4. The role of GIS in support of EAF implementation

4.1 INTRODUCTION

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

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

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

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

4.2 MAPPING IN EAF WITH GIS

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

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

4.2.1 Ecoregions

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

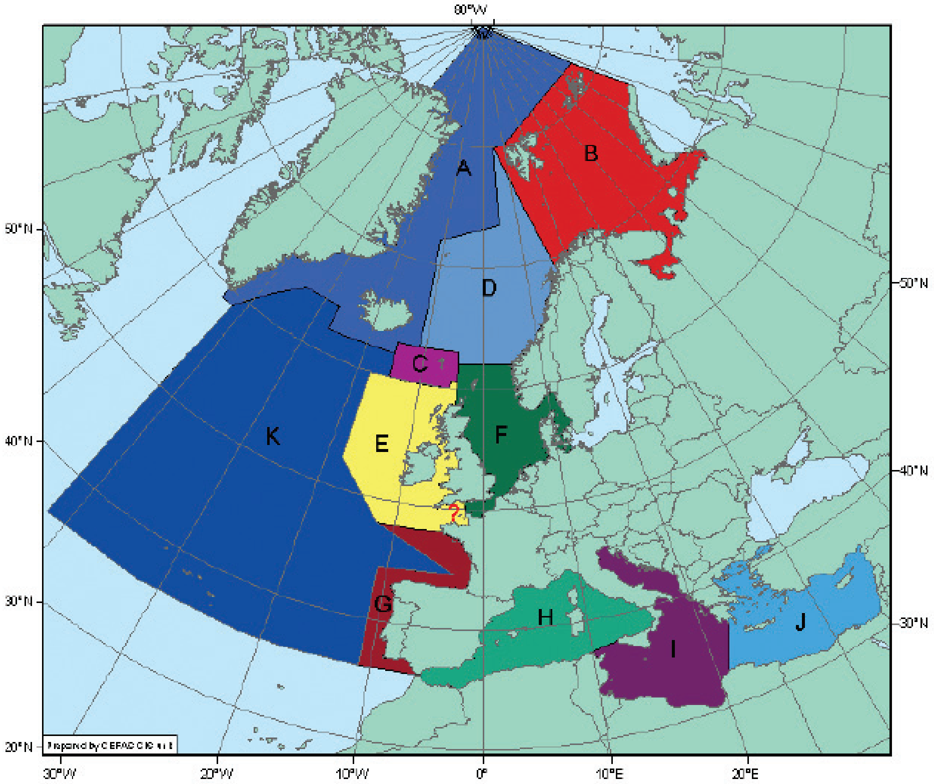
A number of global-scale ecosystem classifications exist and can be used as a broad framework for regional ecoregion characterizations, notably those of Longhurst (1998) and Hempel and Sherman (2003), and more recently those of Spalding *et al.* (2007). Characterizations for smaller sea regions are also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

4.2.2 Species

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

FIGURE 4.1

Proposed ecoregions for the implementation of EAF in European waters



Source: CES, 2005.

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

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

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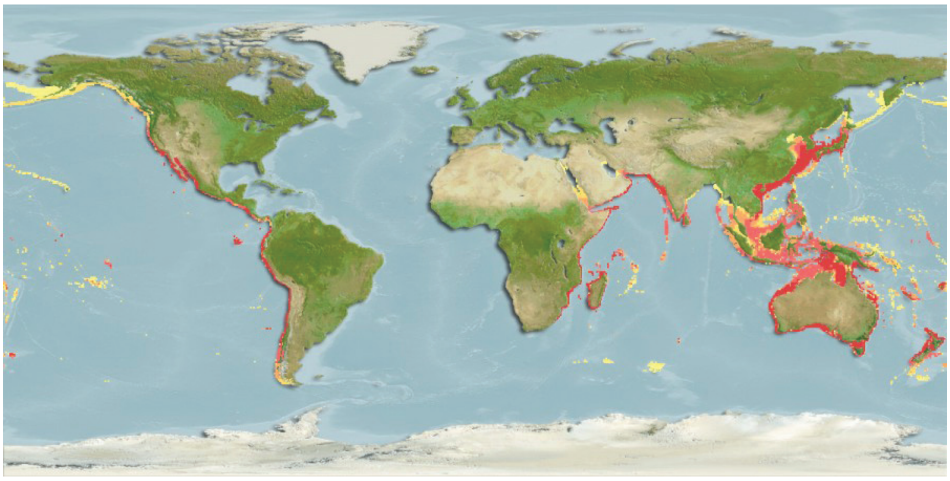
[4] Available at www.aquamaps.org

