11. Emerging themes or issues in fisheries and aquaculture GIS

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11.1 INTRODUCTION

Fish production and consumption worldwide are on the increase. While marine fisheries production has remained at about 80 million tonnes per year between 2001 and 2009, production from aquaculture has increased from 35 million tonnes to over 56 million tonnes in the same period (FAO, 2010a). Fish continues to provide a significant proportion of meat protein for much of the world, especially in poorer countries, and annual world consumption per capita has increased from less than 17 kg in 2000 to over 18 kg in 2010 (FAO Statistics and Information Branch of the Fisheries and Aquaculture Department, 2012). The worldwide value of captured fish sold by fishers was about US$94 billion in 2010 and the value for aquaculture producers was US$98 billion.[247] About 8 percent of the world's population (some 540 million) is supported by fishery activities, either directly as producers, indirectly in fishery-related activities, or as dependents. These overall facts and statistics are provided as indicators of the fact that fisheries and aquaculture are both thriving activities and, as such, they will continue to demand a growing recognition as activities in continued need of research and management. However, from the perspective of GIS and remote sensing, this recognition must be significantly bolstered because, of all the world's production activities, fisheries and aquaculture are the most spatially extensive. Additionally, a large range of production types takes place in hugely varied environments and at vastly differing scales. Because of this importance, it is vital that both significant challenges and emerging themes in the use of GIS for fisheries and aquaculture purposes are now considered.

It is important to mention that considerations in this chapter are only directed to major thematic areas of fisheries and/or aquaculture that have a spatial context (though in reality this is the vast majority). There are six additional considerations needing explanation:

(i) In the title of this chapter, the terms "themes" and "issues" are used, and it is important that they are both included. Although these terms have clearly defined meanings,[248] here the two terms will be used almost synonymously. This is because this technical paper is looking at the application of GIS to resolve spatial problems (issues) across a range of topics (themes) associated with fisheries or aquaculture. So, because GIS is being deployed as a spatially based problem-solving tool, there is an automatic implication that within any specific thematic area there must be an issue that needs addressing. However, although "themes" and "issues" are virtually synonymous here, their content can still be classified into thematic areas.

(ii) This chapter includes what could be called "emerging themes" in fisheries and/or aquaculture GIS, although what is being discussed here might also be called "future trends". It seems safer to use the term "emerging" because there is plenty of evidence

[247] Despite aquaculture producing a lower quantity of fish than capture fisheries, the value of output is higher because aquaculture concentrates on producing more highly valued species, e.g. shrimp and salmon.

[248] A "theme" is a topic or a unified subject area; an "issue" is a problem or difficulty.

that these emerging themes will definitely happen, whereas in respect to a vision of "future trends" then these might be open to too much speculation and guesswork.

(iii) Both emerging or future themes can be part of an integrated chain or sequence of events with each link in the chain being its own "theme/issue". For instance, taking the issue of climate change as it relates to fisheries, it is easy to envisage the sequence: "climate change" > "warmer waters" > "species migration" > "different fish assemblages" > "changed fish landings" > "different markets", etc. Any of these "sub-themes" can be an issue by itself, and this simple chain can be made more complex as there will be numerous "side issues" at any point along the chain.

(iv) The "themes/issues" themselves must arise from drivers or catalysts for change, and it is important to briefly identify the causes that are promoting any change. Again these causes (drivers) can be complex and integrated, or be part of a chain, and it is sometimes difficult to differentiate between a "driver" and an emerging "issue" or indeed a "future trend".

(v) It may also be difficult to differentiate between "current issues" and "emerging themes/issues". To resolve this, "current issues" are those that are presently being actively pursued by those working in fisheries or aquaculture management or research, and which will be continued into the immediate and probably longer term future[249], i.e. as described in Chapters 8 to 10. By contrast, "emerging themes" can be considered as probable trends in this field of study that are likely to become more important in the near future. There requires a certain amount of speculation here, but it is important that these themes are included so as to give an idea on the future range of GIS work that is likely to develop. It is probable that some of this emerging work is already receiving attention, though not necessarily with respect to GIS applications per se.

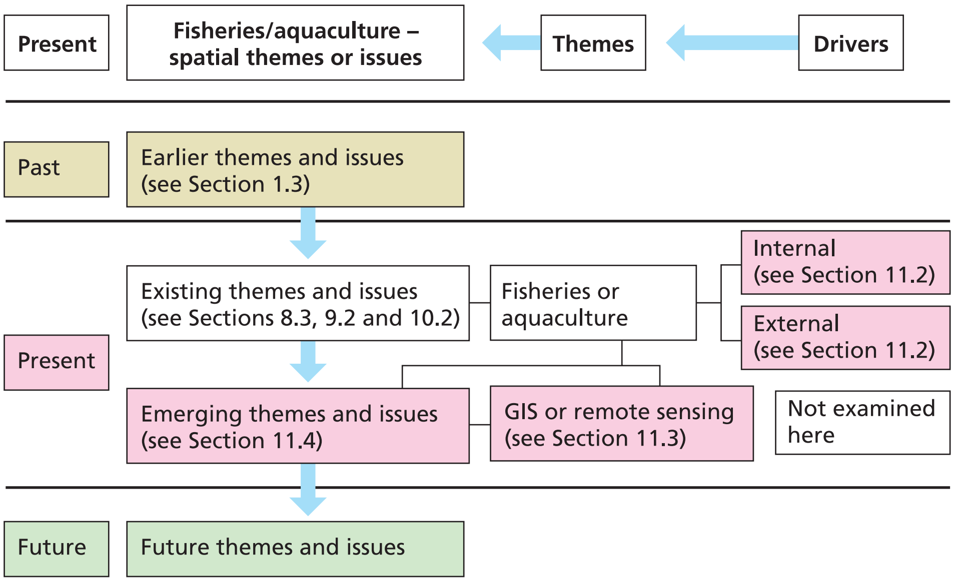
(vi) Emphasis in this chapter has been placed on emerging issues concerning either fisheries or aquaculture that may be rooted in spatial differentiation[250] rather than those relating to GIS or to remote sensing. This is because the latter represent the tools that are used and the main concern is not with investigating how these tools themselves are developing but with how the future of fisheries or aquaculture can be improved through the use of these tools. Having said this, it will be appropriate to mention some drivers that are bringing about change to the spheres of GIS and remote sensing, and in order to match the current issues affecting fisheries and aquaculture (as described in Chapters 8 to 10), a section indicating current issues in GIS has been included (Section 11.3).

In order to conceptualize the progression of the contents of this chapter, i.e. of the emerging themes and the factors influencing them, their logical sequence is shown in Figure 11.1. The boxes highlighted in bold are those that have been discussed in this paper, and the boxes in pink are those discussed in this chapter. It can be seen that spatial themes and/or issues may gradually progress through the "time" dimension (past, present, future) all the while that they remain a relevant issue. During the "present", new spatial themes or issues will join the existing ones, i.e. as various internal or external drivers force progress either in GIS or remote sensing capability, or as new spatial issues arise within the fields of fisheries or aquaculture. Any present emerging themes and/or issues are likely to contribute to future themes and issues, although it cannot be certain which these will be, and over time it is likely that the total number of themes and/or issues will gradually increase.

249 Current issues may prevail for many decades because countries or areas that are at different stages of development will adopt "issues" at different times.

250 "spatial differentiation" refers to the fact that the distribution of all things, objects, etc., on the planet is variable, as are the natural and human-inspired processes that may be affecting these things and objects. So the distribution of everything on the planet varies from place to place.

FIGURE 11.1
Organization of sections 11.1 to 11.4 showing the sequence of materials covered



11.2 MAIN DRIVERS AFFECTING FUTURE SPATIALLY BASED WORK IN FISHERIES OR AQUACULTURE

Box 11.1 lists the drivers affecting spatial approaches to fisheries or aquaculture research or management-related work. Although the drivers are listed in no specific order, they generally proceed from external to internal (to fisheries or aquaculture), though many of them could be seen as both external and internal, i.e. having direct or indirect influences on fisheries or aquaculture. The processes that contribute to driver success, e.g. mainly research, marketing or political decisions, are not discussed here. Drivers will be of differing importance in different situations; indeed, some of the drivers will be of no relevance at all in some areas or regions. Some of the drivers are very specific but others are very wide ranging, and this list may not be exhaustive. Part of the list includes potential sub-categories of drivers. For reasons of breadth and quantity, detailed referencing in this section has not been undertaken, but useful overall sources include Beddington, Agnew and Clark (2007), Brugère *et al.* (2010), FAO (2010b) and Garcia and Rosenberg (2010).

(a) **Human population growth.** The world population has now passed 7 billion, but within 40 years it is likely to grow to more than 9 billion. This represents a huge potential market increase for fish products. Populations are exhibiting spatial shifts from being relatively dispersed and agriculturally based towards being concentrated in urban agglomerations whose locations are more frequently coastally based. Coastal populations are likely to reinforce market demands for fishery products.

(b) **Changes in atmospheric processes.** Here, the concern mostly relates to climate change and its impact on water temperatures. These impacts are already driving change in natural species distributions in both fresh and saltwater environments. It is not only temperature increases that might be a causal process of change; there will also be stronger winds, higher waves, reduced or increased rainfall, greater seasonal variations, higher sea levels, more species invasions, etc., any of which can influence species distributions, and particularly activities associated with inland aquaculture.

BOX 11.1

Main drivers affecting future spatial approaches to fisheries and/or aquaculture research and management

(a) Human population growth
(b) Changes in atmospheric processes
(c) Contractually based supply chains – marketing – industry consolidation
(d) Fuel and/or energy costs
(e) Education and information
(f) Protein needs, food security and poverty alleviation
(g) Socio-economic development – business opportunities – production costs
(h) Improving governance – responsible fisheries and aquaculture
(i) Capital availability – public and private
(j) Changes in consumption preferences
(k) Ecosystems degradation and environmental awareness – recognition of sustainability
(l) Freshwater access and availability – moves to recirculating systems
(m) Stakeholder participation in decision-making
(n) Certification in fisheries and aquaculture – ecolabelling
(o) Genetic modification of aquaculture species
(p) Demise of many commercial wild fish stocks
(q) Global growth in aquaculture production
(r) Controls on recreational angling
(s) Changes in fisheries management – variable scales of management – reduction of fishing effort

(c) **Contractually based supply chains.** As the scale of fisheries and aquaculture has increased, then the activity has followed usual economic trends with respect to consolidation involving forward and backwards economic integration. This may take several forms, but typically contracts are made between fish resourcers (from wild stocks or aquaculture) so that processors can guarantee continued supplies at agreed standards, or single companies may partake in all stages of the food supply chain. These chains may lead to consolidation of activities into well-established and more concentrated production areas.

