10. Current issues, status and applications of GIS to marine fisheries

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10.1 INTRODUCTION

It is worth recalling that in Chapter 1 the fundamental reasons for the demise of many of the world's major marine fisheries were outlined and a range of human and physical reasons were given for this. For those studying this demise it has become increasingly clear that the problems facing fisheries and fish production can best be viewed as disequilibrium[224] in the spatial domain. Thus, the capacity to provide outputs from fisheries activities at an optimum level is dependent upon the variable factors controlling this output to be in balance. This balance might be easy to achieve in fish farming situations where there are tight human controls over the production process. But when the fish feed supplies rely upon captured fish from "the wild", then keeping both fish capture rates and the condition of "the wild" at an optimum level of efficiency (or sustainable) is difficult to achieve. However, the availability of spatial tools (principally GIS and remote sensing) offers the opportunity to carefully appraise and then to manage fisheries and related activities in the marine domain.

Previous chapters have explained how GIS has developed, what it has been generally used for, and considerable detail has been given to the input needs for GIS in terms of software, data, hardware and personnel. GIS implementation considerations have also been discussed. The output achieved by the system has been hinted at in terms of the vast array of functions that GIS can perform and the subsequent decision-making information that is derived. It is now time to concentrate on how GIS can best be used for a range of marine fisheries purposes. First, the chapter examines the main thematic areas currently being addressed so as to give the reader an overview of the wide range of uses for a marine fisheries GIS. Second, it briefly looks at the current issues and status of GIS activity as applied to marine fisheries, and finally the chapter ends with three quite detailed case studies where GIS has been particularly successful. This chapter also provides information as to where further details might be obtained and various recommendations are made with respect to optimizing the use of GIS technology. By the end of the chapter, although readers might not know exactly what is possible with respect to the use of GIS in the marine fishery domain, they should feel fairly confident about the range of spatial problems that GIS can (or might) currently address.

10.2 MARINE FISHERY THEMATIC AREAS CURRENTLY BEING ADDRESSED VIA THE USE OF GIS

In Section 1.4 the scene was set relating to the early developments in the use of GIS for fisheries purposes (since the mid-1980s), and Table 1.1 set out the major GIS and/or fishery themes (issues) that were being followed as of a decade ago[225]. Here, the opportunity is taken to update the situation. The updating is done by reviewing two "levels of issues classification", i.e. first by looking at the broad thematic areas

[224] Disequilibrium here means that the fisheries environment is out of balance and thus must be unsustainable.

[225] Note that Table 1.1 included aquaculture themes as well as those pertaining to marine and inland fisheries.

(Box 10.1)[226] and by giving some examples of each of the thematic areas, and second by examining a more detailed list of specific themes and issues (Table 10.1). The categorization used in Box 10.1 is generalized and there would be an almost infinite way of drawing up thematic categories. In addition, most GIS analyses might be described as interdisciplinary and some of the entries in Box 10.1 could be considered as "processes"while others might best be thought of as "topics". With the exception of ecosystem-related matters and the need for protected areas, the thematic areas in which GIS are now being used have not expanded much from those that were used ten years ago (Table 1.1), but the detail contained within the work is likely to be far more comprehensive (see Table 10.1), as is the use of methods incorporating more complex modelling, geostatistics, animations, 3D and 4D analyses and other processes.

BOX 10.1

The main thematic areas in marine fisheries to which GIS is currently being applied

There are a large number of ways in which GIS is presently being utilized to assist in fisheries management or research. Some of these include:

Distribution displays – this is simply the drawing of maps to show the distribution of any feature or combination of marine and/or fisheries features.

Marine habitat mapping and analyses – establishing the essential components of fish habitats is an ideal way to utilize GIS, e.g. perhaps with a view to aquatic conservation designations.

Resource analyses – to quantify and display the disposition and dynamics of any marine resource or combination of resources.

Modelling – these functions include work on illustrating themes, often in a simplistic or general way, or there may be predictive modelling to show the outcome of potential decisions or actions.

Monitoring management policies – i.e. to best sustain fish yields, fishing effort needs to be optimally deployed, perhaps with the help of electronic logbooks or vessel monitoring system tracking data.

Ecosystems relationships – e.g. predator/prey relationships, or relationships between fish distributions and any environmental parameter.

Marine protected areas – i.e. identifying suitable areas for species protection, or for exclusion of fishing and analysing the results achieved by these areas.

Marine spatial planning – i.e. determining marine allocations, such that competing users of the marine space can all best function sustainably. This is complex given the number of often conflicting parties involved plus the variety of spatial considerations.

The creation of economic surfaces – i.e. allowing researchers to model the likely income derived from fishery products based on alternative management and resource extraction scenarios.

Ecosystem approach to fisheries – GIS is the ideal tool to assist in identifying ecosystems disequilibrium and to predict and depict scenarios for improved management practices.

Source: Modified from Fisher (2007) and updated from Meaden (2009).

In order that readers can further appreciate the types of thematic areas of investigation that are currently being undertaken, the authors exemplify a selection of studies that might appear under most of the thematic areas shown in Box 10.1. A large number of additional fisheries and/or GIS studies, papers and articles can be obtained from much of the literature quoted in Section 4.8.3, plus the conference proceedings listed in Section 4.8.4.

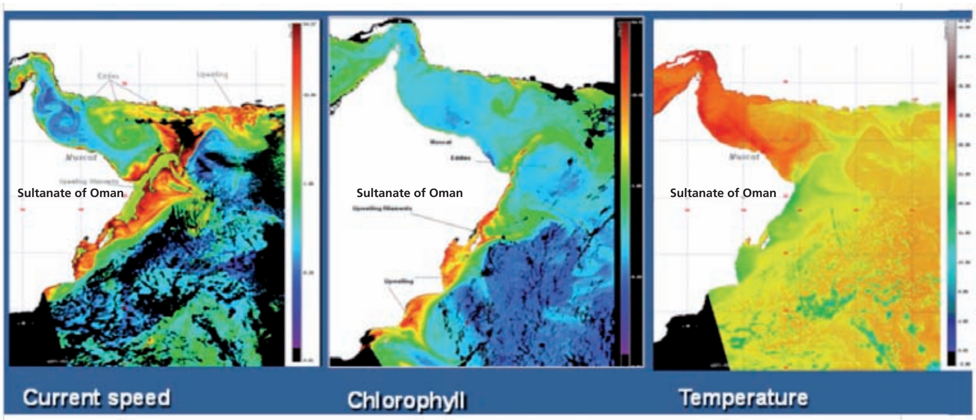
10.2.1 Distribution displays

Whatever GIS analysis work is being undertaken, it will require digital mapping showing the distribution of factors that are relevant to the analysis, i.e. to the production of the resource. These are the so-called "production functions"mentioned in Section 3.2, and they can be maps showing an almost infinite number of factors. Sometimes these maps

226 Box 10.1 is based upon work by Meaden (2009) and it essentially updates Table 1.1.

can be quickly produced for any analyses through acquiring or otherwise downloading the relevant data and then mapping this data, e.g. it is easy for users to acquire the political outlines for most countries in order to obtain a boundary map. At other times, maps may need to be compiled by the GIS user. For instance, Figure 3.6 showed mapped data on commercial fishers' perceptions as to where they were likely to fish in the eastern English Channel. This distribution map could then be used in further analyses, such as querying the relationship between fishing locations and water depth or bottom sediment types. Similarly, Figure 6.6 showing the distribution of"ocean colour"(derived from remote sensing data) and Figure 7.15, showing the distribution of an invasive pond weed, can both be used as a basis for further analyses with respect to mariculture or to inland aquaculture, respectively. Figure 10.1 shows a small range of typical mapped distributions that will be influential in controlling fish and fishery ecosystems in the Gulf of Oman and the Arabian Sea areas. These are enhanced images from remotely sensed data, where for each distribution the colour spectrum ranges from high values in red through yellows, greens and blues to low values in violet (black is unrecorded data). A perusal of the images shows that there seems to be a relationship along the Oman coast between low water temperatures and high chlorophyll values, and this is caused by cold upwelling waters bringing nutrients to the surface that in turn stimulate chlorophyll production. The GIS could provide further and more detailed information on the strength of this and other possible relationships.

FIGURE 10.1
Some typical distributions of marine parameters in the Gulf of Oman and the Arabian Sea



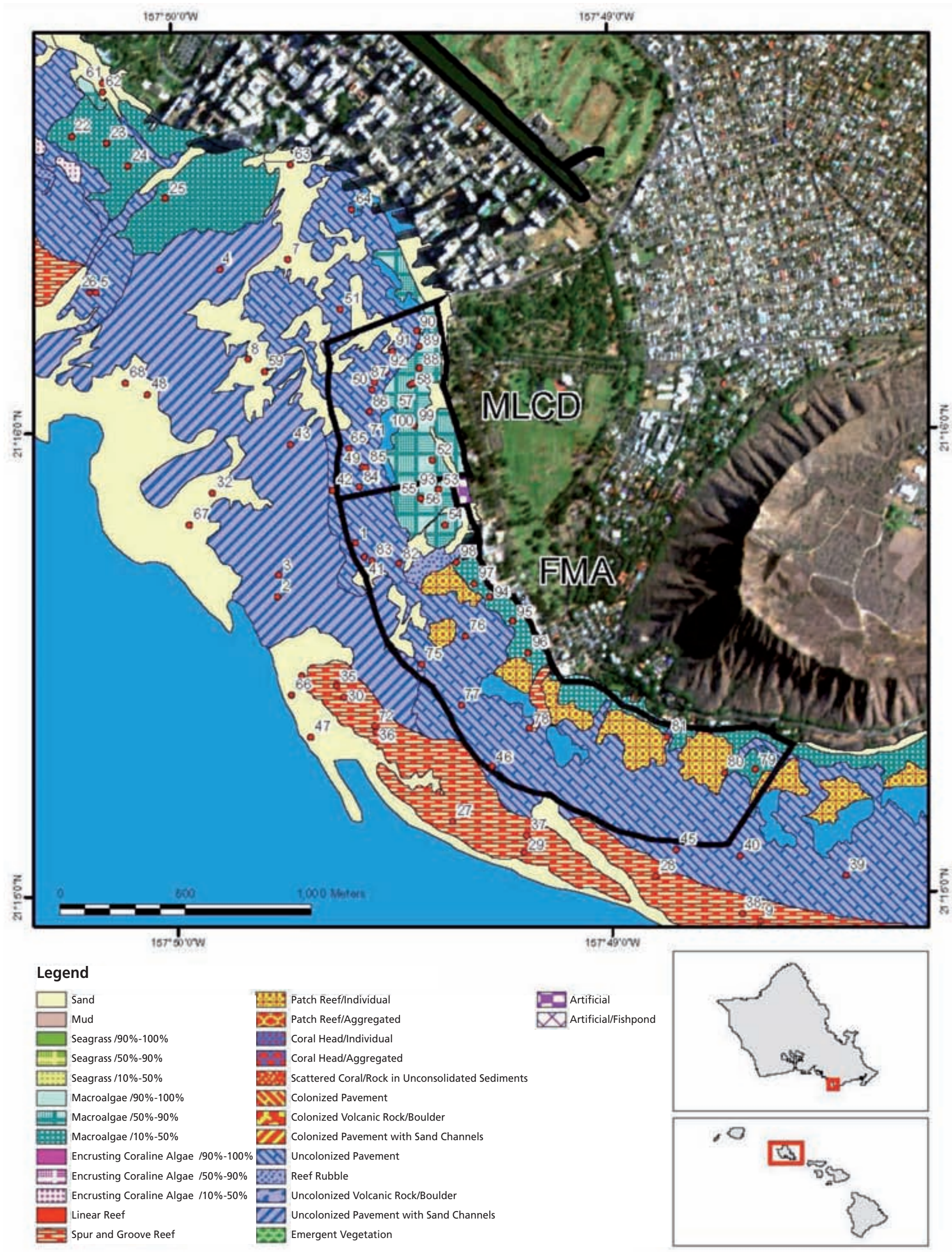
10.2.2 Marine habitat mapping and analysis and/or ecosystem relationships

These two thematic areas can be examined together because they have many similarities, especially concerning any GIS methodologies employed. If the demise of fish stocks is to be reversed, not only will it be important to better manage fisheries but it will also be essential to ensure that existing habitats are conserved and enhanced. This will require that a detailed knowledge of the range of habitats is understood and recorded and that there is a sound knowledge of the part played by various habitat types in the sustenance of marine life. Figure 10.2 provides a detailed recording of the range of benthic habitats found in a small area adjacent to the town of Waikiki Beach on O'ahu Island in Hawaii, the United States of America, in the central Pacific Ocean[227]. Data for this map (and others in a series) came from the visual interpretation of aerial photography, which was possible down to water depths of 25 m (Friedlander *et al.*, 2006). The visual interpretation of the photographs was guided by

[227] A summary of this work can be found at Center for Coastal Monitoring and Assessment, NOAA, United States of America (http://ccma nos.noaa.gov/ecosystems/coralreef/main8hi_mapping/ – accessed 10 December 2012).