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



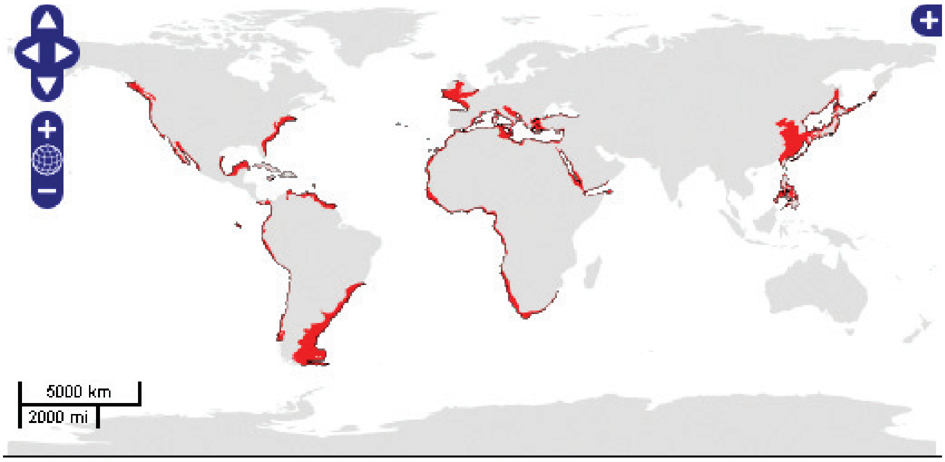
Source: From the AquaMaps server (www.aquamaps.org) based on occurrence data from FishBase (www.fishbase.org). The map is reproduced with permission from R. Froese, Leibniz Institute of Marine Sciences, Germany.

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

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

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

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



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

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

4.2.3 Habitats

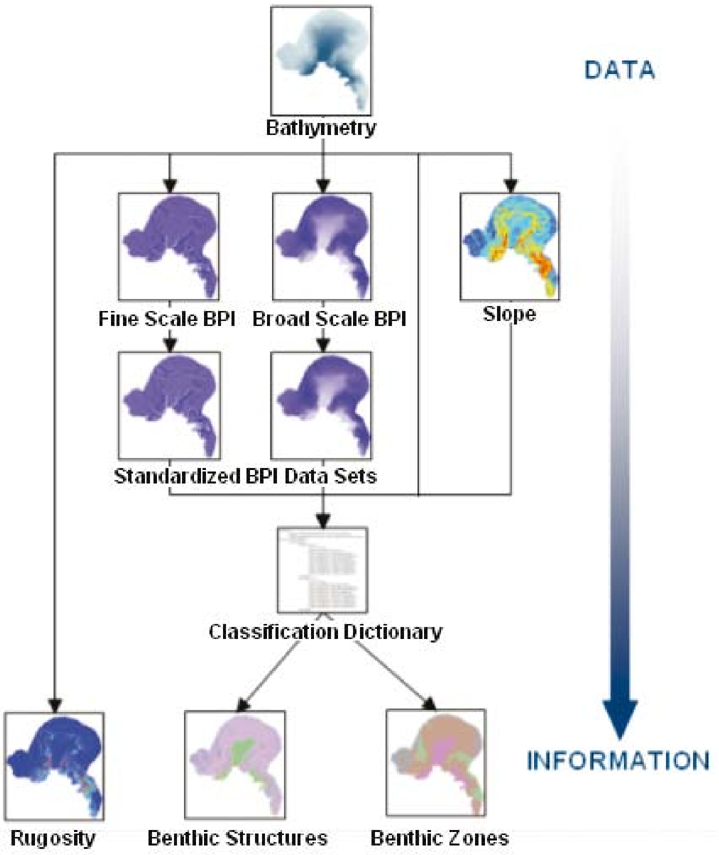
Knowing where critical or sensitive habitats occur is key to successful EAF implementation. A suite of instruments, methods and processes are available for constructing maps of sea-bed physical and biological features over different spatial scales and resolutions (Green *et al.*, 2000; Kenny *et al.*,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