(d) **Fuel and/or energy costs.** These drivers affect the economy as a whole, but they are especially important to the cost of larger-scale fishing activities. With very high fuel and/or oil prices now prevailing, and with little prospect of these diminishing much in the future, fishers are becoming increasingly cognizant of where, and how often, they fish. Aquaculture will be differently affected in the sense that there are relatively smaller direct fuel costs, but some associated input and output activities will incur rising energy and/or fuel costs.

(e) **Education and information.** Increases in production will not occur without a sound knowledge of the potential for, and production methods used, in all aspects of either fisheries or aquaculture. So, education must be seen not only in terms of economic factors but also with respect to social and environmental considerations of fish production. Organizations such as the FAO and the United Nations Educational, Scientific and Cultural Organization (UNESCO) place a huge emphasis on the provision of information in order that the wider public can gain access to the fundamentals involved in fisheries and/or aquaculture.

(f) **Protein needs, food security and poverty alleviation.** With the world population rapidly rising on a finite planet and with income levels also rising rapidly in many areas, the quantitative and qualitative demand for all foods is increasing, as are the average costs for food. However, the percentage of the population that still live in poverty remains high. With fish being both widely available and having high-quality protein, then demand is certain to continue to grow. The impacts of this are that there are accelerating needs to manage the production locations for fisheries and especially for aquaculture (which has often to compete for terrestrial space and available water). In poorer rural areas, the opportunities to engage in micro-scale aquaculture production offer a route to increased incomes and to protein security.

(g) **Socio-economic development and business opportunities.** Despite periodic downturns, the world is undoubtedly going through a period of rapid economic expansion. Increasing affluence creates not only higher consumptive demands, but it also provides greater business opportunities. Entrepreneurs will be obliged to make investment decisions which themselves are multifaceted, involving a range of cost–benefit decisions. Probably the main investment decision for aquaculture is that of optimizing location in terms of not only achieving successful production but also in minimizing input costs.

(h) **Improving governance.** Governance includes factors such as establishing legislation, fisheries management frameworks, fishing access rights, aquaculture strategic frameworks, stakeholder participation, political authority, and monitoring and enforcement. Given the overall expansion of fisheries and especially of aquaculture, a large number of countries have seen it as beneficial to make improvements to the overall means by which these activities are controlled, and although some success is being achieved, there is undoubtedly still a major challenge to be faced from illegal, unreported and unregulated (IUU) fishing. Governance can be enacted at widely varying hierarchical and spatial scales, and can impact on the formation of administrative districts, statistical divisions, data gathering considerations, etc.

(i) **Capital availability** – public and private. It is clear that, apart from developments at a very basic subsistence level, the promotion of fisheries or aquaculture must be reliant on affordability and the ability to accumulate capital or credit to cover necessary costs. Apart from these basic requisites, the availability of capital will vary greatly from time to time and from area to area. It is important to note that capital may be more or less available from either public or private funding sources.

(j) **Changes in consumption preferences.** There are many reasons why consumption preferences may change through time, for example, price or availability of fish species, market promotion of species and familiarity with a new flavour. These changes will affect production quantities among species, which in turn may offer relative advantages for production in different areas.

(k) **Ecosystems degradation and environmental awareness.** Severe ecosystems and environmental degradation continues to affect wide stretches of the global freshwater and marine area. With the growing acknowledgement that sustainability needs to be considered with respect to all activities – especially those that depend upon resource extraction – an awareness of the impact of all activities upon the environment is increasingly seen as essential. This will have major implications for both fisheries and aquaculture, both from a need to moderate impacts in spatial areas that are already being exploited and from the essential need to maintain the integrity and sustainability of existing bio-physical systems.

(l) **Freshwater access and availability.** Freshwater is virtually a finite resource[251], and in many parts of the world access or availability of this resource is already extremely precarious. With the growth of both human populations and income, the demand for freshwater is increasing exponentially. Demand for water for agriculture could rise by over 30 percent by 2030, while total global water demand could double by 2050 owing to pressures from industry, domestic use and the need to maintain environmental flows. In some arid regions of the world, several major non-renewable fossil aquifers are increasingly being depleted and cannot be replenished,

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[251] Freshwater is not absolutely a finite resource because saltwater can be processed into freshwater at desalination plants, although this is energy and capital intensive.

e.g. in Australia, the Arab Republic of Egypt, Libya, and the Punjab (India). From the perspective of future inland aquaculture, this will be an important location consideration, especially given the need to increase the use of water through multipurpose uses.

(m) **Stakeholder participation in decision-making.** With the move towards ecosystem approaches to both fisheries and to aquaculture production, an increasing number of stakeholder participants may be more or less directly influencing fisheries production activities. This is likely to influence production location, and it will mean that a wider range of socio-economic factors will need to be considered, many of which will be spatially related.

(n) **Certification in fisheries or aquaculture.** This is similar in many respects to contractual supply chains, except that here fish producers are entering into agreements with organizations that have set up some kind of accreditation scheme that may offer a range of qualitative and/or standardization guarantees to participants along supply chains or to final fish consumers. This activity tends to favour more prosperous producers who can afford the costs of guaranteeing quality. Closely linked to the ideas behind certification is a "traceability system", a system that may function on a GIS platform (J. Ferreira, personal communication, 2011). It allows all input factors of production to be traced throughout the production system. In aquaculture, for example, water, feedstuffs, broodstock, workers, processing plants and markets all have a geographical component that can be mapped. If required, management controls can be maintained and specific spatial investigations or analyses can be made, e.g. in the event of a disease outbreak.[252]

(o) **Genetic modification of aquaculture species.** Until recently, this has not been a driver consideration, but there are now moves to develop species that have specific traits. In many cases, these traits will be associated with variable production functions and locations, e.g. climatic factors, water quality, shelf life and appearance.

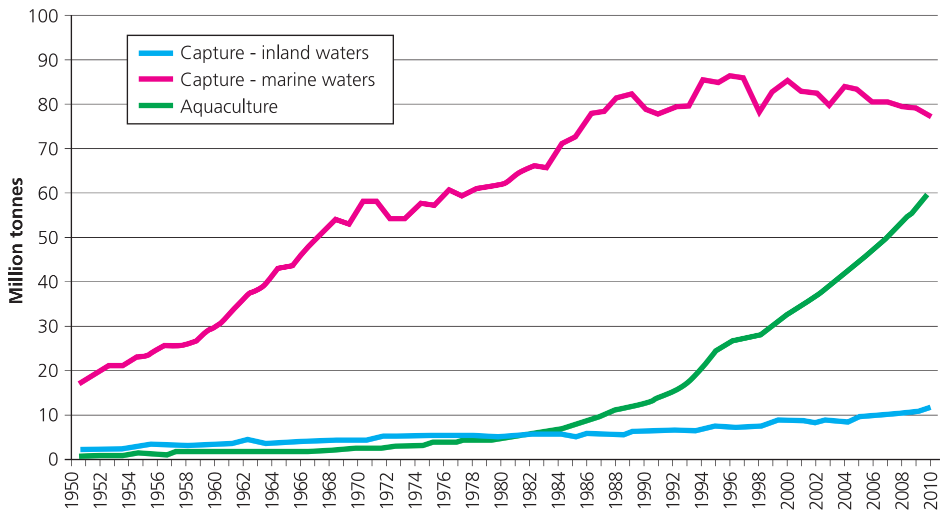
(p) **Demise of many commercial wild fish stocks.** It has already been indicated that wild fish stocks are often static or declining. This will oblige many fisheries activities to change their preferred location, and many areas may be at least temporarily off limits to fishing as stocks are left to recover. Because productivity from marine sources has probably reached the limit in many areas, this demise in commercial stocks may also encourage a shift to aquaculture production.

(q) **Global growth in aquaculture production.** The approximate six percent worldwide growth in aquaculture per year over the last three decades is indicative of an industry that is having considerable success (Figure 11.2). Entrepreneurs and other investors will recognize this and they may wish to give support to groups who desire to enter into or expand aquaculture investments. There is a sense in which the emergence of aquaculture is simply mirroring the growth of terrestrial-based farming in far earlier periods. However, for example, rapid growth rates may have potential negative effects in terms of land availability and costs, water resources, pollution, environmental degradation, energy inputs and poor knowledge of husbandry. It is, therefore, important for aquaculture to be developed in the context of ecosystem functions and services, with no degradation of these beyond their capacity to be easily restored.

(r) **Controls on recreational angling.** Certainly, in the more developed areas, recreational angling is one of the highest participatory leisure activities, and in many areas it is considered that fish catches by this sector may be greater than commercial catches. Partly because of this impact, governments are imposing more regulations on the activity in the form of closed seasons or areas, licensing, bag restrictions, etc. In the future, it is likely that these controls will increasingly be spatially related.

[252] In Thailand, a traceability system is presently being implemented for aquaculture (called "Traceshrimp"). Publications are not yet available on this, but Paiboonrat (2007) provides an example of such a system in use in Thailand's chicken industry.

FIGURE 11.2
A comparison of world aquaculture production (1950 to 2010) with marine and inland fisheries production



Source: FAO Statistics and Information Branch of the Fisheries and Aquaculture Department (2010).

(s) **Changes in fisheries management.** While this is not a new driver, it is certainly one that will rapidly impinge on a greater number of fisheries in a widening variety of ways. Many of the world's fisheries are not being managed in a sustainable manner, and it likely that there will be major moves towards this over the next decade, especially as marine spatial planning and the ecosystem approach to aquaculture (EAA) and the ecosystem approach to fisheries (EAF) are adopted.

11.3 CURRENT ISSUES AND DEVELOPMENTS AFFECTING WORK IN GIS OR REMOTE SENSING

Having briefly described the spatially related drivers for change in fisheries and aquaculture, it is easy to see that their combined influence on fish production is likely to be immense and that the scale of changes may vary enormously from area to area, as will the applications of particular drivers to particular areas. But these are not the only factors driving changes in the use of spatial tools in the fisheries and aquaculture spheres. An array of developments and issues in the spheres of GIS and remote sensing are also driving change (Box 11.2). Many of the issues and trends shown in this box have been around for a number of years, but this does not prevent them from being of current, and probably of future, importance.