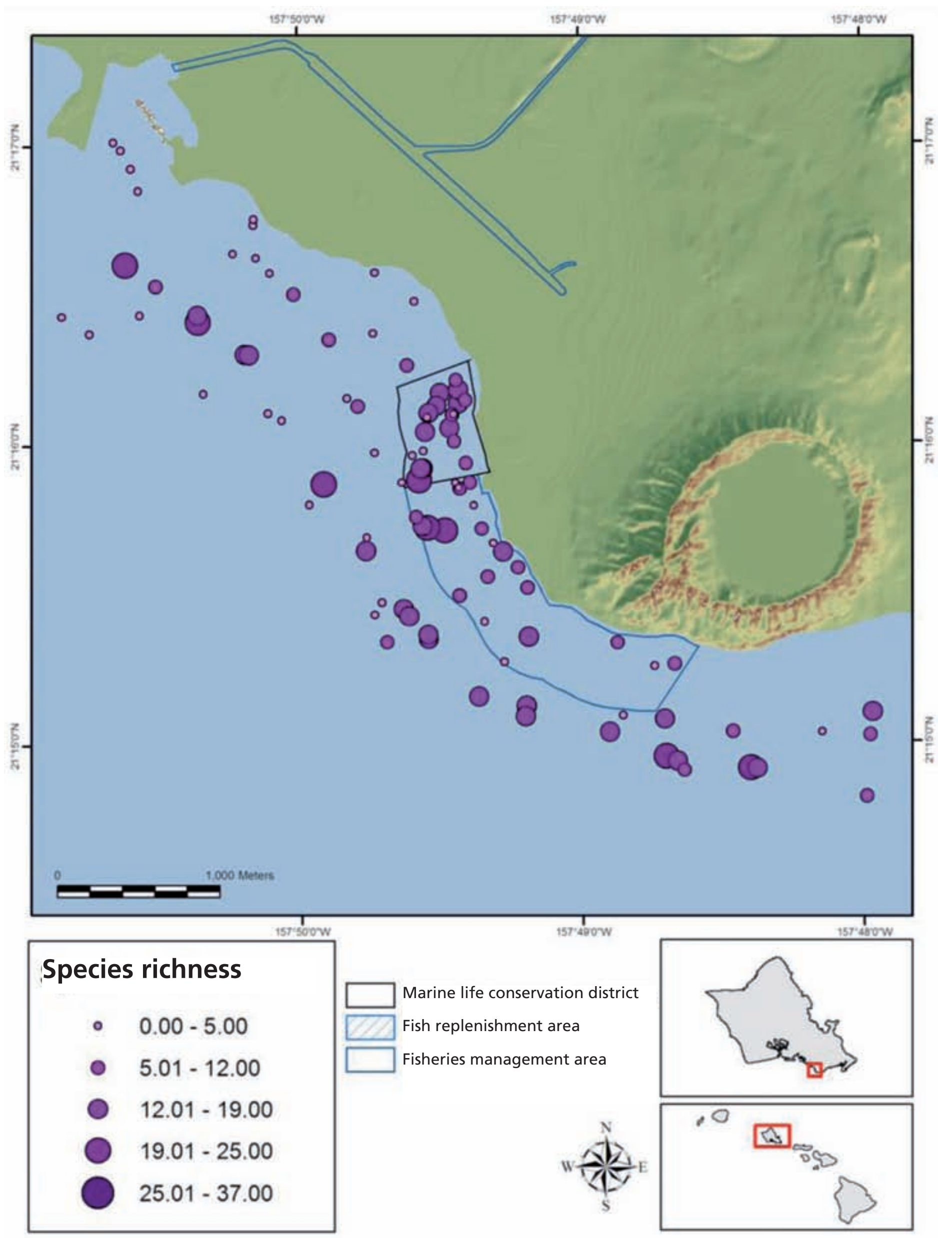
a hierarchical classification scheme that defined and delineated benthic polygon types based on insular-shelf zones and habitat structures of the benthic community. As in many other areas in the world, this popular holiday destination has suffered from fish stock depletions caused by development, sedimentation, loss of coral and other habitats, spear fishing, power boating and intrusions by invasive species. In an attempt to reverse this trend, many marine life conservation districts (MLCDs) have been established. Once mapping has been done, then a range of analyses can be undertaken to show various relationships within each MLCD. For instance, for approximately the same spatial area as shown in Figure 10.2, Figure 10.3 illustrates the species richness, and other analyses carried out by the authors showing, for example, fish densities and fish diversity. This information, in combination, can provide a secure platform on which to set further conservation goals and strategies and, more generally, to allow informed decisions to be taken.

FIGURE 10.2
Main benthic habitats off Waikiki Beach, O'ahu, Hawaiian Islands , United States of America



Source: Friedlander *et al.* (2006).

FIGURE 10.3
Fish species richness in the same area as depicted in Figure 10.2

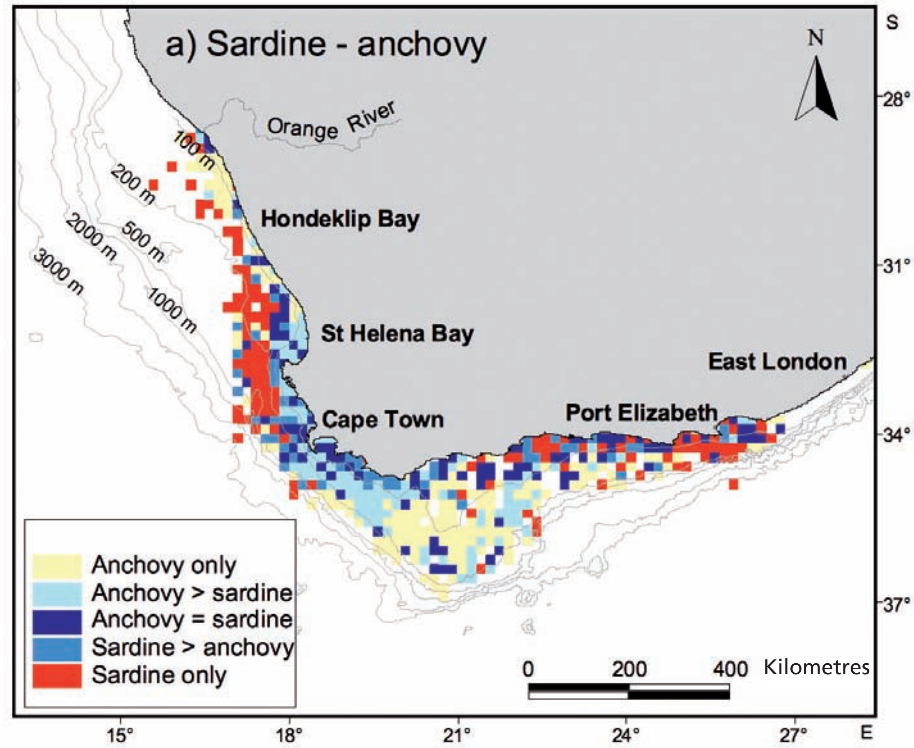


Source: Friedlander *et al.* (2006).

10.2.3 Resource analyses

Under this heading, "resources" can be thought of as consisting of a wide variety of biological or physical features that, in this case, are associated with and contribute to the marine fishing industry. Through the use of GIS, it is possible to map and to analyse the distribution of any of these resources for the purposes of research, modelling or management. Resources might include fish species, other biological species, facets of water quality, various bottom sediment or ecological types. Figure 10.4 shows the potential interactions between anchovy and sardine stocks in South African coastal waters. These waters have been divided into 10' × 10' cells (18 km × 18 km), and for each cell the relative biomass of each species was mapped using five abundance classifications. Although the authors produced data for mapping 13 key commercial species, they chose these two species to map because they are competing for the same planktonic resources and thus there is no predator/prey relationship. Interestingly, there are very similar numbers of cells for each classification category, yet they show quite different distributions. GIS is the optimum tool to further explore reasons why the distributions are as they appear, and it is probably clear to the reader that this type of mapping output could form the basis of a whole range of further spatial queries.

FIGURE 10.4
The interaction between anchovy and sardine stocks in South African coastal waters

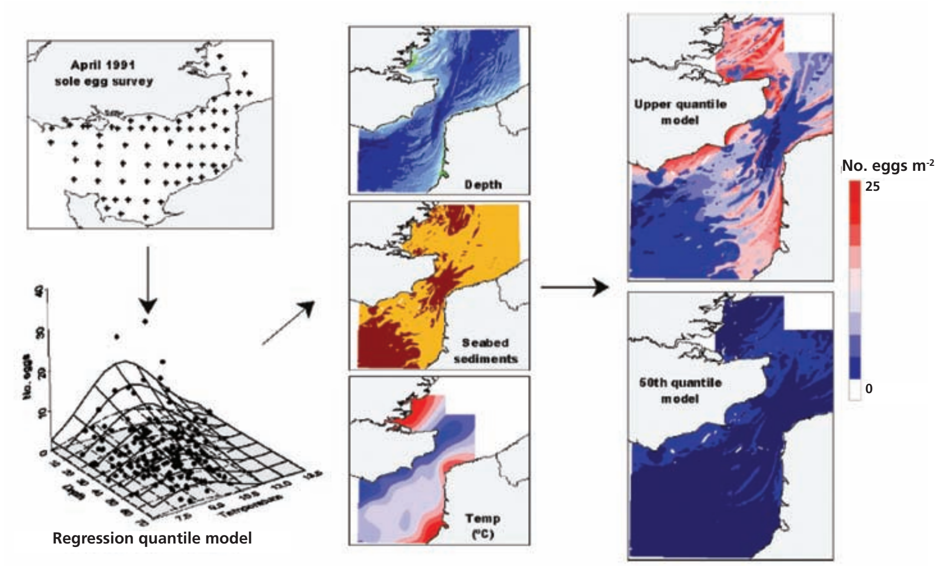


Source: Drapeau *et al.* (2004).

10.2.4 Modelling

As discussed in Section 5.4, modelling is concerned with working out a set of rules that can be established and then used for pursuing further GIS mapping or analytical procedures. It might take much experimentation to establish these rules, but once they are established they should be transferable so as to perform similar modelling procedures under a wide range of different situations. For instance, it can be appreciated that once the working methodology for portraying the information in Figure 10.4 has been worked out, the same methods could be used to compare the distribution of any two fish species in the area shown or, indeed, the relative abundance of fish species in any area. There are an almost infinite set of models that could be devised. Figure 10.5 gives a simple illustration of the basis of GIS modelling that could be used with either raster or vector data. The figure first shows the distribution of randomly selected sampling points in the English Channel where quantitative data for various parameters have been gathered. Based on this data, raster-based maps have been sampled (or values from raster-based maps have been extracted) showing the distributions of three main parameters of depth, seabed sediments and water temperature, which in this case are thought to contribute to the abundance of sole (*Solea solea*) eggs in this marine area. It was also necessary to have data on the abundance of sole eggs in the area so that the model could be developed. Eastwood and Meaden (2004) describe how the contribution of each parameter to sole egg abundance was established using regression techniques. This allowed each map layer to be"weighted"(or recoded) according to its relative contribution to the production of sole eggs. The map layers were overlaid within a GIS, and various final maps could be achieved depending on the exact regression technique being applied (in this case, the regression quantile method, which is fully described in Eastwood, Meaden and Grioche, 2001). The principles being described here show that modelling can be a particularly powerful function that GIS tools are capable of delivering.

FIGURE 10.5
Some modelling procedures for determining spawning habitats in the English Channel

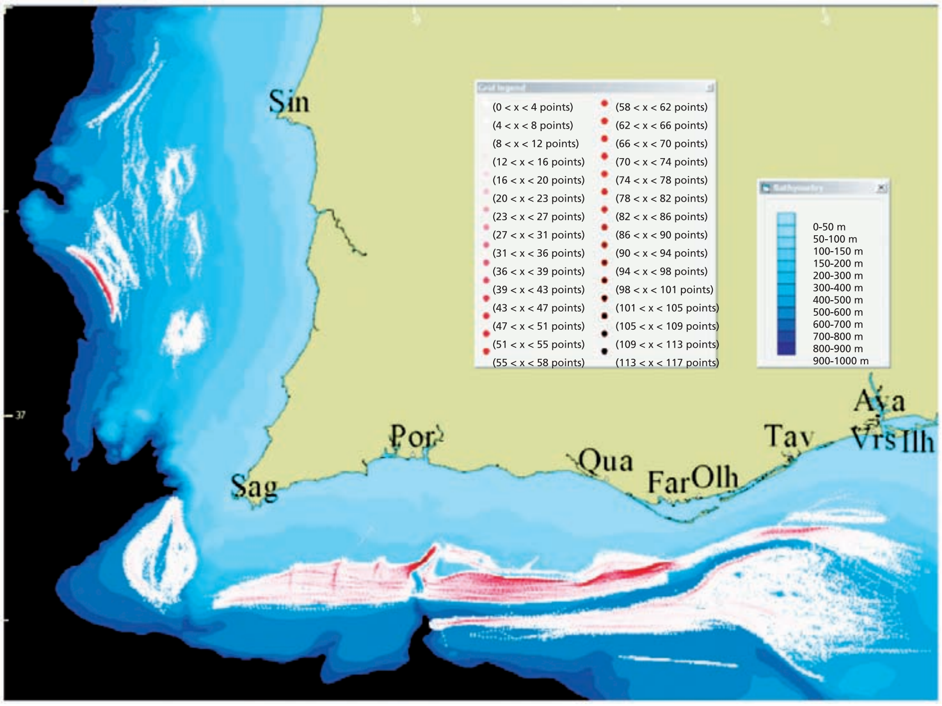


Source: Eastwood and Meaden (2004).

