12. Overcoming the challenges to fisheries or aquaculture GIS work

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12.1 INTRODUCTION

Given the wide range of thematic areas that are encapsulated within the three broad areas of "GIS", "fisheries" and "aquaculture", and thus the spectrum of knowledge that must be absorbed, it is not surprising that there will be challenges to working within any of these areas. This is especially the case given that the work is being attempted in a three-dimensional environment that may be in constant motion, and where the scale of the data needs is extremely large, certainly when compared with the majority of terrestrial GIS work. In this chapter, the purpose is to be both descriptive of a wide range of challenges and to attempt to provide useful clues as to how the challenges might be overcome. It needs to be mentioned that none of the challenges are absolute barriers to GIS work; instead, most challenges are problems that GIS users should be aware of in order that special consideration can be given to the best ways of dealing with them. Much of the material used in this section originates from Meaden (2004) (where more detail can be found), though the coverage of the material has been extended and updated, especially as it relates to tackling and hopefully overcoming the main challenges.

Figure 12.1 provides a schematic diagram showing the main challenges facing the use of GIS for fisheries or aquaculture purposes. Looking at the challenges by main category headings, it is clear that most can be broadly considered as being practical concerns, and, as such, they are likely to vary greatly according to the individual circumstances of GIS users. However, it is important also to note that there are a number of intellectual and/or theoretical challenges, and this demonstrates that the application of GIS requires some considerable thought and perception plus academic training and experience. The rest of this chapter will provide brief insights into the 16 specific challenges listed. Space prohibits detailed referencing, though much of this can be obtained from Meaden's (2004) original work.

12.2 MAPPING MOVABLE VARIABLES

The majority of all GIS work is devoted to spatial analyses of the terrestrial terrain. This is a much easier milieu in which to work (compared with aquatic areas) as the great majority of the features and objects being mapped are static. In aquatic environments, it is not only most of the objects being mapped that move,[288] but it is also the environment within which they exist (the water) that moves. In fact, the only static objects may be permanent features associated with the river, lake or marine area bottom such as coral reefs, seamounts, trenches and solid substrates plus shorelines or river banks, which may only show very gradual change. Even many of the bottom features, e.g. gravel, mud and sand, will be subject to varying degrees of movement. Notwithstanding these difficulties, attempts must be made to map moveable species or objects because without this information very little aquatic-based GIS work could be achieved.

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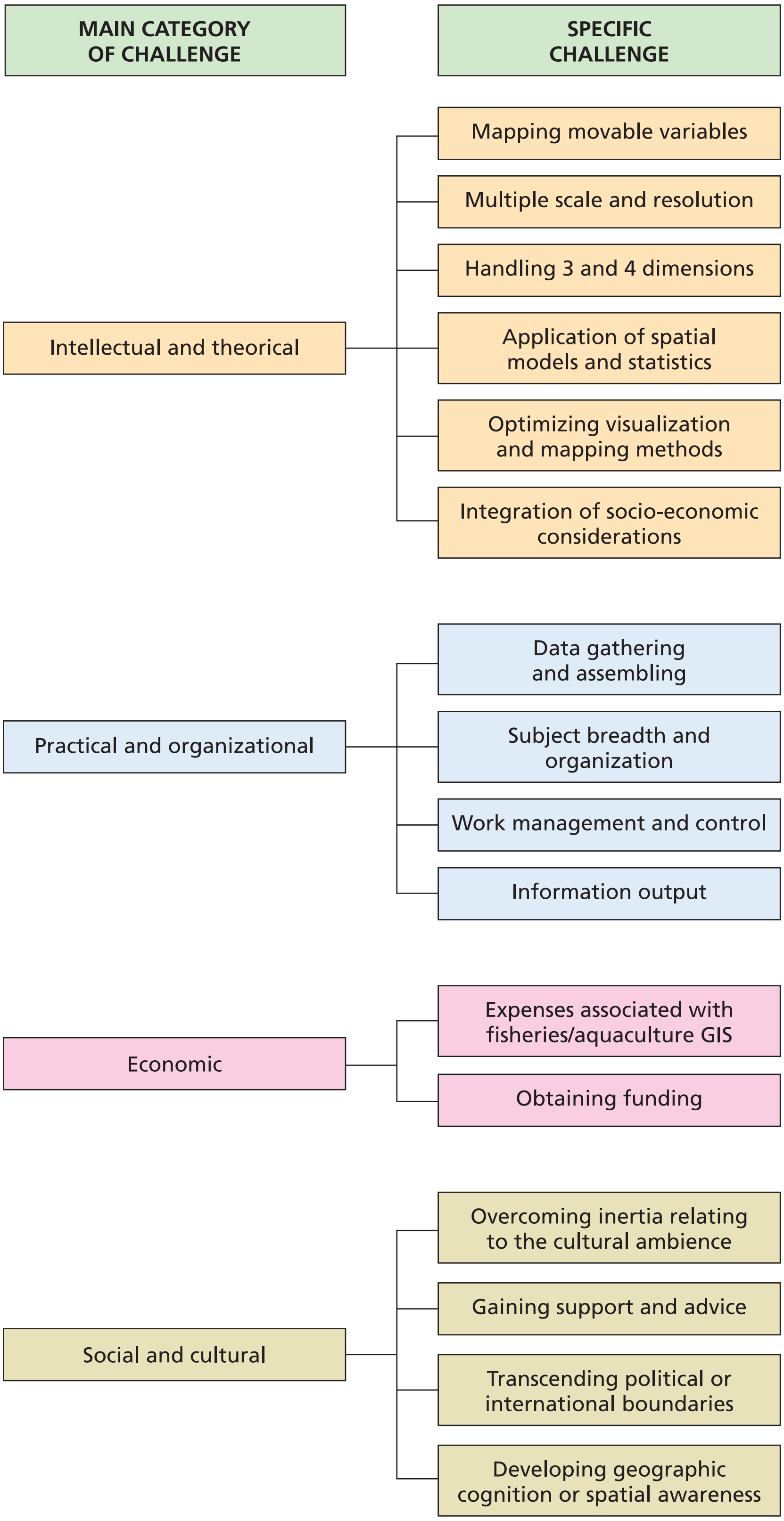
[288] The objects being mapped are typically aquatic animal species, but they can also be fishing vessels whose movements can be digitally recorded.

FIGURE 12.1
Categories of challenge facing fisheries and aquaculture GIS



Source: Adapted and updated from Meaden (2004).

Species movements exhibit different degrees of predictability and this can have a corresponding effect on mapping. For instance, salmon and whale migrations might be highly regular, and many of the larger ocean current or river water movements are also relatively regular. At the other extreme, it is likely that many occurrences of plankton blooms, or the foraging movements of fish, or the positions of ocean fronts are all highly irregular or chaotic. Therefore, the challenge for the GIS worker is – How best can process or object movements be mapped? Clearly, with the progression from regular movements towards chaotic movements, the mapping task becomes more difficult. For the mapping of many species movements, one answer lies in the frequency of data collection; thus, many species have annual cyclic movements perhaps between spawning and feeding areas, or they make other known seasonal migrations. For these species movements, less locational data may need to be collected. For situations where movements are chaotic and unpredictable, then the use of GIS for mapping might be solely for research purposes, i.e. it may be inadvisable to make positive decisions based on GIS output.

Careful thought must be given to the resolution or scale used for mapping of movement, i.e. this must equate to a resolution that can best discriminate important movements. For larger marine animals, including mammals, turtles and reptiles, it is often possible to fit tracking devices that record movements with time, and this can provide good insights into trends for any dominant or regular movements. There is now a body of academic work being deployed into aquatic animal movements, and some interesting GIS-based animations have been produced showing periodic snapshots of movement through time (Pittman and McAlpine, 2003; Rogers and White, 2007). Recent developments in studies of movement are allowing models to be developed that can predict where species are likely to be at given temporal intervals, and there is software that can be integrated to GIS that provide movement analysis tools, e.g. Animal Movement Analysis – ArcView Extension.[289] Given time, it is certain that additional models will accrue that give strong clues to the range and rates of movement recorded for many of the cyclic or seasonal movement patterns that occur with respect to both inland and marine waters.

