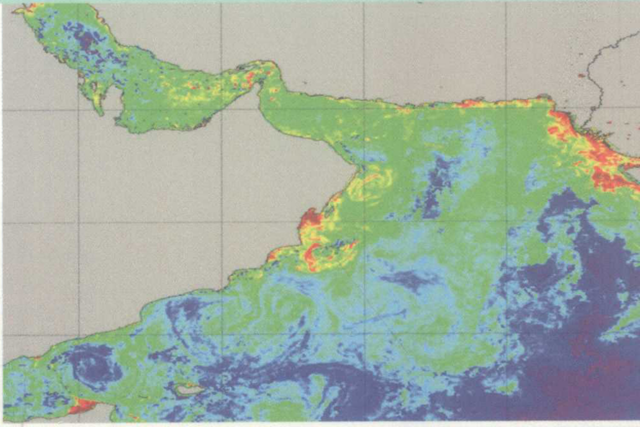
FAO
FISHERIES AND
AQUACULTURE
TECHNICAL
PAPER

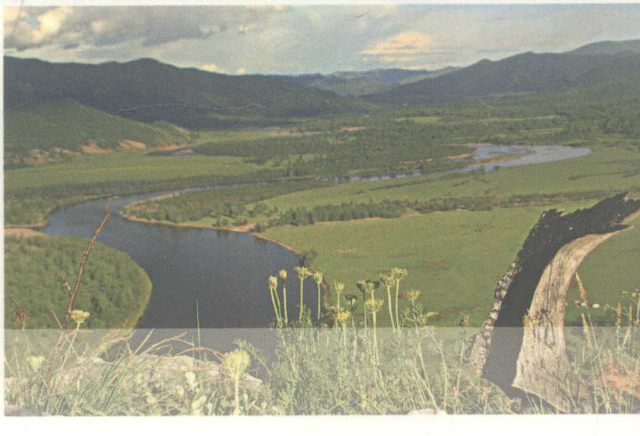
552

ISSN 2070-7010

Advances in geographic information systems and remote sensing for fisheries and aquaculture

Summary version



Advances in geographic information systems and remote sensing for fisheries and aquaculture

FAO FISHERIES AND AQUACULTURE TECHNICAL PAPER

552

Summary version

Edited by
Geoffery J. Meaden
FAO consultant
Canterbury
United Kingdom of Great Britain and Northern Ireland

and

José Aguilar-Manjarrez
Aquaculture Officer
Aquaculture Branch
FAO Fisheries and Aquaculture Department
Rome, Italy

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2013

ISBN 978-92-5-107391-9 (print)
E-ISBN 978-92-5-107585-2 (PDF)

Cover photos:
Clockwise from top left: Double-rigged shrimp trawler with cod end of one net about to be opened (courtesy of Robert K. Brigham, NOAA's Fisheries Collection); Chlorophyll concentrations in the Gulf of Oman region (courtesy of ACRI-ST InfoceanDesk environment monitoring service from EU FP7 and ESA MyOcean GlobColour Products, ESA ENVISAT MERIS data, NASA MODIS and SeaWiFS data); Uur River in Mongolia (courtesy of Zeb Hogan); Gilthead seabream cages, Lavagna, Ligurian Sea, Italy (courtesy of Aqua sarl and Francesco Cardia).

Preparation of this document

A challenge to geographic information systems (GIS) and remote sensing work on fisheries or aquaculture concerns geographic cognition and spatial awareness. There is a lack of appreciation that many or perhaps most of the problems concerning fisheries and/or aquaculture may be rooted in spatial differentiation, thus fisheries managers and others may often not appreciate the importance of the geographic perspective. It is because of this lack of appreciation that there is the need to train people in the use of GIS and remote sensing. The recent emergence of "marine spatial planning" is an exact reaction to this lack of realization about the importance of spatial issues. As a consequence, this technical paper was prepared to provide policy-makers and senior managers, who have to deal with their national fisheries and aquaculture sectors, with an overview of GIS and remote sensing tools to help them lead to more sustainable fisheries and aquaculture. This document will also be of relevance to aquaculture operators, industry organizations, non-governmental organizations and other groups interested in understanding GIS and remote sensing and their influences on master plans, industry regulation and the management of aquatic resources.