It can be seen that many of the developments and issues are concerned with data – mainly because much of the growth has taken place in this area in terms of not only the volumes of data but also in the ways and means of handling data, and in the attempts to make data more "user friendly". In fact, it appears that the emphasis in GIS work may be shifting from "How do we handle the complex software?" to "How do we cope with increasingly larger volumes of data?" However, many of the developments are also centred around geotechnological advances that tend to function in a highly integrated manner, and which may be difficult to isolate into individual developments. Thus, Boyd and Foody (2011; p. 29) note that Zhang and Tsou (2009) refer to "a geospatial cyber infrastructure which integrates distributed geographic information processing technology, high-performance computing resources, interoperable Web services, and sharable geographic knowledge to facilitate the advancement of geographic information science (GIScience) research, geospatial technology, and geographic education."

Despite the interlinked nature of these data and technological developments, an attempt has been made (in Box 11.2) to isolate individual GIS-based developments and issues. Much of the information about current changes, developments, trends and issues can be found in basic GIS texts, and more specifically from Saitoh *et al.* (2011) and Boyd and Foody (2011).

BOX 11.2

Some key current developments and issues with respect to GIS and remote sensing

(a) The continuing advances in computing environments
(b) The development of new spatial tools
(c) Availability of higher resolution remote sensing imagery
(d) Maps as an ideal medium for communication (geovisualization)
(e) Interactive GIS via the Internet
(f) Data ownership and acquisition
(g) Data gathering instrumentation
(h) Advances in geostatistics and data and spatial modelling
(i) Mobile GIS delivery
(j) Continuing standards improvements for data collection and data transfer
(k) The seamless integration of data sets
(l) Accuracy, uncertainty and errors in GIS

(a) **The continuing advances in computing environments.** This development is a "catch-all" issue encapsulating all the advances that are continually ongoing in the world of computing, e.g. the continuing exponential growth in computing power and computing access. It is important to mention this because this trend will continue to ensure that developments in GIS software will expand their functionality and ease of use in the future and there will be relative price reductions in computing environments, making the technology more accessible to more people worldwide.

(b) **The development of new spatial tools.** Similar to the above, but much more specific, are the developments that continue to appear in spatially based tools. These consist of a wide range of software, including many proprietary and open source software, plus "add-on" programs capable of performing an almost infinite array of tasks that aid in mapping and spatial analyses.

(c) **Availability of higher-resolution remote sensing imagery.** Although remote sensing imagery has been available for about 40 years, for the first two decades of this period all satellite-based imagery resolution was extremely coarse (> 10-m resolution). However, resolution has improved significantly during the last two decades, opening up many more opportunities for remote sensing use. Indeed, Boyd and Foody (2011) now point out that the current resolution of some satellite systems is at a level of detail comparable to that derived from the use of airborne sensor data. But just as important as enhanced functional capability is the fact that increased competition among remote sensing data providers has led to significant cost reductions of imagery. It is likely that these trends will continue,[253] that future imagery may cover a wider variety of parameters, that delivery times will be reduced, and that there will be improved ease of use of image processing capabilities.

[253] Over 100 earth observation satellites were launched during the first decade of this century, i.e. in addition to numerous new airborne sensing systems (Boyd and Foody, 2011).

(d) **Maps as an ideal medium for communication (geovisualization).** There is abundant evidence that spatially based information is best conveyed in the form of maps and, in order to ascertain optimum ways of communicating via maps, much work has progressed in the integrated fields of scientific visualization, cartography, image analysis, psychology and visual exploration. The map user is now obtaining increasing control over cartographic output through the ability to control legends, symbology, fonts, etc., and through animation visualization tools and photorealistic visualization techniques. Google Earth has bridged the gap between remote sensing experts and non-experts, resulting in greater understanding of environmental issues. The ability to use Google Earth and drill down from the global panorama to the neighbourhood level enables people to better understand natural and anthropomorphic events on a human scale (Corbley, 2007). The increasing functionality behind Google mapping or in-vehicle navigation systems are examples of the progress being made in spatial visualization. All told, significant progress has recently been made in many aspects of map visualization and spatial literacy, and this will continue in the future. There is now a strong recognition that a map really is "worth a thousand words", and increasing familiarization with maps will be aided by a greater range of enhanced map delivery systems.

(e) **Interactive GIS via the Internet.** Over the last decade, interactive GIS via the Internet has been increasingly practised, and there are now a wide range of mapping possibilities that have been established. Of particular importance have been the possibilities around "hot-linking", whereby it is possible to connect to a wide range of additional materials and contexts[254] that are applicable to any number of georeferenced places or areas of interest within a mapped area. The progress in interactive GIS has been very rapid and it will undoubtedly continue to grow in the future,[255] as will the number of people who are able to gain access to the Internet via increasingly faster broadband delivery rates.[256]

(f) **Data ownership and acquisition.** This is an area that has promoted much controversy in the past, i.e. because owners of data have perceived that they should command some rights to "their" data. But there are many problems associated with this so-called copyright. These mostly involve variable rights by different data users, plus rights associated with "amended" or "enhanced" maps or data. Also, different national policies exist. There is undoubtedly a drive towards a greater freedom of access to data sets, but whether this move will prevail into the future is difficult to foresee, although undoubtedly there will always remain data that command a significant price.

(g) **Data gathering instrumentation.** In Chapter 2, an outline was given of some of the data gathering instruments currently being used. The proliferation of an array of instruments will undoubtedly continue and increasingly they will incorporate georeferencing capabilities aided by GPS technology while working in mobile environments. While much data will be collected and distributed from small mobile devices, there is likely to be a greater proportion that is collected via complex systems such as satellite or sonar technologies. There will also be an

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[254] At "hot-linked" spots photographs, textual information, graphs and tables, video clips, legal documents, etc., can all be added as supplementary materials to maps. (See further details at ESRI: www.esri.com/news/arcuser/0101/hotlink.html).

[255] The United Nations Environment Programme–World Conservation Monitoring Centre (UNEP–WCMC) (http://imaps.unep-wcmc.org/imaps_index.htm) has developed interactive mapping services, and the Interactive Map Service (IMapS) is an authoritative source of environmental data that can freely be accessed, downloaded if needed, and mapped online to user requirements. A number of thematic or regional applications exist on the UNEP–WCMC Web site (e.g. on the Caspian Sea watershed). Jointly developed by FishBase and SeaLifeBase, AquaMaps is another example of the substantial progress made in online interactive mapping (www.aquamaps.org/main/home.php).

[256] It is also likely that fisheries management generally will be considerably enhanced via non-GIS uses of the Internet (Garcia, 2011).

increase in fixed, automated data-collecting systems (e.g. tethered buoys), and Pompili, Melodia and Akyildiz (2009) describe how 3D underwater acoustic sensor networks are being used to monitor ocean phenomena such as water currents, wave action and pollution.

(h) **Advances in geostatistics and data and spatial modelling.** Major developments in GIS applications to fisheries and aquaculture will come in the coupling (or integration) of geostatistics and spatial models to GIS functionality. Although this is already happening, the further scope is almost unlimited because the models and/or statistical functions are virtually infinite in their utility and usefulness. The main problem with respect to the application of geostatistics lies in the fact that most of this work presently involves a capacity to cope with advanced mathematical concepts, an ability that not all GIS users will share. Most modelling is currently devoted to establishing species or habitat distributions, but of course models can be deployed to help investigations of almost any aspect of fishery or aquaculture work.[257] Some important work in model applications to aquaculture is described in a review by Kapetsky, Aguilar-Manjarrez and Soto (2010) on the "Status and potential of spatial planning tools, decision-making and modelling in implementing the ecosystem approach to aquaculture". Another useful review is that by Ferreira *et al.* (2012) on "Progressing aquaculture through virtual technology and decision-support tools for novel management". Among the examples described by Ferreira *et al.* (op. cit.) is the interesting decision-support system called "AkvaVis" for site selection, carrying capacity and management monitoring that is presently under development (see description of AkvaVis in Chapter 8 and Web site www.akvavis.no). Kapetsky and Aguilar-Manjarrez (2013) note that there is a clear trend for "all-in-one" applications (like AkvaVis) that include: multiple objects (species at different trophic levels and varied culture systems); incorporate multiple functions basic to aquaculture development and management (site selection, carrying capacity, monitoring for management including legal aspects); take into account ecosystem-level spatial boundaries; involve active participation or scrutiny by the public; and produce outputs that are highly relevant to managers, commercial entities and to aquaculture practitioners.

(i) **Mobile GIS delivery.** Although this issue crosses the boundaries of several previously mentioned developments, separate attention is drawn to it because of its special importance. GIS is now escaping the confines of the more traditional computing environments. This first occurred via the use of laptop computers and various notebook devices, but now GIS potential is being realized via the host of handheld devices described in Chapters 2 and 4. However, this mobility of delivery incorporates not only the devices themselves (the platforms), but also the delivery of data and software is enabled via wireless connections to the Internet so that complete mobile GIS functionality is attained. A recent development that attempts to overcome the small- screen problem is the release of Apple's IPad3 whose design aims are to provide maximum portability and mobility with a larger screen size, i.e. 24.5 cm compared with less than 8.0 cm for typical mobile devices (see Flex Mappers, LLC: www.webmapsolutions.com/ipad-mobile-arcgis-part-1). Environmental Systems Research Institute (ESRI) has developed a special version of its GIS software called ArcGIS Mobile that is specifically designed to function on a range of the newest generation mobile devices. Drivers in this direction are certain to continue, with the main directions of development

[257] Other major areas for modelling include site selection for aquaculture, examining the effects of climate change, designating marine conservation areas, examining species movement patterns, selecting restocking locations, etc., and Ferreira *et al.* (2012) suggest that additional areas for future modelling applications include disease spread and control, algal bloom dynamics, certification and traceability and modelling in data scarce situations.

concentrating on map size and optimization of visualizing in a small-screen environment and on high-speed delivery in the broadband communications environment. The potential number of GIS users via mobile computing can now be counted in the hundreds of millions.[258]

(j) **Continuing standards improvements for data collection and data transfer.** A development that is often ignored is that of the increasing adoption of standards. Although standards have long been applied in the spheres of technology or hardware development and have been applied to data handling for over a decade, there is still some way to go in achieving the theoretical optimum in data collection and transfer possibilities. Data standardization enters into a wide range of associated fields, including: thematic class definitions; storage methods and means; data formats; symbology; metadata information; management standards; operating systems; data quality and accuracy; and update frequency. The ultimate aim of data standards improvements is to attain the highest possible levels of "interoperability", i.e. the ability of diverse systems to work together in an integrated manner. Some of the issues that need resolving are still quite complex, e.g. agreements on data classification systems or internationally recognized symbology. However, far more data sets are becoming easily integrated with other data sets and it can be anticipated that this issue will gradually become less of a concern to GIS users.