12.3 MULTIPLE SCALE AND RESOLUTION

Scale is concerned with the relationship between distance or area on a map and the corresponding real size of the area under consideration, whereas resolution is concerned with the smallest size of a feature that can be mapped or measured. Both should incorporate a spatial and temporal dimension. The movement and size of aquatic environments or objects take place across a spectrum of scales and resolutions, and there has been a long history of discussion on the appropriateness of the scale of study. Figure 12.2 shows how some time and space bio-physical scales vary within the marine environment, and it is clear that any GIS fisheries-based work might need to gather data at vastly differing scales. A good illustration of the scale problem is provided in Feist *et al.* (2010), who use GIS in an attempt to resolve the optimum scale for studying Pacific salmon and their preferred habitats in the Columbia River basin in the United States of America. Contrasting scale of analyses are also shown in Chapter 9 where Section 9.5.1 provides an example of GIS being used at a microscale (study of a short section of a single stream), whereas Section 9.5.3 showed GIS being used at the whole state level within the United States of America. At any of these scales, GIS analyses can be extraordinarily complex in terms of data needs, models applied and the knowledge of natural processes required by the project participants. Schneider (1998) notes the importance of scale because:

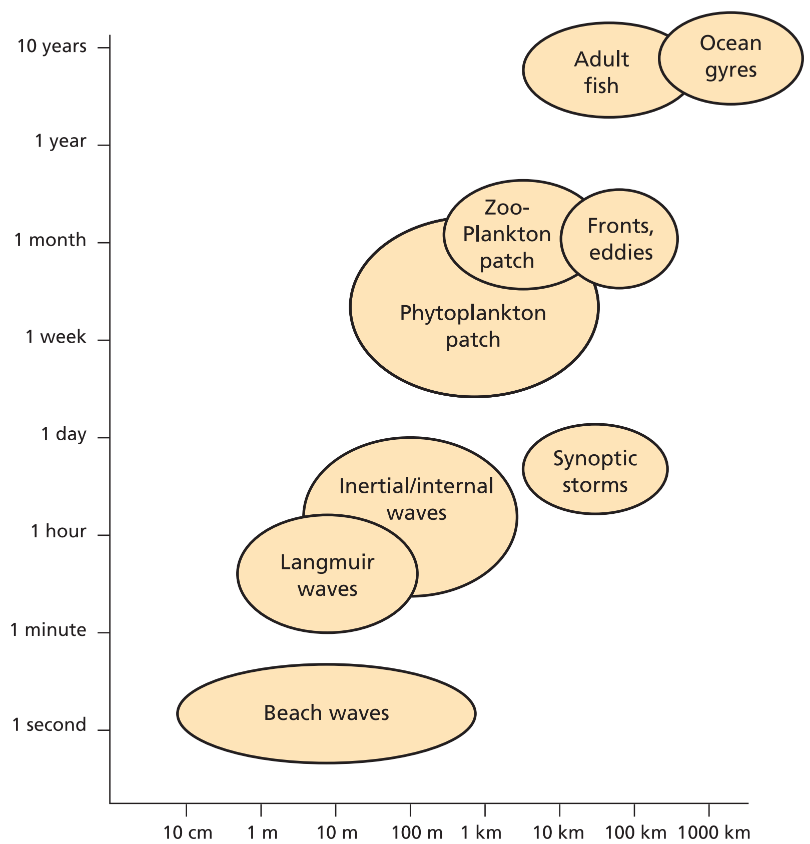
[289] This software derives from the seminal work by Hooge, Eichenlaub and Soloman (1999) and is available free of charge from the United States Geological Survey: http://alaska.usgs.gov/science/biology/spatial/gistools/index.php/animal_mvmt.htm#Introduction, though it is unlikely to be updated.

- spatial and temporal patterns depend on scale;
- experimental results cannot be extrapolated to other scales;
- biological interactions with the environment occur at multiple scales;
- population processes often occur at scales that are difficult to investigate;
- environmental problems arise through propagation of effects across scales;
- there is no single characteristic scale for research.

Fisheries science is concerned with processes that operate at all scales and it is important to determine the optimum scale at which to carry out research and mapping projects and thus spatial analyses. This is because many distributional patterns can only be discerned at appropriate scales. Finding the optimum scale might only be accomplished through trial and error, though clearly project scope and type of process will give sensible clues to an appropriate scale or resolution. However, there will often be complications because projects need to function at varying scales, and with the emergence of the ecosystem approach to fisheries (EAF) and the ecosystem approach to aquaculture (EAA), this problem is likely to be exacerbated.[290] As cautioned in Section 11.4.12, sometimes input data for a single project are only available at highly variable scales. The use of such mixed-scale data should be avoided if at all possible, especially if the thematic area being studied includes production functions that have highly variable spatial distributions.

FIGURE 12.2

Varying time and/or space scales for selected physical and biological marine variables



Source: Adapted from Dickey (1990).

[290] Ecosystems function at a range of scales from highly local to global; therefore, there is a need for a nested approach with different approaches to management according to scale. The EAF/EAA guidelines provide a common, coherent and practical framework for policy-making and promote a process of enhanced sectoral management at different scales, taking full account of environmental limits and the interests of other resource users and stakeholders (FAO Fisheries Department, 2003; FAO, 2010b).

If work proceeds using mixed-scale data, then the GIS output will be highly generalized and completely lacking in precision and reliability. Other questions arise, such as the optimizing of temporal scales, i.e. over what period should a study last and what might be the best time and/or space intervals between data sampling times and/or points? With respect to resolution, it is easy to appreciate the nature of the challenge by thinking of the simple perceptual problem of "How many data points (readings) are needed to construct a statistically valid single-time surface temperature map of the Pacific Ocean?" A single answer is impossible to state because it depends on the resources available for data gathering relative to the accuracy required for the map. All GIS-based projects involve similar scale and resolution challenges. A useful guide to the subject area concerned with creating maps (and their validity) based on different sampling strategies, scale, resolution and interpolation methods, mainly with respect to species distributions, is given in Rempel and Kushneriuk (2003).

12.4 HANDLING 2.5D, 3D AND THE 4TH DIMENSION

It is probable that proprietary marine (and other aquatic) GIS programs have been slow to develop because of the challenges of handling 3- or 4-dimensional mapping. Thus, terrestrial GIS work is mostly confined to just the two horizontal dimensions plus the fourth dimension of time, and most of the mapping can be readily accomplished. GIS are also capable of working in what has been called "2.5D", i.e. the two horizontal dimensions plus a height dimension that is fixed to the ground elevation (altitude), and imagery of ocean bathymetry is typical of this output (see Figure 10.20). But the majority of GIS fisheries work[291] is obliged to consider the true third dimension (in the marine case – depth), perhaps to analyse or map varying water temperatures by depth, or the location of schools of fish, or perhaps the depth and location of tagged marine species. While it is feasible to construct database facilities that store, manipulate and carry out statistical functions using x, y and z data, it is clear that maps produced on a flat surface cannot easily display information on all three axes at the same time. So the challenge for GIS work is how best to illustrate true 3-dimensional data. A number of attempts at 2.5D, 3D or 4D marine mapping have been made, and these attempts have usually taken one of three approaches:

(i) Using GIS software that contains embedded applications for producing 2.5D displays (typically of bathymetry). Examples of the first approach include "Marine Explorer" (described in Section 2.3.2), and EASy (Environmental Analysis System), which is a research-focused GIS having the capability to view, analyse and store diverse types of marine data, and the data can be displayed in 2.5D utilizing time, depth and added geospatial information[292]. A further major 3D product is Environmental Systems Research Institute's (ESRI) ArcGIS 3D Analyst, which allows viewing of large sets of data in three dimensions from multiple viewpoints, the querying of surfaces, and the creation of realistic perspective images that drape raster or vector data over a surface.[293]

(ii) Using specialist software applications that can be independent or integrated to GIS to plot a range of 2.5D to 4D imagery.[294] With respect to this second approach, showing the third dimension of variables that are continuous in 3D space, e.g. water temperature, salinity and pH. These can be shown via a series of static images through parallel "slices" of the area under study, with "slices" being at any prescribed orientation or distance frequency. These "slices" could of course be animated, for instance, to show how water temperature changes with incremental changes in

[293] Aquaculture is not usually concerned with the third dimension, though with offshore mariculture coming to prominence, this will be changing.