The FAO Fisheries and Aquaculture Resources Use and Conservation Division has been active in promoting the use of GIS and remote sensing in fisheries and aquaculture for many years. Promotional activities have been carried out by means of technical publications, training courses and workshops as well as the FAO GISFish Web site also created for this purpose.

The need for technical papers for understanding and applying GIS and remote sensing in fisheries and aquaculture was recognized in the 1990s; in fact, the Food and Agriculture Organization of the United Nations (FAO) commissioned and published the first technical papers on the subject: *Geographical information systems and remote sensing in inland fisheries and aquaculture* (Meaden and Kapetsky, 1991) and *Geographical information systems: applications to marine fisheries* (Meaden and Do Chi, 1996). The present technical paper aims to update these papers.

Abstract

Marine fisheries around the world remain seriously threatened from fishing overcapacity plus a range of environmental problems. As a result, the rising demand for fish products is largely being supported from increased aquaculture output. Changes in the sourcing of fish will continue to cause significant spatially variable effects on the marine and other aquatic environments, effects that are best managed through the application of geographic information systems (GIS) and remote sensing methods. Furthermore, changes need to take into account wider approaches to addressing aquatic problems, i.e. via marine spatial planning and/or ecosystem approaches to both fisheries and to aquaculture. This publication is an essential guide to understanding the role of spatial analysis in the sustainable development and management of fisheries and aquaculture. The publication is an easy-to-understand publication that emphasizes the fundamental skills and processes associated with geographic information systems (GIS) and remote sensing. The first chapter initially puts the array of spatially related problems into perspective and discusses the earlier applications of GIS and remote sensing. Chapters, 2, 3 and 4 outline what are considered to be the basics on which GIS can function, i.e. hardware and software; spatial data; and how GIS systems themselves are best implemented. Chapter 5 looks at preparing the data for GIS use and Chapter 6 explores what remote sensing consists of and the main purposes for its use. Chapter 7 discusses the functional tools and techniques offered by typical GIS software packages. Chapters 8, 9 and 10 examine respectively, the current issues and status, including extensive case studies, of the application of GIS and remote sensing to aquaculture, to inland fisheries and to marine fisheries. The final two chapters examine the emerging thematic issues that will be faced by fisheries and aquaculture in the near future, and then provides useful clues as to how challenges in accomplishing GIS work might best be overcome. The paper concludes with a series of recommendations underlining the paramount need to recognize that it is mainly through the application of a spatial perspective and approach that problems in fisheries and aquaculture will be better addressed. This technical paper is an update of previous FAO publications.

This publication is organized in two parts to inform readers who may be at varying levels of familiarity with GIS and remote sensing. One part is a summary and is addressed to administrators and managers, while the other is the full document and is intended for professionals in technical fields and for university students and teachers. The latter part is available on a CD–ROM accompanying the printed part of this publication.

Meaden, G.J. & Aguilar-Manjarrez, J., eds. 2013. *Advances in geographic information systems and remote sensing for fisheries and aquaculture.* Summary version. FAO Fisheries and Aquaculture Technical Paper No. 552. Rome, FAO. 98 pp. Includes a CD–ROM containing the full document (425 pp.).

Acknowledgements

This document was edited by G.J. Meaden (FAO consultant, Canterbury, United Kingdom) and J. Aguilar-Manjarrez (FAO Aquaculture Branch, Rome, Italy). The editors would like to acknowledge the authors of the review chapters contained in FAO Fisheries and Aquaculture Technical Paper No. 552, on which this technical paper is based. They were, in alphabetical order: F. Carocci (FAO Marine and Inland Fisheries Branch, Rome, Italy), A.M. Dean (Hatfield Consultants Partnership, North Vancouver, Canada), W. Fisher (Cornell University, Ithaca, United States of America), J. Jenness (FAO consultant, Flagstaff, Arizona, United States of America), J. M. Kapetsky (FAO consultant, Wilmington, North Carolina, United States of America), J. Populus (IFREMER, Plouzané, France), and S.Walker (NOAA Coastal Services Center, Charleston, United States of America).