(k) **The seamless integration of data sets.** Of major importance to all GIS work is the acquisition, management and use of digital data, and it was noted above that the standardization of all facets of data is highly desirable. However, for various reasons complete standardization will never be possible because, for instance, any classification categories and boundaries used may be different according to specific project or management aims. Nevertheless, rapid strides are being made either in developing formats or structures allowing for seamless data set integration or in developing simple algorithms that permit different data sets to be integrated. Specialized software is now available that are typically industry specific, i.e. perhaps concentrating on oil exploration, geology, utilities, etc., and that allow for a range of data integration functions to be performed. The LEACAT Data Cataloguing and Archiving software suite provides an example of the capabilities of this type of software (see Lynx Information Systems: www.lynx-info.com/gis-datamgmt.html). As of late 2011, it is also possible for any data being stored on one digital device to be seamlessly accessible across all of the user's devices (see iCloud at www.apple.com/uk/).

(l) **Accuracy, uncertainty and errors in GIS.** The validity of output from GIS is clearly limited by accuracy, uncertainty and error issues. Unfortunately, certainly with respect to fisheries and aquaculture data, this may often be characterized by GIS having a high degree of uncertainty or error, and lack of metadata may lead to an underestimation or lack of concern about this problem. A clear example of uncertainty is that actual fish distributions may be error prone because either absence or presence of species in a location is often highly uncertain. Data set size may also lead to lack of accuracy or errors because it is almost impossible to establish statistical significance with regard to most marine distributions. Boyd and Foody (2011) provide useful detail on the range of measures that can be taken to avoid accuracy, uncertainty and error-based problems.

[258] According to figures quoted in GigaOM (2011) available at http://gigaom.com/mobile/stat-shot-mobile-computing-has-won-2/, there will be 400 million mobile computers sold each year by 2014.

11.4 EMERGING THEMES RELATING TO SPATIAL ASPECTS OF FISHERIES AND AQUACULTURE

As a result of the previously described drivers, forces are continuously driving change with respect to spatial factors relating to the broad subject areas of fisheries and aquaculture. Given that these are such wide ranging and complex thematic areas, it is likely that a number of themes can be identified as "emerging" from these drivers. Here, an attempt is made to identify the main themes and to classify them into broad headings. It again needs to be stated that there is undoubtedly integration among the identified themes, that the themes can also be considered as "issues", and that the themes are themselves in different stages of "emergence". These stages will vary with both an actual time that may be delineated for the emergence of a theme and with when any group or area first becomes familiar with a particular issue. In stating that these themes are those that are currently emerging as important, it could be argued that they will also form the core of "future themes" in any fisheries and/or aquaculture GIS-based work (see Figure 11.1), i.e. they will be extensions of much of the current work that is being practiced. In this section, discussion of those issues that have already been mentioned in Chapters 8, 9 and 10 as being presently important is not repeated. For additional insights into future themes in fisheries and aquaculture GIS, see Fisher (2010) and Bostock *et al.* (2010). Emerging themes are identified in Box 11.3; they are not defined in any specific order.

BOX 11.3

The main emerging themes in fisheries and aquaculture to which GIS will be applied

(a) The production of different aquaculture species
(b) The potential impacts of aquaculture on the environment
(c) Management of freshwater resources for aquaculture
(d) Offshore mariculture
(e) Growth of inland fisheries and recreational angling
(f) The consolidation of the fishing and aquaculture industries
(g) Rebuilding depleted marine and freshwater stocks
(h) The recording of fishing vessel activities
(i) Evaluating fisheries management practices, including sustainability
(j) Threats and changes to marine and freshwater ecosystems
(k) The standardization of habitat (and other) classifications
(l) Working at variable scales and resolutions
(m) Studies of temporal change in fisheries and aquaculture thematic areas

11.4.1 The production of different aquaculture species

There is some debate concerning what biological species (and types of fish species) would be best produced (farmed) in the future. Basically, there are three main lines of thought here:

- Should the emphasis in developed countries still remain with the production of higher trophic level fish species? Thus, given that these species generally fetch high market prices compared with lower level species and given that high fish farming costs need to be covered, then it is likely that this rationale might be retained into the future. This idea is supported by Christensen (2011), who argues that the future may see the marine area used simply as a "farm" for producing low-value aquaculture feed inputs (fish meal), i.e. because most of the larger fish have already been extracted from the sea and stock recoveries may be very difficult.

- A second line of reasoning is that, because inputs to higher level species rely mainly on high inputs of fish meal derived from capture fisheries, this is inefficient in terms of energy inputs. Therefore, there needs to be a move towards the production of lower trophic level herbivorous species, i.e. as has been practiced for millenniums in countries and areas such as the People's Republic of China and, the Socialist Republic of Viet Nam and Eastern Europe.[259]
- An important third consideration is that there are consumer food preference changes resulting from changing product costs and experimentation in "newer" farmed species, e.g. fish species such as tilapia, pangasius and cobia are presently showing considerable demand increases (Asche, Roll and Trollvik, 2009), while catfish farms in the southern states of the United States of America are suffering production declines because they cannot compete with lower production costs on Asian farms.[260] It is also likely that there will be further successes with the production of colder water species that are suffering from overfishing, e.g. farmed cod and halibut are now being marketed. Consumption preferences are likely to have major impacts on fish farming locations and fish markets in the future.

It can be seen that the balance of changes in production preferences could have significant changes in the spatial organization of aquaculture. This is likely to lead to future GIS-based economic and spatial rationalization work as the balance of production cost advantages shifts from area to area. Other GIS work could also focus on the different physical requirements needed to optimize production location among the different species.

11.4.2 The potential impacts of aquaculture on the environment

Although this might not be strictly speaking an "emerging issue", i.e. because it has long been an area of interest for GIS work, it has been included here both because of the huge increase in its importance that will be occurring as aquaculture rapidly expands and because the range (or variety) of potential impacts is likely to significantly increase. The various case studies in Chapter 8 have hinted that there are a wide range of cultured fish species and that their production uses a variety of production systems. Most of the production systems are sited in aquatic environments that are on or adjacent to terrestrial areas. Because production typically involves the transference of large quantities of water through the production system, then the propensity for causing some kind of environmental impact is very high. Impacts are not only felt at the sites of production because waterborne impacts can be transferred over large distances by running or moving waterbodies. Additionally, the provision of inputs to the aquaculture process can cause environmental impacts thousands of kilometres from production locations. Aquaculture production does not have to be detrimental to the environment, as can be seen by the inland pond culture techniques that have been applied sustainably in the People's Republic of China for at least 4 000 years. However, as can be seen from Figure 11.2, over the last three decades aquaculture production has increased at previously unprecedented rates, and it is this that has given rise to environmental concerns.

According to FAO (2012e) (see www.fao.org/fishery/topic/14894/en), the main impacts of aquaculture on the environment are:

- discharging of suspended solids into the water;
- nutrient and organic enrichment of recipient waters leading to a build up of anoxic sediments and to eutrophication;
- a loss of coastal habitats, e.g. wetlands and mangroves, through the construction of shrimp ponds;

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[259] The debate about species production preferences is discussed in Tacon *et al.* (2010).

[260] According to the United States Department of Agriculture, total live weight production of catfish from farms in Mississippi State went down from 355 million pounds in 2004 to 249 million pounds in 2009.

- the salinization of agricultural and drinking water supplies;
- land subsidence owing to groundwater abstraction;
- pollution owing to the misapplication of chemicals;
- the release of disease pathogens and parasites into surrounding waters;
- the use of fishery resources as feed inputs.

With the increased demand for the high-quality (and high-value) foods that are produced by the range of aquaculture practices, there are strong possibilities that production will become more intensive. If inappropriate or poor-quality management and planning practices prevail, as is so frequent in too many areas, then this intensified production has a strong probability of causing increasingly negative results. Further details of environmental impact assessment and monitoring in aquaculture can be found in FAO (2009a).

Just as in marine fisheries (FAO, 1995b), FAO suggests that a strong commitment to responsible aquaculture is needed. This commitment must come not only from producers, but also from consumers and various government authorities. Special consideration must be given to the better management of aquaculture developments that might affect sensitive habitats, such as estuaries, mangroves, wetlands, riparian fauna and vegetation, or specific breeding and nursery grounds. It is also essential that environmental impact assessments are carried out before larger-scale enterprises are developed and that the development guidelines contained within them must be strictly adhered to. There is an argument made for terrestrial-based, more intensive production systems using recirculated water. This is because of the possibility of exacting very strict controls over the production processes. It is easy to see that GIS has the potential to play a major role in helping to reduce any potential environmental impacts from aquaculture development. For instance, there is a range of GIS-based modelling that can simulate environmental effects of discharges made from production facilities (Kapetsky, Aguilar-Manjarrez and Soto, 2010). Most of this modelling should be used before aquaculture facilities are constructed, though modelling can also be deployed to assess remediation possibilities, or to work out maximum acceptable quantities of negative discharges from fish farms. The appropriate application of GIS work in this field could see a rapid decline in the negative effects on the environment.

11.4.3 Management of freshwater resources for aquaculture

In this section, the concern is mostly with freshwater provision because at present this is a much larger issue than that of sustaining supplies of salt water for mariculture purposes.[261] Having said this, it is clear that marine algal blooms are a major constraint on aquaculture in various marine areas, and that GIS is being used as a means of monitoring this (see Section 6.8.2). The concern here is also with the effect of the environment on aquaculture, which is being discussed here because nearly all environmental effects on aquaculture will be "delivered" via the prevailing water resources.