[292] Details on EASy are available at www.runeasy.com.

[293] Details at ESRI: www.esri.com/software/arcgis/extensions/3danalyst/index.html.

[294] The use of the term "maps" has been deliberately avoided here because most of the output from these 3D applications tend to be diagrammatic or they show oblique 3D images.

depth. An example of these specialist software applications is IDV produced by UNIDATA and which is freely obtainable,[295] and Booth and Wood (2004) show one of a series of convincing 3D images (that can be animated) illustrating the distribution of the hoki catch off the west coast of New Zealand's South Island.

(iii) Use of specialist 3D or 4D marine databases that have been developed for storing marine data and that are linked to GIS to achieve mapped output. However, attempts at the mapping of objects that are in the 3D waterbody but which are non-continuous have been more difficult to resolve. Figure 12.3 is a recent attempt at this, one that also includes a 4D (time) element. The figure shows aggregated herring catches from 2006 to mid-2010 along survey tracks in the Norwegian Sea and Arctic Sea areas bordered (clockwise) by Svalbard (top right), the Kingdom of Norway, Scotland, the Republic of Iceland and Greenland (top left).[296] Each year's catch per sampling point is shown by proportionally sized located circles.[297] It can be perceived that catches might have been at different depths, and although this depth data could easily be captured (recorded), it would be difficult to illustrate this on a paper map. Other interesting and novel attempts at true 3D displays have been reported by Wood and Baird (2010).

Examples of this third approach, i.e. using 3D specialist marine databases that can be integrated to most proprietary GIS, include "Ocean Database" by Oceanwise, Hampshire, the United Kingdom of Great Britain and Northern Ireland,[298] and "ArcMarine" by ESRI of Redlands, California, the United States of America.[299] It is relatively easy to show the time (4th) dimension, either through time sequential video-based animations or through a simple series of regular interval, static images. Additional information on various aspects of 3D or 4D GIS work can be found in Wright *et al.* (2007) and in Abdul-Rahman and Pilouk (2010).

In the realm of aquaculture, some progress has been made in recent years with regard to the use of 3D. For example, Moreno-Navas (2010) and Moreno-Navas, Telfer and Ross (2011a,b) developed a model in a 3D hydrodynamic model (MOHID) to predict coastal environmental vulnerability for Atlantic salmon cage aquaculture, the outcomes from which were subsequently imported into ArcView 3.2. This 3D hydrodynamic model, coupled to a particle-tracking model, was applied to study the circulation patterns, dispersion processes and residence time in Mulroy Bay, Co. Donegal, Ireland, an Irish fjord (shallow fjordic system), an area with important aquaculture activities. The results of this model could be used to facilitate decision-making for site locations and these could be integrated with wider ranging spatial modelling projects, such as coastal zone management systems and effective environmental management of fish cage aquaculture.

Of interest to note is the use of time series animations, effectively 2D + time and generated within GIS, for assessing aquaculture development potential. The Institute of Aquaculture in Stirling, Scotland, presents two examples (in the Argentine Republic and the People's Republic of Bangladesh) and to show the flood cycle over long-time periods, based on data from the Moderate Resolution Imaging Spectroradiometer (MODIS) operated from the Aqua and Terra satellites.[300]

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[295] Details on UNIDATA: www.unidata.ucar.edu/publications/factsheets/2010sheets/IDVHandout.pdf.

[296] Produced using "Eonfusion" software by Myriax Pty Ltd. Tasmania, Australia (www.eonfusion.com/uploaded/263/13400529_19eonfus ontechnicalwhite.pdf).

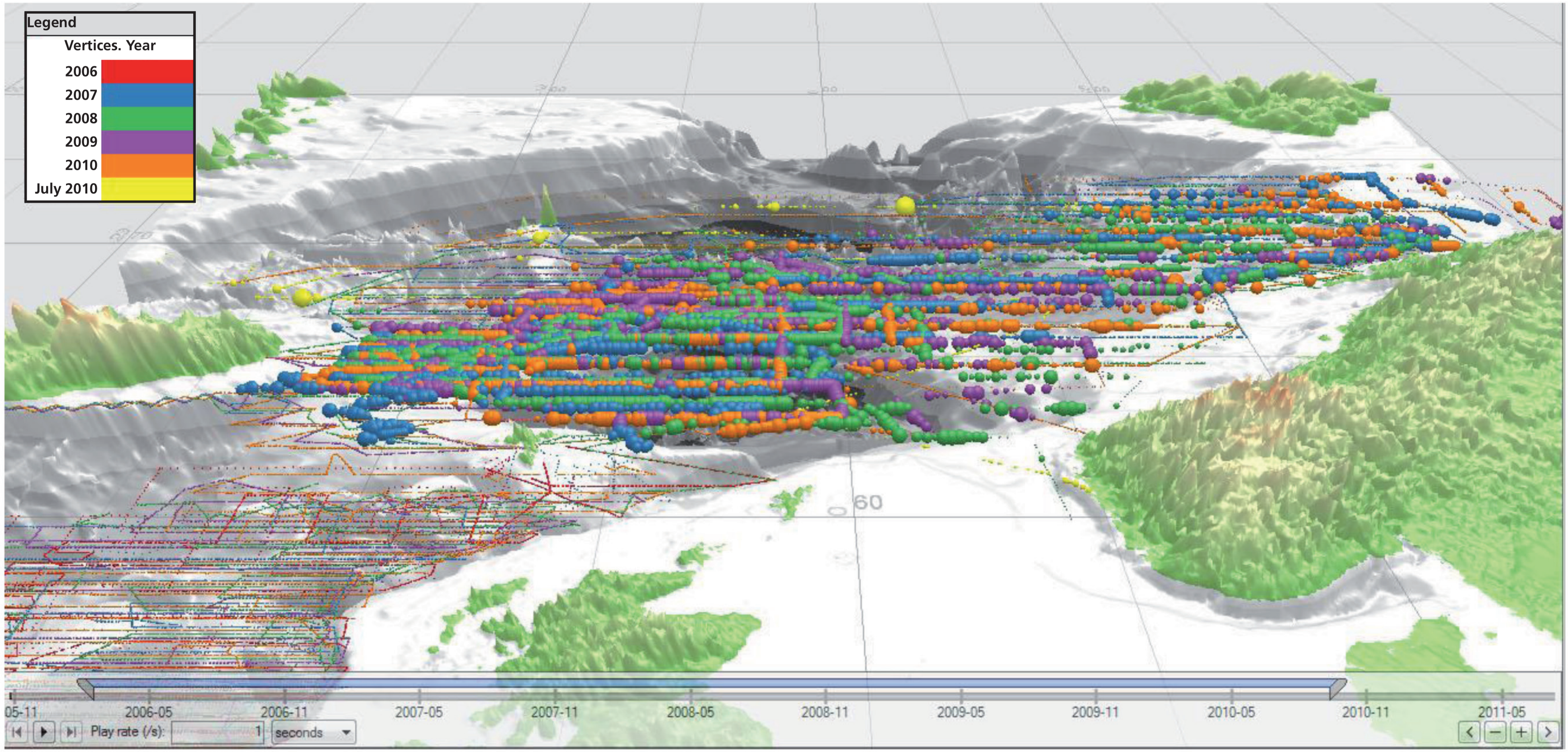
[297] Data on herring catches was supplied by the International Council for the Exploration of the Sea (ICES) and are based on acoustic measurements of stock biomass. The data are visualized through the use of Eonfusion V.2.1 software. No indication is given on the scale of the proportional circles.