In addition, many thanks are also due to reviewers for their many valuable comments: R. Asmah (Water Research Institute, Accra, Ghana), D. Dauwalter (Trout Unlimited, Boise, United States of America), W. Fisher (Cornell University, Ithaca, United States of America), J.M. Kapetsky (FAO consultant, Wilmington, North Carolina, United States of America), J. Long (Oklahoma State University, Stillwater, United States of America), P. Longdill (Environmental Science and Economics COWI, Doha, Qatar), C. Martin (UNEP, Cambridge, United Kingdom), L.G. Ross (Institute of Aquaculture, Stirling, United Kingdom), P.C. Scott (Universidade Santa Ursula, Rio de Janeiro, Brazil), O. Strand (Institute of Marine Research, Bergen, Norway), and P. Suvanachai (Department of Fisheries, Bangkok, Thailand).

The editors would also like to thank M. Giannini (FAO consultant, Rome, Italy) for proofreading the document, and M. Guyonnet (FAO Statistics and Information Branch, Rome, Italy), for supervising its publication. K. Ivens (FAO consultant, Rome, Italy) prepared the layout design and assisted in the cover design. Last, thanks are due to many colleagues who kindly provided copies of their papers, articles and technical reports for review. The editors acknowledge, with thanks, the financial aid provided by the Aquaculture Branch (FIRA) and the Marine and Inland Fisheries Branch (FIRF) of the FAO Fisheries and Aquaculture Department, and the support provided by J. Jiansan (FIRA Chief) and G. Bianchi (FIRF Coordinator).

Abbreviations and acronyms

ASFA	Aquatic Sciences and Fisheries Abstracts (FAO)
AUV	autonomous underwater vehicles
CHARM	Channel Habitat Atlas for Resource Management
COAs	conservation opportunity areas
DEM	digital elevation model
DMBS	database management systems
EAA	ecosystems approach to aquaculture
EAF	ecosystems approach to fisheries
EMR	electromagnetic radiation
ERS	Earth Resources Satellite (from ESA)
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
FOSS	free or open source software
GIS	geographic information system
GISFish	Global gateway to geographic information systems, remote sensing and mapping for fisheries and aquaculture
GPS	global positioning systems
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer
ISO	International Organization for Standardization
IT	information technology
LAN	local area network
LiDAR	light detection and ranging
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MPA	marine protected area
NASO	National Aquaculture Sector Overview
PDA	personal digital assistant
SAR	synthetic aperture radar
SMOS	Soil Moisture and Ocean Salinity
SPEAR	Sustainable options for People, catchment and Aquatic Resources
SPOT	Système Pour l'Observation de la Terre
TIN	triangulated irregular network
TOREDAS	Traceable and Operational Resource and Environment Data Acquisition System
UNESCO	United Nations Educational, Scientific and Cultural Organization
USB	Universal Serial Bus
UTM	Universal Transverse Mercator
WAN	wide area network

Foreword

Global ecosystems are under enormous pressure. The pressure comes mainly from the increasing human population, which is attempting to extract resources at an accelerating rate from a planet that is finite. The pressure on fishery resources is manifested in a variety of ways, including: (i) reduced access to, and availability of, land and water (especially freshwater); (ii) overfishing of commercial fish stocks; (iii) degradation of fish habitats; (iv) pollution and deoxygenation of waters; (v) increasing competition for the use of the aquatic space; and (vi) changes in atmospheric processes, such as climate change and its consequences.

The FAO Fisheries and Aquaculture Department is charged with the important responsibility of tackling these issues. Its principle "mission" is to "promote policies and strategies aimed at sustainable and responsible development of fisheries and aquaculture in inland and marine waters." More specifically, within the Fisheries and Aquaculture Resources Use and Conservation Division (FIR), the Aquaculture Branch (FIRA) is responsible for "programmes and activities related to development and management of marine, coastal and inland aquaculture, with regards to technical, socio-economic and environmental aspects, and conservation of aquatic ecosystems, including biodiversity", and the Marine and Inland Fisheries Branch (FIRF) is "responsible for all programmes and activities related to management and conservation of fishery resources, including mainstreaming biodiversity and ecosystem concerns in fisheries management through an ecosystem approach to fisheries". Readers of this technical paper will see that its subject matter goes right to the heart of both of these remits.

In order to directly address the serious aquatic issues described above, how is it best possible for FAO to meet its responsibilities? Although each of the issues has to be dealt with in an individual way, a detailed look at the full range of issues reveals that spatial problems are an important commonality.

