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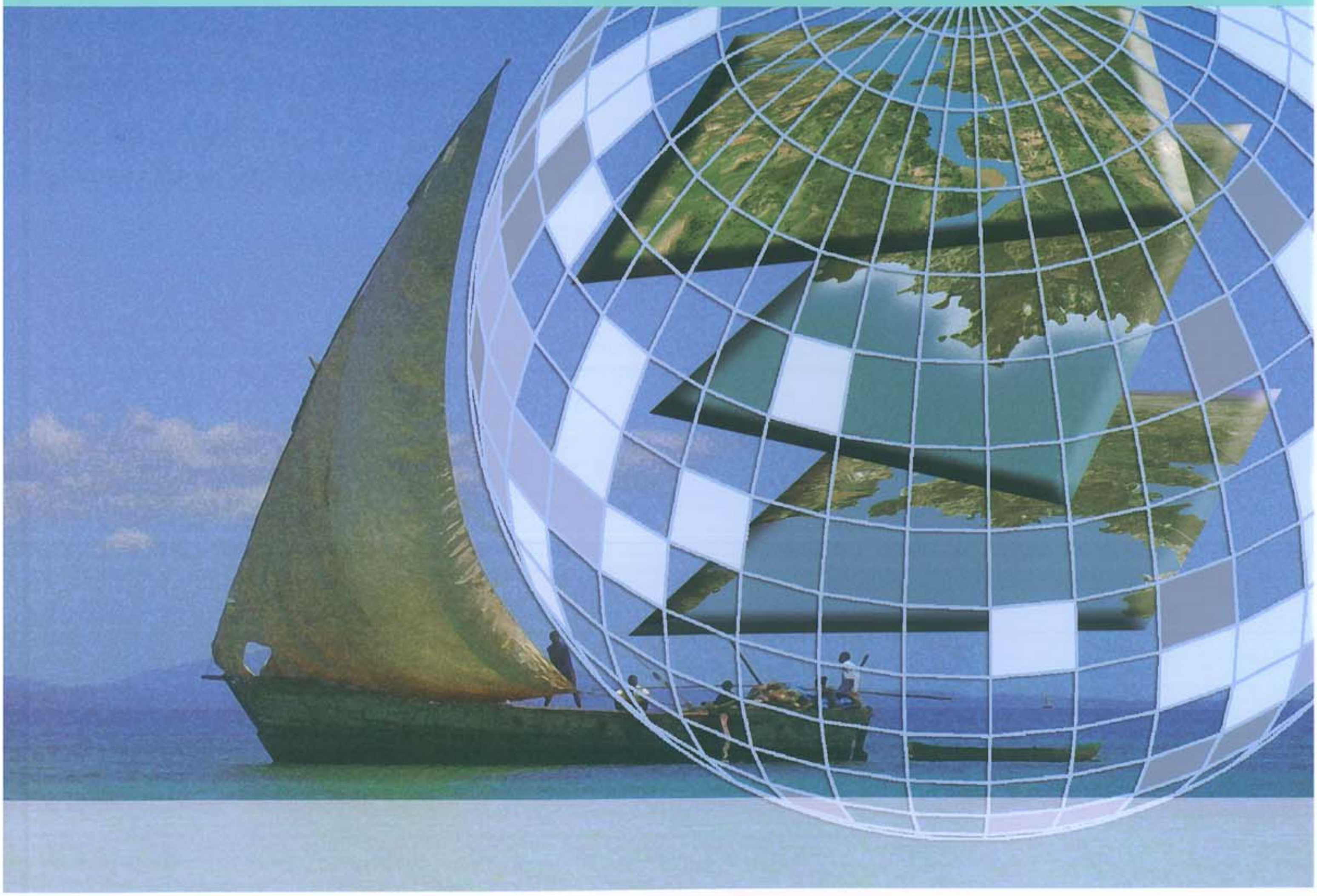
Geographic Information Systems to support the ecosystem approach to fisheries

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.