture, land use, forestry, coastal zones) and thus lacks the required functionality to examine those aspects that are peculiar to the marine environment, i.e. an environment that is highly dynamic in space and time; where there is limited access to information concerning processes beneath the sea-surface (where most of the processes occur); and where there is a high degree of uncertainty and a lack of data. Another concern relates to the fact that applications and conceptual frameworks based on 2D or 2.5D models of the real world are still being used while, in fact, there is a need to move to 3D or, even better, 4D (3D plus time) models of reality. Data models, i.e. the conceptual framework to translate reality into a logical and physical model stored in a relational database, are now emerging to help solve this problem (Wright *et al.*, 2007) but this is still a challenging area in which to work[48].

From a practical viewpoint, a major challenge to working with GIS in a marine ecosystem environment is that everything in the environment, and indeed the environment itself, is constantly moving. This immediately implies that any map derived from the data gathered is almost instantly obsolete. However, movement itself varies from fast to slow and from regular to chaotic. This means that mapping can only be undertaken within a wide range of confidence levels. For instance, at a large scale, one can be fairly certain of the movement and general trajectory of the North Atlantic Drift and indeed many of the world's major ocean currents. However, the appearance of oceanic gyres within or adjacent to some of the major currents is a chaotic phenomena that is almost impossible to predict. Similarly, some biotic movements are predictable, e.g. upstream movement of salmon to spawn or annual whale migrations, whereas other biotic movements are entirely unpredictable, e.g. foraging movements of fish on a coral reef. Unfortunately, much marine data gathered during specific survey cruises may only be related to one point in time. The uncertainty caused by movement can prove a major challenge to those people wishing to undertake marine modelling exercises, which are often crucial to EAF and to other GIS work.

BOX 6.3

The main categories of ecosystem-based management tools

- Data collection tools:
  - *Geophysical data collection tools*
  - *Biological data collection tools*
  - *Socio-economic data collection tools*
- Data processing and management tools
- Stakeholder engagement and outreach tools
- Conceptual modelling tools
- Modelling and analysis tools:
  - *Tools to develop models*
  - *Geographic information systems*
  - *Watershed models*
  - *Estuarine and marine ecosystem models*
  - *Oceanographic and dispersal models*
  - *Habitat suitability and species distribution models*
  - *Socio-economic models*
  - *Other modelling and analysis tools*
- Visualization tools
- Decision support tools
  - *Conservation and restoration site selection tools*
  - *Coastal zone management tools*
  - *Fisheries management tools*
  - *Hazard assessment and resiliency planning tools*
  - *Coastal and watershed land-use planning tools*
- Project management tools
- Monitoring and assessment tools

Source: From www.ebmtools.org.

[48] Additional information at: http://support.esri.com/index.cfm?fa=downloads.dataModels.filteredGateway&dmid=21

BOX 6.4

Support offered by the TerraLib open-source software project

- Ease of customization. Little effort is required to use the library to develop applications. Developers should concentrate only on specific user needs and the library should provide powerful abstractions that cover the common needs of a GIS application.
- Upward compatibility with the OGC simple feature data model. Considering the impact and popularity of the OGC specifications, a TerraLib spatial database should be compatible with the OGC simple feature specification (SFS).
- Decoupling applications from the database management system (DBMS). The library should handle different object-relational databases transparently.
- Supporting large-scale applications. Useful for environmental and socio-economic application, the library should provide efficient storage and retrieval of hundreds of thousands of spatial objects.
- Extensibility. A GIS library should be extensible by other programmers and the introduction of new algorithms and tools should not affect existing codes.
- Enabling spatio-temporal applications. Emerging GIS applications need support for different types of spatio-temporal data, including events, mobile objects and evolving regions.
- Remote sensing image processing and storage. The library should be able to handle large image databases and inclusion of image processing algorithms should be easy.
- Spatial analysis. The library should be able to support spatial statistical methods to improve the ability to extract information for socio-economic data.
- Environmental modeling. The library should be able to support environmental and urban models, including dynamic models using cellular automata.

The authors expect that a major challenge for many marine areas will be that of "ecosystem partitioning" or boundary definition. Thus, it might be argued that the marine areas of the world function as one very large ecosystem. If one thinks in terms of many of the top predators, marine areas indeed range very widely, and the same might be said of the aquatic milieu itself in the sense that it can infinitely drift around with hydrodynamic processes mixing the "ingredients" (salinity, temperatures, pollutants). However, in practical terms of an EAF, the marine space needs to be divided into "sensible" management units. While this will be relatively easy in some areas, it could be a real challenge in other areas. Although FAO (2008a) notes that for best practice "Boundaries should be based on biological rather than anthropogenic considerations such as national boundaries", this may not always be the case. Boundary definition may be a function of the EAF analytical process that is being performed. For example, an EAF analysis relating to a localized abalone fishery is unlikely to utilize the same boundary area that would be requisite for a study involving tuna. If the purpose for using GIS in EAF is to support management of a specified jurisdiction, then the ecosystem boundary needs to be delimited pragmatically, i.e. as close as possible to decision-making boundaries. So ecosystem boundaries could be both highly porous and variable. The authors envisage that each ecosystem area to be identified will probably have a unique set of core themes. But they also caution that data gathered on each theme will have to be spatially and temporally flexible according approximately to the mobility or uniqueness of the theme. In practical terms of a GIS, this means that each map layer may be at a different resolution and may cover a different area around the identified (and designated) ecosystem area. The layer (map theme) should have the capacity to be integrated into data being collected by those people who are managing neighbouring marine ecosystems and this capacity will lead to a need for "inter-ecosystem" dialogue.