The use of spatial planning tools such as Geographic information systems (GIS) and remote sensing for fisheries and aquaculture can greatly help in the identification, analysis and possible allocation of specific geographical areas to be used for fisheries and aquaculture, particularly in those countries that have limited natural resources that are in high demand by competing users. Spatial tools can also simplify the process of zoning and site selection for aquaculture and can match other demands on the marine space. These tools, therefore, become important considerations in bridging the future supply and demand gaps in fishery products. And now that planning, management and research in the marine and other aquatic spaces is dominated by "ecosystem approach" considerations, and with the need to better consider other users of marine space through "marine spatial planning", it is certain that GIS will prove to be an indispensable tool. GIS and remote sensing technologies are invaluable technologies to support sustainable aquaculture expansion and intensification as well as sustainable fisheries.

Árni M. Mathiesen
Assistant Director-General
FAO Fisheries and Aquaculture Department

Contents

Figures

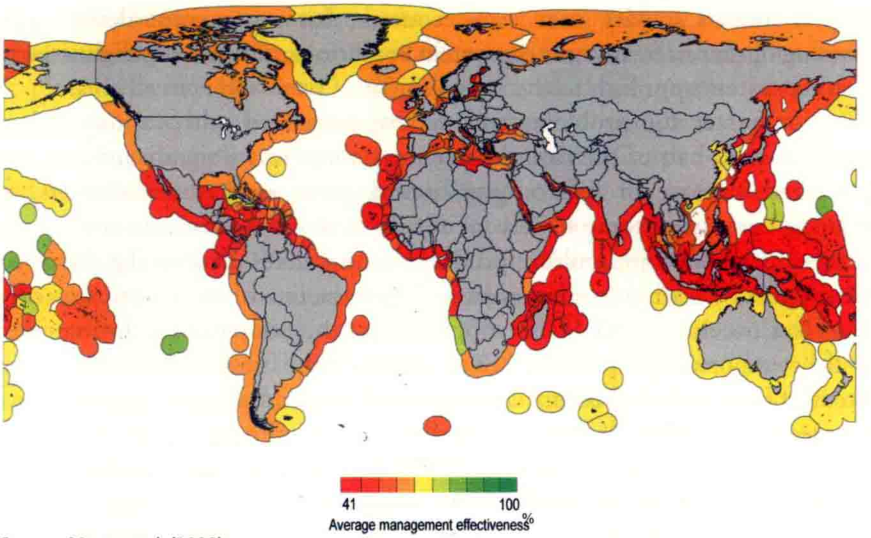
Boxes

1. Introduction

G.J. Meaden (FAO consultant, Canterbury, United Kingdom) and
J. Aguilar-Manjarrez (FAO Aquaculture Branch, Rome, Italy)

For several decades it has been recognized that the world's fish stocks are becoming increasingly depleted, with the Food and Agriculture Organization of the United Nations (FAO, 2012) recognizing that 57 percent are fully exploited, 30 percent overexploited and 13 percent are not fully exploited. Even a decade ago, Myers and Worm (2003) established that stocks of higher trophic level species were only about 10 percent of their pre-industrial fishing levels, and now in specific areas or fisheries the spawning biomass has been reduced by over 97 percent. Throughout the developed world there is evidence of a rapid growth in fish landings and effort during the early twentieth century, with declining catches occurring after the 1960s. In less developed areas, this rise and fall of fisheries is a more recent phenomenon. Stock overexploitation results not only from too much fishing pressure from highly capitalized fleets, but also from poor fishing practices and management (including illegal fishing), from conflicts in the use of marine space, from political decisions prioritizing short-term socio-economic considerations over longer-term environmental realities, and from various forms of environmental degradation. In less developed areas, fishery problems are compounded by the high demand for fish in protein-restricted circumstances, the lack of alternative employment,

FIGURE 1
Overall effectiveness of fisheries management in the world's exclusive economic zones



Source: Mora *et al.* (2009).

poor governance, and the lack of knowledge and data. Worldwide, the impacts of stock depletions are felt on the unsustainability of remaining stocks, on massive economic waste, increasing social costs and food insecurity. There is now an urgent need for fisheries to be managed more effectively, especially in lower income areas (Mora *et al.*, 2009). Figure 1 provides an indication that none of the fisheries in the world's exclusive economic zones are being managed at more than an 80 percent effectiveness level, with the majority at about 50 percent.

