3. Spatially defined global ecosystems, their issues and their relevance to the ecosystem approach to aquaculture

In order to gauge development prospects for aquaculture there is a need to understand actual and potential impacts imposed on aquaculture from anthropogenic sources and through natural variation in the environment. It is also essential to have an appreciation of the status of ecosystems in which aquaculture resides, and to be able to identify the main issues affecting ecosystems because aquaculture issues have to be resolved in the light of broader issues. This chapter therefore has two objectives from which GIS practitioners and EAA implementors can benefit. The first is to provide an overview of various assessments of the state of, and associated issues of marine, coastal and terrestrial ecosystems mainly using global data. The second objective is to indicate how the ecosystems data are relevant to the EAA and in particular to spatial analyses in support of the EAA. With regard to spatially defined ecosystems, emphasis is placed on global data. This has several purposes. The first is that the global perspective is useful in order to place ecosystem issues in a geographic perspective that allows for worldwide comparisons. The second is that many countries will not have defined their ecosystems at national and sub-national levels. In these cases, in order to place aquaculture in the context of ecosystems, global data must be used. The compilation of spatially defined ecosystems as summarized in Table 3.1, is useful as a starting point for that purpose as is the spatial data overviewed in Chapter 4. The datasets, many supported by maps, are grouped according to their geographic coverage or category.

3.1 ECOSYSTEMS INCLUDING BOTH LAND AND WATER

The 2008 Environmental Performance Index (EPI) (available at http://epi.yale.edu/Home), a collaboration between Yale and Columbia Universities (United States of America), ranks 149 countries on 25 indicators tracked across six established policy categories: environmental health, air pollution, water resources, biodiversity and habitat, productive natural resources and climate change (Figure 3.1). The EPI identifies broadly-accepted targets for environmental performance and measures how close each country comes to these goals. As a quantitative gauge of pollution control and natural resource management results, the Index provides a powerful tool for improving policy-making and shifting environmental decision-making onto firmer analytic foundations (Esty *et al.*, 2008). Country level indicators among all categories and overall EPI score data are downloadable in Excel format (www.yale.edu/epi/files/2008EPI_Data.xls). Although, the EPI is spatial only to the country level, the indices offer the opportunity to infer the impact of the environment on aquaculture by a country level by re-weighting of indicators to favour ecosystem vitality as the most important criterion (Chapter 5) or to tailor an impact assessment based on a selection of indicators attuned the various aquaculture environments and systems.

TABLE 3.1
Summary of spatially defined global ecoregions and ecosystems relevant to the EAA and GIS in support to the EAA

Title	Author	Year	Technical documentation and scale	Uniform Resource Locator (URL)
Ecosystems including both land and water				
Environmental Performance Index	Esty *et al.*	2008	Country reports	http://epi.yale.edu/Home
			Excel files	www.yale.edu/epi/files/2008EPI_Data.xls
The Global Environmental Outlook	UNEP	2007	Report on Land and Water	www.unep.org/geo/geo4/media
The GEO Data Portal	UNEP	2007	National, Subregional, Regional scales	www.unep.org/geo/Docs/GEODataPortalBrochure.pdf
			Excel files	http://geodata.grid.unep.ch/extras/indicators.php
The Global 200: Priority Ecosystems for Global Conservation	Olson and Dinnerstein	2002	Global and continental scales	www.worldwildlife.org/science/ecoregions/WWFBinaryitem4810.pdf
			Vector data	www.worldwildlife.org/science/data/item6373.html
The coasts of our world: Ecological, economic and social importance	Martínez *et al*.	2007	1 km grid cell size sources were used	www.rpdc.tas.gov.au/__data/assets/pdf_file/0006/123495/Martinez_et_al_2007_Coasts.pdf
Aquatic ecosystems				
Global International Water Assessment	UNEP	2006b	Attribute data should be available	www.unep.org/dewa/giwa www.unep.org/DEWA/GIWA/PUBLICATIONS/FINALREPORT
Global Map of Human Impacts on Marine Ecosystems	Halpern *et al*.	2008	Global	www.nceas.ucsb.edu/globalmarine
			GIS data variety of formats	www.nceas.ucsb.edu/GlobalMarine/impacts www.nceas.ucsb.edu/GlobalMarine/ecosystems
Marine and Coastal Ecosystems and Human Well-Being	UNEP	2006a	Global Attribute data available	www.unep.org/dewa/assessments/EcoSystems/water/Marine_Coastal_Ecosystems.pdf
Large Marine Ecosystems	Sherman and Hempel	2008	Global report	www.edc.uri.edu/lme/intro.htm
			Global (vector)	www.edc.uri.edu/lme/gisdata.htm
Marine Ecoregions of the World (MEOW)	Spalding *et al*.	2007	Global	www.worldwildlife.org/science/ecoregions/marine/WWFBinaryitem6091.pdf
			Vector	http://conserveonline.org/workspaces/ecoregional.shapefile
Eutrophication and Hypoxia in Coastal Areas: A Global Assessment of the State of Knowledge	Selman *et al*.	2008	Global and regional point locations. Spatial data and attribute data may be available upon on request	http://pdf.wri.org/eutrophication_and_hypoxia_in_coastal_areas.pdf
In Dead Water – Merging of climate change with pollution, over-harvest, and infestations in the world's fishing grounds	Nellemann, Hain, and Alder	2008	Presumably spatial data and attribute data might be available upon request	www.grida.no/publications/rr/in-dead-water/