10.2.5 Monitoring management policies

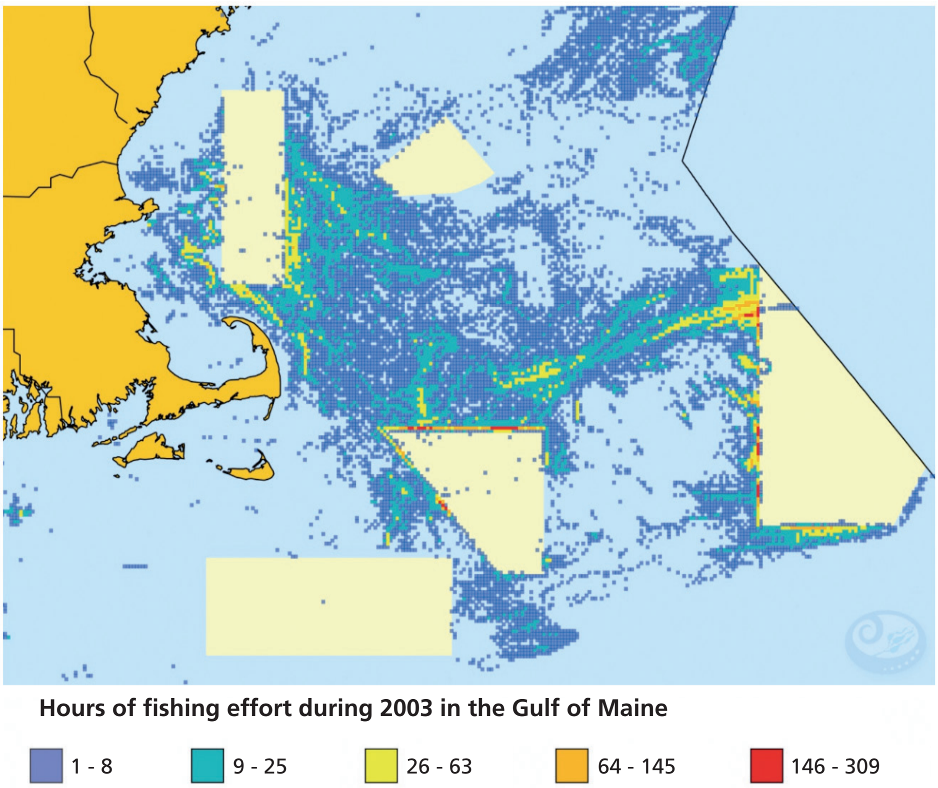
There are a large number of management policies that can be mapped or analysed using GIS. For instance, Figure 10.6 shows the disposition of the crustacean trawl fishery fleet off south-west Portugal. Here, all the individual trawl tracks (in pink) captured by the vessel monitoring system (VMS) for the 2003 season, can be seen and they show a pattern that conforms markedly with ocean depth. Thus, the trawlers are deploying their nets along contours, usually at depths of between 300 and 500 m. This is because the target species are adapted to living at specific depths – certainly at either certain times of the season or of the diurnal cycle. Clearly, stocks may become depleted in specific areas and fleet dispositions and their behaviour may need to change over time. Longer-term GIS-based analyses are likely to identify species location preferences by time, and once these are established then specific fishing strategies can be refined and economic savings can be made. Changes in fleet deployment may also be required when new regulations are introduced or when some form of marine protected areas (MPAs) are established (see Section 10.2.6). These changes can have severe consequences because they may either concentrate fishing activities into smaller areas or fisher groups can find that they are receiving unwanted additional fishing effort in their traditional locations. Figure 10.7 clearly illustrates the effects that MPAs can have on the distribution of fishing effort. Here, the areas having low effort inputs (dark blue) are widely distributed across the Gulf of Maine, the United States of America, whereas areas having medium to high effort inputs (yellow to red) are highly concentrated, almost exclusively around the edge of the MPAs. Because these MPAs have been in place for a number of years, their

FIGURE 10.6
Fishing effort in the south-west Portuguese crustacean trawl fishery as registered by VMS location data (2003)



Source: Afonso-Diaz, M, Simoes, J. and C. Pinto (2006).

FIGURE 10.7
Hours of fishing effort in 2003 in the Gulf of Maine, United States of America, and the location of marine reserves



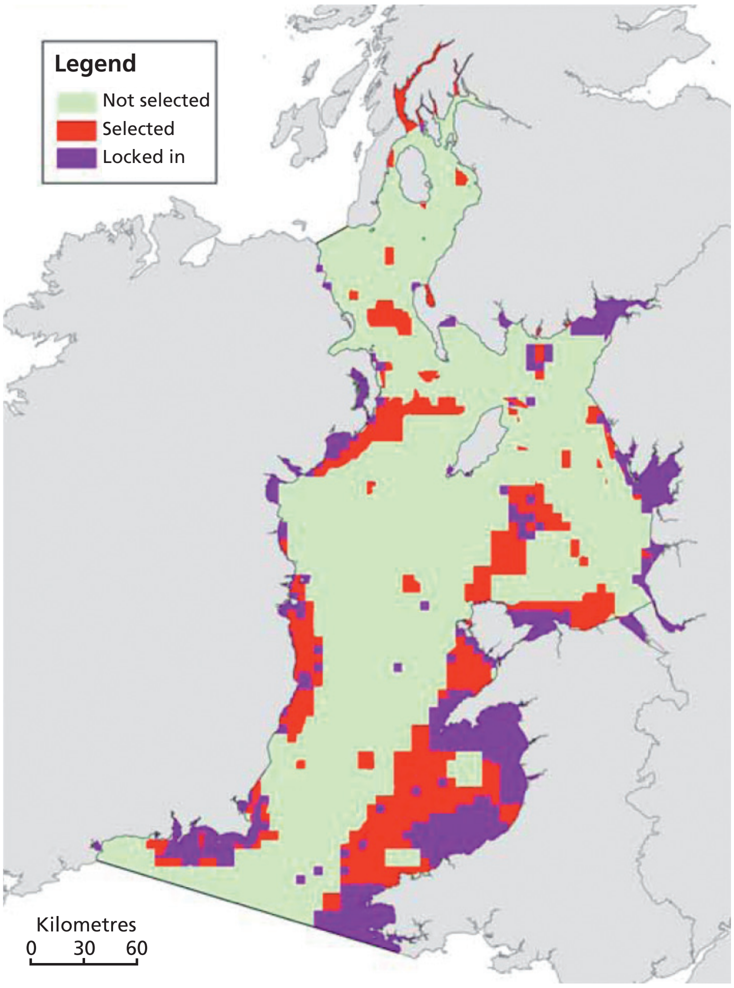
Note: Areas in beige colour represent the marine protected areas.
Source: Murawski *et al.* (2005).

fish populations are high and there is an overspill effect whereby excess fish are leaving the areas. These locations present good fishing opportunities. For management purposes, most fleet disposition mapping relies upon the use of some sort of VMS-based location capture equipment. Without this equipment only very generalized data can be gathered on fishing activity locations, though the deployment of some types of fishing activity can be monitored by other means, for example, at small scales the georeferenced location of fixed nets or the position of crab traps and lobster pots can be collected by means of handheld GPS equipment.

10.2.6 Marine protected areas

Throughout many parts of the world, it is now recognized that there is an imperative to identify marine areas that offer some degree of protection from specific marine-based activities. These marine protected areas (MPAs) might be called conservation zones, marine parks, no-take zones, vulnerable marine ecosystems (VME), etc. To this end, a large number of countries have recently issued guidance on their objectives for MPAs, how much area should be protected and on the procedures for designating MPAs in their territorial waters, and almost all the practical work in making these spatial allocations has involved the use of GIS. For example, Figure 10.7 shows the areas

FIGURE 10.8
Suggested marine protected areas (MPAs) in the Irish Sea



Note: Purple (Locked in) areas are selected as definite MPAs; red (Selected) areas are potential MPAs.

Source: Lieberknecht *et al.* (2004).

identified for MPA placement in the Gulf of Maine, the United States of America, as well as the impact of MPAs on fish production and on fishing effort in this area. As another example, Figure 10.8 shows selected and potential MPAs in the Irish Sea. To produce this type of output, the GIS software is being increasingly linked to software called Marxan, which has been specially developed as a conservation planning tool (see Ball and Possingham, 2000). Marxan is able to suggest optimum areas for conservation depending on the objectives for conservation, the percent of a marine area that users require to be conserved, and the degree of consolidation required among the individual designated conservation areas, e.g. from a highly fragmented to a very consolidated suite of conservation areas. Therefore, a range of conservation scenarios can be explored and visualized such that all stakeholders can consider a variety of options. Marxan is explained in greater detail in Section 10.4.1 and details on the application of Marxan for MPAs can be found in Smith *et al.* (2009).

10.2.7 Marine spatial planning

A Marine Spatial Plan (MSP) is a national or international plan devised in order to make certain that the marine space is equitably partitioned such that competing activities for the space can best be sustained. GIS has recently begun to play a major role in the delineation of these planning areas[228], in which the Marine Management Organisation of the United Kingdom of Great Britain and Northern Ireland has developed a GIS-based interactive mapping system for the display of most of their MSP data layers. MSP is urgently needed in areas where the marine space is congested and/or in areas where there are potential or actual resource conflicts, or, similarly, in areas where one marine activity is likely to have a major impact on another[229]. Figure 10.9 illustrates a portion of an MSP for a small nearshore area of southern California, the United States of America. Here, there are heavily congested activities along the coastal zone, and some of these activities are potential sources of conflict generation, e.g. sewage discharge points, ports, oil and gas facilities, and other activities are those that might be easy recipients of disturbance or conflict such as hatcheries, aquaculture, marine sanctuaries and conservation areas. Clearly, MSPs need to be instigated by neutral authorities and their implementation and future management may involve a considerable number of interested stakeholders. As with the ecosystem approach to fisheries (EAF) (see Section 10.2.9), a range of spatial tools can be linked to GIS for purposes of integrating physical and socio-economic factors for MSP, e.g. a detailed example is given by Snickars and Pitkänen (2007). The fisheries and aquaculture authorities in Newfoundland, Canada, have recently issued a clear and comprehensible analysis of the background considerations for MSP (see Department of Fisheries and Aquaculture, Government of Newfoundland and Labrador, 2011) and Douvere *et al.* (2007) provide an interesting case study of the actual inception of MSP in the case of Belgium. The United Nations Educational, Scientific and Cultural Organization (UNESCO) has also provided a useful publication combining EAF and MSP (Ehler and Douvere, 2009).

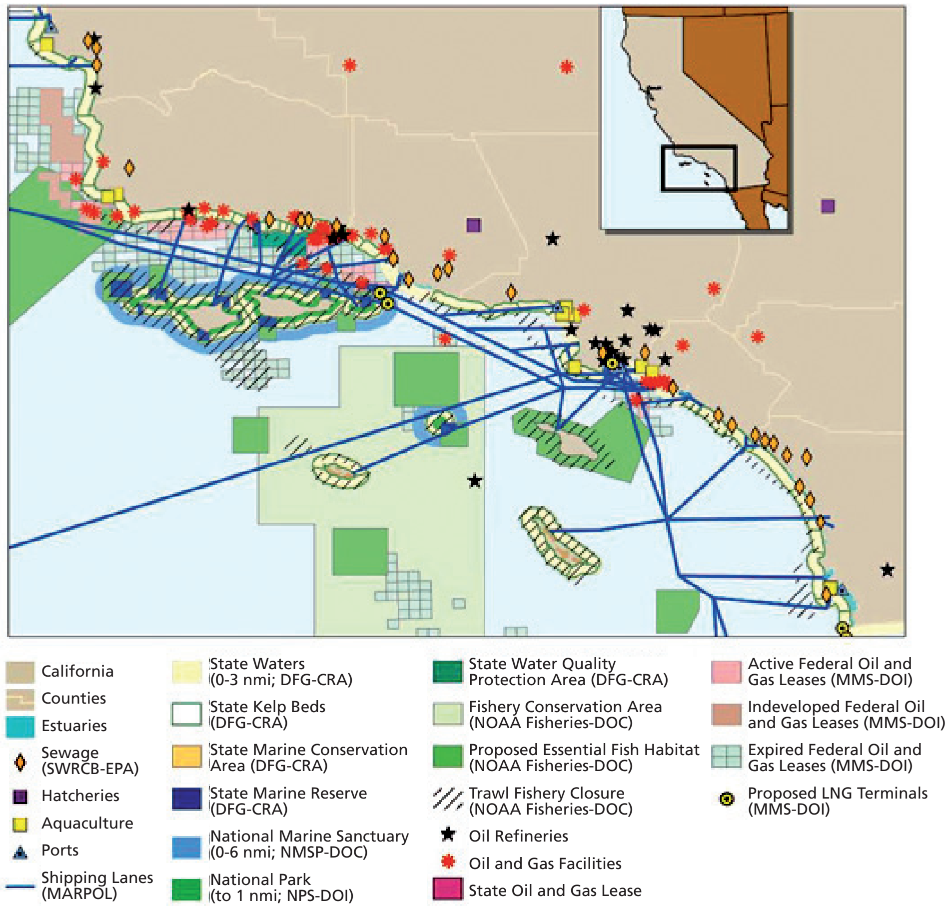
10.2.8 The creation of economic surfaces

Fishing vessels will almost certainly wish to deploy to locations where catches can be optimized in terms of maximizing economic returns. Figure 7.21 showed the central part of the New York Bight, the United States of America, in terms of where economic returns could best be maximized based on the known values of groundfish that are

[228] For example, see http://planningportal.marinemanagement.org.uk/

[229] The potential benefits of MSP include more coordinated decision-making among government agencies and with stakeholders; improved efficiencies in granting permits; leveraging of limited resources for ocean and coastal management; better stakeholder engagement; improved data collection, coordination and management leading to more informed decision-making; reduced conflicts among users; and greater regulatory predictability leading to enhanced economic opportunities and private-sector investment, particularly with regard to emerging ocean uses (National Ocean Council, 2011).