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

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

In tropical waters, satellite and aircraft-mounted optical sensors

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



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

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

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

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

4.2.4 Human activities

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

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

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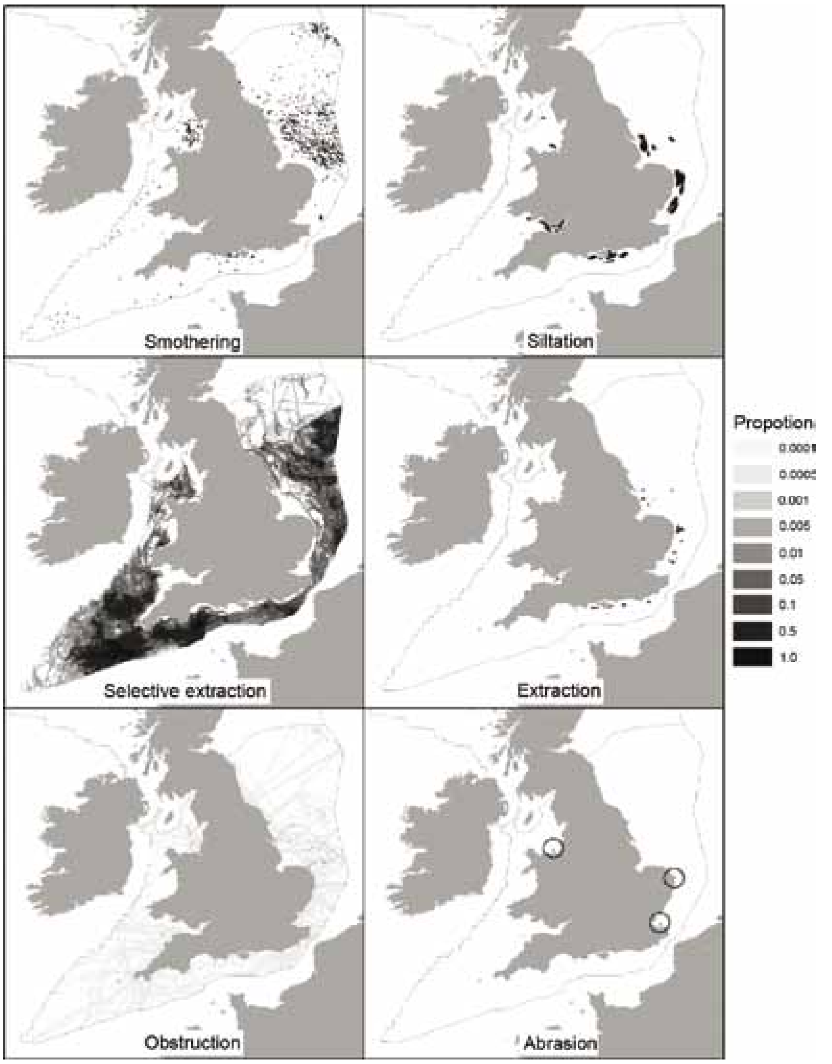
[6] Available at http://landsat.usgs.gov/

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

FIGURE 4.5

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

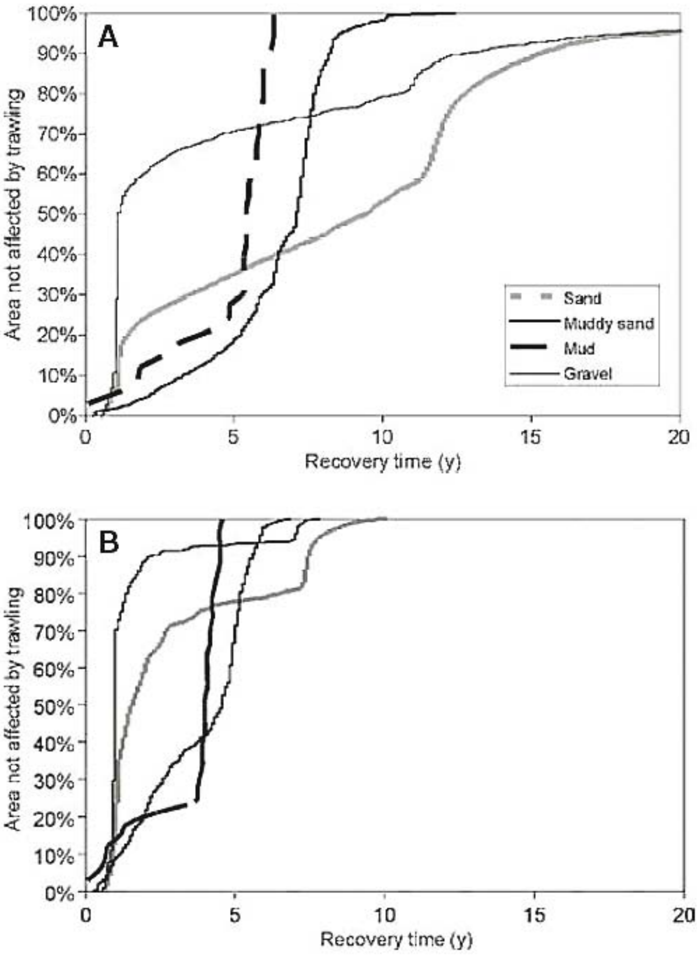


Source: Reproduced from Eastwood *et al.,* 2007. © Crown copyright.