TABLE 3.1 Cont.

Summary of spatially defined global ecoregions and ecosystems relevant to the EAA and GIS in support to the EAA

Title	Author	Year	Technical documentation and scale	Uniform Resource Locator (URL)
Terrestrial ecosystems				
Last of the Wild, Version 2	WCS and CIESIN at Columbia University.	2009	Report	http://sedac.ciesin.columbia.edu/wildareas
			1 km grid cell size	http://sedac.ciesin.columbia.edu/wildareas/downloads.jsp#last
Pilot Analysis of Global Ecosystems (PAGE) - Agroecosystems	Wood, Sebastian and Scherr (2000).	2000	Report	www.ifpri.org/publication/pilot-analysis-global-ecosystems
	World Resources Institute and the International Food Policy Research Institute.	2005	9.2 km at the equator	www.ifpri.org/pubs/books/page.htm
WWF Terrestrial ecoregions of the world	Olson *et al.*	2001	Documentation	www.worldwildlife.org/science/ecoregions/item1267.html
			Full GIS Database	www.worldwildlife.org/science/data/item6373.html
HydroSHEDS	Lehner, Verdin, and Jarvis	2008	Documentation	http://hydrosheds.cr.usgs.gov
			Available resolutions range from approx. 90 meters at the equator to approx. 10 km at the equator	http://gisdata.usgs.net/website/HydroSHEDS/viewer.php

Notes: Vector. A coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each vector feature, as opposed to a raster data model, which associates attributes with grid cells. Cell. The smallest unit of information in raster data, usually square in shape. In a map or GIS dataset, each cell represents a portion of the earth, such as a square meter or square mile, and usually has an attribute value associated with it, such as soil type or vegetation class. See Glossary in Chapter 11.

FIGURE 3.1
Interactive map of the Environmental Performance Index countries in the Caribbean Region

Source: Esty *et al*. (2008).

The Global Environmental Outlook and the GEO Data Portal

The fourth "Global Environment Outlook: environment for development (GEO-4) assessment"is a comprehensive and authoritative UN report on environment, development and human well-being, providing incisive analysis and information for decision-making (UNEP, 2007). As overviews of issues there are two chapters of particular interest to the EAA, Chapter 3 on Land and Chapter 4 on Water in which aquaculture impacts are dealt with qualitatively mainly as they relate to the use of fishmeal in fish feeds, and thus an indication of the impact on marine ecosystems, as well as maps and graphs that preview the underlying data.

From the viewpoint of GIS in support of the EAA, the GEO Data Portal (www.unep.org/geo/Docs/GEODataPortalBrochure.pdf) gives access to a broad collection of harmonized environmental and socio-economic datasets from authoritative sources at global, regional, sub-regional and national levels, and allows for data analysis and the creation of maps, graphics and tables. Its on-line database currently holds more than 450 variables. The datasets can also be downloaded in a variety of formats, supporting further analysis and processing by the user. The contents of the Data Portal cover environmental themes such as climate, forests and freshwater and many others, as well as socioeconomic categories, including education, health, economy, population and environmental policies. A set of core indicators offers useful starting points for directed analyses pertinent to the EAA (e.g. Freshwater BOD); however, not all of the information is at country level. (http://geodata.grid.unep.ch/extras/indicators.php).