As the world's population increases and the planet becomes warmer under the effects of climate change, the demand for freshwater increases at an accelerating rate. While many areas still have water in abundance, the variety of areas that see a water deficiency is constantly growing. Water has been scarce in traditionally dry areas, but these scarcities are now occurring in places where water tables have sunk to impractical levels; where underground supplies have been completely exhausted; where tropical rain forests (and other areas) are experiencing previously unknown droughts; or where people have abstracted water at rates that are unsustainable. Clearly, this deteriorating situation means that less water may be available in the secure quantities needed for aquaculture, and there may be increased competition for available water resources. These factors are certain to have an effect on water costs.

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[261] It is important to note that freshwater supplies will also influence brackish-water aquaculture.

As mentioned in Section 11.4.2, there is the potential for aquaculture to have an impact on the environment, but as inferred above, there is also the important consideration of environmental effects upon aquaculture. Here, the concern is mainly with the effects felt in riverine or lacustrine environments, i.e. mostly fresh- or brackish-water situations – environmental effects felt on aquaculture in marine waters are mentioned in Section 11.4.4. Because aquaculture uses water as the production medium, then any environmental effect is likely to be delivered via the water entering the culturing site. Ideally, the environment will be providing high-quality water in sufficient quantity on a constant and sustainable basis. In some systems, the water will also deliver (usually supplementary) nutrient supplies. However, there are a number of ways in which the environmental impacts on aquaculture can be negative:

- Especially during periods of high water flow in a catchment, turbidity levels can be high and this can suppress feeding activity.
- Disease pathogens can be transported by water, sometimes from neighbouring aquaculture facilities.
- A range of point source or more diffuse pollutants can be delivered to the production facility, e.g. sewage effluents, inadvertent point source leaks, farm-sourced chemicals, oestrogens, toxic algae, etc.

Before establishing an aquaculture facility, the investor should take the precaution of checking past environmental incidents in an area, or at least have a good idea of what potential problems are sited upstream, and there should be emergency plans that can be activated in case of any environmental incident.

Planning for water management is, therefore, increasingly necessary in a large number of areas. GIS offers a number of models and procedures that can assist with this, and it is certain that this modelling will be more important in the future, especially given the fact that water is a ubiquitous asset that needs to be shared across the wider community (e.g. Jenness *et al.*, 2007a,b). It is also certain that more use will need to be made of recycled water. For aquaculture, this will be in the form of recirculation systems. Already such systems exist though they are largely experimental and on a small-scale. To an extent, such systems make the siting of aquaculture independent of large water supplies and thus alternative location preferences may become available and/or profitable.

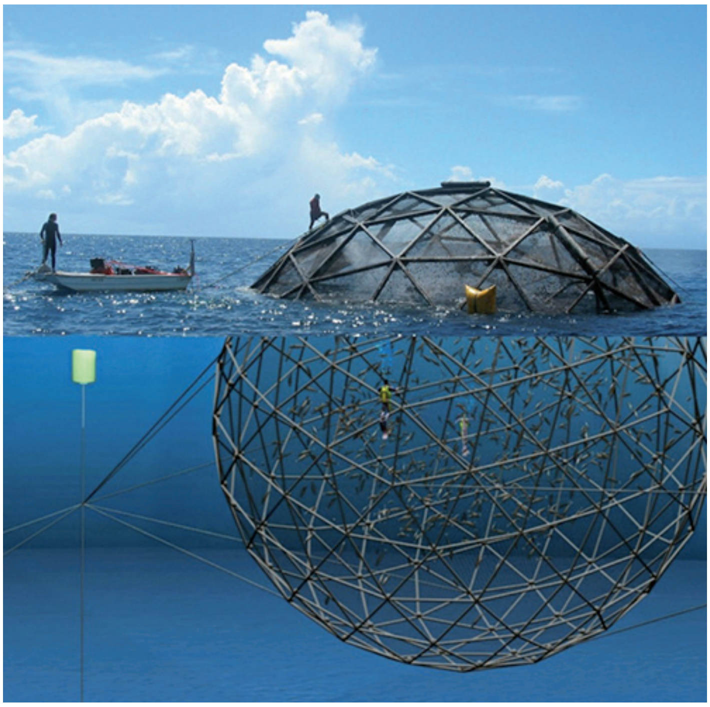
11.4.4 Offshore mariculture

During the past decade there has been a trend to move mariculture further off-the-coast. Traditionally, aquaculture practices were very much terrestrial based with all early fish production being in land-based artificial or natural ponds. As production intensified, it moved towards artificial structures such as earthen or concrete raceways on land, and then into various pens or cages that were located in shallow inshore waters or in highly sheltered lakes, lagoons, estuaries or fjords. These nearshore locations were chosen because of easy access for various management purposes and because of the shelter that could be offered from storms and high energy waves. However, recently it has become clear that facilities based in open marine waters might offer a number of advantages. Kapetsky and Aguilar-Manjarrez (2007) note that the advantages can take several forms, for example:

- fewer environmental impacts (to water quality, bottom sediments, other species, etc);
- decreasing conflicts with other on-shore or near-shore activities;
- more consistent quality of water supplies;
- fewer incidents of harmful algal blooms;
- large potential for industry expansion;
- greater potential for economies of scale;
- reduced visual impacts.

It is clear that there would also be drawbacks, such as increased capital and servicing costs, difficulties of monitoring and security and the need for greatly strengthened holding structures. It is also clear that there are likely to be considerable efforts put into optimizing cage structure, design and functionality, and the outcome of this might be that a wide range of systems are developed for different culturing regimes and locations. Figure 11.3 gives an example of a submersible cage structure for finfish offshore mariculture. The balance between costs and benefits with respect to offshore mariculture may still be uncertain, but given the need to greatly expand fish production, then further movement of mariculture facilities into open waters is certain to increase.

FIGURE 11.3
A typical "aquapod" submersible finfish structure being used for mariculture



Source: Ocean Farm Technologies (2012).

It is clear that the siting of offshore cages cannot be done without a great deal of careful analysis, and as all of the factors that need consideration have a strong spatial component, GIS and remote sensing will clearly have an important locational role to play. Among the factors that need to be considered are the direction of prevailing winds, location of any regular shipping routes, depth of water (cages and longlines need to be tethered), strength of tidal and other currents, distance to servicing facilities, other competing water resource users and adjacency to conservation features. Given these potential restrictions, many countries are already investigating their coastal zones in an effort to identify open sea areas that might serve as suitable offshore cage sites/zones, and they may also be using GIS to identify the optimum species for culture given the prevailing conditions. With Marine Spatial Planning already being instigated or considered, then it is clear that cage and longline location may well become part of an integrated marine strategy. A useful study of how coastal countries might investigate the potential for open ocean aquaculture using a low-cost GIS is provided in Chapter 4 of Kapetsky and Aguilar-Manjarrez (2007); see also Kapetsky and Aguilar-Manjarrez (2010) and Kapetsky, Aguilar-Manjarrez and Jenness (2013).

11.4.5 Growth of inland fisheries and recreational angling

Much of the concern in this technical paper is with commercial marine fisheries and with various forms of aquaculture, and this is because by far the largest proportion of consumed fishery products is derived from these sources. However, it has been pointed out (FAO, 2010a) that the activities of inland fisheries and of recreational angling are increasingly worthy of discussion. Although precise figures are hard to come by,[262] and reporting remains unreliable, FAO shows that inland fisheries grew from 8.6 million tonnes in 2004 to a record 10.1 million tonnes in 2009, with some 61 million people being involved in the sector. However, "the poor state of knowledge on inland fishery resources and their ecosystems has led to differing views on the actual status of many resources. One view maintains that the sector is in serious trouble because of the multiple uses of and threats to inland water ecosystems. The other view holds that the sector is in fact growing, that much of the production and growth has gone unreported and that stock enhancement through stocking and other means has played a significant role." (FAO, 2010a; p. 9).

Inland fisheries take place in both impounded waters and natural lakes, plus in various categories of naturally flowing freshwater. Fish are caught for both food and recreational purposes. Until recently, management of this sector has been minimally applied, with the interest in developed countries largely being centred on where closed seasons could be implemented (by fishery, season or area) and on issuing of fishing licences, with receipts from licence payments often being fed back to support a fishery. But with declining catches in many areas, with increasing number of fishers and with environmental degradation, it is frequently necessary to instigate more intensive forms of management. In developing countries, facts concerning the status of inland fisheries are often unreliable, but it is known that irresponsible fishing practices, habitat loss and degradation, water abstraction, drainage of wetlands, dam construction and pollution (including eutrophication) often act together to the detriment of these fisheries. It is urgent that these problems are addressed because the future importance of fish production from the inland sector is recognized as a means to helping poverty alleviation and food security. Little GIS work has been done in this sector to date, but significant increases are likely in the future.

The recreational fishing sector is characterized by huge diversity, i.e. in terms of the number or proportion of participants per country, methods of fishing, species targeted, sites fished, degree of management, intentions of fishing, environmental impacts, capital inputs to the fishery, etc. There has been little quantification as to the extent of this fishing sector in terms that allow either a comparison between countries, total volume of catches, total numbers involved, etc. The only data available consist of various short time scale or small-area surveys,[263] and these offer no standardization in terms of methodology employed. However, it has been estimated that in many fisheries, the quantity of fish caught by recreational anglers now exceeds the total of commercial catches (Ireland, 2010). This is especially so in the most advanced economies.[264] Again, past management practices have been minimal, but according to Ireland these advanced country fisheries are unlikely to thrive in the future without greatly increased management interventions. It appears that the future management of these fisheries offers vast scope for the use of GIS, certainly at localized scales.

[262] The extent and reliability of data collection for inland fisheries is highly suspect, with one-third of countries providing no data to FAO.

[263] For examples see Beckley, Fennessey and Everett (2010), Veiga *et al.* (2010) and Ireland (2010).

[264] Ireland (2010) reports that in Western Australia nearly one-third of the total resident population are recreational anglers.

11.4.6 The consolidation of the fishing and aquaculture industries

Over at least the last two decades there have been contrasting movements in terms of the scale and organization of fish production. These changes have affected both the capture fishery industry and fish farming. With a whole range of movements towards economies of scale, production consolidation and agglomeration and vertical integration, there is undoubtedly a much higher proportion of total fish output coming from larger-scale production facilities or operations. The securing of increased aquaculture space comes about either through the merging of neighbouring production facilities (clusters of farms), through deliberate zoning, or through the development of new facilities. Regarding capture fisheries, consolidation has mostly come about through cooperative vessel ownership groups or through mergers whereby individual vessel owners form business partnerships in order to take advantages of reductions in working costs. Whatever the means, it may be vital to examine aquaculture location preferences in terms of site advantages or limitations, and consolidation in the capture fisheries may have spatial effects in terms of the changing number, dispersion and fortune of "growth poles".[265]

However, in contrast to the moves towards industry consolidation, in the case of aquaculture there is a perception that this activity can either form an additional strand to existing farming practices or that an income can be achieved from access to a relatively small land holding. This has led to a growth in the number of small and even micro facilities, usually in the less-developed economies. These movements towards both larger- and smaller-scale operations in aquaculture have been well documented for the Asia-Pacific region in NACA (2007). Again site selection for such activities is extremely important if enterprises are to be successful.