Again, from a practical viewpoint, a great amount of data is still not easily accessible. There is a need to increase accessibility and spatial coverage and to update such data, especially the data relating to the biological components of the ecosystems and to fishing activities. Making the results of many years of scientific surveying available to scientists in detailed or aggregated format can enhance knowledge and provide reference points when long time series data are also available. Related challenges concern the high cost of collecting marine or other EAF data combined with the sheer volume of data that must be collected if GIS output is to be recognized as having statistical significance. Failure to confront high collection costs and to collect the required volume of data at the appropriate resolution may significantly affect the validity and reliability of GIS output.

Fishery monitoring and data logging systems in many areas of the world are being implemented as a means to provide control and surveillance over fishing operations (VMS, blue boxes, logbooks). Frequently they are becoming an effective way to better understand interactions among fishery resources and to provide management guidelines in areas that are otherwise difficult to access and to monitor (see Section 4.4.2). However, there remains the challenge of obtaining acceptance of these surveillance systems, especially by smaller-scale fishers. Acceptance involves changing the perceptions that the business activities of fishers are being "spied" upon and that preferred fishing locations may be revealed to third parties, as well as getting fishers to assume the costs of adopting monitoring systems, to deal with the impracticality of implanting monitoring devices on smaller vessels and to confront the added bureaucracy. Although the costs of the systems in terms of implementation, maintenance and possible loss of goodwill are high, their importance as a spatial aid to the management of fishery ecosystems should increase the diffusion and utilization of monitoring equipment.

Another challenge that receives growing interest is the development of conceptual frameworks that include the social and economic aspects of an EAF, including their spatial components. Thus, while there is already a great deal of expertise in the mapping of material objects, the mapping of many social phenomena may be rather "vague" and subject to different perceptions by different stakeholders or participants. This is a relatively new area for mapping, where little experience exists and where further investigations are needed. In a similar perceptual mode, there are the challenges associated with map visualization. What is an optimum map in terms of its appearance? The answer will vary from person to person but great progress has been made recently on map appreciation. Producing appealing and appropriate maps can be a learned skill but in many parts of the world the teaching of map production skills has yet to commence.

The practical and organizational implementation of EAF has implications for an effective use of GIS, especially in developing countries. Collaboration and the exchange of data and information among countries are crucial to the success of EAF. In this context, regional fisheries organizations and international institutions can certainly play a role in facilitating data exchange and cooperation. It must be remembered that marine ecosystems are by definition very unlikely to have well-defined and fixed boundaries and certainly only a cooperative effort among countries or regions can cope with the complexity and the variety of interactions and requisite analyses.

6.5 CONCLUSIONS

The authors recognize that readers come to the subjects of both GIS and EAF from diverse experiences, and given that both subjects are extremely diverse and relatively complex, it is inevitable that all of the issues will not have been covered in this paper. Indeed, given the breadth of the subject material, the authors have been obliged to assume that the reader is somewhat familiar with material covering both GIS and

EAF and to focus the discussion of this paper on the main considerations regarding implementation of GIS for EAF and to indicate numerous directions along which readers could pursue their own lines of enquiry. GIS-based EAF work will eventually evolve and be operational using an infinite variety of system configurations, software combinations, support services and data types and sources. One concern the authors have is that this effort may lead to a great deal of "reinventing the wheel" whereby numerous separate attempts are made to find optimum solutions to specific GIS-based EAF demands. Given the plight of many of the world's fisheries and marine ecosystems, this would be a serious waste of time and resources. To avert duplication of effort, it is imperative that workers in this field pay particular attention to what is happening elsewhere and that central organizations such as FAO cooperate in providing an appropriate and efficient reservoir of expertise.

7. Conclusions and recommendations

There is now worldwide recognition that for their long-term sustainability, fisheries need to be managed as part of a wider ecosystem. This review has outlined how various moves towards implementation of EAF are being made and presents a number of cases studies.

This review primarily attempted to demonstrate how GIS can facilitate implementation of EAF, considering the key steps required for EAF planning and implementation and the importance of the spatial features of the fishery socio-ecological systems for successful EAF implementation. Knowledge of the distribution of key ecosystem components, such as fish, benthos, fishers and markets, as well as knowledge of key ecosystem processes and attributes, such as tides, currents, level of pollutants, spawning, migrations and fishing, are fundamental for EAF application. Also important is spatial information on social, economic and governance aspects such as geography of subsistence fishing, of legal access rights and market prices. For the relevant ecosystem attributes, components and processes, GIS can deliver maps but it can also perform additional functions such as data editing, manipulation, modelling and analyses. It is the final analytical function that gives GIS the vast potential to examine fisheries and EAF-related problems.