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

FIGURE 4.6

State indicators of an ecosystem in the North Sea



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

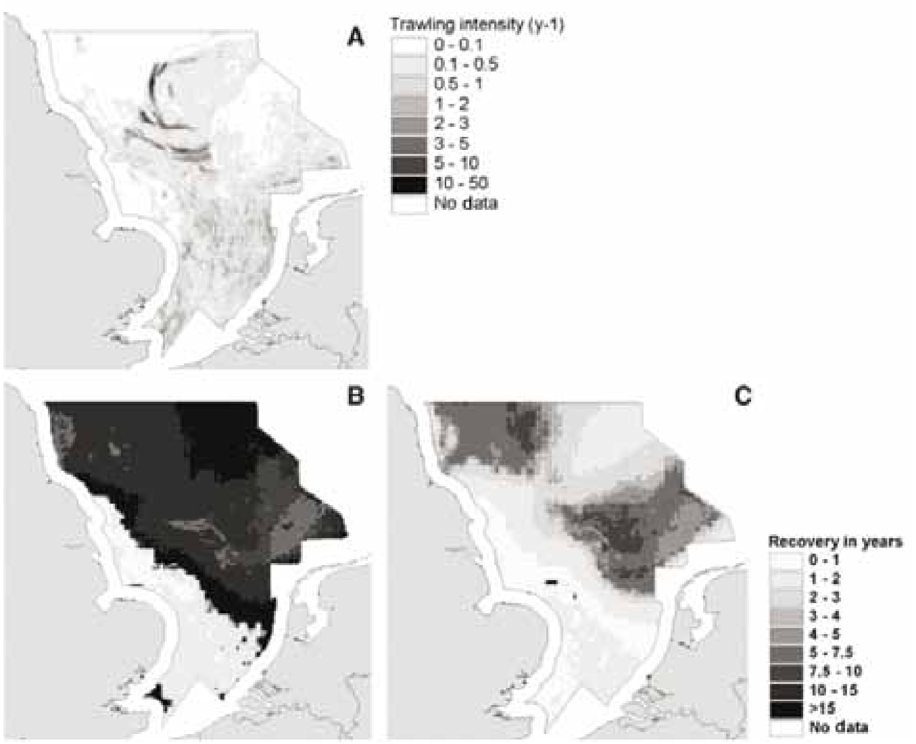
Note: Indicators were developed after a single trawl pass for (A) benthic biomass and (B) benthic production.

4.2.5 Indicators

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

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

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



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

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

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

4.2.6 Management regulations

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

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

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

4.3 MODELLING IN EAF WITH GIS

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

4.3.1 Spatial stock assessments

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

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

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

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

4.3.2 Ecosystem interactions

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

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

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

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

4.3.3 MPA placement and design

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

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

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

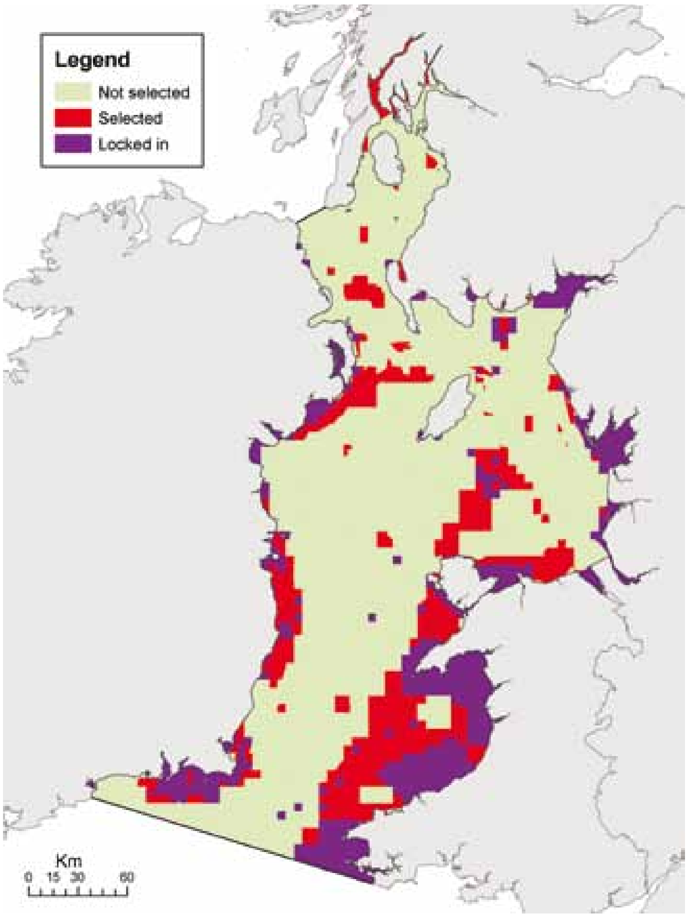
One of the strengths of both Ecospace and Marxan is that they allow a range of MPA network scenarios to be explored and visualized so that the stakeholders may consider a variety of options. Within an EAF framework, strong engagement by stakeholders is critical to facilitating common agreement and finding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