As with changes in production scale, there will inevitably be changes in production practices. For aquaculture, ponds, pens, cages, raceways, etc. all have varying physical requirements and GIS will continue to be an asset in establishing preferred production practices for specific locations. With increased consolidation, it is also likely that increased emphasis will be given to a range of factors important to site selection that may not be directly connected to production per se, e.g. aesthetic factors, access factors, rights to land, and other socio-economic factors that are compatible with the EAF and/or EAA, any of which may be introduced into spatial modelling exercises. With a more complex array of inputs to aquaculture,[266] it is also likely there will be a higher degree of specialization in the future, and many farmers in rapidly developing countries will choose to give greater emphasis to increasing incomes through their aquaculture facilities. Perhaps the greatest impact on farming production practices will come from what are known as "Good Aquaculture Practices" (GAP). This means that standards and certification schemes are being introduced, which will have the effect of promoting consumer trust in products and will ensure sustainability of production methods used; however, these GAP practices will also raise production costs.[267] This may force many smaller fish farmers out of business and farms may consolidate into larger enterprises. In marine fisheries, some of these changes in production practices will also occur, e.g. certification schemes, ecolabelling and changes in working conditions, and there will be additional concerns such as safety at sea, training needs and increasing bureaucratization of the working environment. For marine fisheries, general moves towards consolidation will have less of a spatial impact than it does for aquaculture.

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[265] Growth poles are locations of concentrated economic activity from which wealth may disperse outwards to surroundings locations.

[266] This includes aquaculture skills, energy, supply or market linkages, pelleted foods, insurance and hygiene practices.

[267] Further details on the FAO's guidelines to certification can be found at FAO (2012f): www.fao.org/fishery/topic/13293/en

11.4.7 Rebuilding depleted marine and freshwater stocks

For many years, large numbers of freshwater rivers and lakes have been restocked with a range of fish species that accord to desired local species mixes. Restocking has usually been a response to reductions in fish numbers owing to the overfishing caused by often unregulated freshwater angling, though sometimes it has been necessary to restock following pollution incidents, disease outbreaks or stresses caused by drought, etc. Restocking may also be necessary where ecosystem balance needs correction, or simply where new fisheries have been created. The amount of attention devoted to restocking marine or estuarial waters has been far more restricted, yet depleted fishery resources not only have a severe impact on economic activity and on food availability, but they are also likely to give rise to instability in marine ecosystems as trophic relationships become unbalanced or changed. There are also problems concerning the large areas that might need to be stocked (and the costs involved in this), plus the considerable uncertainties as to the viability of restocking or the requisite cost–benefit advantages that may accrue. It seems certain that the future will see increased efforts to restock marine areas, but this is unlikely to be carried out without extensive GIS-based analyses whose aims are to establish factors such as the optimum time for restocking, optimum species mixes, quantities and costs involved and locations or sites that would be preferred. Higher-value species such as lobsters are already heavily restocked in many marine areas, but it is still questionable as to how far down the food (or recreation) value chain restocking might be viable. But stock improvements will be a complex issue to resolve because local ecosystems may already be changed in ways that are virtually impossible to amend. Additionally, factors such as climate change will prevail against returning individual marine ecosystems to their former condition. Already there is some considerable scepticism that stocks can be returned to former levels (Froese and Proelfs, 2010),[268] and initially it will take considerable GIS-based modelling expertise to demonstrate optimum carrying capacities for local marine species combinations, though attempts at doing this will certainly be forthcoming.

But of course in many cases depleted stocks of fish can also be rebuilt by improved management techniques, and attempts at doing this have been practiced for many decades. The methods deployed are variable and may include:

- reducing fishing effort or fishery power;
- applying various systems of output quotas;
- implementing no-take fishery zones or other conservation areas;
- instigating closed seasons.

While in practice any of these management methods should positively impact on fish stocks, too often stock levels are not rebuilt and this may be because there is insufficient monitoring of fishery areas (to prevent illegal or overfishing), or because the methods deployed are not stringent enough, or agreement cannot be reached on the real state of the stocks, or because it is difficult to compromise between scientific and/or environmental observations and the livelihood of fishers.

One reason for the failure to rebuild marine stocks is simply that there is insufficient understanding of the natural factors that are controlling species distributions. Although this facet of fisheries management and research is already being pursued, it will become of increasing importance in the future. For instance, Kaplan *et al.* (2010) note that until recently the ability to implement and assess spatial marine management approaches has been limited by a lack of information regarding processes that bind marine ecosystems, including habitat locations, larval and adult movement, trophic interactions and fisher behaviour. However, recent advances in habitat-mapping technologies, genetics, marine microchemistry, animal tracking and numerical modelling have greatly enhanced the knowledge of these processes. For instance, MacKenzie *et al.* (2011) have recently

[268] Two important stocks that have never returned to previously high levels are the cod stocks of Newfoundland, Canada, and the large yellow croaker in the People's Republic of China waters.

shown that, as the carbon isotope composition of animal tissues varies with sea surface temperature, the marine location occupied by individual fish can be identified by matching time series of carbon isotopes measured in tissues to sea surface temperature records. Using this technique, the authors were able to identify where salmon from different United Kingdom rivers had been feeding in the North Atlantic Ocean. Although these advances have yet to be fully integrated into management decisions, they have the potential to revolutionize spatial marine management. Nevertheless, this revolution will require advances in the ability to share and integrate data into models of marine ecosystems. No doubt the future will see great efforts in this direction.

11.4.8 The recording of fishing vessel activities

For a number of years, FAO (2010a) has recognized the need to have a global database of fishing vessels, and that in the future this is likely to be extended to having a record of their activities – fishing locations, catches, landings, etc.[269] In an era when overfishing and illegal fishing are worldwide problems, there are a number of obvious reasons why the activities of fishing vessels might need to be recorded. These reasons could be associated with management, research or science, or for the vessel owner's purposes. The recording of vessel activities can be an on-board activity carried out via fishery logbooks or through observer activities. They can also be external through observations from fishery patrol vessels or aircraft, or, indeed, they can be based on vessel monitoring systems (VMS), which rely on external observations that collect data via on-board electronic equipment and communication satellites. At the present time, VMS-based recording is mostly restricted to larger commercial fishing vessels operating in territorial waters, and the data captured does not positively discriminate between fishing locations and other vessel movements. Despite this, many attempts have been made to establish vessel fishing locations based on calculations of vessel speeds (see Figures 10.6 and 10.7). Finally, fishing vessel activities can be recorded through direct interviews with fishers. In an era of overfishing and the need to take on EAF advice, from the social and economic perspectives especially, it is important that fishers are able to explain and record their fishing ground locations as allied to species and perhaps to some measure of catch volume. Figure 10.12 gave an example of such fishing ground mapping, but work is now in progress to improve the sophistication of such techniques (des Clers *et al.* 2008; des Clers, 2010).

Because electronic data capture equipment is now becoming more sophisticated, miniaturized and ubiquitous, the possibility of gathering more precise data on vessel activities is becoming viable even for relatively small vessels, e.g. the European Union made fishery electronic logbooks mandatory on all commercial vessels more than 15 metres in length in July 2011, and on all vessels from 12 to 15 metres in length from January 2012.[270] For the first time, this will make a large proportion of total European commercial fish landings instantly able to be recorded and georeferenced.[271] Not only will e-logbooks be supplying real-time landings data that can be matched to haul locations and subsequently matched to

[269] There are ongoing discussions with the IMO regarding this initiative and it would appear likely to emerge in the near future.

[270] From January 2010 all European Union commercial vessels more than 24 metres were obliged to complete electronic logbooks, and European Union Directive 1077/2008 stated that from July 2011 all commercial fishing vessels more than 15 metres would need to do the same. As set out in European Directive 1224/2009, as from January 2012, all vessels between 12 and 15 metres would be required to use electronic logbooks, and vessels between 10 and 12 metres will optionally be allowed to use them.

[271] Unfortunately, the data being captured only requires that fish "landings" are recorded, and given that the European Union fisheries require the discarding of over quota or undersized fish, then catches could be considerably greater than recorded landings. However, the European Union fishery authorities are indicating that in the future all catches will need to be landed (see footnote 22).

quantity landings of each species, but this information can then be mapped at levels (resolutions) that can provide useful and precise information on fish extraction rates per unit of marine area. Though theoretically this capability is already attainable, the widespread use of such systems is rarely achieved for reasons of data privacy and perceived intrusiveness,[272] the complexity and costs of the systems, and for reasons associated with obtaining widespread agreement. However, it is clear that the possible value of the derived data to the fishery management and research sectors will be huge, i.e. in that it offers the potential for an essential data source to be integrated throughout the data hierarchies contained within the EAF. A useful summary of the uses of VMS and e-logbooks can be found in Gerritsen and Lordan (2011).

11.4.9 Evaluating fisheries management practices, including sustainability

Fulton *et al.* (2011) have recently highlighted the increasing complexity of ways in which fisheries might be managed. For instance, very different approaches would be taken if management used a top-down approach compared with a bottom-up approach. Fulton *et al.* further note that even in well-managed fisheries where sole jurisdiction exists, significant numbers of stocks are still overfished, and where stocks are shared (or in high seas fisheries), the situation is much worse. Sources of uncertainty for fisheries managers include: resource dynamics, e.g. recruitment variability; catch misreporting; poor fleet monitoring; dubious stock assessments;[273] political pressure on management decisions; incorrect adoption of management procedures; and inappropriate fishing methods. Mackinson *et al.* (2011) add to this list by noting the importance of more frequently engaging with stakeholders as part of a move towards effective governance. Because by far the largest total marine area is that of the so-called “high seas”,[274] the effective management of these seas is highly important. These areas are managed by 18 regional fisheries management organizations (RFMOs). The effectiveness of RFMOs in conserving the fish stocks has been recently questioned by Cullis-Suzuki and Pauly (2010), i.e. because many stocks have significantly declined. The results of surveys by these authors show that two-thirds of stocks fished on the high seas and under RFMO management are either depleted or overexploited and thus are considered as being poorly managed. The use of GIS is likely to be invaluable in addressing many of these issues.