Despite its obvious advantages, utilization of GIS in fisheries management, and in particular in support of EAF implementation, is only at its infancy. EAF itself is at an early stage of application and it is important that GIS developments within institutions be closely linked to the information requirements in support of fisheries management planning and its implementation. A GIS team could provide useful inputs to the decision-making process, for example, in determining ecosystem boundaries, in mapping relevant stakeholder groups and in selecting indicators and reference points.

It seems that most matters at the core of EAF have a spatial component and thus will be susceptible to being incorporated into GIS analyses. In Section 5, examples were given of potential analyses that can be handled by GIS. For any specific analysis, a spatial boundary needs to be established, including a detailed consideration as to the spatial and temporal resolution for prospective analyses. Then much of the GIS-based work will involve modelling scenarios. Work needs to be done on devising or obtaining creditable models, to populate models with suitable data and algorithms, and to evaluate the outcome or outputs of modelling. Over and above these more direct GIS-based considerations, there needs to be intensive work on forging cooperation and working relationships with other teams of people who might, for instance, be working on projects in neighbouring thematic or geographic areas, or between different levels of governance, or among varied but interested stakeholder groups. To this end, the FAO Fisheries and Aquaculture Department is committed to developing synergies and opportunities between the spatial components of the EAF and the Ecosystem Approach to Aquaculture (EAA) in terms of sharing data and developing tools, methodologies and guidelines (see Aguilar-Manjarrez, *et al.*, in preparation). There are also practical matters concerning centres of GIS work, training, software preferences, financing of projects, GIS team composition, all of which can make a huge difference to project success. In order not to keep “reinventing the wheel”, avenues of information dissemination, reporting and communications need to be clearly established at the commencement of any project.

The following recommendations may be useful if GIS is to successfully be adopted as a key tool for EAF planning and implementation (the costs involved are not being considered but the authors *recognize* that projects will need to be very cognisant of them). The recommendations, not in any specific order, are shown in Box 7.1. Although not complete, the list indicates the major issues to be considered before embarking upon work with a GIS.

BOX 7.1

Recommendations to aid the adoption of GIS for EAF

- Define the spatio-temporal boundaries to any specific GIS task and define overall project objectives.
- Consider carefully the time and spatial resolution that is needed for each project component.
- Carefully explore the various software possibilities before finally deciding upon one. Remember that work will be done in cooperation with other partners.
- Establish data needs and sources, and identify any barriers to project implementation.
- Seek practical, working partners both within your physical project area and with neighbouring management areas.
- Clearly ascertain the principal stakeholders in the total fisheries ecosystem and establish a good working relationship with them.
- Consider carefully the "scale" of the GIS in terms of personnel and computing needs.
- Consider the various expertise and training needed for each project.
- Make certain that most members of the GIS team have a solid grounding in fishery ecology in its broadest sense.
- Build the capacity to undertake GIS carefully by seeking expert advice, for instance, and by exploring in-depth the GIS/EAF support that is now available.
- Look carefully at the GIS work being done elsewhere and learn from others.
- Start off with fairly simple projects, e.g. a small area and limited thematic coverage.
- Have frequent project meetings and make sure that everyone is aware of what is happening and can work well as a group member.
- Make strict time deadlines for project components.
- If possible, make sure that the project leader is competent and lines of authority are clear.
- Recognize the limitations of the project outputs and the fact that there may be considerable challenges to overcome before achieving success.
- Broadcast your successes as widely as possible. Are you actually saving/sustaining the fishery?

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Glossary

Abiotic	Non-living (resource)[a].
Abundance	Degree of plentifulness. The total number or biomass of fish in a population or on a fishing ground. Can be measured in absolute or relative terms[a].
Access rights	Permission from the holder to take part in a fishery (limited entry) or to fish in a particular location (territorial use rights or "TURFs")[b].
Adaptive management	A management process involving step-wise evolution of a flexible management system in response to feedback information actively collected to check or test its performance (in biological, social and economic terms). It may involve deliberate intervention to test the fishery system's response[a].
Bathymetry	The science of measuring and charting the depths of waterbodies to determine the topography of a lake bed or sea floor[c].
Biodiversity	The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. Diversity indices are measures of richness (the number of species in a system); and to some extent, evenness (variances of species' local abundance). They are, therefore, indifferent to species substitutions, which, however, may reflect ecosystem stresses (such as those due to high fishing intensity)[d].
Biotic	Live and living (organisms)[a].
Biotope	An area or habitat of a particular type, defined by the organisms (plants, animals, microorganisms) that typically inhabit it, e.g. coral reef, mangrove and deep sea hot vents or on a smaller scale a microhabitat[a].
Bycatch	Part of a catch of a fishing unit taken incidentally in addition to the target species towards which fishing effort is directed. Some or all of it may be returned to the sea as discards, usually dead or dying[a].