To add to these anthropogenic and institutional problems, fisheries are experiencing pressures that are externally imposed. The rapid world population increase means that food demands are soaring, giving rise not only to uncertainties in supplies but also to price increases and instability. Energy costs have also been rising sharply in response to strains on both demand and supply, and this affects the price of most goods and services, including the direct cost of fishing. The most worrying externally imposed problem, however, is that caused by climate change, with its profound effect on species distributions, ecosystems stability, trophic web interactions, and the very existence of many aquatic ecosystems. Climate change will have other impacts on fisheries through changing weather patterns and sea levels, and it will necessitate rapid and diverse changes in the socio-economics of most fishery activities (FAO, 2008).

It is not only marine fisheries that are undergoing rapid change and uncertainty. Mainly in developing countries, inland fisheries for local consumption have shown significant growth since the 1970s; this contrasts with the situation in developed countries, where catches from recreational fishing have now overtaken commercial inland fish production. However, there are generally large uncertainties on the stock situation for most inland fisheries, and appropriate management of fish stocks is minimal in most areas, especially in developing countries. All stocks in inland waters are particularly vulnerable to increasing environmental pressures and to climate change, which often negatively impacts water quality and quantity. But it is human activity near water courses that prove most detrimental to sustaining optimum freshwater ecosystem conditions, and this highlights the need for an ecosystem approach to the management of freshwaters in all areas.

To counteract the problems and demise associated with capture fisheries, over the second half of the twentieth century there was a significant and almost exponential increase in fish output coming from aquaculture systems, with production providing some 46 percent of fish for worldwide human consumption. About 90 percent of aquaculture production now takes place in the Asia-Pacific region. Recently, various pressures have caused the rate of increase in aquaculture output to slow down, and, if fish supplies from this source are to be maintained, it will be important to produce lower trophic level fish to reduce the fishmeal content of feeds and to promote environmentally sound aquaculture practices and resource management. Of critical importance will be the successful integration of fish production into a wide range of conventional farming practices. These various requisites for successful aquaculture are themselves totally dependent on a good site location, with this applying to both marine and inland farmed production.

Although not all problems of securing adequate future fish supplies are within human control (fish recruitment is also exacerbated by biological and natural physical perturbations), there remains a fundamental necessity to develop improved fishery management measures. This is being addressed through new approaches, such as the ecosystem approach to fisheries or the ecosystem approach to aquaculture, and to more holistic marine spatial planning. Arising from the above discussion, it is the thesis of this technical paper that the majority of the problems currently faced by world fisheries and aquaculture lie in the spatial domain. Thus, there is spatial dis-equilibrium among the factors of production (production functions) that control, regulate or best determine a successful fishery or aquaculture unit. The technical paper describes the main production functions; explains how the distribution of these functions may vary from area to area, and how each function's relative importance to fish production success also varies. Through analyses of the relationships between spatially variable production functions, it is possible to establish optimum input combinations so as to achieve successful production outputs. Fisheries managers will increasingly need to consider the spatial aspects governing output, and this is best done through the use of geographic information systems (GIS).

GIS are essentially spatial analysis software, though for the system to function properly, it is necessary to consider the hardware, data, personnel and procedures that are essential to obtaining useful output from the software. The types of spatial analyses that GIS provides include measurement (linear, aerial, volumetric and temporal), distribution and relationship analyses, network analysis, geostatistical analyses, interpolation, and a wide range of modelling. GIS is now used in a broad spectrum of application areas, including by government, business, academia, industry, military and natural resource management (including fisheries and aquaculture).

Because it is useful to have information on the development stages through which any technology has evolved, the emergence of GIS as a tool for spatial analysis is described in terms of three historical stages. First, early innovations took place between 1960 and 1980 when digital developments in graphical representation and database management allowed for simple mapping output using mainframe computers and line printers or plotters. Output costs during this period were extremely high, so work was limited mainly to government or major institutions or businesses. Second, the era of GIS commercialization spans the years between 1980 and 1995: costs rapidly came down and allowed markets to expand and data became far more abundant, mainly from remote sensing sources. The migration of computing capability from mainframe to micro computers (personal computers) contributed greatly to GIS proliferation, and it was in this period when application areas for GIS expanded, aided by necessary supporting infrastructure developments. At the end of this period, the world market for geospatial systems and services was growing at a rate of 14 percent per year. Finally, the period since 1995 has been an era of mass spatial exploitation. The use of spatial analyses has been recognized in many fields of study. GIS software companies have consolidated to produce some six to eight major proprietary software brands, and a whole infrastructure of support industries and associations has developed, including GIS educational programmes at all levels. Recent developments have been greatly facilitated by the Internet.