It is important to mention that management practices in many areas are undergoing urgent reforms. For instance, after criticisms about the lack of success of fisheries policies in European waters (Khalilian *et al.*, 2010), the European Union launched reforms of its Common Fisheries Policy in 2009.[275] Thus, management reform policy areas that are likely to emerge in the European Union and perhaps other regions include:

- fleet overcapacity;
- regionalization of fishery policies and management;
- protection and promotion of small-scale fisheries;
- licensing of recreational angling;
- locationally based fishing effort (or other output) controls;
- adjustments of fishing subsidies;
- banning of fish discarding;
- improvements in stock assessment capabilities;
- on-board monitoring of catches through closed-circuit television (CCTV).

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272 There are signs that some fishers are becoming less concerned with what has been regarded as “bureaucratic intrusiveness” by fishery authorities, e.g. see paragraph 13.10 of the Scottish Government: www.scotland.gov.uk/Publications/2010/11/02103454/15.

273 Beddington, Agnew and Clark (2007) note that the status of stocks in some of the world’s best-managed fisheries has still to be determined.

274 Marine waters that are beyond the 200-mile exclusive economic zone of coastal nations.

275 Details of the stages in the European Union legislation for policy changes can be found at the European Parliament: www.europarl europa.eu/oeil/FindByProcnum.do?lang=en&procnum=INI/2009/2106.

It is clear that any of these management areas are spatially linked and can thus be examined, analysed, mapped, etc., via the use of GIS.

It is also important from the management perspective to mention that we are now living in an era when sustainability must lie at the root of all activities, especially those that are concerned with resource production or extraction and energy creation, and to this end the number of national and international marine conservation organizations is proliferating.[276] Marine users generally, and fisheries managers more particularly, must be aware that each action they permit by those who they manage will have a variable impact on the marine space and marine resources. The fishery authorities in New Zealand are so aware of the importance of spatially based planning that they have set up a specialist "spatial allocation" team to carry out a range of tasks, including the assisting of applications for new aquaculture space, marine reserves, freshwater fish farms and aquatic transfers.[277] Cotter and Lart (2011) have recently drawn attention to the important matter of the risk to aquatic ecosystems of different fishing practices, e.g. it is well known that trawling can severely degrade benthic ecosystems, and they advocate careful comparative analyses of different methods of fishing in order to ascertain those that are most sustainable under different conditions and that are targeting different species. Another management measure that is likely to come to future prominence, and one in which GIS offers the potential for a range of analyses, is that of the introduction of effective forms of rights-based management. With species populations in many aquatic environments being critically low or endangered, as are some important marine and freshwater habitats, all management actions will need to increasingly imbue a sense of sustainability. The use of GIS will play an important part in this through allowing spatial manifestations of resource distributions that may be of important or of critical concern to sustainability to be entered into spatial analysis and modelling.

11.4.10 Threats and changes to marine and freshwater ecosystems

The world is witnessing a slow but observable exponential increase in threats to all aquatic ecosystems. Clearly, these threats can be from many quarters and occur on vastly differing scales, and only the main threats can be briefly discussed here.

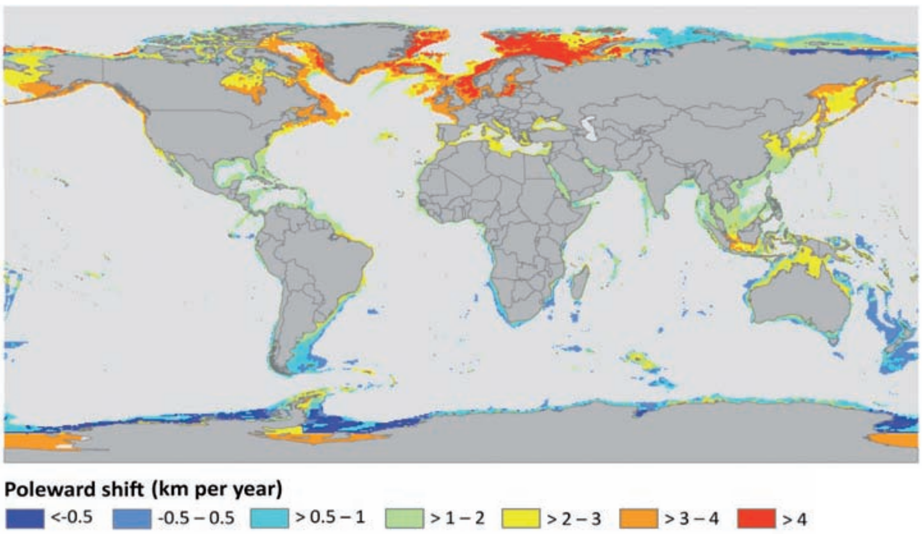
- It has been reported that within the central Pacific Ocean there is now a vast gyre consisting basically of "plastic garbage" (e.g. Dameron *et al.* 2007; Yamashita and Taminura, 2007). Similar concentrations of "refuse" occur in other oceanic areas. This has accumulated from materials brought down by rivers, washed from shores or discarded from ships and smaller vessels. Much of this material forms a major hazard to marine life. Thus, the plastics undergo photodegradation in the surface layers of the sea, eventually breaking down into extremely small particles. Many species then ingest these particles, and bioaccumulation of toxic organic compounds occurs as compounds are progressively passed up the food chain in quantities that are markedly concentrated at each trophic level.
- Many seas, especially those that are predominantly enclosed, e.g. the Adriatic, the Black Sea and the Baltic Sea plus many lakes, rivers, estuaries or fjords, are suffering from severe oxygen depletion (hypoxia) at lower depths. This largely results from a reduction of dissolved oxygen (DO), i.e. down to levels such that aquatic life cannot be supported. The reduction of DO itself is caused by pollution or by stratification of the poorly mixed water column in areas where freshwater inputs may be high.

[276] Major marine conservation organizations include: The Deep Sea Conservation Coalition; Marine Stewardship Council; Marine Conservation Society; Marinet; Ocean2012; and World Ocean Council.

[277] See details at http://fs.fish.govt.nz/Doc/21837/Spatial%20allocation%20across%20fisheries%20 sectors.pdf.ashx – accessed 10 December 2012.

- Biosecurity is the management of biological risks in order to protect the health and well-being of animals, plants and people and to maintain the functions and services of ecosystems. Biosecurity as applied to aquaculture is best explained by the following extract from FAO (2010b). "As aquaculture intensifies and diversifies, the biological hazards and risks to farmed animals, people and ecosystems also increase in number and diversity, with potentially serious consequences. Some of these hazards include infectious diseases, animal pests,[278] public health concerns on residues and resistance of antimicrobial agents, zoonosis,[279] invasive alien species, release of genetically modified organisms and biosecurity risks posed by climate change. The growing number, complexity and seriousness of these risks have driven the development of the concept of biosecurity and its increasing application. An integrated strategy to manage biosecurity, business, environmental and social risks will better promote sustainable growth of the aquaculture sector." The management of biosecurity will be heavily dependent on adequate data, nearly all of which will need to be spatially referenced.
- The evidence for climate change is now overwhelming. In most marine areas, this is causing waters to become warmer, which is causing sea-water levels to rise through ice melt and thermal expansion, i.e. such that they are likely to be at least 1 metre higher by the end of this century. Warmer waters (marine and fresh) will undoubtedly cause species migration shifts[280] as fish, etc., respond to water quality and to food availability changes. Pereira *et al.* (2010) have predicted that there will be a latitudinal range shift for demersal marine species of up to 4 km per year from 2005 till 2050 (Figure 11.4), and that pelagic species will migrate even faster because of higher water temperatures nearer the surface.[281] There are other climate change consequences that will impede species distributions, such as increased storminess

FIGURE 11.4
Predicted latitudinal shift of demersal marine organisms between 2005 and 2050 as caused by climate change (excluding areas > 2 000 m in depth)



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

[278] Note here the huge concern over the effect that farm-caged salmon might be having on wild salmon through spread of diseases, parasites infections, and the threat of genetic weakening if inbreeding occurs.

[279] Zoonosis is any infectious disease that can be transmitted from non-human animals to humans.

[280] A recent account of the dominant species shift occurring in Icelandic waters can be found in Stefansdottir *et al.* (2010).

[281] Cheung *et al.* (2009a) note that species turnover rates at any single marine station could be over 60 percent between 2010 and 2050.

and wave heights, and increased marine acidification as larger amounts of carbon dioxide are deposited into the seas. Additionally, the effects of climate change will severely impact marine ecosystems such as coral reefs,[282] and, to a lesser extent, specialist aquatic habitats such as mangroves, coastal lagoons and deltas. All of these bio-physical changes will impact upon the social, cultural and economic lives of fisher communities,[283] and recent studies have indicated some likely effects of climate change upon both fisheries and aquaculture, e.g. Handisyde *et al.* (2006); Cochrane *et al.* (2009). In an interesting and important recent case study, Jeffers (2010) noted that the Arctic is currently undergoing unprecedented shifts in marine species, and climatic conditions in the region are changing at a rate nearly twice as fast as those at lower latitudes. This is bringing unprecedented alterations in an area that is extremely important for fisheries. Ecological and socio-economic alterations will have a significant effect on fisheries governance structures and on interactions between Arctic countries and could potentially destabilize existing management regimes. Positive changes to fishery stock compositions and distributions may also lead to conflicts between Arctic nations owing to overlapping jurisdictional claims, unregulated fishing and a lack of multiregional agreements. The current Arctic regulatory and governance framework is not sufficient in scope and flexibility to adequately address future fishery changes brought on by climate change.[284] Clearly, the varied effects of climate change will be another potent area for spatial analyses.
- Often associated with climate change and biosecurity, another major threat to aquatic ecosystems is that caused by invasive species. Within marine ecosystems species, invasions are almost impossible to control, and warming waters are seeing accelerations in these species movements. Some invasions have occurred for different reasons, e.g. species have accidently escaped from fish farms, or they have been purposefully released, or newly constructed waterways such as canals or seaways have created pathways for migration, e.g. the Suez Canal has allowed many species to move from the Red Sea into the Mediterranean Sea. Invasive species often lack natural enemies and they may introduce pathogens that are transmitted to native species. In some cases, invasive species may not be a problem, but in far more cases they both upset naturally existing ecosystems and they slowly impact on existing fishery regimes. It has been suggested that the concept of alien species might be changed to that of "naturalized species" or "established exotic", i.e. because of the near impossibility of reversing the situation once invasion has been successful. Thus, in terrestrial farming, almost all species cultivated are not local and/or native. Undoubtedly, the impact of aquatic alien species has been highly variable, and it needs careful monitoring. The Conference of the Parties to the Convention on Biological Diversity in 2008 invited relevant international organizations to work together to fill the gap in the international regulatory framework on invasive alien species, and reaffirmed the need for capacity and expertise to deal with invasive alien species in many countries, especially in developing countries (Shimura, Coates and Mulongoy, 2010).
- A range of other spatially variable threats include "Abandoned, lost or otherwise discarded fishing gear"; point source pollution from a wide range of sources; increased resource extraction from marine or riverine areas; flow modification in rivers; natural perturbations in species numbers, e.g. explosive populations or species-specific disease events; and increases in El Niño type events, any of which are legitimate and deserving subjects for spatial analyses.