Catch	To undertake any activity that results in taking fish (sensu lato) out of their environment dead or alive. To bring fish on board a vessel dead or alive. The total number (or weight) of fish caught by fishing operations. Catch includes all fish killed by the act of fishing, not just those landed. The catch is usually expressed in terms of wet weight (or round weight). It should refer to the total amount caught but is sometime erroneously used to refer only to the amount landed. The catches that are not landed are called discards[a].
Code of Conduct for Responsible Fisheries	The code, formulated by FAO in 1995, sets out internationally agreed Responsible Fisheries principles and international standards of behaviour for sustainable and 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[e].
Community	A social group of organisms sharing an environment, normally with shared interests. In human communities, intent, belief, resources, preferences, needs, risks and a number of other conditions may be present and common, affecting the identity of the participants and their degree of cohesiveness[a].
Conventional fisheries management	The historical approach to fisheries management in which the interaction of the stock of the target species with other components of the ecosystem is not explicitly considered in the management actions[d].
Cost-benefit analysis	Assessment of the direct or indirect economic and social costs and benefits of a proposed project for the purpose of project or programme selection. The cost-benefit ratio is determined by dividing the projected benefits of the programme by the projected costs. A programme having a high benefit-cost ratio may take priority over others with lower ratios[a].
Discards	The components of a catch that are thrown back into the habitat after capture. Normally, most of the discards can be assumed not to survive[d].
Ecoregion	An area of relatively homogeneous species composition, clearly distinct from adjacent systems. The species composition is likely to be determined by the predominance of a small number of ecosystems and/or a distinct suite of oceanographic or topographic features. The dominant biogeographic forcing agents defining an ecoregion vary from location to location but may include isolation, upwelling, nutrient inputs, freshwater influx, temperature regimes, ice regimes, exposure, sediments, currents and bathymetric or coastal complexity[f].

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[d].

Ecosystem approach to fisheries (EAF) An approach to fisheries management and development that strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries. The purpose of EAF is to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems[d].

Ecosystem functions An intrinsic ecosystem characteristic related to the set of conditions and processes whereby an ecosystem maintains its integrity (such as primary productivity, food chain, and biogeochemical cycles). Ecosystem functions include such processes as decomposition, production, nutrient cycling, and fluxes of nutrients and energy[a].

Ecosystem-based fisheries management *(see Ecosystem approach to fisheries)*

Ecosystem-based management An integrated approach to management that considers the entire ecosystem, including humans. The goal is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. It considers the cumulative impacts of different sectors; emphasizes the protection of ecosystem structure, functioning and key processes; is place-based in focusing on a specific ecosystem and the range of activities affecting it; explicitly accounts for the interconnectedness within systems, recognizing the importance of interactions between many target species or key services and other non-target species; acknowledges interconnectedness among systems; and integrates ecological, social, economic and institutional perspectives, recognizing their strong interdependences[a].

Ecosystem models Models that represent a wide range of technological, social, economic and ecological processes affecting the species and their use in the ecosystem (including multispecies and whole ecosystem). They are potentially important tools for providing broad scientific information on the impacts of ecosystem use (e.g. by the fishery) on the main ecosystem components and processes and to take into account changes in the ecosystem other than those caused by fishing, whether of natural or anthropogenic origin, that may be impacting the fishery[d].

Ecosystem services

The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services, such as spiritual and cultural benefits; and supporting services, such as nutrient cycling or waste degradation, that maintain the conditions for life on earth[a].

Enforcement

In fisheries, a series of measures and action to constrain fishers to catch the right quantities and type of fishes as set by fishery laws or other regulations in order to achieve sustainable objectives over a stock and an area. Measures include: completion of fishery logbooks, equipping vessels with VMS, placing observers on board vessels, aerial or at-sea observation of the fishing fleet and inspections. These measures are usually backed up by the law.

Environmental impact assessment (EIA)

A set of activities designed to identify and predict the impacts of a proposed action on the biogeophysical environment and on man's health and well-being, and to interpret and communicate information about the impacts, including mitigation measures, that are likely to eliminate the risks. In many countries, organizations planning new projects are required by law to conduct an EIA. Usually it is carried out by three parties, the developer, the public authorities and the planning authorities.

Essential fish habitat (EFH)

Essential fish habitat can consist of both the water column and the underlying surface (e.g. sea floor) of a particular area. Areas designated as EFHs contain habitat essential to the long-term survival and health of a fishery. Certain properties of the water column such as temperature, nutrients, or salinity are essential to various species. Some species may require certain bottom types such as sandy or rocky bottoms, vegetation such as seagrasses or kelp, or structurally complex coral or oyster reefs. An EFH includes those habitats that support the different life stages of each managed species. A single species may use many different habitats throughout its life to support breeding, spawning, nursery, feeding and protection functions. An EFH encompasses those habitats necessary to ensure healthy fisheries now and in the future[g].

Fish habitat (see also habitat)

The physical and biological environment in which the fish live, including everything that surrounds and affects their lives, e.g. water quality, bottom, vegetation and associated species (including food supplies)[a].

Fish population

A group of interbreeding organisms that represents the level of organization at which speciation begins[a].