What are the reasons for this successful growth of GIS? They are briefly examined under four headings:

- **The growth in computing power.** Over the past 50 years, there has been an unremitting growth in computing power in terms of not only computers themselves, but also in terms of peripheral hardware devices, data storage capacity, associated software, computer graphics capability, and so on. This computing power increase has been at the rate of an order of magnitude every six years.
- **Progress in parallel developments.** GIS forms one specialized part of a complex and integrated array of mainly digital-based technologies; these include the Internet, remote sensing and global positioning systems, software and hardware, geostatistics, visualization, computer-aided design, and digital cartography. Developments in all of these fields have been essential to the success of GIS.
- **The proliferation of data.** The success of GIS is greatly dependent upon the quantity and quality of input data, and this is especially important for activities such as marine fisheries, which take place in extensive 3D aquatic environments. Numerous technical developments have allowed for both an ease of data collection methods, plus significant data cost reductions and greatly enhanced data storage and transfer capabilities.
- **The increasing demand for GIS output.** Demand for output has been fuelled by reduced costs of GIS processing, by a realization of the wide capabilities of GIS, and by the fact that so many problems are rooted in the spatial domain. Demand has also been spurred by a proliferation of GIS books, conferences, courses and exhibitions.

Because of the complex milieu in which these activities function, early uses of GIS for fisheries or aquaculture purposes were slow to materialize. Complexity is mainly in terms of data gathering, the mapping of moving objects, the 3D nature of aquatic space, and the generally fragmented nature of the organization of fisheries management or research. The first applications of GIS appeared in the mid-1980s, with most early work being led by FAO and aiming at aquaculture location, e.g. Kapetsky, McGregor and Nanne (1987). During the 1990s, GIS applications to fisheries and aquaculture proliferated into thematic areas such as atlases, mapping of habitats and marine productivity, fisheries management, aquaculture location and human impacts on fishery environments. About half of GIS work was directed towards marine fishery subjects, with the balance between inland fisheries and aquaculture. During this period, the first books were published (by FAO): Geographical information systems and remote sensing in inland fisheries and aquaculture (Meaden and Kapetsky, 1991) and Geographical information systems: applications to marine fisheries (Meaden and Do Chi, 1996). And towards the end of the 1990s, the first GIS conferences aimed specifically at fisheries and aquaculture were organized. In the past ten years, there has been considerable further expansion in GIS activity, with the emphasis being on quantitative and qualitative expansion in the work, and with far more sophisticated work being attempted. This is especially true in respect to sophisticated modelling and geostatistical analyses. The promotion of fisheries and aquaculture GIS through activities at FAO has been a major impetus to the recent proliferation of activity in this area.

Chapter 1 concludes with stating the aims of this publication. These aims are basically to outline the ways in which GIS can contribute to resolving many of the problems associated with fisheries and aquaculture, i.e. by taking an approach that assumes that most problems can be perceived as lying in the spatial domain and are thus conducive to GIS applications through relevant mapping and analysis functions. A secondary aim is to update and consolidate the earlier 1990s FAO publications mentioned above.

In preparing a technical paper that impinges on a complex mixture of themes and topics, there is inevitably a problem in arranging a logical sequence of the material. Although a consensus has been reached on the arrangement of chapters, some readers might find it necessary to "skip around" the document in the order that it makes best sense to them. Figure 2 shows the progression of stages through a GIS project and the human influences affecting these process stages. The left-hand column divides all the human inputs into internal (from within the group or organization) and external inputs (outside sources that may influence the GIS process stages). The main body of the right-hand flow diagram shows the linkages among successive stages that will typically be performed during the completion of any individual GIS-based project. It is important to note the feedback loop, which essentially means that the final information output from the GIS can either: (i) be directed towards any of the human inputs so that they are better informed on spatial-based matters relating to fisheries or aquaculture; and (ii) inform any further GIS work, e.g. perhaps as a result of models developed or any methods used. All of the process stages are covered by this technical paper.