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.

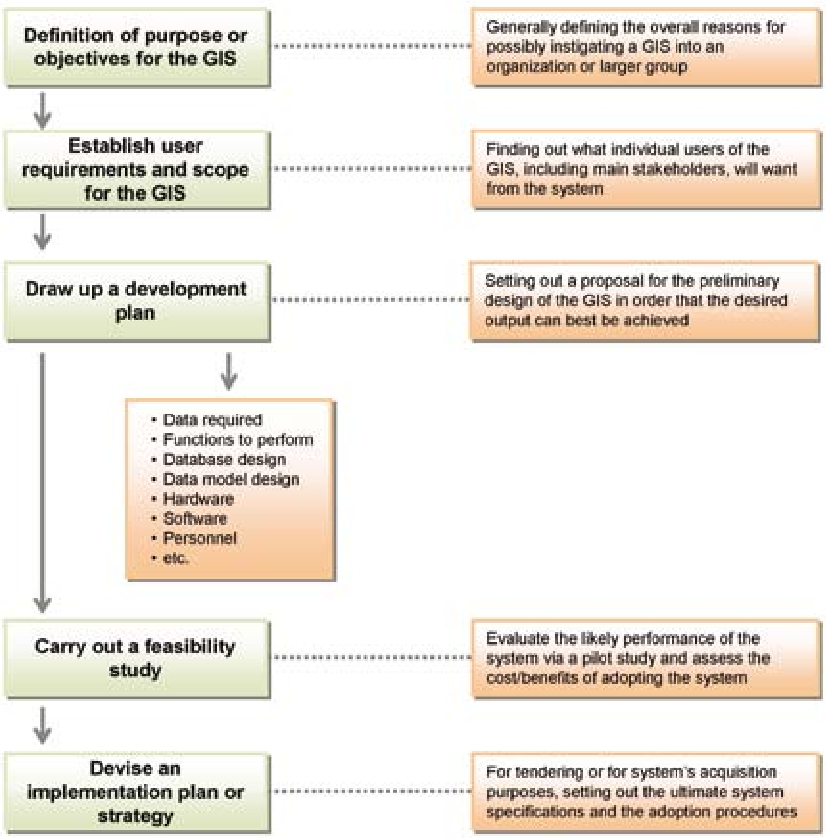
Figure 6.1 shows the steps in the design of a typical GIS. In the literature, there are many variations on this system development model. Further details of system design are given in Tomlinson (2007) and Peters (2008)[17]. The first two steps of the system development process are examined in this section. 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

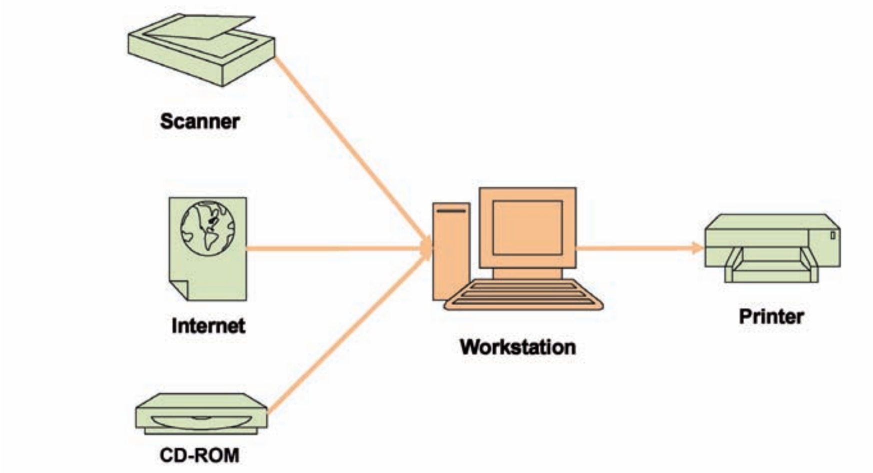
- Who are the main partners likely to initially participate in the broader GIS work?
- Who will be taking the lead role in GIS work or decision-making?
- What is the current range and state of the computing facilities?
- What type and range of GIS output needs to be produced?
- What are the main options 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.

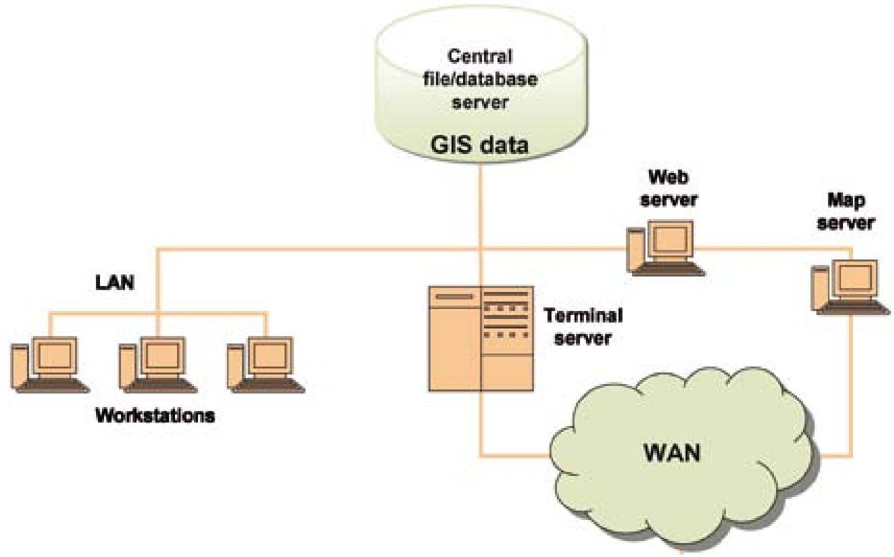
FIGURE 6.2
A minimal stand-alone computing configuration for GIS work



Source: The authors.

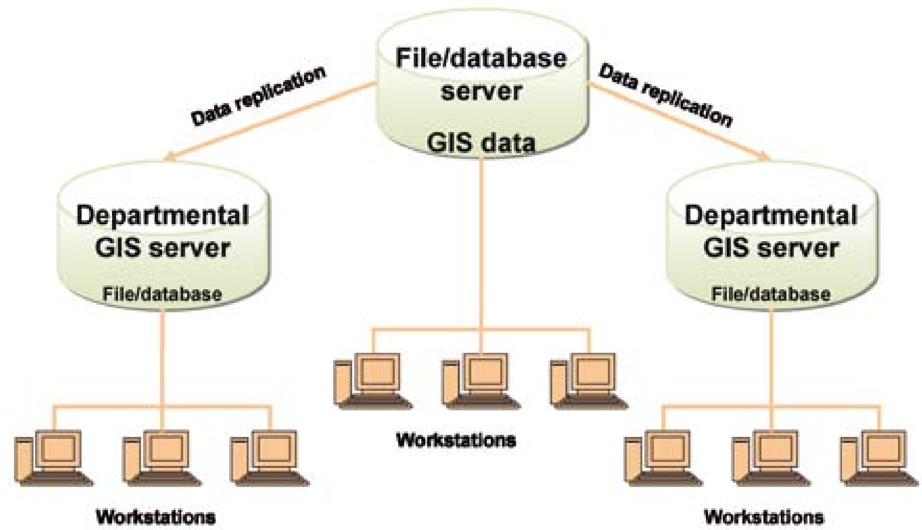
[18] For further details see www.isotc211.org
[19] For further details see www.opengeospatial.org

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.

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[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.

[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.

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[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.