Fisheries management	The set of measures affecting a resource and its exploitation with a view to achieving certain objectives, such as the maximization of the production of that resource. Management includes, for example, fishery regulations such as catch quotas or closed seasons. Managers are those who practice management[a].
Fishing effort	The total amount of fishing activity on the fishing grounds over a given period of time, often expressed for a specific gear type, e.g. number of hours trawled per day, number of hooks set per day or number of hauls of a beach seine per day. Fishing effort would frequently be measured as the product of (i) the total time spent fishing and (ii) the amount of fishing gear of a specific type used on the fishing grounds over a given unit of time. When two or more kinds of gear are used, they must be adjusted to some standard type in order to derive an estimate of total fishing effort[d].
Fishing fleet	The set of units (vessels) of any discrete type of fishing activity exploiting a specific resource. For example, a fishing fleet may be all the purse-seine vessels in a specific sardine fishery or all the fishers setting nets from the shore in a tropical multispecies fishery[d].
Fishing vessel	Any vessel, boat, ship or other craft that is equipped and used for fishing or in support of such activity. For management purpose, particularly for monitoring and surveillance, may be considered to include any vessel aiding or assisting one or more vessels at sea in the performance of any activity relating to fishing, including, but not limited to, preparation, supply, storage, refrigeration, transportation or processing (e.g. mother ships)[a].
Geographic Information Systems (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 they can be displayed and analysed[c].
Geostatistics	A class of statistics used to analyses and predict the values associated with spatial or spatio-temporal phenomena. Geostatistics provides a means of exploring spatial data and generating continuous surfaces from selected sampled data points[c].
GIS	*(see Geographic information system)*
GLM	*(see Generalized linear models)*
Generalized linear model (GLM)	A modelling process that attempts to accommodate variance heterogeneity and asymmetric, non-normal behaviour by offering a range of distributional types that cover at least the more common mean–variance relationships[h].

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 United States Department of Defence, the system is used in navigation, mapping, surveying and other applications in which precise positioning is necessary[c].
GPS	*(see Global positioning system)*
Governance	The formal and informal arrangements, institutions, and norms which determine how resources or an environment are utilized, how problems and opportunities are evaluated and analysed, what behaviour is deemed acceptable or forbidden, and what rules and sanctions are applied to affect the pattern of resource and environmental use[a].
Ground truthing	The process of assessing the accuracy or validation of remotely sensed or mathematically calculated data based on data actually measured in the field[c].
Habitat (see also Fish habitat)	The place where an organism lives or the place one would go to find it. The habitat is the organism's address, and the ecological niche its profession, biologically speaking.
Hardware	The physical equipment in a computer system[a].
Hatchery	A facility used for the artificial and controlled breeding, hatching and rearing of aquatic organisms, on a commercial or experimental basis, through their early life stages. A hatchery is usually closely associated with a nursery facility where the cultured organisms are grown to the appropriate size before being released to the wild or an ongrowing structure.
Index of abundance	A relative measure of the weight or number of fish in a stock, a segment of stock (e.g. the spawners) or in an area. Often available in time series, the information is collected through scientific surveys or inferred from fishery data[a].
Indicator	A variable pointer, or index, of the state of a system. Its fluctuation reveals the variations in key elements of a system. The position and trend of the indicator in relation to reference points or values indicate the present state and dynamics of the system. Indicators provide a bridge between objectives and actions[a].

Integrated management	A continuous process through which decisions are made for the sustainable use, development and protection of areas and resources. Integrated management acknowledges the relationships that exist among different uses and the environments they potentially affect. It is designed to overcome the fragmentation inherent in a sectoral approach, analyses the implications of development and conflicting uses, and promotes linkages and harmonization among various activities[a].
Landings	Weight of the product landed at a landing site. Landings may be different from the catch (which includes the discards)[a].
Landsat	A series of United States polar orbiting satellites, first launched in 1972 by NASA, which carry both the multispectral scanner and thematic mapper sensors[9].
Large marine ecosystem	Large area of ocean space of approximately 200 000 km^2 or greater, adjacent to the continents in coastal waters, that has distinct bathymetry, hydrography, productivity and trophically dependent populations[a].
Logbook	A detailed, usually official record of a vessel's fishing activity registered systematically on board the fishing vessel, usually including information on catch and its species composition, the corresponding fishing effort and location. Completion of logbooks may be a compulsory requirement for a fishing licence[a].
Management measures or regulations	Specific controls applied in the fishery to contribute to achieving the objectives, including some or all of the technical measures (gear regulations, closed areas and time closures), input controls, output controls and user rights[d].
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[c].
Map 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 000th of the same unit on the earth[c].

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 subpopulation (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[d].
Marine spatial planning (MSP)	A process of analysing and allocating parts of 3D 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[j].
Modelling	The construction of physical, conceptual or mathematical representation of the real world. Models help to show relationships between processes (physical, economic or social) and may be used to predict the effects of changes in, for instance, marine ecosystems[a].
Monitoring	The collection and analysis of information performed for the purpose of assessment of the progress and success of a management plan. Monitoring is used for the purpose of assessing performance of a management plan or compliance scheme and revising them or to gather experience for future plans[a].
MPA	*(see Marine protected areas)*
Non-retained species	*(see Discards)*
Population dynamics	The part of fishery biology which studies the abundance of biological populations (including fish) and their changes[a].
Quota	A share of the total allowable catch (TAC) allocated to an operating unit such as a country, a community, a vessel, a company or an individual fisher (individual quota) depending on the system of allocation. Quotas may or may not be transferable, inheritable and tradable. While generally used to allocate total allowable catch, quotas could be used also to allocate fishing effort or biomass[d].
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 a single 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 or measurement[c].