FIGURE 10.9
Extracts from the Marine Spatial Plan for California's Channel Islands, United States of America, marine area

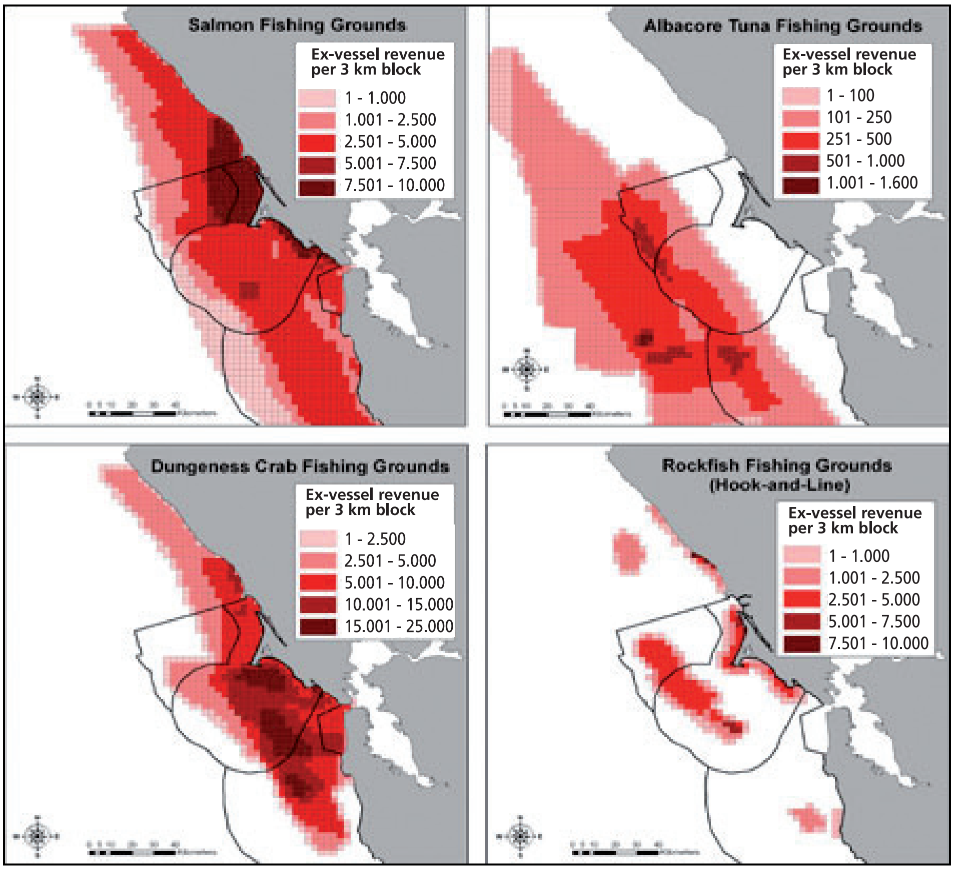


Source: Crowder *et al.* (2006).

likely to be caught by trawlers. In this figure, it can be seen that the fleet is likely to be well distributed over this broad continental shelf area, i.e. where bottom conditions are relatively homogenous and where the sea depth is only 100 m even at some 130 km from the coast. The legend reveals the considerable variations in ex-vessel value of groundfish from one area to another. Reasons for such wide variations include distance from ports, variable food availability, number of competing fishing vessels and micro-habitat variations, though it is clear that there are benefits accruing to those who can successfully fish as close inshore as possible. For a smaller area off the central coast of California, the United States of America, Figure 10.10 shows the ex-vessel value per 3 km^2 block (cells) for catches of four main commercial species caught in this area. Also shown are the boundaries of three contiguous national marine sanctuaries (NMS)[230]. Being so close to large areas of population, these species have suffered from excessive exploitation and other recruitment and oceanographic pressures over the last few decades. Fish landings have consequently declined dramatically with some species appearing to have become locally extinct. A result of stock declines was a rise in fish catch values and it is these values (averaged for the years 1997 to 2003) that are shown in Figure 10.10. Mapped economic surfaces can represent a vast number of different aspects of a fishery, including not only fish catch values by species or aggregated, but also seasonal values, changes in values over time, fuel costs for fishing in different areas and values of the differences between species.

[230] From north to south, these are the Cordell Bank National Marine Sanctuary, Gulf of the Farallones National Marine Sanctuary and Monterey Bay National Marine Sanctuary.

FIGURE 10.10
Ex-vessel values of four fisheries off the central California coast, United States of America



Source: Office of National Marine Sanctuaries (2009).

10.2.9 Ecosystem approach to fisheries

As mentioned above, this is a main new area within marine fisheries to which GIS is now being applied, one that has evolved mainly during the last decade. Although the ecosystem approach to fisheries (EAF) is a new thematic framework for fisheries management, effectively it is a process and as such it is not a theme within fisheries that needs to be illustrated by GIS-based examples. Thus, any of the figures shown in this section might well have been constructed as part of the EAF, and the whole of Section 10.4.1 is based on the EAF. Having stated this, it is important to remind readers that an EAF encapsulates much more than traditional fisheries management. Therefore, it is likely that the range of mapping output from GIS analyses will greatly increase and those using GIS or EAF-based tools will have to become familiar with a far wider range of parameters than they might have been used to handling (such as social and economic factors) as well as factors from other economic sectors. It can also be foreseen that a range of challenges will arise with respect to data gathering and mapping, and classification systems might become more difficult as it is likely that there will be a greater reliance on a range of subjectively based data. This is in contrast to most of the traditional fisheries data inputs that, although complex to handle in temporal terms, are at least fairly objective (precise) in terms of their classification boundaries. For further details on the applications of GIS to EAF, see Carocci *et al.* (2009) or Nelson, Haverland and Finnen (2009).

10.3 THE CURRENT STATUS OF GIS APPLICATIONS TO MARINE FISHERIES WORK

There are several ways in which the "status"of GIS as applied to marine fisheries might be examined. Looking generally at the main thematic areas currently being addressed (as has been done in the previous section) is one way. But it is also useful to look at other indicators concerning the status of GIS work. Here, the current thematic areas are tabulated in some detail and this is discussed. Four indicators of status have been selected: (i) main issues being addressed by fisheries GIS work; (ii) the geographic area in which the GIS work is being undertaken; (iii) the main institutions that are carrying out fisheries GIS work; and (iv) observations made by the Chair at the final session of the Symposium on GIS/Spatial Analyses in Fisheries and Aquatic Sciences held in Rio de Janeiro, Brazil, in August 2008 (Nishida and Caton, 2010).

Looking first at detailed issues and themes, in 2009 FAO compiled a database showing the main uses of GIS for marine fisheries purposes (Table 10.1) and this has been updated to 2012. This database comprises of 360 records covering 22 years, and it was compiled as part of FAO's work in developing the GISFish Web portal.[231] Table 10.1 shows that, relative to what was happening a decade ago, there has been a proliferation of GIS work, and it is now being applied over substantial areas of interest. The table also clearly highlights that marine ecosystems have become a particular area for attention, with 61 records of GIS having been directly or specifically used to help with an ecosystem approach to fisheries, plus 23 records of where GIS has been used to help address ecosystems more generally and 35 records for ecosystem modelling.[232] In many ways, this attention to ecosystems is hardly surprising. Thus, not only is EAF now seen as the only valuable approach to the comprehensive management of fisheries, but GIS offers an ideal platform and tool whereby the complex array of spatio-temporal considerations inherent in an ecosystem approach can be realistically examined. This GIS-based examination can encapsulate an array of data integration, functional manipulations and process modelling all on the same platform, and the output obtained can be viewed with a high degree of confidence, i.e. such that the visualized output is of major benefit to decision-making. Other prominent issues addressed include factors relating to both conservation and to fisheries management, which are clearly subjects of escalating importance in a world suffering from rapid species populations decline.

231 See www.fao.org/fishery/gisfish/index.jsp.

232 The zeros shown in Table 10.1 indicate areas where it was suspected that GIS issues would have been covered but where in fact no publications were found.

TABLE 10.1
Marine fisheries – main issues and themes from the GISFish database (1990–2012)

Main marine fishery issues and themes	Number of literature records
Ecosystems/ecoregions	23
Impacts of climate change	0
Multispecies analysis	9
Migration and individual movements	1
Catch and effort estimation	5
Habitats	27
Species distribution	20
Biodiversity	9
Human activities	6
Impact caused by fisheries	9
Management regulations	6
Spatial stock assessment	10
Ecosystem modelling	35
Marine protected area (design, implementation, monitoring)	30
Fishing vessel movements and behaviour	4
Social/economic impact studies	6
Ecosystem approach to fisheries management (EAFM) and indicators	21
Integrated marine management and planning	41
Fisheries development	1
Food security	0
Fisheries management systems	20
Monitoring and enforcement	0
Training	3
Promotion	13
Foundations for an ecosystem approach to fisheries (EAF)	61
Total	**360**

Source: FAO (2012d).

Table 10.2 addresses the 207 papers compiled from the FAO Aquatic Sciences and Fisheries Abstracts (ASFA) literature database under the keywords of "marine fisheries"and "GIS"for the period 1996 to 2010. The table is ranked according to the geographic area that the papers are covering.[233] Twenty-seven percent of the papers cover no geographic area because they are mainly methodological in content. Of the remaining 150 records, it is clear that there is an overwhelming dominance of work directed towards the developed world, i.e. especially in the United States of America, but also in the Caribbean, Australia, Canada, New Zealand, the North Pacific and the Bering Sea. These seven areas alone contain 55 percent of all records, and developed countries as a whole have the vast majority of all records. These facts are hardly surprising given the potential complexities and costs associated with undertaking GIS work that relies on data collected from a widespread and often hostile physical environment. Nevertheless, these records show a decade of what is often pioneering work, and in this current technical paper a wealth of demonstrable material has been

[235] Where a designation is made to a country, it signifies that the work was carried out by an institution or group from that country and that the work was within the exclusive economic zone of that country.

illustrated that can form the basis of new GIS and/or marine fisheries work. This is work that can be relatively easily duplicated by fisheries researchers and managers in less developed countries. Indeed, it is encouraging to note the work that is now being done by emerging economies such as the Federative Republic of Brazil, the People's Republic of China, the Republic of India, the Republic of Indonesia, the United Mexican States and the Philippines. This research is especially important because all of these countries have: (i) large populations; (ii) rapidly developing fisheries; (iii) large marine jurisdictions; and (iv) areas where fisheries production is extremely depleted.

TABLE 10.2
Country or marine area of application for 207 literature records on papers covering marine fisheries + GIS in the FAO ASFA database (1996–2010)

Country of application	Marine area of application	Number of applications
United States of America		80
	Caribbean Sea + Gulf of Mexico	16
Mexico		5
	North Pacific	5
Australia		3
New Zealand		3
Canada		3
	Bering Sea	3
	Indian Ocean	3
	English Channel	3
China		2
Africa		2
Italy		2
France		2
	North Sea	2
	South Atlantic	2
	Baltic Sea	1
	Barents Sea	1
	South Pacific	1
Brazil		1
Thailand		1
Philippines		1
Portugal		1
Spain		1
Japan		1
Indonesia		1
South Africa		1
India		1
Greece		1
Argentina		1
No specific area		57
Total		**207**

Source: FAO (2012b).

An additional background area indicating the status of GIS applications to marine fisheries is that of where much of the major and innovative work on marine fisheries GIS (in terms of the institutions) is being conducted. Box 10.2 gives an overview of some of the major organizations that are pursuing work in fisheries GIS. Given the highly technical nature of much of the work, nearly all of these institutions are in North America, Europe or Japan. However, there are now institutions in the People's Republic of China,

BOX 10.2

Overview of major organizations carrying out fisheries-related GIS research and projects

Clearly, this box can only be illustrative and it is impossible to give the exact range or number of institutions carrying out fisheries-based GIS work.

- **Australia.** The Marine and Atmospheric Research section of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) undertakes a wide range of fisheries-related GIS work at several of its research laboratories.
- **Canada.** The Fisheries Centre at the University of British Columbia. Arguably the premier academic institution for fisheries research, GIS is integrated into much of their output. Many projects integrate Ecopath and Ecosim modelling.
- **France.** French Research Institute for Exploitation of the Sea (IFREMER). This institute has a large number of GIS initiatives, many of them being highly innovative including complete marine GIS systems.
- **Greece.** Hellenic Centre for Marine Research. Among many fishery-related activities, the Centre has made significant advances in GIS, mainly from their marine GIS laboratory in Heraklion, Crete.
- **Italy.** The Food and Agricultural Organization of the United Nations (FAO). Supportive work is undertaken at its Rome headquarters and a number of international projects incorporate GIS as a means of better developing fisheries in less-developed areas. GISFish and COPEMED are examples of its supportive work.
- **Japan.** Environmental Simulation Laboratory. This private company has worked with government fisheries research institutes to produce an advanced marine fisheries GIS.
- **Japan.** Hokkaido University. The Graduate School of Fisheries Science has a thriving programme that includes many GIS-based projects, with much emphasis also being placed on the use of remote sensing imagery.
- **South Africa.** The large-scale VIBES (Viability of exploited pelagics in the Benguela Ecosystem) project uses GIS to research and manage this extremely productive marine area off the southwest African coast. It is largely a combined French government and South African universities integrated project.
- **United Kingdom.** University of Aberdeen, Scotland. In the university's Zoology Department, there is a small but thriving fisheries research team that has made innovative uses of GIS on a range of projects.
- **United Kingdom.** University of Stirling, Scotland. A wide range of GIS-based projects are being worked on. It was the premier United Kingdom university to cover fisheries and aquaculture GIS, and some of its Master's modules incorporate fisheries-related GIS.
- **United Kingdom.** Centre for Environment, Fisheries and Aquaculture Science (CEFAS). This is the government fisheries research agency in the United Kingdom having a specialist GIS office at its Lowestoft headquarters.
- **United States of America.** National Marine Fisheries Service of the National Oceanic and Atmospheric Administration (NOAA). Through NOAA, the United States government sponsors a large number of research initiatives that utilize GIS, e.g. the mandate to develop essential fish habitats.
- **United States of America.** University of Miami. Here, the Fisheries Ecosystems Modelling and Assessment Research Group is doing very advanced GIS-based fishery and ecosystem-related research work.
- **United States of America.** Woods Hole Institute of Oceanography. This world renowned institute carries out many fisheries research studies that frequently exploit its GIS prowess.

Source: Updated from Meaden (2009).

the Republic of India and in some Middle East countries where applications of GIS to fisheries research projects and to management are innovative. There is also advanced work being done in Australia (chiefly by the CSIRO[234]) and in New Zealand[235]. Valavanis (2002) provides more detail on the range of work being undertaken at various institutions.

Finally, with respect to the current status of GIS applications to marine fisheries work, Box 10.3 describes some individual observations made at the conclusion of the Rio de Janeiro, Brazil, GIS/Fisheries Symposium in 2008. This box needs little discussion, but it provides a useful insight into some of the perceived trends and/or status in GIS use. From the observations made, it is clear that strong advances are being made in the range, depth and overall sophistication of GIS work. But it is also clear that there is a range of thematic areas into which GIS has barely made any headway. It is anticipated that some of these areas will prove "unavoidable" once both marine spatial planning and an ecosystem approach to fisheries are pursued more vigorously.

BOX 10.3

Observations made at the conclusion of the Symposium in GIS/Spatial Analyses in Fishery and Aquatic Sciences (Rio de Janeiro, Brazil, August 2008)

These observations are not in any particular order and they may apply to more than just marine uses of GIS for fisheries purposes:

- The noticeable use of remote sensing in work based on the Pacific Ocean.
- A wide variation in the complexity of the GIS projects presented.
- Variations in the nature of the more sophisticated work.
- Dominance of ArcView (ESRI) as the GIS-favoured tool – but also GRASS, Manifold, IDRISI, plus other unidentified commercial GIS and Marine Explorer were used.
- It is clear that very large data sets are now more available and being used.
- There was very little concentration on social or economic themes.
- Very little attention was given to sport fishery or recreation angling.
- Few demonstrations of GIS to river fisheries or river habitats.
- No use made of GIS for work on restocking.
- No mention of why attendees chose the GIS software that they utilized.
- Few indications pointing to where GIS-based work has proven to be beneficial.
- The exciting range and quality of GIS work being undertaken.