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[282] Butchart *et al.* (2010) estimate that the condition of 38 percent of all corals has deteriorated since 1980 and that 38 percent of reef corals are at a high risk of extinction.

[283] A full range of climate change impacts are given in FAO (2010b).

[284] Jeffers (2010) further explains the range of governance changes that must be introduced, including overhauling the Arctic Council and establishing a new Arctic Ocean regional fisheries management organization.

A summary of all aquatic ecosystems changes can be found in Polunin (2008). The spatial impact of these existing but rapidly accelerating threats and changes will clearly be very significant and solutions are only likely to be successfully sought via expertly managed spatial analysis. One of the ways in which future GIS will progress is through "cumulative impact mapping" that will involve modelling combinations of the various threats as a means towards understanding and perhaps ameliorating the threats.

11.4.11 The standardization of habitat (and other) classifications

Because we live and work in such a complex social, economic and environmental world, then any analyses of our bio-physical or economic activities will oblige us to simplify the subject matters being studied. This essentially means that a classification method must be used, i.e. grouping similar objects or themes into a number of identified categories – which themselves might vary according to the analysis being carried out. For example, finfish species may be classified into pelagic, demersal and benthic species, or perhaps into species that are considered as being of high, medium or low trophic levels. It is important to mention that classifications can be both of a non-hierarchical basis (e.g. pelagic, demersal, benthic) or hierarchical (high, medium, low). Classification introduces problems associated with standardization, which may include:

- The number of classes to be used.
- Where to draw borderlines between classes.
- The basis on which classification is best based.
- Different classifications may be needed for different purposes.

Because of these problems, it has often been extremely difficult to be precise on any categories used and to obtain agreement on the standardization of classes.

To briefly illustrate this, a particular problem encountered in carrying out GIS work, especially that which is associated with habitat modelling and various ecosystems analyses (in both river and marine waters), is that of habitat classification. It is clear that in both marine and freshwater environments, it may be essential to establish mapped layers in which habitat characteristics can be plotted; Box 11.4 gives a hierarchy of requirements for a good habitat classification system. This box also gives a useful clue to the range of reasons why agreement on classification standardization may be important. Given that precise habitat characteristics are almost infinite, then much work has gone into identifying and trying to agree to these classifications (Todd and Greene, 2008; Al-Chokhachy and Roper, 2010; Guarinello, Shumchenia and King, 2010). Despite this work, as yet, there is no international agreement on standard marine habitat classes,

BOX 11.4

Requirements of a global marine habitat classification system

The requirements of a global marine habitat classification may be listed in the following order of importance:

1. Facilitate data and information exchange and interoperability.
2. Comprehensive glossary of terminology.
3. Be hierarchical.
4. Enable capture of marine habitat information from existing Ocean Biogeographic Information System data sources.
5. Enable capture of marine habitat information from potential Ocean Biogeographic Information System data sources.
6. Relevance to end-users, including conservation, fisheries, researchers and educators.
7. Use simpler terms and avoid jargon.
8. Be consistent with existing use of terminology in marine ecology.
9. Be possible to relate to existing marine habitat classifications.

Source: Costello (2006).

though a number of well-developed classification systems exist.[285] In the future, habitat classifications might serve to offer standards by which alternative locations can be assessed and judged, and no doubt habitat classifications will need to be monitored and moderated – so there is much future GIS-based work to be done in this area. It will be clear to the reader that the standardization of classifications of all types could bring enormous benefits to GIS use in fisheries or aquaculture. This is especially true when it comes to the exchange of data. However, it must be borne in mind that universal classification is only ever likely to be practical at the top end of any hierarchical classifications. Thus, further down a classification gradient the items being classified are increasingly likely to be unique to specific areas and thus not subject to international standardization. Once agreements have been reached on a wide range of standardized data classifications, then this will mean that the exchange and use of data sets will be greatly expedited allowing GIS work to be both broadened and more universally understood.

11.4.12 Working at variable scales and resolutions

There is now a rapidly accelerating rate at which data is being captured directly by either managers or researchers who are working specifically in fisheries or aquaculture fields or by others who are working in parallel fields or in associated technologies. There is unlikely to be a halt to this rising rate of data acquisition and of course data will be acquired on an increasing range of relevant themes. An abundance of data provides opportunities not only for a wider range of GIS-based analyses but also for the opportunity to carry out analyses in far more detail and at a wider variation of scales. This may be extremely important in the sense that, with the adoption of EAF/EAA, the fisheries and/or aquaculture researcher is obliged to consider a greatly increased range of ecosystems any of which may be considered at micro through to macro scales. Until recently, the lack of data has frequently meant that scale and resolution options have been severely curtailed. Many GIS workers have found that data for any specific project may only be available at mixed scales, i.e. perhaps varying from detailed remote sensing imagery to highly generalized socio-economic data where single values may be assigned to complete political or administrative areas. Extreme caution needs to be applied when mixing input data at different scales. Improvements in software will allow for easy switching (or "sliding') between scales and users will soon learn to optimize scale and resolution choices for specific analyses or themes.

To illustrate future trends in scale and resolution, it is worth briefly examining the single field of bathymetry. Most readers will be well aware that the world's marine areas are highly varied in terms of depth. While vast regions of the world's oceans consist of abyssal plains (or basins) where depths are typically in the range of 3 500–4 500 m, marine areas also consist of smaller geomorphic units that are typically highly varied in depth, form and texture. Examples of such units include continental shelves, coral reefs, deep ocean trenches, seamounts and mid-ocean ridges. It is immediately clear that the scale and resolution required for a study of part of an abyssal plain will be significantly different than that required, for instance, for any coral-reef-based study. Traditionally, data on bathymetry have been obtained from either single- or multi-beam echosounders. These utilize sonar technologies that are capable of reading the time taken for an "echo" to travel from the source transducer, typically mounted on the hull of a vessel, to the sea bottom and back again, and from this recorded time the depth can be calculated. However, recently bathymetry is making use of LIDAR[286] technology that itself makes use of a high-powered laser to transmit

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285 For instance, in the United States of America, the National Oceanographic and Atmospheric Administration (NOAA) has developed the NatureServe classification and in the European Union the EUNIS system is the best developed marine habitat classification.

286 Light detection and ranging. Recent developments in LIDAR are well explained in Boyd and Foody (2011).

electromagnetic energy, again measuring the time taken to get from the platform being used to the seabed. LIDAR can be mounted on the hull of a ship or on low flying aircraft. Using LIDAR up to 14 million measurements per hour can be captured in waters up to 70 m in depth,[287] and discriminating to 50 cms resolution (Kearns and Breman, 2010).

It can be appreciated that this detailed and superabundant data can allow for spatial analyses at multiple scales and for identifying underwater features, and GIS-based output can include contour-based mapping as well as 3D bathymetric models. The exponential increase in data from numerous capture source instruments that are directed towards most aquatic themes means that the potential for GIS-based work across a full spectrum of scales and resolutions is likely to feature prominently in the coming decades. However, deciding on optimal scales and resolutions to be working at can still be a challenge to GIS work, as is shown in Section 12.3.

11.4.13 Studies of temporal change in fishery and aquaculture thematic areas

It seems highly likely that considerable efforts will be made in the immediate future to study temporal changes with respect to both fishery and aquaculture themes. Thus far, very little attention has been given to this subject, partly because spatial changes in fishery activities have not been considered as important, and aquaculture (at least on a large-scale) is only a recent development and has thus not yet developed a history of change. However, it should now be recognized that both GIS and remote sensing have been active as important spatial technologies for over 40 years, and this is time enough for the original results (outcomes) of research applications to be revisited with the aim of examining change detection and the validity of some of the early GIS and/or remote sensing work.

With respect to GIS work, it may be important to revisit early studies in an attempt to show the progress that may have accrued over time. So, what was the validity of any early GIS work? Were the results accurate? Were they useful? How do they compare with analytical output that is being achieved today? It is surely useful for any branch of science to see where it has been and to be able to identify and assess progress (or not!). In many cases, the original digital data sets might still exist and clearly these could be easily used as the basis for spatial comparisons with present output. With respect to remote sensing work, there is much useful work that will be achieved. Thus, it is widely appreciated that change detection has been well deployed in terrestrial situations whereby, for instance, the areas of clearance of mangroves for shrimp pond construction have been shown and the rates of this clearance have been calculated. Similar work can be usefully undertaken in aquatic environments. Examples of change detection that rely completely on satellite derived data of aquatic themes include:

- Changes in the extent of coastal biotopes. Here, the main themes might be mangrove destruction; diminishing of deltaic areas under sea-level rise and/or coastal erosion; bleaching or destruction of coral reefs; loss of seagrass beds, etc.
- Spatial changes in temporary phenomena such as red tides, chlorophyll concentrations, water temperatures, seasonal aquatic vegetation, etc.
- Changes in the distribution of sediments in rivers and especially estuaries.
- The number of, and fluctuations in sizes of, inland waterbodies, i.e. mainly shallow lakes sited in semi-arid areas.

This type of remote sensing analysis can be simple to accomplish and can be very useful, especially in forming one of the essential inputs to model development and to future forecasting and planning.

[287] 70 m depth is very relevant to most mariculture production.