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, acoustic sonar and satellite imaging[c].
Restocking	The release of cultured juveniles into the wild to restore the spawning biomass of severely overfished stocks to levels at which they can once again provide sustainable yields. Restocking requires some level of management to protect the released animals and their progeny until replenishment has occurred[d].
Retained species	*(see Landings)*
Satellite imagery (see also Remote sensing)	Imagery acquired from satellites and aircraft, including panchromatic, radar, microwave and multispectral satellite imagery[c].
Seamounts	A large isolated elevation characteristically of conical form. Seamounts are undersea mountains whose summits lie beneath the ocean surface. They are usually volcanic in origin and are generally defined as having an elevation of greater than 1 000 m from the sea bed[a].
Spatial patterns	Recognition of regularities in the geographic distribution of natural phenomena or human activities on which the prediction of successive or future events may be based.
Spatial scale	*(see Scale)*
Species	Group of animals or plants having common characteristics, able to breed together to produce fertile (capable of reproducing) offspring, and maintaining their "separateness" from other groups[a].
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[d].

Stock A group of individuals of a species occupying a well-defined spatial range independent of other stocks of the same species. Random dispersal and directed migrations due to seasonal or reproductive activity can occur. Such a group can be regarded as an entity for management or assessment purposes. Some species form a single stock (e.g. southern bluefin tuna) while others are composed of several stocks (e.g. albacore tuna in the Pacific Ocean comprises separate northern and southern stocks). The impact of fishing on a species cannot be fully determined without knowledge of the stock structure[d].

Stock assessment The process of collecting and analysing biological and statistical information to determine the changes in the abundance of fishery stocks in response to fishing, and, to the extent possible, to predict future trends of stock abundance. Stock assessments are based on resource surveys; knowledge of the habitat requirements, life history, and behaviour of the species; the use of environmental indices to determine impacts on stocks; and catch statistics. Stock assessments are used as a basis to assess and specify the present and probable future condition of a fishery[a].

Sustainable development Development that meets the needs of the present without compromising the ability of future generations to meet their own needs[d].

Target species Those species that are primarily sought by the fishers in a particular fishery. The subject of directed fishing effort in a fishery. There may be primary as well as secondary target species[d].

Territorial waters The area beyond the tidal baseline of the open coasts of a country over which that country exercises full control except for innocent passage of foreign vessels. Set at a maximum of 12 nautical miles in breadth by the 1982 Law of the Sea Convention, its width depends on countries[a].

Total allowable catch (TAC) Total amount of resource allowed to be taken in a specified period (usually a one-year period) for a specified area, as defined in the management plan. TAC may be allocated to the stakeholders in the form of quotas as specific quantities or proportions[d].

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[c].

Vessel monitoring system (VMS) A part of modern monitoring, control and surveillance systems (MCS) the VMS is a vessel tracking system (usually satellite-based) which provides management authorities with accurate information on a fishing vessel's position, course and speed at time intervals. Detail of VMS approved equipment and operational use will vary with the requirements of the nation of the vessel's registry and the regional or national water in which the vessel is operating[a].

Vulnerable habitats *(see Vulnerable marine ecosystems)*

Vulnerable marine ecosystems (VME) Marine areas where a population, community or habitat will experience substantial alteration from short-term or chronic disturbance, and will require some time to recover after a disturbance. The vulnerabilities of populations, communities and habitats must be assessed relative to specific threats. Some features, particularly ones that are physically fragile or inherently rare, may be vulnerable to most forms of disturbance, but the vulnerability of some populations, communities and habitats may vary greatly depending on the type of fishing gear used or the kind of disturbance experienced[11].

Zoning Dividing an area in zones or sections with different characteristics, or reserved for different purposes or uses, or conditions of use such as no-take zones or reserves (see MPAs), biodiversity corridors, non-trawling areas and areas for exclusive use by small-scale fisheries or aquaculture. Ocean zoning is an element of marine spatial planning.

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[a] From or adapted from FAO Fisheries and Aquaculture Department Glossary. www.fao.org/fi/glossary/default.asp

[b] From or adapted from Cochrane, K.L. (ed.). 2002. *A fishery manager's guidebook. Management measures and their application.* FAO Fisheries Technical Paper 424. Rome. 231 pp.

[c] From or adapted from the ESRI GIS Dictionary. http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.gateway

[d] From or adapted from FAO. 2003. *Fisheries management. 2. The ecosystem approach to fisheries.* FAO Technical Guidelines for Responsible Fisheries No. 4, Suppl. 2. 112 pp.

[e] From or adapted from FAO Fisheries and Aquaculture Department Aquaculture Glossary. www.fao.org/fi/glossary/aquaculture/default.asp

[f] From or adapted from Spalding, M.D., Fox, H.E., Allen, G.R., Davidson, N., Ferdaña, Z.A., Finlayson, M., Halpern, B.S., Jorge, M.A., Lombana, A., Lourie, S.A., Martin, K.D., Mcmanus, E., Molnar, J., Recchia, C.A. & Robertson, J. 2007. Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. *Bioscience*, 57(7): 573–583.