10.4 CASE STUDIES OF APPLICATIONS OF GIS TO MARINE FISHERIES

Perhaps the most useful way of conveying the usefulness of any methodology or tool is through illustrations provided by case studies. A major reason why case studies are so useful is that they are applications that have been worked through and thus should readily be applicable in different areas or for different species or perhaps at different scales. They can also, of course, be modified in an infinite number of ways to suit any prevailing circumstances. The case studies are as varied as possible and include a variety of GIS-based techniques. The three case studies chosen were:

- a sophisticated example from a developed world area where a fairly large group of research workers was deployed (Section 10.4.1);
- a less sophisticated study in a developing world area involving the extensive use of remote sensing (Section 10.4.2);
- a fairly basic study carried out by a master's level student using precollected data and looking at both habitats and artisanal fishers and their methods (Section 10.4.3).

[234] The Commonwealth Scientific and Industrial Research Organisation.

[235] Fisheries are particularly important to the New Zealand economy and the country has one of the world's premier fisheries management systems.

10.4.1 Towards the use of GIS for an ecosystem approach to fisheries management (EAFM): CHARM 2 – A case study from the English Channel

Original publication reference: Meaden, G., Martin, C., Carpentier, A., Delavenne, J., Dupuis, L., Eastwood, P., Foveau, A., Garcia, C., Ota, Y., Smith, R., Spilmont, N. & Vaz, S. 2010. Towards the use of GIS for an ecosystems approach to fisheries management: CHARM 2 – a case study from the English Channel. In T. Nishida, P.J. Kailola & A.E. Caton, eds. *GIS/Spatial Analyses in Fishery and Aquatic Sciences (Volume 4)*. pp. 255–270. Saitama, Japan, International Fishery GIS Society. [GISFish id: 5490]
Spatial tools: GIS; remote sensing (minimal); Marxan; other digital mapping; spatial statistical tools.
Main issues addressed: Ecosystems/ecoregions; multispecies analysis; habitats; species distributions; biodiversity; human activities; vessel activities; spatial stock assessment; ecosystem modelling; MPA; fishers' behaviour; ecosystem approach to fisheries management (EAFM) and indicators; foundations for an EAF; integrated marine management and planning.
Duration of study: Six years (three consecutive two-year research projects).
Personnel involved: 12 members of an academic research group based at four institutions in the French Republic and the United Kingdom of Great Britain and Northern Ireland.
Target audience: Fisheries researchers, marine scientists, marine ecologists, fisheries and resource managers, local fishers, European Union and other government fishery departments, and the general public interested in marine resources.

Introduction and objectives: This paper presents the results of the third of a linked series of marine resources research projects, all largely funded under the European Union's INTERREG programme.[236] The aim of the CHARM (Channel Habitat Atlas for Resource Management) projects has been to develop materials for a series of atlases and a Web site to help with the resource management of the very busy marine area (the English Channel) located between northern France and the United Kingdom of Great Britain and Northern Ireland. Successive atlases have expanded their spatial and thematic coverage. Passing through this marine area is much of the shipping serving northern Europe, and some of the world's busiest ferry services pass back and forth across the Channel. Additionally, there are holiday resorts around the coast, wind farms are being developed, there is recreational yachting and angling, marine aggregates are being extracted, and there has long been commercial fishing activities. The current demise of fish catches provided a research challenge, i.e. can scenarios be proposed whereby the marine area functions so that all resource extraction or exploitation activities are sustainable and that fishery prospects are improved? Thus, the project is seen as a demonstration of some important considerations that are necessary in taking an ecosystem approach to fisheries management. The paper gives a brief overview of the latest CHARM project, concentrating especially on the role of GIS in creating a wide range of newly mapped resources and developing habitat models and conservation area proposals, especially with respect to managing local fisheries.

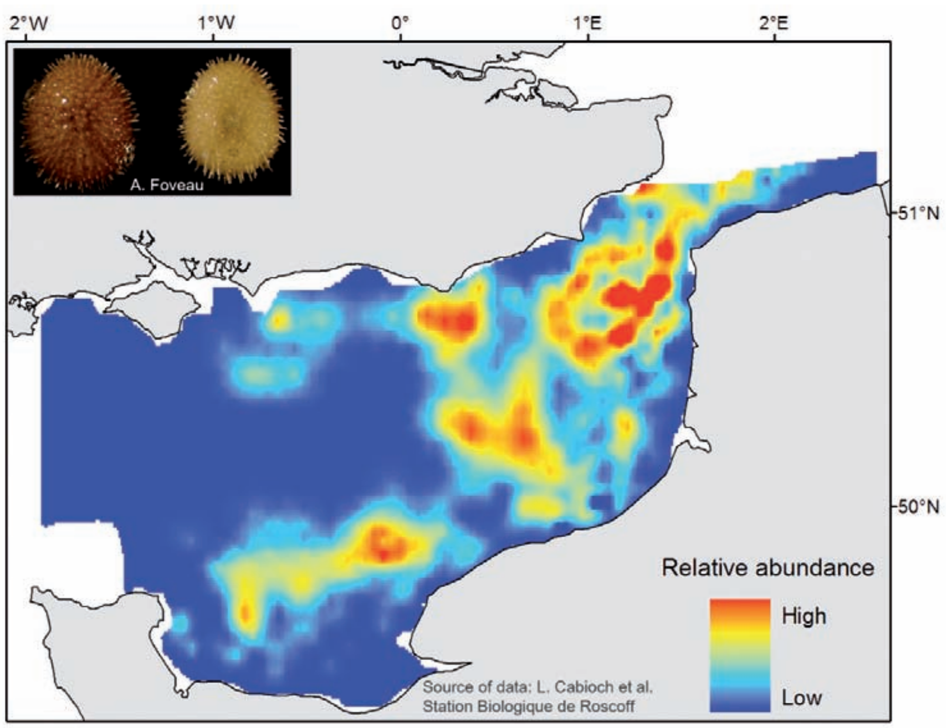
Methods and equipment: Each participating institution had responsibility for different aspects of the research project. For the work reported here, teams were involved with benthic species distribution (the Université des Sciences and Technologies de Lille – Lille University of Science and Technology); developing modelling techniques to establish essential fish habitats, commercial fish distributions and modelling to establish trophic food webs (the Institut Français de Recherche pour l'Exploitation de la Mer [IFREMER –French Research Institute for Exploitation of the Sea]); modelling

[236] The project successfully secured European Union INTERREG funding for a fourth period from 2009 to 2012.

required to show different conservation scenarios and research into various social and legal aspects relating to fishing activities (the University of Kent); and developing a Web-based marine resources atlas (see www.ifremer.fr/charm) (Canterbury Christ Church University). While work was carried out within institutions as described, there was complete integration of activities. This involved frequent project meetings and workshops, stakeholder participation, project reports, academic papers and development of the holistic atlas and Web site. Most of the data on fish distributions came from seasonal fishery surveys, carried out for over 20 years by either the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) or by IFREMER. Additional data sets were needed for more specific subject areas, e.g. physical water parameters, bottom sediment distributions, some biological and chemical parameters, fish catches, fisher perceptions of their activities, etc., and remote sensing data was used for chlorophyll-*a* and water temperatures, and these data were obtained from a variety of sources. All GIS work was performed using the Environmental Systems Research Institute's (ESRI) ArcView 9.2.

Results: Space in the 2010 conference proceedings precluded anything but brief examples of some output from the 626-page atlas (Carpentier, Martin and Vaz, 2009). The atlas includes a wide range of photographic, tabular, graphical, textual, and mapped data and information. Included in the range of maps presented was Figure 10.11, which illustrates the distribution of one benthic species in the English Channel. From the EAF perspective, benthic distributions are a vital component of the ecosystem. It can be seen that this species prefers mid-Channel areas where the higher hydrodynamism (current speeds) generally provide for coarser seabed sediments. The map was constructed using data recorded between 1972 and 1976 from 1 495 sampling stations in the eastern

FIGURE 10.11
Distribution of the echinoderm *Echinocyamus pusillus* in the eastern English Channel, with inset showing the species

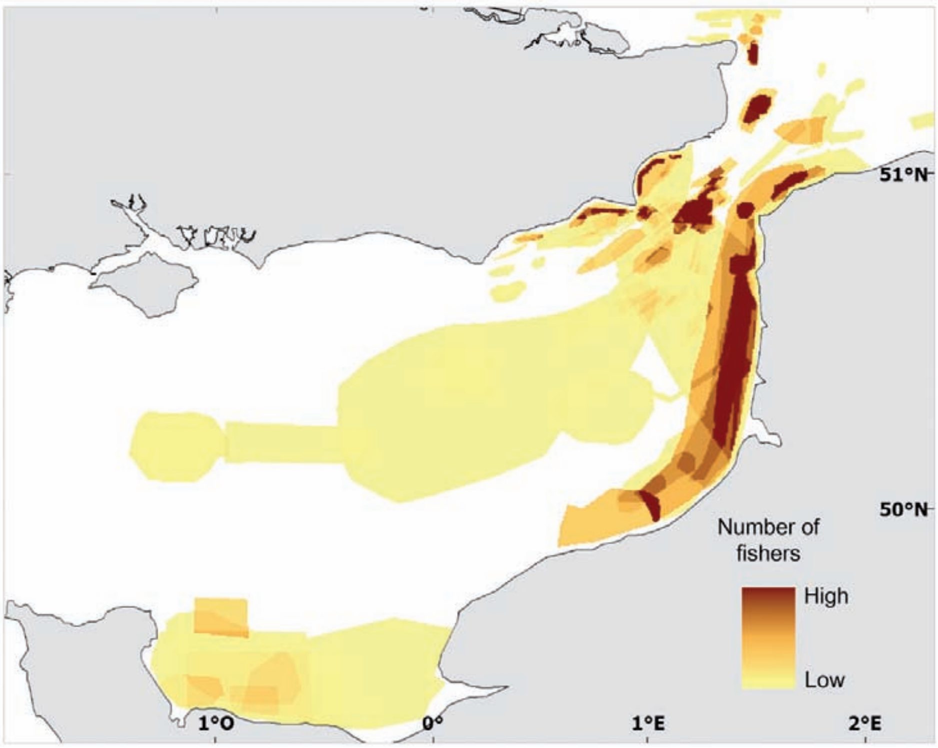


Source: Meaden, *et al.* (2010).

Channel.[237] Production of this map, and others showing species distributions, relied on the kriging interpolation procedure that itself uses a model describing the spatial structure and variation in the data, i.e. the variogram. The use of GIS for creating maps based on quite complex geostatistical inputs is now becoming widespread, and some GIS already contain a range of algorithms for geostatistical analyses.

Figure 10.12 illustrates a relatively unusual aspect of GIS-based output, i.e. the mapping of spatial perceptions. From the EAF perspective, it is important to know where fishers prefer to fish; this is because it will give a good indication of areas that usually provide good catches and where there might be controversy if fishery or other authorities declare these areas to be off limits, perhaps for conservation purposes. Fifty-one fishers from ten ports on either side of the Channel were asked to pencil in on a base map their preferred fishing locations. Figure 10.12 shows the aggregated preferred fishing areas for nine main commercial species. It is clear that inshore French waters are more favoured than elsewhere, and this is a function of there being more fishers on the French side of the Channel plus a general likelihood of the ecosystem providing for an increased abundance here.

FIGURE 10.12
Collective perceptions of fishers from selected ports in south-east England and northern France as to where they fish for nine main commercial species



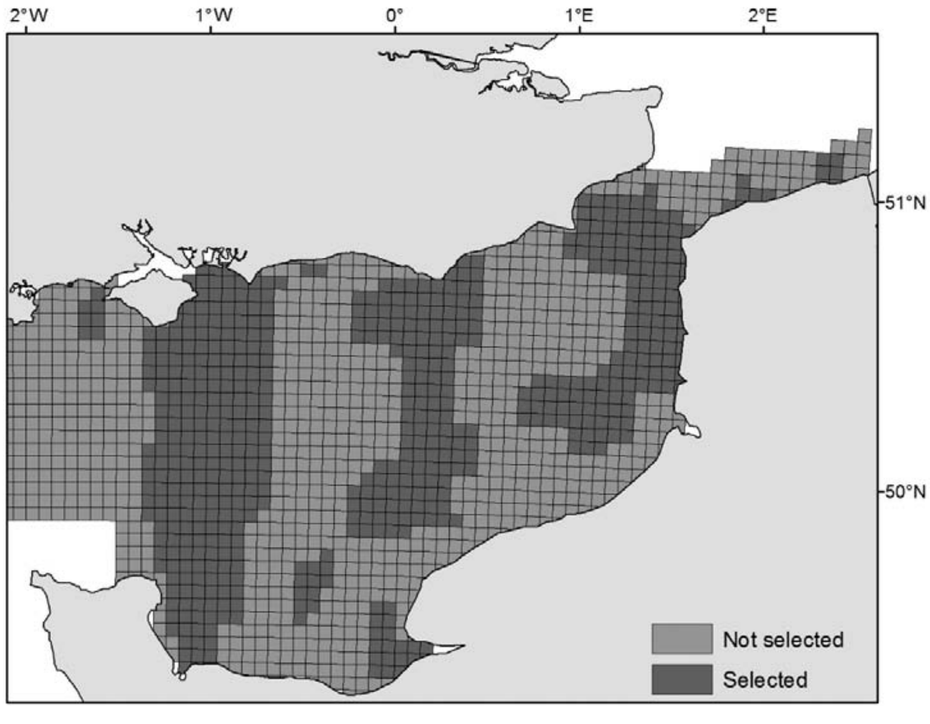
Source: Meaden *et al.* (2010).