[298] OceanWise: www.oceanwise.eu/Ocean_Database_latest.pdf.

[299] A detailed presentation of ArcMarine is available at www.esri.com/industries/marine/docs/arcmarine_techwork09_final.pdf.

[300] See examples for the People's Republic of Bangladesh at www.aqua.stir.ac.uk/GISAP/gis-group/neil_climate, and Río Paraná, the Argentine Republic at www.aqua.stir.ac.uk/GISAP/gis-group/daniel.

FIGURE 12.3
4-dimensional image to show aggregated herring catches in northern Atlantic and Arctic Ocean waters from 2006 to mid-2010



Source: Gastauer (2010).

12.5 APPLICATION OF SPATIAL MODELS AND STATISTICS

As with most other areas of scientific investigation, the spatial analyses of themes relating to fisheries and aquaculture are subject to modelling and spatio-temporal, geostatistics and other statistics, and this gives rise to a range of intellectually complex challenges. For present purposes, spatial statistics and spatial modelling can be considered as one, i.e. because the challenges posed are virtually the same as are the methodologies employed by GIS (and other modelling software) to meet modelling requirements. So what is being considered here is the use of GIS as a software platform or activity surface on which numerical models, usually in the form of equations, may be conceived, evaluated or tested. As an example, Figure 10.5 and the accompanying text in Section 10.2.4, explained how a statistical model was developed by Eastwood and Meaden (2004) to account for the variable abundance of sole (*Solea solea*) eggs in the English Channel area, and other examples of modelling have been given in Chapters 7, 8 and 9. Once established, a model can be used again in similar situations (or at different times), having been suitably adjusted to suit perhaps different species or changes in geographic area. Once suitable models have been developed, they can be integrated to most GIS, either internally via appropriate functions or externally through specialist software, including a wide range of modelling tools. Some advantages of modelling within a GIS include:

- The raster data structure provides an ideal platform for many spatial modelling procedures.
- Most GIS have built-in, or self selecting, formulas that can be used.
- It is easy to add extra variables that might influence or improve the models.
- A range of types of weightings can be applied during modelling.
- Temporal iterations can be accomplished to achieve dynamic modelling.
- GIS is ideal for exploratory data analyses.
- GIS can easily accommodate scale, time or area changes.

Notwithstanding these advantages, spatial modelling and the use of geostatistics can be a challenge for many GIS users. Developing the models frequently relies on a strong mathematical ability. For instance, in developing the type of model shown in Figure 10.5, it was essential that the lead author understood the detail of regression quantile techniques, and most modelling requires a strong background in algebra as well as geostatistics. Another challenge is to be able to positively identify the variables that are influencing distributions. While in many cases these variables may seem fairly obvious, there will be occasions when distributions will be influenced by unexpected factors. It is not always easy to have access to sufficiently detailed data distributions on all of the required variables, and it has already been stated that gathering additional data within aquatic environments can be an expensive challenge. A further challenge is one that faces many geographic surveys and that is the problem of spatial autocorrelation and the identification of true dependence or independence between variables. Much modelling also tends to be scale dependent. A statistical problem that may be often encountered, but also probably frequently ignored, is that of securing statistical significance of the data being used. Frequently, expensive marine surveys are compelled to utilize minimal amounts of sampled data, and in some instances GIS fisheries output is likely to be based on very questionable mathematical (statistical) significance. In order to overcome challenges relating to modelling, it is recommended that familiarization with, and use of, some of the spatial analysis tools be made. A wide range of free analysis tools are listed in Spatial Analysis Online.[301] Other spatial modelling tools have been developed[302] and a worked model, developed to establish suitable fish habitat in a reef environment, is given in Granados-Dieseldorff (2009). Additional useful reading includes Kanevski

301 Spatial Analysis Online: www.spatialanalysisonline.com/SoftwareFree.pdf.

302 See Geospatial Modelling Environment (www.spatialecology.com/gme) and Stanford University (www-sul.stanford.edu/depts/gis/tools.html).

and Maignan (2004), Maguire, Goodchild and Batty (2005), Hengl (2007), Wright *et al.* (2007) and Aguilar-Manjarrez, Kapetsky and Soto (2010).

12.6 OPTIMIZING VISUALIZATION AND MAPPING METHODS

It is clear that the basic ways in which GIS conveys its output is via tables, graphs and dominantly maps. In order that any of these illustrative methods puts across a clear message, it is most important that the message conveyed is both accurate and perceptually easy to synthesize. For maps, this is especially important. Good-quality cartography should follow a number of basic rules concerning legend construction and content, scale delineation, number of classes used, word placement, etc., though there is freedom within the rules to accommodate individual mapping styles and preferences. The challenge for GIS workers lies in constructing well-designed cartographic input data and to achieve output maps that form acceptable and comprehensible visualizations.

In constructing good visual images, the GIS operative is able to gain some support from most GIS software in that all mapping functions include preset styles that are typically acceptable to most map recipients. Within these basic styles, there is adequate freedom to adjust images in many ways. The greatest challenges to good visualization occur with respect to the following:

- Classification. Here, the challenge is to find suitable numerical boundaries between classes or to establish acceptable classes among non-numeric themes.
- Data representation. It is usual to show symbols on maps and these must be chosen with care so that they are meaningful in terms of easy comprehension.
- Font size, style and placement. Font size must be a compromise between legibility, the number of names (words) on a mapped area, and the need to avoid clutter and inappropriate name placement. Styles should invariably be relatively plain.
- The information to include. This will be a balance between including generally important features and those that are related to the thematic content of the map.
- Colour arrays. Users should avoid too many colours, and "bright" colours should be used sparingly (if at all).
- Fuzzy boundaries. Because much mapping output may be with reference to widespread marine areas and to features that are moving, e.g. currents, fronts, sandbanks, then there is often a problem of boundaries that might be indeterminate or changeable. For instance, the classification of habitats in streams has given many problems in terms of their delineation, and exactly which part of the North Atlantic could be called the "Gulf Stream", and how can a species range be exactly defined?

It can readily be seen that good-quality visualization is no easy matter to achieve and a large amount of research goes into this field. This research is both from a purely cartographic perspective but more frequently from a psychological viewpoint. The problem here is that all individuals have differing perceptual aptitudes and thus one set of maps will not suit all. Putting this another way, there is no such thing as "the best visualization", although there certainly are good maps and bad maps. It might be of interest for readers to peruse the large number of maps in this manual to see that they also may have very individual preferences.

The problems of visualizing any 3D marine features on a 2D-mapped surface have been discussed and ways in which problems might be overcome have been indicated. It has also been suggested that animations or map series are suitable ways of exhibiting distribution changes over time. But additional problems may still be of concern to cartographers. Thus, imagine the complexity of mapping a coral reef surface or features within a typical rock pool. Here, there can be almost infinite variability within a small area, yet all the variables might be of importance to the visualization. Where possible, visualization here is best achieved through the use of annotated photographs or pictures and videos can be linked to Web-based mapping delivered via the Internet. From this description, it is probably easy to deduce that scale is very relevant to what is being shown. So, at a broad scale, a coral reef can easily be delimited as a linear feature on a map (as in Figure 10.18), and a rock pool may be shown as being part of an area of the intertidal shoreline. It is also true that all mapped features will have to be variably portrayed on a map according to the scale of the project area. Useful sources to help with the challenges of visualization include Cartwright, Peterson and Gartner (2006), Ghadirian (2009), Kraak and Ormeling (2010), Robinson (2010), and any number of general books on cartography.