4.3.4 Fishing vessel movement and behaviour

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

FIGURE 4.8

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



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

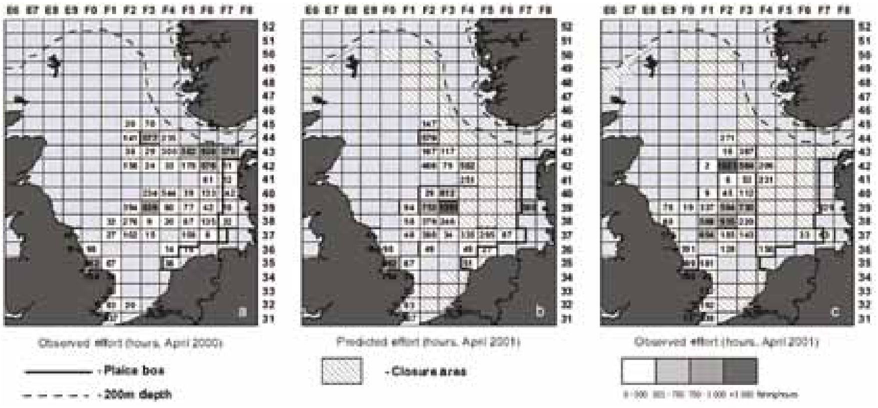
Note: MPAs are marked as "Locked in" on the map.

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

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

FIGURE 4.9

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



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

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

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

4.4 MANAGEMENT IN EAF WITH GIS

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

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

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

4.4.1 Integrated marine management and planning

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

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

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

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

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

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

4.4.2 Monitoring and enforcement

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

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

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

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

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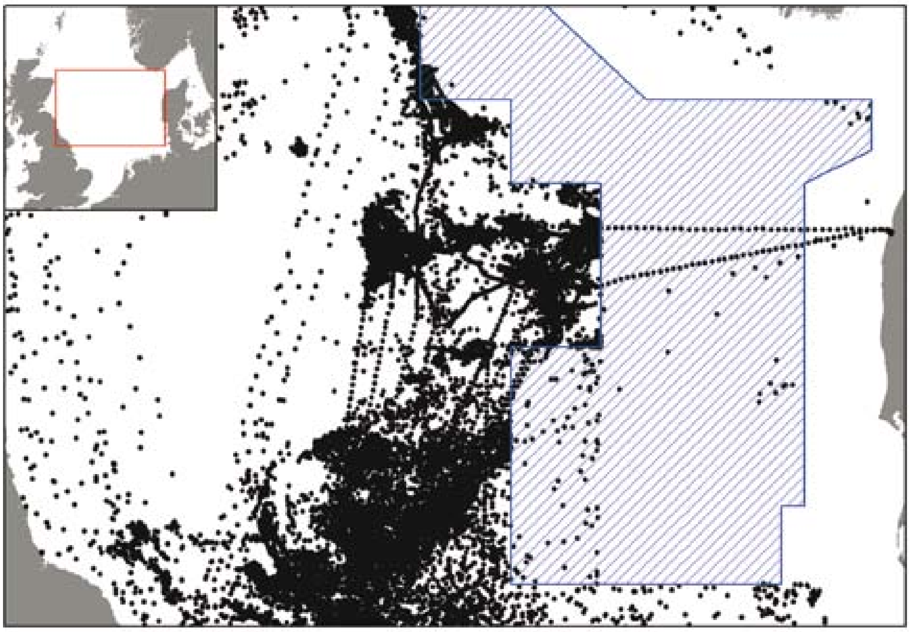
[8] For more details see http://www.fao.org/fishery/topic/14837/en

FIGURE 4.10

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



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

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

4.5 COMMUNICATION IN EAF WITH GIS

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

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

4.6 CONCLUSIONS

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

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