Given the demise of commercial fisheries in the English Channel (and many other areas), and as part of an EAF, public authorities are working with other interested parties in an effort to designate MPAs (often conservation or no-take zones). This is a complex matter because the resulting areas and/or zones must often be a function of many competing aims and objectives for use of the marine space. The conservation

[237] Notice that even in the well-studied waters of the English Channel, it is necessary to use fairly old data if other suitable data sets cannot be found.

planning tool, Marxan, has been developed in response to this need.[238] Marxan involves identifying a list of conservation features, which may include important species, habitat or ecological processes, and setting numerical targets for how much of each should be conserved. Data are acquired showing the relative incidence of each identified conservation feature in each cell of the cell matrix that is imposed on the area of study (cell size is optional). A "cost score" is also allocated to each cell, which can relate to any actual cost that might be involved, e.g. loss of earnings from aggregate extraction in cells, extra costs of diverting shipping around specified cells and costs involved in travelling further to fishing areas. Marxan's output is based on setting goals corresponding to how much of the area is required to be conserved and what the total boundary length of the conservation areas should be. Marxan then performs numerous iterations to produce a portfolio of optimum conservation scenarios. Figure 10.13 shows optimum areas in the eastern English Channel whereby 40 percent of the marine area is conserved and where the boundary length[239] is relatively minimized. GIS provides the ideal platform upon which Marxan can function.

FIGURE 10.13
Areas selected for potential conservation in the eastern English Channel given a target of 40 percent of the total marine area



Source: Meaden *et al.* (2010).

Discussion, conclusions and recommendations: There are numerous challenges to work such as that carried out by the CHARM team. These include the lack of data; costs of data acquisition; the fact that data sampling provided only snapshots in time; CHARM methods tend to utilize a "top-down" approach to EAF; the time-consuming nature of some analyses; deciding optimum resolutions to be working at; the difficulty of including all essential EAF aspects; and the infinite complexity of many marine ecosystems. Having stated these challenges, the output actually achieved by the CHARM team allowed for a vastly increased knowledge of the Channel's

[238] See www.uq.edu.au/marxan/index.html?p=1.1.1
[239] This is the total length of the boundary areas shown as "selected" in Figure 10.13.

ecosystems and resource distributions. Although almost all of the mapping work was accomplished with the aid of GIS, it should be mentioned that GIS is far more likely to be an aid to the physical, biological and environmental aspects of EAF, i.e. rather than the requisite work on the economic and social sides of the ecosystems approach. In sum, the authors anticipate that GIS uses will be increasingly developed in an effort to minimize economic and social spatial disparities.

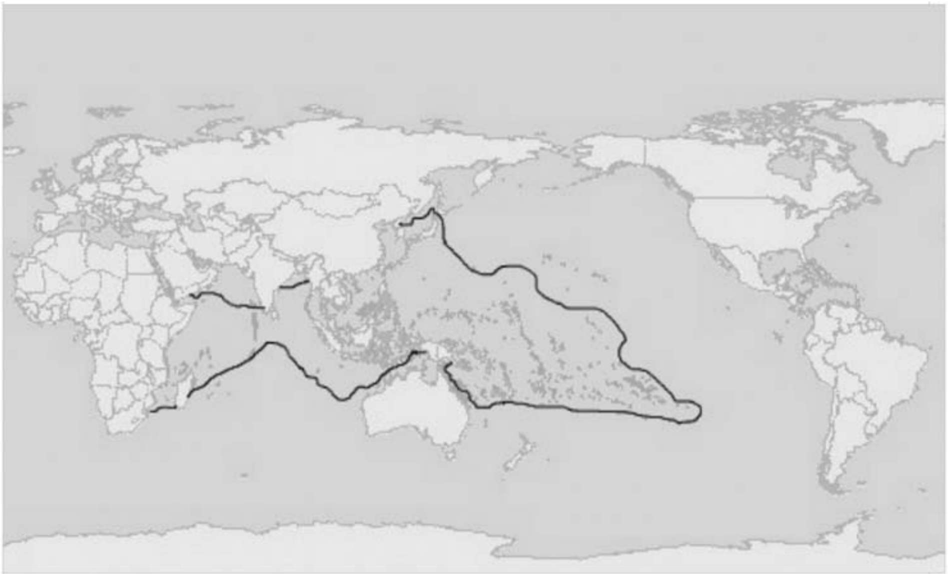
Challenges and lessons from the case study: The case study itself recognized that there are some considerable challenges to be met in doing this type of GIS/EAF work (see above). The authors also rightly acknowledged that their work concentrated almost entirely on the marine physio-biological aspects of the whole ecosystem at the expense of socio-economic aspects. And it was clear from the publication that some thought must be given as to whether an approach to EAF (or, indeed, the ecosystem approach to aquaculture – EAA) work is best directed from the "top-down" or "bottom-up" perspective, i.e. should those who form part of the fishery or aquaculture working environment make the major contribution to aims and specific objectives for the EAF or EAA, or should these contributions come from a range of fisheries and/or marine ecosystems experts? From the GIS perspective, it is clear that the work carried out by the CHARM team was sophisticated, calling for considerable inputs from persons having thorough geostatistical knowledge and practical GIS expertise. The scale of the project was wide ranging in space and time, with data inputs relying on access to national government fisheries survey records stretching over more than 20 years, plus access to a wide range of more general data. The authors believe that the type of GIS work carried out in this project would only be possible from a fisheries research institute or from university teams and that there would need to be considerable funding available. At the "high end" of GIS work CHARM was clearly a valuable project, both for what it achieved in terms of output and as an example of what is possible.

10.4.2 Estimating reef habitat coverage suitable for the humphead wrasse, *Cheilinus undulates*, using remote sensing

Original publication reference: Oddone, A., Onori, R., Carocci, F., Sadovy, Y., Suharti, S., Colin, P.L. & Vasconcellos, M. 2010. *Estimating reef habitat coverage suitable for the humphead wrasse, Cheilinus undulates, using remote sensing*. FAO Fisheries Circular No. 1057. Rome, FAO. 31 pp.
Spatial tools: GIS; remote sensing.
Main issues addressed: Ecosystems; species distribution; habitats; spatial stock assessment.
Duration of study: Two years.
Personnel involved: Four fisheries resources experts, two GIS experts, one remote sensing expert.
Target audience: fisheries managers, fisheries scientists, remote sensing and GIS experts, marine ecologists, governmental fishery departments and conservationists.

Introduction and objectives: The humphead wrasse (Napoleon fish), *Cheilinus undulatus*, is the largest living member of the family Labridae, with a maximum size exceeding 2 m and 190 kg. The species is a protogynous hermaphrodite (i.e. adults can change sex from female to male); these species have a low productivity and occur in naturally low densities in coral reef-associated areas throughout its geographical range in the Indo-Pacific (Figure 10.14). Diminishing stocks in most tropical waters means that the species is cited on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II list and that management and export regulations must be applied.

FIGURE 10.14
Area of distribution of Napoleon fish (within line). The species is closely associated to coral reefs within its range



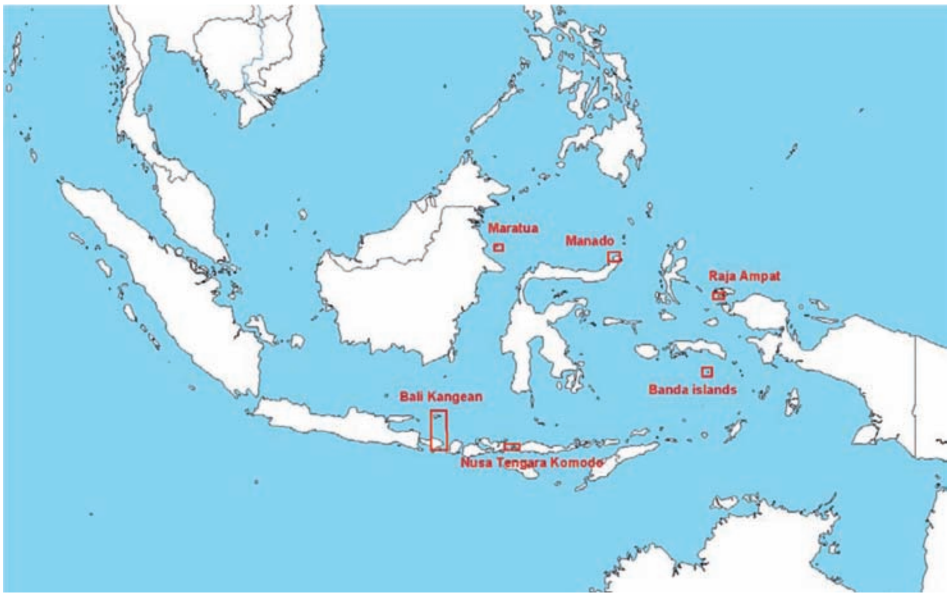
Source: Oddone *et al.* (2010).

This study evaluates the use of freely available satellite imagery, collected between 1999 and 2003, for the mapping of shallow reef areas in order to locate the habitat of humphead wrasse. The habitat suitability mapping for adult humphead wrasse is based on the location of reef edges as discerned from available Landsat remotely sensed images and on the application of a buffered area around the reef edges, where the probability of finding adult humphead wrasse is highest according to underwater visual census (UVS) data conducted during a previous phase of the study. GIS and remote sensing methods are used to estimate the habitat coverage of the species in the Republics of Indonesia, Malaysia and Papua New Guinea, three of the most important exporting countries for the species.

Methods and equipment: The study consisted of two phases. In the first phase, it was necessary to evaluate whether Landsat-7 images could be used to identify the habitat of humphead wrasse in the Republic of Indonesia. To perform this, a set of satellite images was collected for six areas in the Republic of Indonesia (Figure 10.15) that had been previously surveyed for humphead wrasse using UVS. The second phase applied the methodology developed in the Indonesian test phase to calculate the total suitable habitat areas for humphead wrasse in the Republics of Indonesia, Malaysia and Papua New Guinea. Each of these phases is now described in more detail.

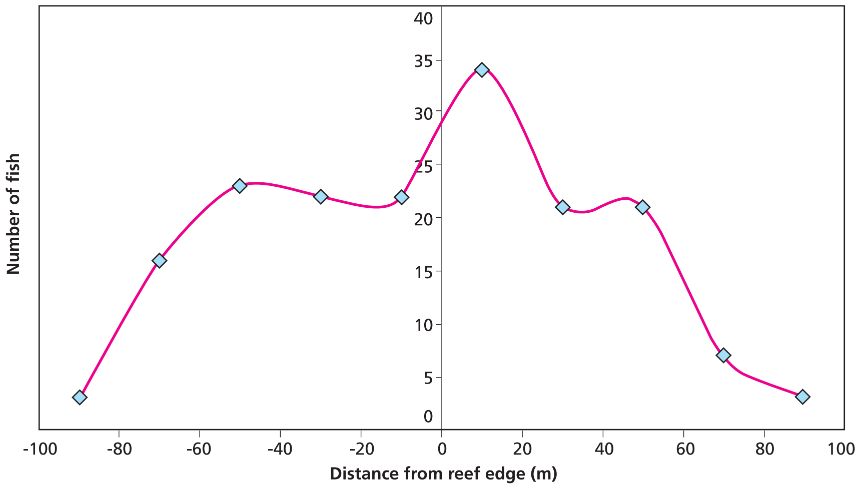
First methodology phase: identifying humphead wrasse habitat – underwater visual survey. Between 2005 and 2006, UVS were conducted in six areas of the Republic of Indonesia to estimate humphead wrasse densities in areas with contrasting levels of fishing exploitation. The diving team used a floating GPS that allowed a detailed tracking of the diving paths at 15-second intervals. The surveys were made in reef edge areas that showed all the typical aspects of the habitat of the humphead wrasse with a focus on adult habitat. Divers recorded the position of all humphead wrasse encountered during the surveys. Figure 10.16 shows the position of 180 humphead wrasse detected during the surveys relative to the calculated position of reef edges. Results indicate that 96 percent of all the fish detected were within a 200-m buffer zone.

FIGURE 10.15
Map showing the extension of the six surveyed areas in Indonesia analysed in this study



Source: Sadovy (2005).

FIGURE 10.16
Distribution of humphead wrasse detected in UVS relative to the position of the reef edge shown in the satellite images



Note: A positive distance means that fish are located towards the open sea (slope area); a negative distance means that fish are detected in the inshore Fore reef zone (see Figure 10.17).

Source Oddone *et al.* (2010).

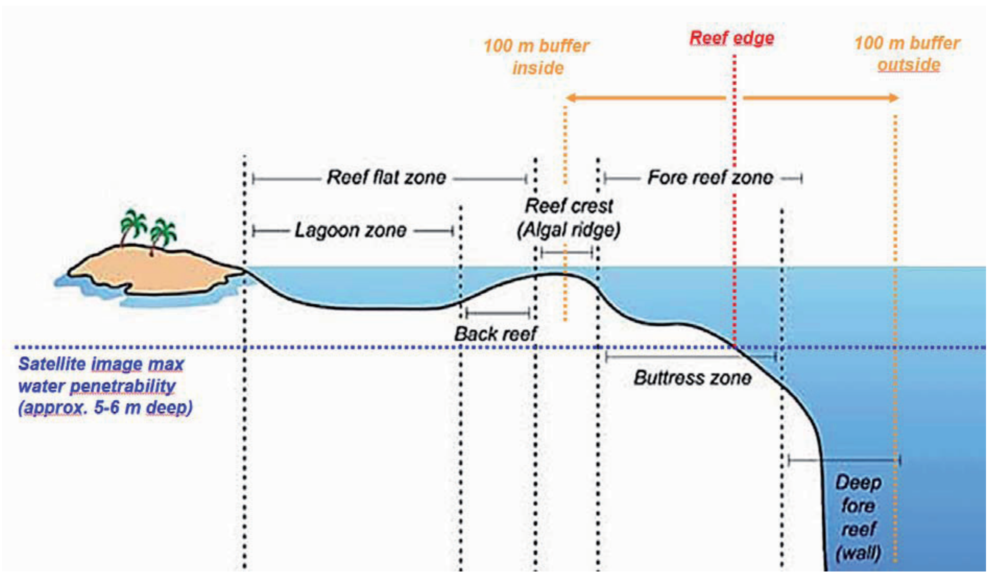
Selection of Landsat images. To perform the initial study, Landsat-7 images available from the Millennium Coral Reefs Landsat Web site (http://oceancolor.gsfc.nasa.gov/cgi/landsat.pl) for the six surveyed areas were downloaded. The authors give a detailed account of why Landsat images were preferred, this being based on a compromise concerning availability, cost, spatial coverage, their medium-scale optical resolution and the wavelengths in the electromagnetic spectrum that are captured. In total, 12 Landsat-7 images were used to cover the study area. Every Landsat image is identified by three numbers that define it in a unique way:

- Track – this number refers to the satellite orbit and can be generalized as the "longitude" of the image.
- Frame – this number represents the reference scene along the orbit and can be generalized as the "latitude" of the image.
- Acquisition date – the parameter that differentiates all the Landsat scenes acquired over the same area (i.e. same track and frame).