12.7 INTEGRATION OF SOCIO-ECONOMIC CONSIDERATIONS

As has been mentioned frequently throughout this technical paper, all future work in respect to the management of fisheries and/or aquaculture will need to adopt respectively an ecosystem approach to fisheries (EAF) or an EAA. The implications of this are wide ranging and they have been discussed in many publications, for example: FAO Fisheries Department (2003); Christensen, Aiken and Villanueva (2007); Carocci *et al.* (2009); FAO (2010c); Aguilar-Manjarrez, Kapetsky and Soto (2010). The use of an ecosystem approach to either fisheries or aquaculture means that optimization of the management of either of these activities will involve a consideration of social and economic factors as well as the more direct bio-physical factors that have been traditionally recognized as controlling these activities. So, it is now very clear that a sustainable future for both fisheries and aquaculture can only be achieved if full recognition is given to matters such as the provision of paid employment, the availability of labour, the benefits of sustaining local communities, dietary advantages of secure food supplies and the achievement of equity in the use of marine space. This approach to management, therefore, considers the whole of a fisheries or aquaculture ecosystem and not just the immediate production environment.[303] However, this approach presents some quite distinct additional challenges with respect to the use of GIS. Recall here that whatever data are used in any spatial analyses, the data have to be capable of being mapped to a reasonable level of precision. Some of the challenges to working with social and economic data can be exemplified as:

- Socio-economic factors may be difficult to categorize into agreed classes, e.g. imagine drawing areas on a map exhibiting different "degrees of wealth". So, different means of assessing wealth may result in quite different pictures of "reality" being portrayed by the different maps (Minot, Baulch and Epprecht, 2006).
- Exact socio-economic values may be difficult to measure and to attribute to exact locations.
- Existing social data are often scarce in most areas, and may only exist at a small scale (very generalized) for complete administrative areas.
- Many participants in projects may be reluctant to divulge social or economic information.
- The breadth of social information is extremely wide and judging the relative relevance of information or data may be difficult.
- Social or economic spheres may be far broader than the bio-physical production spheres that have traditionally been used in management. This has implications for the scale of a project. Where should boundaries be drawn between neighbouring ecosystems? How easy will it be to work across administrative boundaries?
- Many fisheries or aquaculture activities take place in very mixed social and/or economic areas, or conversely the fishing or fish farming activities themselves may be very diverse within a single geographic area. How can the exact stakeholder mix best be determined?

303 A useful and succinct summary of the EAF approach is available at FAO (2012g).

- Much of the social data may be subjectively and differentially construed by the different players (stakeholders) in the fishery or aquaculture activities.

Generally, it would be true to say that socio-economic data integration presents greater challenges to GIS work than does the use of traditional bio-physical data.

Although the challenges of incorporating socio-economic considerations into GIS-based project work might seem daunting, these challenges are certainly not insurmountable and they will be gradually overcome. It might be anticipated that most of the initial GIS projects involving full ecosystem approaches may be somewhat tentative and exploratory, i.e. lots of decisions will be made that may lack certainty and lots of experimentation may be necessary. Initially, there may be little other option than the use of "trial and error" techniques, whereby input variables and/or data are constantly adjusted or experimented with. It is useful if this GIS work can be carried out in situations where the results expected are fairly certain and thus the degree of success can be reasonably estimated. It is also useful if GIS workers who are attempting to integrate socio-economic data can form working alliances with other groups who might be using GIS for a range of social or economic-based tasks. These alliances might become a form of regularized networking. Now that whole ecosystem approaches are being adopted in a range of natural science or resource-extraction-based disciplines, networking will be easier and it is likely that specific GIS-based training or workshops will begin to proliferate, i.e. concentrating not only on mapping per se but also on social and economic concepts, issues, methods and resources. As with some of the other challenges to GIS work in fisheries or aquaculture, it will be beneficial to consult the FAO Web site for literature and more especially for relevant resources on EAF and EAA, e.g. see GISFish. Finally, many of the models that are associated with ecosystem approaches to fisheries or aquaculture are now incorporating socio-economic considerations (see NatureServe),[304] and it is likely that this will be a significant area for future model development.

12.8 DATA GATHERING AND ASSEMBLING

Although data provision lies at the heart of all GIS work, and thus its means of provision might have been thoroughly researched and provided for, this is very far from being the case. Indeed, data gathering and assembly could well be the greatest practical challenge that workers in GIS must regularly resolve. Upon starting any GIS project, data needs must be identified and this can be problematic given that the subject matter being investigated is likely to be conceived as "a problem" which itself must involve uncertainty – and this is likely to be relative to what are the exact causative factors (or production functions – see Section 3.2) about which data are needed. When this is established, it is still necessary to make decisions on a range of other factors such as:

- By what means can the data best be obtained?
- From where can the data be obtained?
- Are there existing suitable data?
- How much data can be afforded?
- To what precision is the data needed?
- What standards are required in terms of structure, format, projections, classifications, etc.?

The challenges facing data gathering and assembly can best be further reviewed under the subheadings of primary and secondary data challenges (Box 12.1).

Despite the numerous challenges associated with data gathering and assembly, huge advances have been made over recent years in data provision. In Chapter 3 reference was made to the vast array of data providers. Chief among these has been the availability of data sourcing and delivery via the Internet, and Boxes 3.9 and 3.10 gave clues to some of the main data sources. Many large data centres have been established that usually

[304] NatureServe: www.ebmtools.org/faqs.html# Question 16 Fisheries.

concentrate upon specific themes or geographic areas. There are many specialized projects or programmes in place that are seeking data to resolve identified marine problems. Remote sensing via a continually expanding range of satellite and airborne sensors is providing vast quantities of marine data as are various sonar acoustic devices. Other data gathering technology is being deployed, such as the tagging of a range of marine species, the tethering of marine buoys on the surface, in the water column or on the seabed, the implementation of electronic fisheries logbooks, and the deployment of automatic or manned submersible vessels. The assemblage and storage of this exponentially increasing data supply is accommodated via ever larger digital storage devices and servers.

BOX 12.1
Some challenges to gathering and assembling data

Acquiring primary data for marine projects (marine fisheries or mariculture) will offer more challenges than for inland fisheries or inland aquaculture projects. These challenges include:

- There may be large costs and time considerations as much data comes from the marine environment.
- Survey vessel booking schedules may need adhering to.
- Specialized data-gathering equipment (and sometimes skills) is often necessary.
- Gathering data may be impeded by the weather or marine conditions.
- From what size area should data be gathered?
- What is the ideal sampling strategy and can the strategy provide statistically valid data?
- All data may need 3D georeferencing.
- Who will be responsible for storage and upkeep of each data set.

Some major challenges associated with the collection of secondary data include:

- Many data sets must be paid for, and prices can be high reflecting data-gathering costs. Data costs may have a severe impact in many developing countries.
- There are many parts of the world for which data do not exist or there are very few data available, and these facts may be difficult to establish.
- Some data have strict copyright rules that apply. If this applies to mapping data held by central mapping agencies, access to copyright freedom is usually granted for research purposes.
- There may be a range of barriers to sharing data (privacy and confidentiality issues, licensing and ownership issues, liability issues and broader data sensitivities).
- Marine or fisheries data are often four dimensional and can relate to any of numerous variables and areas. The chances of obtaining suitable data may be low unless the user requires more commonly held baseline data, e.g. on water temperature, bathymetry, river, coast and lake outlines.
- There is great diversity in the types of data that may have to be acquired: physico-chemical, geological, meteorological, socio-economic and biological data; all have to be integrated, and analyses and information may be necessary that draws on any combination of these variables.
- There will be large variations in the standards of metadata provision (see Section 5.5). Effectively, this means that users will find much more information available about some data sets than others.
- Data have frequently been collected at an inappropriate resolution for a planned project, or the data are out of date or have been collected at the wrong season, or are somehow of a dubious quality.
- Simply coping with the deluge of marine and fisheries data that are now being captured. This includes the organizing, storing, documenting, publicizing and disseminating of data, plus a range of challenges in using such a diverse range of data.
- Use of the Internet for data collection incurs an expectation that the user will be familiar with English as an international language for communications.