[g] From or adapted from Habitat Protection Division of NOAA National Marine Fisheries Service (NMFS), Office of Habitat Conservation. www.nmfs.noaa.gov/habitat/habitatprotection/efh/index_a.htm

[h] From or adapted from Venables, W.N. & Dichmont, C.M. 2004. GLMs, GAMs and GLMMs: an overview of theory for applications in fisheries research. *Fisheries Research*, 70: 319–337.

[i] From or adapted from Meaden, G.J. & Do Chi, T. 1996. *Geographical information systems: applications to marine fisheries.* FAO Fisheries Technical Paper 356. Rome. 335 pp.

[j] From or adapted from Ehler, C. & Douvere, F. 2007. *Visions for a Sea Change.* Report of the First International Workshop on Marine Spatial Planning. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides No. 48. IOCAM Dossier (pdf, 3.01 MB) No. 4. Paris, UNESCO.

[k] Adapted from FAO. 2009. *Report of the Technical Consultation on International Guidelines for the Management of Deep-sea Fisheries in the High Seas. Rome, 4–8 February and 25–29 August 2008.* FAO Fisheries and Aquaculture Report 881. Rome. 86 pp.

Annex

Major fisheries and marine data providers on the Internet

FISHERIES DATA[1]

Organization	Description and Web site URL
Alaska Fisheries Science Center	Fisheries data for the Alaska marine areas www.afsc.noaa.gov/databases.htm
Australian Government	Various fishery datasets www.daff.gov.au/fisheries
CEFAS – Centre for Environment, Fisheries and Aquaculture Science, United Kingdom	A wide range of fisheries for mainly UK waters www.cefas.co.uk/products-and-services/data-and-technology/fisheries-management-systems.aspx
CEPHBASE	Extensive database on cephalopods www.cephbase.utmb.edu/
Coastal and Ocean Information Network Atlantic (COINAtlantic)	Metadata records covering Atlantic Canada http://coinatlantic.ca/
CCAMLR – Commission for the Conservation of Antarctic Marine Living Resources	Fisheries data for the Antarctic region www.ccamlr.org/pu/E/sc/dat/intro.htm
European Commission (Eurostat)	Comprehensive Fisheries data http://epp.eurostat.ec.europa.eu/portal/page/portal/fisheries/introduction
European Union (FIDES)	A "one stop" shop that automates the management of fishery data http://ec.europa.eu/idabc/en/document/2254/5926
FAO, Rome	Statistical data available from FAO Fisheries and Aquaculture Department www.fao.org/fishery/statistics/en
FishBase	www.fishbase.org/home.htm A global information system on fishes
GISFish – FAO, Rome	A "one stop" site from which to obtain the global experience on Geographic Information Systems (GIS), Remote Sensing and Mapping as applied to Fisheries and Aquaculture. www.fao.org/fishery/gisfish/index.jsp
ICCAT – International Commission for the Conservation of Atlantic Tuna	Fishery statistics for all fisheries in the Atlantic www.iccat.int/en/
ICES – International Council for Exploration of the Seas	A range of fisheries data covering the North Atlantic www.ices.dk/datacentre/index.asp
INTUTE	Portal to detailed archives including marine biology www.intute.ac.uk/cgi-bin/browse.pl?id=117967
Marine Life Information Network for Britain and Ireland	Marine environmental data www.marlin.ac.uk/marinedata.php
National Biological Information Infrastructure	Extensive biological information www.nbii.gov/portal/server.pt
National Oceanographic Data Center of NOAA	Access to indexing and abstracting databases covering a wide range of fisheries related topics www.lib.noaa.gov/researchtools/journals/databases.html
NOAA Fisheries – Office of Science and Technology	Fisheries statistics for USA www.st.nmfs.noaa.gov/st1/index.html
Northeast Fisheries Science Center	List of worldwide fisheries databases www.nefsc.noaa.gov/nefsclibrary/dbs.html
NAFO – Northwest Atlantic Fisheries Organization	Supplies data on fisheries catches and landing for 12 North Atlantic countries www.nafo.int/fisheries/frames/fishery.html
United States Geological Survey (USGS) – Fisheries Data Center	List of fisheries data servers in the USA www.umesc.usgs.gov/data_library/fisheries/fish_page.html
Woods Hole Institute, United States of America	Library search facilities for databases on fisheries www.mblwhoilibrary.org/databases/index.php?search=fisheries
WRI – World Resources Institute	Searchable database on coastal and marine ecosystems http://earthtrends.wri.org/searchable_db/index.php?theme=1

[1] All Internet addresses correct as of 14 October 2009.