Image processing and analyses were accomplished using ERDAS Imagine software because it is fully compatible with ESRI's ArcView GIS software used later.

Definition of habitat for humphead wrasse. Figure 10.17 shows a schematic representation of a typical barrier reef section, with the indication of the reef edge and other main features.[240] The reef edges detected on the Landsat images are in reality the boundaries where the reef disappears from the image into the deeper sea (on average at 5 to 6 m depth). If it is considered that the reef drops into the ocean with a 45° slope inclination, a 100-m buffer would cover an area down to 100 m depth (the limit of humphead distribution) on the offshore face of the reef. The 100-m buffer towards the inside reef would cover the low water reef area. As can be seen in Figure 10.17, in some cases the 100-m buffer may be too wide for islands with narrow fringing reefs, while in others it can be too small and may thus underestimate the actual extent of reef areas. However, overall a buffer area of 100 m on either side of the reef edge seems to best fit the different morphological types of fringing reefs in the Republic of Indonesia. The definition of a more complex buffer (e.g. asymmetrical on the two sides of the reef edge or customized for every single reef area) would create a more difficult and time-consuming methodology whose effects on the overall definition of the habitat area would probably not be significant. It must also be remembered that 100 m on a Landsat image is equivalent to only 3 pixels, which is almost the visual limit of detection of objects in a Landsat image.

FIGURE 10.17
Section of barrier reef with an indication of the reef edge and 100-m buffer area (linear structures are not to scale)



Source: Oddone *et al.* (2010).

240 In this example, there is a steep reef wall, but this would not be the generic situation of all reef slopes.

Digitization of the potential humphead wrasse habitat. Attempts were made to identify all coral reef edge areas by means of various automatic pixel value or edge detection methods. However, for numerous reasons, these methods were rejected as being unreliable. An empirical procedure was therefore used to map the habitat of the humphead wrasse. First, an operator manually draws (digitizes) the external borders of all the reef areas he or she is able to identify on the Landsat images. Second, a fixed 100-m buffer zone is applied on both sides of the reef edge margins, thus including part of the reef habitat of young fishes and the slope area habitat of adult fishes (Figure 10.18). The extent of the habitat can therefore be calculated based on the area of the polygon formed by each buffered zone.

FIGURE 10.18
Example of identification and manual vectorization of reef edges and automatic buffering on the reef edges in the Maratua Atoll, Indonesia

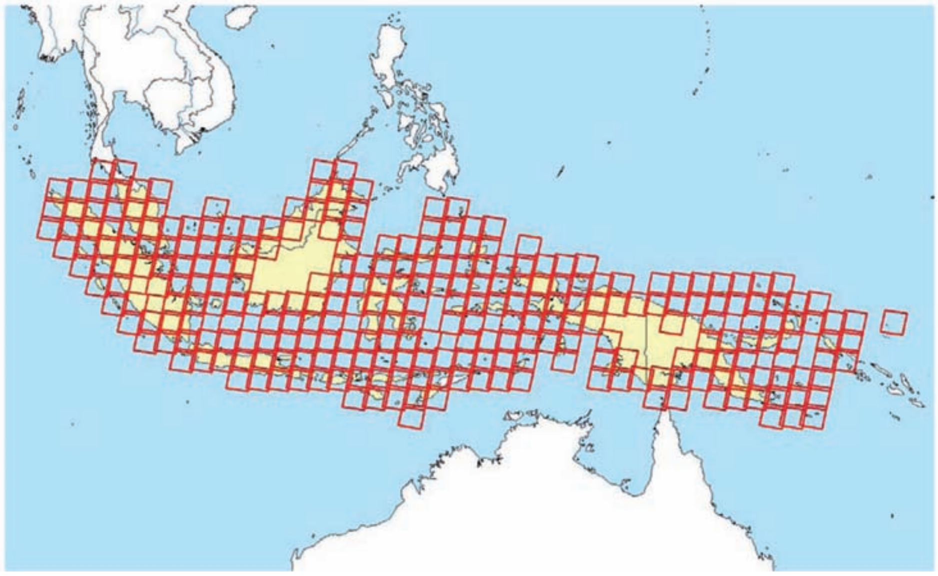
Source: Oddone *et al.* (2010).

Second methodology phase: calculate the total area of humphead wrasse habitat. Following the empirical procedures defined above, the next phase of the study was to calculate the suitable adult habitat areas in the Republics of Indonesia, Malaysia and Papua New Guinea. To perform this work, 279 Landsat-7 scenes covering the entire area of interest were used (Figure 10.19). The scenes were downloaded free of charge from the Millennium Coral Reefs Landsat Web site (http://oceancolor.gsfc.nasa.gov/cgi/landsat.pl). All scenes were based on imagery acquired between 1999 and 2002.

Discussion, conclusions and recommendations: The results of the mapping methods devised were tested against the true location of the 180 humphead wrasse recorded in the UVS survey mentioned above, and it was found that 96 percent of the wrasse were located in buffers defined by the GIS procedures. This was regarded as a strong confirmation of methodological suitability. Using the GIS methods described, the total reef areas suitable for humphead wrasse were 11 892 km^2 in the Republic of Indonesia, 941 km^2 in the Republic of Malaysia, and 5 254 km^2 in the Republic of Papua New Guinea.

It is concluded that, for the purpose of estimating the suitable areas of humphead wrasse habitat, i.e. as a basis for defining population size and sustainable export quotas, the results obtained in the present study are more conservative and appropriate than

FIGURE 10.19
Grid of 279 Landsat-7 scenes used to calculate the humphead wrasse habitat areas in Indonesia, Malaysia and Papua New Guinea



Source: Oddone *et al.* (2010).

previously available estimates. Thus, previous estimates of reef areas, available only for the Republics of Indonesia and Malaysia, were approximately four times larger than the habitat areas for the wrasse calculated in the present study. This discrepancy mainly results from the much coarser satellite imagery resolution used in a previous study by Burke, Selig and Spalding (2002). The methods used and results obtained from this study can be used for other locations and species and they will act as useful information in the siting of MPAs and in any detailed marine ecosystems analyses. Additional information on monitoring and management of humpback wrasse can be found in Sadovy *et al.* (2007) and Gillet (2010).

Challenges and lessons from the case study: The case study recognized some main issues and challenges related to the above approach to mapping. In relation to the remote sensing analysis, they are concerned with aspects such as:

- Reefs that are not well defined or too small to be detected in a Landsat image.
- Areas close to river mouths where the discharge of sediments affects the ability to visualize features below the surface (although areas with high turbidity are naturally unsuitable for coral reefs).
- It is difficult to discriminate between live and dead coral.
- It is helpful if the GIS worker has some experience in remote sensing image analysis.
- Habitat mapping can be a complex and time-consuming work, especially for large and complex areas such as the Republic of Indonesia.

It is also likely that in reality the distribution of humphead wrasse would be affected by other factors than those of the position of the edge of the reef. These include the availability of food, wave strength and height, and existence of algae.

This case study illustrates a valuable and effective methodology for showing some basic uses of both remote sensing and GIS analyses. Both of the main techniques used, i.e. (i) that of using remote sensing imagery as a backdrop for digitizing and (ii) creating buffers around digitized features, are fundamental functions for many GIS projects.

This study could also form the basis of additional GIS-based work that might be carried out given access to appropriate data. For instance, given that an average wrasse density might be established for specific reefs or specific islands or administrative areas, then the total potential biomass of wrasse could be estimated for a known areal unit (which the GIS can calculate). This could give clues to the economic productivity of the area, which of course might be estimated for other extracted species. It is also apparent that if the reef edge can be digitized from the remote sensing imagery, then so too can other useful features. Therefore, the area of lagoons can be calculated, the area of the reef itself, the size of estuaries, lengths of coastline, the size of sand banks in shallow waters, etc. With respect to locations along the reef edge, these could be matched up to perhaps distance from urban areas so as to discern areas at risk from biomass overexploitation and thus in need of enhanced management practices. And the methods described here can certainly contribute to both ecosystems-based local analyses and to site selection for potential marine conservation zones. With the pressure likely to seriously increase on the world's coral reefs, especially in view of enhanced ocean acidification, then comprehensive adoptions of GIS-based methods can only be beneficial.

10.4.3 Spatial assessment and impact of artisanal fisheries activity in Cap de Creus

Original publication reference: Purroy Albet, A., Requena, S., Sarda, R., Gili, J.M. & Serrao, E. 2010. Spatial assessment and impact of artisanal fisheries activity in Cap de Creus. *In* H. Calado & A. Gil. eds. *Geographic technologies applied to marine spatial planning and integrated coastal zone management,* pp. 15–22. Centro de Informação Geográfica e Planeamento Territorial. Portugal. 164 pp.

(This work was presented by the first author in order to complete the requirements to achieve the degree of Master of Science in Marine Biodiversity and Conservation within the ERASMUS MUNDUS Master Programme (EMBC) at the Benthic Ecology Group, Department of Marine Biology and Oceanography (S-236), Instituto de Ciencias del Mar (Marine Sciences Institute) (ICM-CSIC), Passeig Marítim de la Barceloneta, 37–49, 08003 Barcelona, Spain) August 2010. [GISFish id: 6543]

Spatial tools: GIS.

Main issues addressed: Ecosystems; habitats; species distributions; human activities; impact caused by fisheries; MPA designation; social and/or economic impacts; integrated marine management.

Duration of study: Two years.

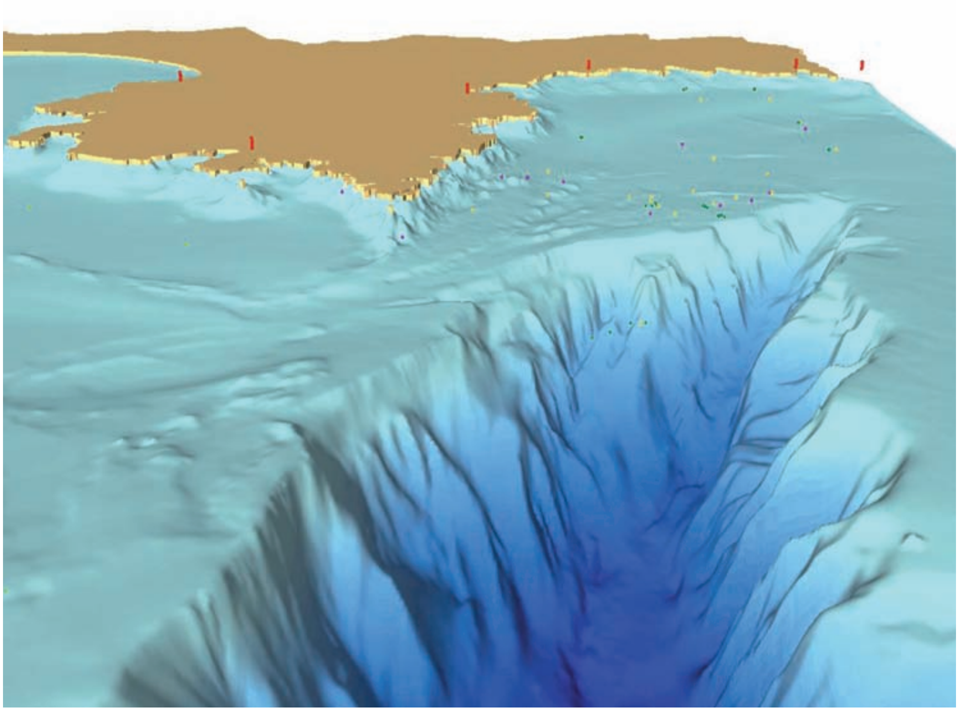
Personnel involved: One master's degree student plus assistance from four academic staff from two institutions in the Portuguese Republic and the Kingdom of Spain, and from the FAO in data collecting, plus other technical assistance.

Target audience: European Union officials, fisheries managers, local fishers, GIS experts, marine ecologists, governmental fishery departments and conservationists.

Introduction and objectives: As with many other marine areas, the Spanish Mediterranean Sea coast has long suffered from intensive and extensive overfishing, which has led to severe stock depletions and widespread habitat degradation. This is especially noticed in the inshore benthic communities that are easily accessible to the coastal communities, though also in some of the deeper benthic communities. There is now a strong recognition that steps need to be taken to reverse this degradation, and there are a number of institutional initiatives aimed at supporting work to improve the situation, for example: the Spanish government and European Commission funding; FAO-Cooperation Networks to facilitate Coordination to Support Fisheries Management in the Western and Central Mediterranean (COPEMED) projects; the creation of MPAs; Natura 2000 initiatives; habitats directives; fishing regulations; and local conservation by-laws.

This case study focuses on the Cap Creus area of north-east Spain. The area was chosen as part of a programme to assess locations for a network of Natura 2000 sites, and this location also offered the potential for the expansion of a small previously designated inshore MPA. It is also seen as being important to safeguard the long-term future of the local area artisanal fisheries. The area has an interesting marine topography resulting from the adjacency of the coastal shelf area and a major marine canyon, thus theoretically providing contrasting fishery ecosystems, a rich species biodiversity, highly variable bottom substrates and a range of ecological niches. Waters are relatively nutrient rich owing to many coastal streams entering the Gulf of Lyon, so marine productivity is potentially high.[241] However, evidence from various remotely operated vehicles (ROVs) and manned submersibles show that much of the shelf area is biologically impoverished. Figure 10.20 graphically depicts the study area with a view looking west directly at Cap Creus. Most of the coastal shelf is less that 150 m deep, but the canyon descends to over 2 000 m and is 95 km long. The area is presumably fished by large numbers of recreational anglers and spearfishers and by commercial fishing vessels, including many artisanal fishers. There is a major problem with the lack of monitoring and enforcement of fishery activities. The main objective of the study was to try to find out more about the impact of the artisanal fishers[242] on the benthic communities by asking questions on the number of the fishers, the main areas fished and species targeted, plus the varied fishing methods used. Thus, it was suspected that the different fishing methods deployed would variably affect different benthic ecosystems and GIS was seen as the ideal tool to identify any important spatial relationships.