12.9 SUBJECT BREADTH AND ORGANIZATION

The core subject application areas covered by this technical paper, i.e. "fisheries", "aquaculture" and "GIS", must be recognized as "non-pure" areas. Thus, although each of these areas is easily identified, their very existence is intrinsically and essentially linked to many other main subject areas, including, for example, oceanography, marine ecosystems, climatology, agriculture, biology, remote sensing and various branches of information technology and marine construction. The necessity of working in this extremely wide applications area substantially increases the complexity of the work undertaken in terms of the overall knowledge required, the linkages and communications channels that must be established, and the range of information and data that might be required. As if these challenges were not sufficient, over the last decade they have been significantly increased through recognition of the necessity for marine spatial planning and for an adoption of an ecosystem approach to both fisheries and to aquaculture.

GIS is typically applied to either fisheries or to aquaculture for management or research purposes, and it may be pursued in both the public (state) or private sectors. Although some of the work will be carried out in large, centralized governmental offices, by far the majority of management or research takes place in relatively small, fragmented and isolated institutions or consultancy companies, e.g. small government research stations that are coastally located or a range of universities that may specialize in GIS per se or in any of the sectors mentioned above that may be integrated to fisheries or aquaculture. So, most of the work being pursued in these fields is small scale and extremely scattered, and these conditions are not conducive to optimizing the chances of successful and well-tested applications. Added to these challenges is the fact that change can be very rapid in the associated technology fields, especially those applying to computing and remote sensing. These changes can be very costly, not only for those developing the technologies but also for groups who may be required to constantly reinvest in new hardware. So, simply keeping abreast of all that is going on is a challenge in itself.

How might challenges associated with the breadth and organization of the fisheries and aquaculture GIS fields be addressed? This is being challenged on several fronts, some of which have already been alluded to. Thus, in Section 4.8.3 information was given on a wide range of published information, with Box 4.11 specifically indicating publications that could be valuable in addressing the wider area of fisheries and aquaculture GIS; Section 4.8.4 covered the important mode of information dissemination via conferences, workshops and exhibitions; and Section 4.8.5 covered other support groups including professional organizations. Box 10.2 also gave leads on the major organizations carrying out research in the area of fisheries-based GIS work. Additional to this support, there is that offered through FAO's Global Gateway to Geographic Information Systems, Remote Sensing and Mapping for Fisheries and Aquaculture (GISFish). There is undoubtedly a rapidly growing recognition that the planet is becoming increasingly crowded, and that "spatial optimization" is of increasing importance in a world where sustainability is of the essence. GIS and remote sensing are being recognized as two of the ideal tools to bring this about, and the timely appearance of the Internet as a vehicle for information acquisition, for data exchange, and for interactive GIS can only serve to reduce the challenges of subject breadth, fragmentation and isolation that were previously prevalent.

12.10 WORK MANAGEMENT AND CONTROL

This challenge is connected to the previous one (Section 12.9), but whereas that looked at practical and organizational factors from a widespread viewpoint, these challenges are at the scale of an individual GIS worker or small organization. As was mentioned in Section 12.9, it is likely that the majority of fisheries- or aquaculture-related GIS work will be carried out within small institutions or small groups within such organizations. Effectively, this is likely to mean that GIS projects are carried out by either a single individual or at most just a few people. Workers on projects are thus obliged to carry out all or most of the many tasks necessary for the successful completion of a project. It is often a challenge to be able to undertake this, if only because of the great breadth of knowledge that must be acquired and because it is quite likely that any human support is fragmentary, not readily available, and thus could be difficult to access. Also, when working individually or as part of a small team, if there are several different GIS projects to be undertaken, then this could greatly expand the range of challenges. Clearly, GIS personnel working under any of the conditions described here need to have a fair degree of initiative, probably a technological aptitude, and would require the confidence to experiment and/or to seek advice from a wide variety of potential sources. There could clearly be a very sharp learning curve.

The challenges concerned with work management and control must be resolved through advice and help from someone at management level within the institution, or through "teaming up" with GIS offices or personnel working in other public or private sector departments. Thus, as hinted in Chapter 4, it will be crucial that the GIS work is fostered and encouraged by a "manager" or "champion" who has a distinct interest in, and understanding of, the requirements for attaining successful GIS output. He/she will need to offer the required guidance and to make certain that all physical working requirements are met, including access to further training, advice and support. If, perhaps due to the size of the institution or the nature of its working environment, these challenges are difficult to resolve, then serious consideration must be given to establishing different working patterns within the institution or even to working collaboratively with other groups or organizations where know-how, capacity building or technical support might exist. If these solutions are not practicable, then it may be necessary to contract out any required GIS work.

12.11 PROMOTION OF GIS OUTPUT

The concern here is with the promotion of any output achieved from the use of GIS. It would be fair to say that this output does not tend to get wide recognition, certainly with respect to the scale of the spatially based problems that are associated with worldwide fish production. What are the challenges associated with achieving a higher threshold of output recognition? These can be identified as:

- There are very few fisheries and/or aquaculture conferences or workshops that might act as showcases for the work being done.
- Much of the output from fisheries or aquaculture GIS work is of a highly specialized nature and thus only gets to a very small audience.
- Much GIS work only appears in what is termed the "grey literature" – these might be an array of little known, limited distribution publications.
- Because GIS is basically a tool for spatial analyses to help resolve problems, then it is the problem itself that rightfully attracts attention. Therefore, GIS might not be mentioned in any "key words" listing.[305]
- The vast majority of GIS output is only passed to decision-makers. It is unlikely to be published or it may simply be displayed in internal reports or in a few published papers.

Given the scale of needs for the resolution of space-based problems in fisheries or aquaculture, there is certainly every reason for this output dissemination problem to be resolved. It is mainly through the publicity on what is possible that other GIS workers will find out about what to them may be new creative possibilities.

[305] This problem is likely to be exacerbated in the future as GIS use becomes more mainstream, widespread and ubiquitous. Thus GIS will not be recorded in publication titles or in key words, and thus may not be easily detected by search engines.

It has already been noted that there is a growing list of fisheries-related publications covering GIS plus a limited number of other "publicity outlets". However, it is the Internet that offers the greatest scope for finding out about the potential of fisheries and/or aquaculture GIS. A large number of sites are conveying the data for use in GIS, and possibly a larger number of sites are publishing outputs from research and other GIS projects. Of special note is FAO's GISFish Web site, where there is the opportunity to submit case studies and to read about other fisheries or aquaculture GIS-related projects.[306] There are rapidly increasing chances to undertake interactive fisheries GIS mapping and analyses and this will become even more commonplace in the future. Ferreira *et al.* (2012) report that there are currently 1 800 items on YouTube (a video-sharing Web site) under the theme of "aquaculture", and that there are Web sites emerging (e.g. http://longline.co.uk/winshell) where interactive aquaculture-based simulations can be performed. Another spur to fisheries or aquaculture GIS work will be with the increased demands placed on GIS by the need for both marine spatial planning and for the EAA or EAF. Additionally, there is likely to be far greater output from various types of spatial and geostatistical models that will accrue in the effort to reverse environmental and ecosystems degradation. And finally this push for sustainability will see the worldwide appearance of various kinds of marine conservation zones, and these are certain to be sited with respect to decisions based upon the output achieved by GIS. It can be anticipated that exposure to GIS will rise quite markedly in the near future.