MARINE DATA

Organization	Description and Web site URL
APL Ocean Remote Sensing	Wide range of satellite data http://fermi.jhuapl.edu/
Australian Government – Bureau of Meteorology	Meteorological and marine data for Australia and Antarctica www.bom.gov.au/
Australian Government – Department of the Environment, Water, Heritage and Arts	Marine data products for Australia www.environment.gov.au/erin/index.html
Australian Ocean Data Centre	Marine data from a multi-agency distributed data system www.aodc.gov.au/
Baltic Sea Region GIS	Regional datasets for the Baltic Sea www.grida.no/baltic/
British Antarctic Survey	Various marine data for the Antarctic waters www.antarctica.ac.uk/bas_research/data/index.php
British Oceanographic Data Centre	Worldwide marine data sets www.bodc.ac.uk/
BSH, Germany	Marine data and data holding centres in Germany www.bsh.de/en/index.jsp
Centre National D'Etudes Spatiales (CNES), France	Various microwave satellite altimetry data products www.aviso.oceanobs.com/en/data/index.html
CISL Research Data Archive	A range of collections of oceanographic observations http://dss.ucar.edu/catalogs/free.html
CSIRO – Marine and Atmospheric Research, Australia	Marine datasets for Australia www.marine.csiro.au/datacentre/
CSIRO – Observing the Ocean, Australia	Marine satellite data for Australia www.marine.csiro.au/~lband/
DLR – Applied Remote Sensing Cluster	German satellite remote sensing data www.dlr.de/caf/en/desktopdefault.aspx
EOWEB – Earth Observation on the web	Various remote sensing data sets http://eoweb.dlr.de:8080/servlets/template/welcome/entryPage.vm
EPIC – Pacific Marine Environmental Laboratory	Access to earth observation data www.epic.noaa.gov/epic/
European Commission – Sea-Search	Gateway to oceanographic and marine data for Europe www.sea-search.net/
Fisheries and Oceans Canada (DFO) – Ocean and Ecosystem Science	Oceanographic data for eastern Canada www.mar.dfo-mpo.gc.ca/science/ocean/sci/sci-e.html
IFREMER, France	Access to French oceanographic data www.ifremer.fr/sismer/index_FR.htm
INFORAIN	Searchable database of geographic data for western USA and Canada www.inforain.org/dataresources/datalayers.cfm
Integrated Science Data Management (ISDM), Canada	Marine buoy and satellite data for Canada www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/index-eng.html
IRI/LDEO Climate Data Library	Various historical marine and atmospheric datasets http://iridl.ldeo.columbia.edu/
Lamont-Doherty Earth Observatory	Wide range of datasets at global and regional level www.ldeo.columbia.edu/research/databases-repositories
MarineGIS, Canada	List of marine data centres www.marinegis.com/
MARIS – Marine Information Service, Netherlands	Oceanographic and marine data and information in Europe www.maris.nl/
NASA – Earth System Science Data and Services	Listing of NASA's satellite data archives http://nasadaacs.eos.nasa.gov/about.html
NASA – Goddard Earth Sciences Division	Various NASA's satellite data http://disc.sci.gsfc.nasa.gov/
NASA – Goddard Space Flight Center	Various worldwide oceanographic datasets http://gcmd.gsfc.nasa.gov/
NASA – Goddard Space Flight Center	Worldwide SeaWIFS data http://oceancolor.gsfc.nasa.gov/SeaWiFS/

MARINE DATA (cont.)

Organization	Description and Web site URL
NASA – Goddard Space Flight Center	Various colour and thermal satellite products http://oceancolor.gsfc.nasa.gov/
National Geophysical Data Center	World shoreline and coastline data http://geodiscover.cgdi.ca/gdp/index.jsp?language=en
Naval Research Laboratory – Ocean Sciences Branch	Marine satellite data for selected areas http://www7240.nrlssc.navy.mil/
NEODASS – Dundee Satellite Receiving Station	Archived AVHRR, Modis and SeaWifs satellite data www.sat.dundee.ac.uk/auth.html
NOAA – Comprehensive Ocean Atmosphere Datasets	Worldwide satellite images http://icoads.noaa.gov/
NOAA – National Data Buoy Center	Worldwide Meteorological and oceanographic buoy data http://seaboard.ndbc.noaa.gov/
NOAA – Shoreline Data	Worldwide shoreline data http://shoreline.noaa.gov/
NOAA – Tropical Atmosphere Ocean Project	Ocean buoy data for the central Pacific www.pmel.noaa.gov/tao/
NOAA – Global Drift Program	Worldwide drifter buoy data www.aoml.noaa.gov/phod/dac/gdp.html
NODC – National Oceanographic Data Center, USA	Worldwide marine biological and physical data www.nodc.noaa.gov/
NODC – National Oceanographic Data Center, USA	Global ocean temperature and salinity data www.nodc.noaa.gov/GTSPP/gtspp-home.html
OBIS – Ocean Biogeographic Information System	Worldwide marine biogeographic data www.iobis.org/

The ecosystem approach to fisheries (EAF) has been developed over the last decade in response to perceived and actual deficiencies in previous methods of management. The EAF recognizes that fish are only one albeit important part of a much wider ecosystem incorporating an array of physical and biological components that humans interact with and exploit. Rather than managing single fish stocks, an EAF is concerned with the impacts of fisheries on the marine ecosystem, the interactions between different fisheries, of fisheries with the aquaculture sector, as well as with other human activities. Geographic Information Systems (GIS) are considered an ideal platform upon which to perform necessary information management and decision-support analysis for the implementation of an EAF. This technical paper is intended to be a guide to methods that readers could adopt for their own use of GIS for an EAF. The planning considerations for appropriate GIS in terms of objectives, scope and geographical area are outlined. The practical considerations are discussed and include hardware architecture, various software possibilities, sources and types of data that will be needed, and the array of backup and support that is available.

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