FIGURE 10.20
3D bathymetry view looking west over the study area towards Cap Creus, Spain



Source: Purroy Albet (2010).

[241] The authors give very detailed descriptions of the atmospheric and marine processes leading to region-specific hydrological conditions.

[242] It is important to study artisanal fishers as they make up more than 80 percent of the Mediterranean fishing fleet.

Methods and equipment: For this exercise, a wide variety of data had to be acquired. The following were the main data types and sources:

- Social data on the fisheries. These data had previously been collected (in 2000–01) by regional FAO consultants using questionnaires directed at artisanal fishers, and data included fishing seasons, times, gear and/or methods[243], target species, metiers and ports. Where required these data had been georeferenced.
- Substrates, biology, bathymetry data. Acquired from the Spanish National Research Council (CSIC) offices, these data had been gathered for use in previous projects.
- Coastlines, rivers, ports. Data acquired from local and regional sources, such as the Department of Agriculture and Fisheries.

The area under study included an "inner" area (covering the existing MPA) of 216 km^2 and a wider area covering 1 145 km^2. For the purposes of mapping, the whole study area was divided into a grid of 500 m × 500 m cells; this resulted in there being a total of 4 581 marine cells. Any of the data collected under the first two bullets above could be mapped per these 0.25 km^2 cells. Data were entered and stored in a PC running ArcView and ArcCatalog 9.3 GIS (ESRI). Various geoprocessing functions of this software and MGET[244] were used to bring the data into a usable format. The project used the Universal Transverse Mercator (UTM) coordinate referencing system and WGS84 as the geodetic datum for storage and analysis.

Results: The project produced a wide range of GIS output only some of which can be illustrated and discussed here. Figure 10.21 shows how the distribution of fishing methods and/or gear preferred by artisanal fishers varies geographically around the study area. It can be seen that there are some considerable spatial variations. For instance, gillnets are easily the preferred gear type in Port de la Selva, whereas the neighbouring port of Llançà apparently has no gillnetters. Only one fishing method (pots) is used by fishers from all ports. It appears that gillnets are the most widely used method and/or gear, but this is uncertain as the individual proportional circles used give no clue to actual numbers of fishers using each method. It should also be mentioned that there are strong seasonal variations in the gear type used.

In order to detect the degree of impact of various fishery systems (methods or gear), a so-called "overlap value" was assessed for the whole study area. This represented the number of different fishing methods deployed per 0.25 km^2 cell as reported by fishers in the 2000/2001 FAO survey.[245] Figure 10.22 shows the "overlap values" for the main part of the study area. It can be seen that about 60 percent of the marine study area is either not fished at all (white) or is fished using only one method and/or gear (green); this leaves approximately 30 percent as being fished by two methods and some 10 percent fished by three methods. It is clear that there is a general relationship between the distance from the coast and number of fishing methods used, mainly for the reason that some methods can be more easily deployed in shallower waters.

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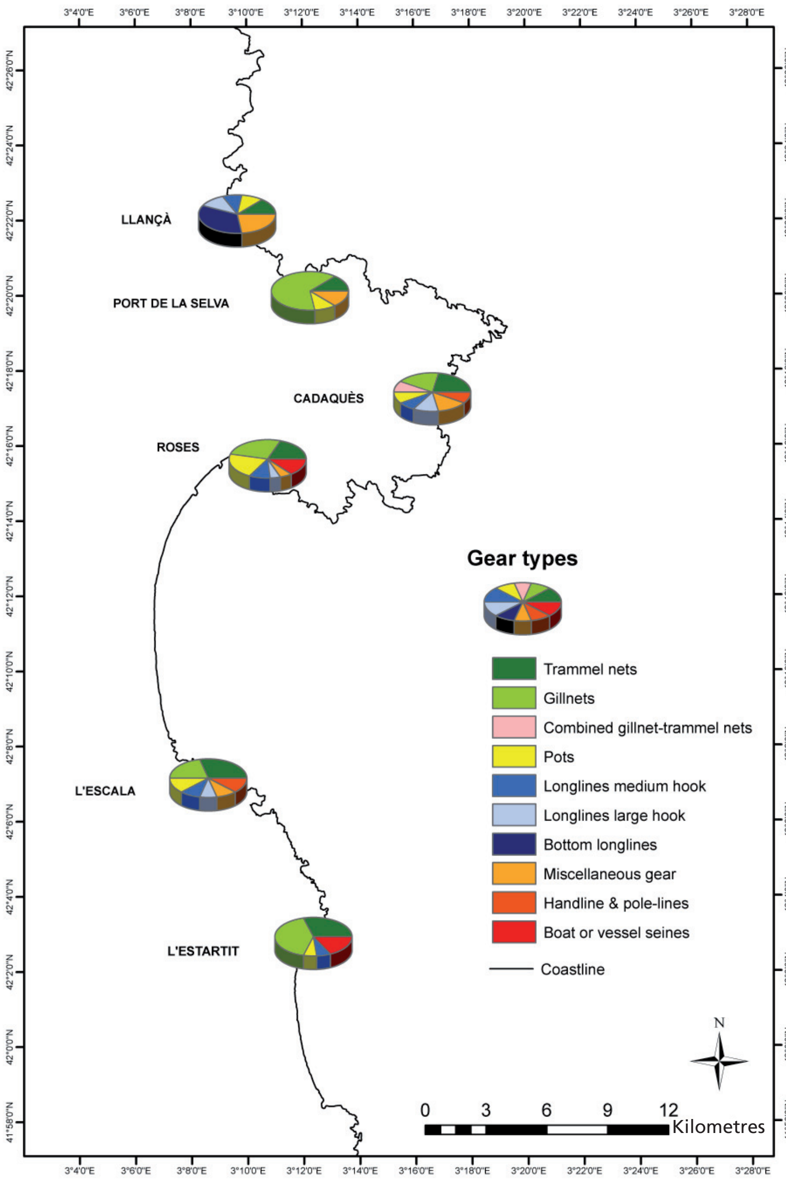
243 Fishing gear used FAO classification and included trammel nets, gillnets, longlines, pots, handlines and poles, boat dredges and miscellaneous gear (plus some combinations of these).

244 Marine Geospatial Ecology Tools, developed by Duke University, Marine Geospatial Ecology Laboratory (http://code.env.duke.edu projects/mget).

245 Minor deployments of particular gear in cells were not counted.

FIGURE 10.21
Gear types used by fishers from the six main ports in the study area



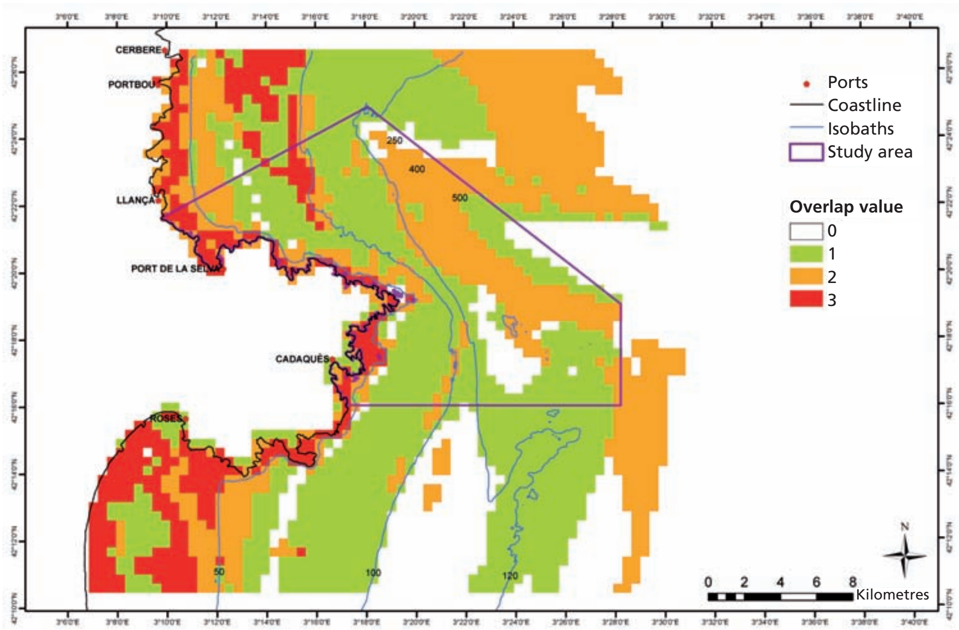
Source: Purroy Albet (2010).

Discussion and conclusions: Figure 10.23 shows the species communities in the Cap de Creus area that the authors consider to be most valuable in conservation terms, i.e. these are mostly the rarer and thus smaller communities that are living along the edge of the canyon, plus a wider area designated as "detritic litoral sandy mud". The authors conclude that these areas have been conserved because they are mainly those areas that have only been subjected to one type of fishing method (or less). Figure 10.23 does indeed show that at least one type of fishing activity, that using trammel nets, mainly appears to avoid the favoured conservation areas[246]. The authors also discuss further factors that might need to be considered when decisions are taken on selecting areas for MPAs or when "no-take" zones for fishing are designated, e.g. the spatial extent and patchiness of fishing activities and the use of seasonal or rotational management zoning. But whichever methods are chosen, it will be important to involve a range of stakeholders and to utilize full decision-making transparency.

[246] Unfortunately, there are no details on the distributions of most of the other fishing methods and/or gear.

FIGURE 10.22

Number of fishing methods (overlap value) deployed per cell in Cap de Creus waters, Spain

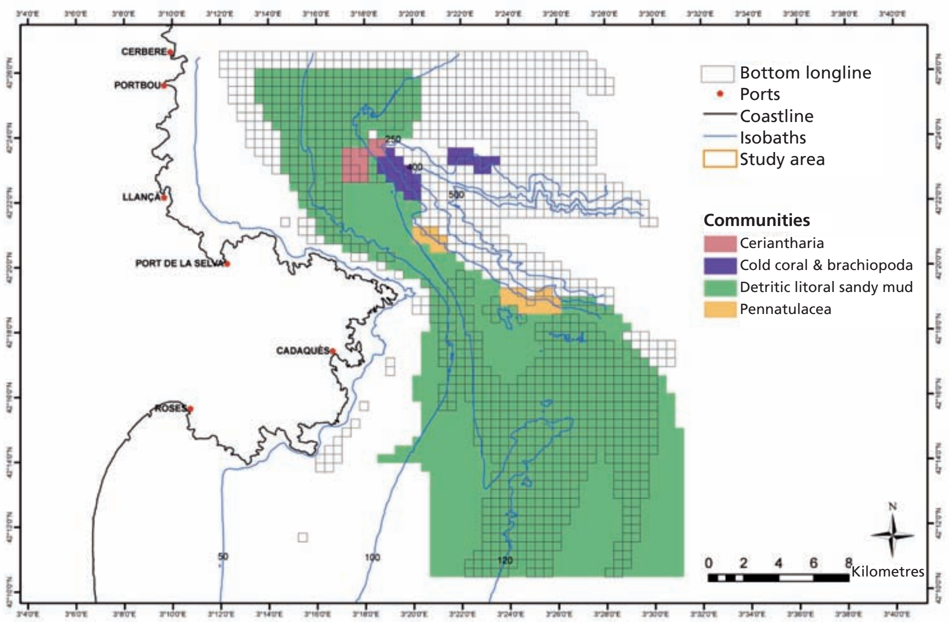


Note: The area enclosed by the purple line is the inner study area, i.e. the existing marine protected area.

Source: Purroy Albet *et al.* (2010).

FIGURE 10.23

Relationship between the species communities most in need of conservation and the distribution of trammel nets in the Cap de Creus, Spain, marine area



Source: Purroy Albet *et al.* (2010).

Challenges and lessons from the case study: From a number of perspectives, this is an interesting case study. The authors acknowledge that there are some limitations that might need to be corrected before the findings could form the basis of future actions. For instance, the study relied on an FAO questionnaire survey covering aspects of artisanal fishing methods and these data would need to be updated. It was also not clear what the relationship was between different gear, fish species and existing benthic habitats and/or substrates. However, the study gave pointers to a range of GIS-based methods and types of analyses that could be deployed, as well as other problems that needed to be overcome in order for the study to be more successful. Particular examples are as follows:

- Because data being used came from various sources, there was the necessity of standardizing projections and spatial scales and probably using standard classifications, e.g. for sediment types.
- Similarly, the data needed to be in the same format and many of the data sets needed to be merged and refined and otherwise made compatible.
- The usefulness of designating gridded cells that cover the area of study. For some data, e.g. data collected in a raster format, this might not be necessary, but if vector-based data are used, then this may be essential. The size of cells may need to correspond to the degree of detail required, any computer-storage capacity and relevant to the resolution or spatial accuracy of the data collection methods used.
- The huge range of possible thematic areas or subjects that could have been included in a study such as this if appropriate data had been available, e.g. the inclusion of recreational angling, the seasonality of fishery activities, the impact of larger fishing vessels and the calculation of various economic cost surfaces.
- It would have been useful to study the nearshore zone in more detail, and to investigate the variable impact of the different fishing gear and/or methods deployed here.
- The difficulties of involving fishers in studies concerning their activities.
- The inefficiency of legislation in controlling at-sea fishery operations.
- It would have been interesting to study the effect of the canyon on fish yields for artisanal fishers.
- The need to utilize modern data gathering methodologies such as fishery logbooks, GPS and VMS.
- Detailing how the results of the study could contribute to a wide range of future marine considerations, e.g. the siting of “no-take” zones or other MPAs, protection of individual rarer ecotypes or habitats, reservation of fishing areas for artisanal fishers, zone allocations for different gears and marine spatial planning.

This study is thus useful at indicating some problems to be avoided and useful lines to be followed, including the huge potential for the success of GIS if access to appropriate data can be secured. Once a study like this one has been accurately accomplished, then it will be an ideal foundation for future follow-up work. It could also be expected to play a large part in any future EAF work and studies relating to MPA selection and the cost benefits of specific MPAs. In places such as this part of the Mediterranean, but also in many other parts of the world where artisanal fishery activities survive, then studies like this one can be crucial for the future success and the livelihoods of the participants.