12.12 EXPENSES ASSOCIATED WITH FISHERIES AND/OR AQUACULTURE GIS

A recurring theme throughout the technical paper is that the implementation and pursuance of fisheries or aquaculture GIS might be an expensive applications area, and various reasons have been given as to why data costs are likely to be especially high, i.e. perhaps amounting to 80 percent of the operating costs for a GIS project. These high costs are mostly associated with vessel charter needs for any survey/sampling work. Other high data costs might be for satellite imagery plus the purchase of other off-the-shelf digital data sets. Apart from data costs, there may be initial high capital expenses for acquiring the system's hardware and software. There could then be an array of operating costs involved in rent, salaries, office overheads, equipment upgrading or replacement, training, consultancy fees plus other maintenance and support costs. For those operating in developing countries, these costs can be seen as prohibitive, certainly relative to other costs, to resources available and relative to what is obtained as an output for the monetary inputs made, i.e. GIS may not be perceived as a priority, certainly when measured on the basis of a cost–benefit analysis. It is more than likely that high costs have been a major reason for the slow growth in GIS in developing countries, especially when these costs are virtually all related to high "western" prices.[307] Without some financial investment in GIS, not only might there be an inability to undertake specific projects requiring spatial analyses, but also the country or region, in a much wider sense, will be lacking in the capacity to realize or understand the importance of the spatial dimension, or to have the personal or material infrastructure available to pursue this work. It is likely that only in those developing countries where fisheries and/or aquaculture play a prominent role in the economy will there be a positive incentive to implement GIS. Even in developed economies it might be hard to justify the inclusion of the necessary funding, especially for those areas or regions where fisheries or aquaculture might be a marginal activity.

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306 ESRI also welcomes case studies on a range of applications (see www.esri.com/showcase/case-studies/index.html).

307 Readers should be reminded that costs do not have to be high to initiate GIS work. If projects can be implemented at a small scale, then start-up costs are quite low; there are substantial quantities of spatially based freeware available; and many data sets can be freely obtained and remote sensing imagery costs have significantly reduced in recent years.

For countries, regions or organizations where finance plays a severe challenge to the adoption of decision-making technologies such as GIS, it is suggested that there are a number of approaches that can and have been successfully taken. It is always advisable to start with small, simple GIS-based projects and the costs implications here can be very low indeed, especially if existing hardware can be used. There is often the opportunity of sharing facilities with other computer users or GIS software users. A careful investigation should be made on the possibilities of using free and open source software (FOSS), especially since some of these consist of extensively developed GIS packages (Section 2.3.3). Use should be made of Internet search engines as a way of locating data needs. The editors of this technical paper are continually being surprised at exactly what data are "out there". For inland aquaculture GIS purposes, the national mapping authorities may be able to provide many data requirements, and what they cannot provide could perhaps be obtained from government offices or from universities or research establishments. Clearly, there is a need to be both imaginative and flexible in the search for inexpensive data (and other) inputs.

12.13 OBTAINING FUNDING

Despite the fact that fisheries is probably the world's second largest economic activity (after agriculture) in terms of the numbers directly or indirectly employed, and certainly the most widespread in terms of its spatial extent (and thus possible impact), the fact that the activity largely takes place within a small-scale or semi-subsistence economy means that it seldom is able to generate surplus income that can finance anything other than the most fundamental needs. This is also often the case in more developed economies. Therefore, funding for activities such as "fisheries GIS" must invariably come from government sources – though occasionally funding for GIS as applied to aquaculture investment might come from private sources. Much fisheries-related GIS work in developing areas must rely completely on donor support. During the current world financial crisis, then many funding sources have dried up completely, especially as many governments have cut back on state funding across all departments. Funding for activities where financial rates of return are difficult to verify is likely to suffer additional disadvantages. Therefore, any cost–benefit analyses on the value of GIS to fisheries or aquaculture are invariably difficult to substantiate. Similarly, funding is difficult to acquire if it is for purposes where the utility of the system is difficult to prove, i.e. success can be only a "subjective evaluation" – with output from different projects varying enormously in their utility. The challenge for the GIS enthusiast may be to convince their organization that GIS is very much more than a "luxury, peripheral add-on".

Any funding obtained is unlikely to be on a large-scale, and the future of funding may depend on the perceived output results from the GIS project. So, one challenge is to make certain that GIS-based output is appreciated and is well received at the workplace by all important sectors. The likelihood of GIS and/or remote sensing work proliferating (and thus being funded) will probably be much higher if these tools can be integrated as essential elements of wider projects. The possibilities for doing this must be high, especially as Chapter 11 has emphasized that assistance given to developing countries must be a response to a perceived "issue", and it is more than likely that part of the issue is rooted in spatial dis-equilibrium (see Section 1.1). At a time when spatial matters are coming to the fore through approaches such as marine spatial planning, EAA and EAF, it should be easier to convince budget holders within organizations of the paramount importance of spatial analyses. To this can be added the plight of so many of the world's fisheries (see Chapter 1), so it could be argued that any financial outlay on GIS is a very small outlay (price to pay) relative to the success that would be achieved if successful spatial allocation models could be developed. The marine space could then be sensibly partitioned so as to suit all stakeholders, thereby allowing for a range of aquatic activities to be sensibly and positively sustained over a longer planned period.

12.14 OVERCOMING INERTIA RELATING TO THE CULTURAL AMBIENCE

The less obvious challenges that are shown in Figure 12.1 as being "social or cultural" can now be reviewed. These challenges are really concerned with the "working milieu" of the country or area in which the GIS work is being undertaken, plus the "social or cultural ambience" that might prevail in either the country, or more specifically, the workplace. To some extent these challenges relate to levels of economic development, though importantly they also relate to the set of working norms that prevail at any level of development. Most of the challenges here are less direct than other challenges, though it is important to describe these since they may strongly pertain to individual areas or circumstances.

It is easy to believe that both the cultural ambience and working milieu may not be conducive to GIS adoption in some institutions and/or in some areas of the wider working world. In the first place, what are the chances of a "GIS champion" ever emerging from those groups or institutions that may be seen as inward looking, especially with respect to technological adoption? Even if they do emerge, it is reasonable to suppose that many "champions" of GIS will have a hard time selling the idea in establishments where outdated or entrenched attitudes may persist. This might especially be the case where little evidence of GIS success has ever been presented at the managerial level, so what reason might the institution wish to give for adopting GIS when it (the institution) has survived for possibly long periods of time without it? There may also be strong reticence by many who are participating in capture fisheries, to passing on geographic information to others about the locations and records of catches, i.e. as would be demanded from, for instance, the submission of fisheries electronic logbooks. Fishing locations are sometimes long-held secrets allied to understandable beliefs that livelihoods may be dependent upon keeping this knowledge a secret both from other fishers and from the authorities. In a surprisingly large number of areas, there is natural hostility to what scientists or politicians might do with data handed over to them. It appears that there is often a poor appreciation among international institutions and donor organizations as to the realities of working with sophisticated information technology systems in developing countries where these technologies may have little real relevance to the cultural setting.

There are a number of potential ways of overcoming challenges relating to inertia and the prevailing cultural and working ambience. It is important that some of these challenges can be tackled from either a "top-down" or "bottom-up" approach. In reality, a "top-down" approach means that measures are taken to introduce those who are in positions of control and management (within perhaps an institution or at senior government level) to the potential that GIS has to offer in solving problems relating to the spatially based challenges that may confront either fisheries or aquaculture in their administration (geographic) area. Any challenges might need to be resolved by those working for development agencies, donor institutions or through FAO, and can be instigated via workshops, seminars, demonstrations, etc. For a recent example of this approach, see FAO/Regional Commission for Fisheries (2011).

The "bottom-up" approach to overcoming challenges relating to prevailing cultures or to the working ambience involves a completely different strategy. Here, the idea is to "engineer" a demand for change from within the country or organization. This might be carried out through education schemes, probably at university level, through the dissemination of ideas about spatially based management, GIS, etc., via the Internet or other means of communication, or through middle-level employees approaching management with well-supported ideas on how progress can be expedited through technological innovation and thereby through GIS implementation (see Chapter 4). The adoption of ideas that may bolster either "top-down" or "bottom-up" approaches may be fostered by perceptions of the poor status of local fisheries and/or aquaculture, and by any consequent requirement to consider marine spatial planning and ecosystem approaches to both fisheries and aquaculture. Another approach that appears to have a strong potential for breaking down (or penetrating) social or cultural barriers is that of getting fishers or aquaculturists to work with scientists as a means of appreciating their often opposing perspectives on managing their activities. A good example of this is the Fisheries Science Partnership that was established by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS, 2012) in the United Kingdom of Great Britain and Northern Ireland in 2003. The aim of this partnership is to build strong and productive relationships between scientists and the fishing industry, and to achieve this, an annual programme of cooperation has been successfully pursued over the last 11 years.[308] Other approaches at working in partnership with other marine sectors or competing resource users are becoming apparent as the trend towards designating sizable portions of the seas as marine conservation zones or protected areas is now accelerating (see Section 10.2.6).

12.15 GAINING SUPPORT AND ADVICE

This subject area of "gaining support and advice" has been listed in Figure 12.1 as an area where challenges to pursuing GIS for fisheries or aquaculture are likely to be encountered. This is certainly very much the case with many GIS workers, usually working in more isolated circumstances or perhaps in areas or institutions having limited resources, and who are finding it difficult to gain access to the support and advice that they should have. As this subject area has already received much coverage in Section 4.8 of this technical paper, there is little reason to discuss this further here. However, it is worth mentioning that support for GIS and/or remote sensing work will probably be much higher if these tools:

- can be integrated as essential elements of wider projects, e.g. climate change implications for fisheries and aquaculture; strategic planning for offshore mariculture development, etc.;
- focus on issues/themes that illustrate the many benefits that the use of these tools can provide to support problem solving and decision-making, e.g. see the case studies presented in Chapters 8, 9 and 10 of this publication;
- are designed to match the needs, interests, finances and capacities of the target users or stakeholders.

12.16 TRANSCENDING POLITICAL OR INTERNATIONAL BOUNDARIES

It is clear that all of the world's political borders will have been established without regard to factors that control the distribution of fishes or the ecosystems in which they live. Fish species may each have different but complex life cycles that often involve stages where they either undertake extensive migrations or where they inhabit perhaps spawning, nursery or adult areas, each of which may conform to different types of ecosystem. By contrast, most maritime nations will have jurisdictional boundaries (exclusive economic zones) that either extend for 200 nautical miles out to sea or that end along agreed median boundaries between neighbouring countries in areas where the extent of the marine space is limited.[309] This duality of marine space division (natural ecosystems versus political jurisdiction) may lead to sources of challenge with regard to resource management, and especially where the more mobile marine species are concerned. It is clear that this dichotomy is likely to have important implications for

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[308] Centre for Environment, Fisheries and Aquaculture Science (CEFAS): www.cefas.defra.gov.uk/our-services/fisheries-management fisheries-science-partnership.aspx.

[309] There are also areas known as the "high seas" that are located more than 200 miles from the coast of the nearest territorial claimant nations. In these areas, 17 regional fisheries management organizations control the fish resources.

any GIS work in terms of setting spatial boundaries for analyses, for acquiring funds, for the management of projects, for the content of projects, and for data resourcing.

Many attempts have been made to achieve regional fisheries cooperation between neighbouring counties or within groups of neighbouring countries. For instance, in waters of the European Union, there is the Common Fisheries Policy that sets out the fishery rules for all 27 European Union member countries, and in the Caribbean the fisheries management for 38 island states is under the control of the Caribbean Regional Fisheries Mechanism (CRFM). However, to a substantial degree, these attempts at regional cooperation have been unsuccessful, and this has required constant initiatives to try to improve the situation. As with some of the other challenges, it is likely that the instigation of both marine spatial planning and EAF and/or EAA considerations will have the effect of "concentrating minds", and it is to be hoped that far greater regional cooperation will ensue in the future. Without strong cooperation in many geographic areas, then ideal applications for most GIS projects are unlikely to ensue.

12.17 DEVELOPING GEOGRAPHIC COGNITION AND SPATIAL AWARENESS

A final area of challenges to GIS work on fisheries or aquaculture concerns geographic cognition and spatial awareness. Basically, what this is referring to is an appreciation of geographical thinking and perception. Readers may not appreciate exactly what this means, but it is almost certain that readers will consider themselves as either good or bad at "reading maps". Map reading essentially entails many of the basic skills necessary for geographic cognition. Other aptitudes exhibited by persons having good geographic cognition include:

- Able to identify and prioritize which are the spatially based production functions that may control fisheries and/or aquaculture processes.
- Ability to understand which combination of production functions can best lead to successful analyses.
- Able to identify and explain different zonations among different activities.
- A grasp of what locations are suitable for the establishing of various kinds of activities.
- A sound "atlas" type knowledge of the local area and of main countries or continents.
- Being able to quickly grasp or to visually discriminate the implications shown by any mapped distributions.
- Knowing the best types of analyses that could be applied in spatial situations.
- A recognition of spatial patterns such as clustering, adjacency, ubiquity, contiguity, etc.
- An awareness of any patterns, surface trends and zonal forms across a real or mapped area.

The ability to recognize many of these cognitive geographic ideas provides an extremely valuable insight into most GIS work. It allows the GIS worker to have a feel for the sort of work or project that can best be undertaken, as well as allowing the final output from the GIS to be evaluated with respect to the validity of the work, i.e. is this output believable?, and what the spatial implications might be for any management decisions, e.g. this mapped distribution tells me that x, y and z need doing. But perhaps a more widespread problem concerns the lack of appreciation that many (perhaps most) of the problems concerning either fisheries or aquaculture may be rooted in spatial differentiation; thus, fisheries managers and others may often not appreciate the importance of the geographic perspective, i.e. the paramount importance of being able to "assemble" the required balance of production inputs at any chosen location. In fact, this is a problem that goes much further than the fisheries or aquaculture spheres. For almost every productive pursuit on this planet, there are better or worse locations in which to be productively engaged. Location is usually the key to business success. Optimum locations provide the best aggregate combination of those production functions that are essential to business success. Moving away from optimum location centres means that more and more problems are encountered with respect to the factors of production, and this reasoning can apply to actual human production activities, e.g. aquaculture, or to resource gathering activities such as fishing.

An area that has received little attention is that of securing awareness of the importance of spatially based planning (and therefore GIS) among higher levels of management or governance. Thus, it appears that the underlying importance of location and spatial association is a subject that is little appreciated at strategic planning levels. It is likely that workshops, seminars, reports and other meetings devote a good deal of attention to a range of thematic areas and issues concerning fisheries or aquaculture, but it is thought that these are rarely posited within a spatial context. So there is a need to couch themes and issues within this spatial context and to highlight the fact that GIS is available as a very versatile tool for use in analyses, descriptions and explanations of probable imbalances in the relationships between production functions (see Section 3.2). An appreciation of the importance of spatial considerations is clearly beginning to be recognized as witnessed by the emergence of EAA and EAF and by the perceived necessity for marine spatial planning at both regional and international levels (see Section 12.16 above). Aguilar-Manjarrez, Kapetsky and Soto (2010) give further observations on capacity-building measures that need adopting in order to improve spatial awareness (and thus GIS use) at various levels of management and governance.

Although it is doubtful that thorough geographic cognition can be taught, obviously the aim of school geography lessons was to instil some of these perceptual traits into the students. If readers find that these traits are almost completely lacking, then it is unlikely that they will ever succeed as GIS workers. However, if they do have some (or a degree) of the traits exemplified, then it is always possible to enhance geographic capabilities through reading more general geography texts, journals or better-quality magazines, or even watching many of the natural world or geographically based programmes on television. With respect to a lack of awareness of the fact that the failure of so many production activities is due to spatial dis-equilibrium in the factors of production, then it is the job of those people already working in GIS to spread this message via publications such as this, and via the many resource, guidance, support and training means described in Chapter 4. Perhaps it is fortunate that geospatial data collection devices based on integrated global positioning systems (GPS) are proliferating and that a GeoWeb environment is emerging on the Internet allowing for the integration and sharing of geographical information and data on a scale that might have been unimagined just a decade ago. So, without realizing it, Google Earth, cell phones, GPS-based navigation systems and iPhone and iPad mapping facilities are all helping to create and enhance geographical cognition and spatial awareness.