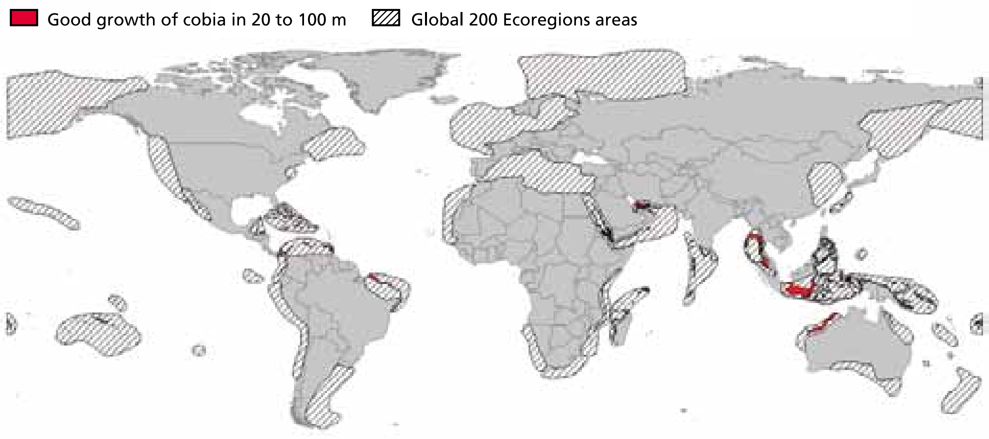
The Global 200: Priority Ecosystems for Global Conservation

Olson and Dinnerstein (2002) analyzed global patterns of biodiversity to identify a set of the Earth's terrestrial, freshwater, and marine ecoregions that harbor exceptional biodiversity and are representative of its ecosystems. As a means of facilitating a representative analysis, the authors placed each of the Earth's ecoregions within a system of 30 biomes and biogeographic realms. Biodiversity features were compared among ecoregions to assess their irreplaceability or distinctiveness. These features included species richness, endemic species, unusual higher taxa, unusual ecological or evolutionary phenomena, and the global rarity of habitats. This process yielded 238 ecoregions—the Global 200—comprised of 142 terrestrial, 53 freshwater, and 43 marine priority ecoregions. Effective conservation in this set of ecoregions would help conserve the most outstanding and representative habitats for biodiversity on the planet. This dataset is useful for the EAA in that Olson and Dinnerstein have already identified areas of exceptional biodiversity importance in which, at first glance, special care should be taken for planning aquaculture development and for its operation.

From a GIS perspective, the Global 200 areas can be integrated with other measures of ecosystem status by incorporating the freely downloadable GIS database (www.worldwildlife.org/science/data/item6373.html).

The Global 200 Ecoregions were used by Kapetsky and Aguilar-Manjarrez (2008) as an example of spatial data in support of the EAA. The example was an estimate of the loss in potential area for open ocean culture of cobia, *Rachycentron canadum*, by excluding the Global 200 areas. About one-third of the global area with potential for good growth of the cobia), in sea cages at 25 to 100m depth would be excluded by using the Global 200 Ecoregions as a constraint (Figure 3.2).

FIGURE 3.2
Potential for open ocean aquaculture of cobia within the Global 200 Ecoregions



Source: Kapetsky and Aguilar-Manjarrez (2008).

The coasts of our world: Ecological, economic and social importance

Martinez *et al.* (2007) integrated the emerging information on the ecological, economic and social importance of the coasts at a global scale. They defined coastal regions to range from the continental shelf (to a depth of 200 m), the intertidal areas and adjacent land within 100 km inland of the coastline. They used the 1 km resolution Global Land Cover Characteristics Database to calculate the area covered by 11 different land cover classes (natural and human-altered ecosystems) within the 100 km limit. Cover of aquatic ecosystems was calculated based on several world databases.

Multivariate analyses grouped coastal countries according to their ecological, economic and social characteristics. Three criteria explained 55 percent of the variance: degree of conservation, ecosystem service product and demographic trends.

This study is valuable for integrating EAA economic and social perspectives. Each criterion has a country specific value and a world map integrates the results into eight classes for the criteria. Presumably the data could be obtained in database or spreadsheet formats by request to the authors.

3.2 AQUATIC ECOSYSTEMS

In overview, most of Earth (70.8 percent or 362 million km^2) is covered by oceans and major seas. Marine systems are highly dynamic and tightly connected through a network of surface and deep-water currents. The physical properties of the water form stratified layers, and various processes cause tides, currents, fronts, gyres, etc. Upwellings break this stratification by mixing layers and creating vertical and lateral heterogeneity within the ocean biome. The total global coastlines exceed 1.6 million kilometres, and coastal ecosystems occur in 123 countries around the world (UNEP, 2006a).

Global International Water Assessment (GIWA)

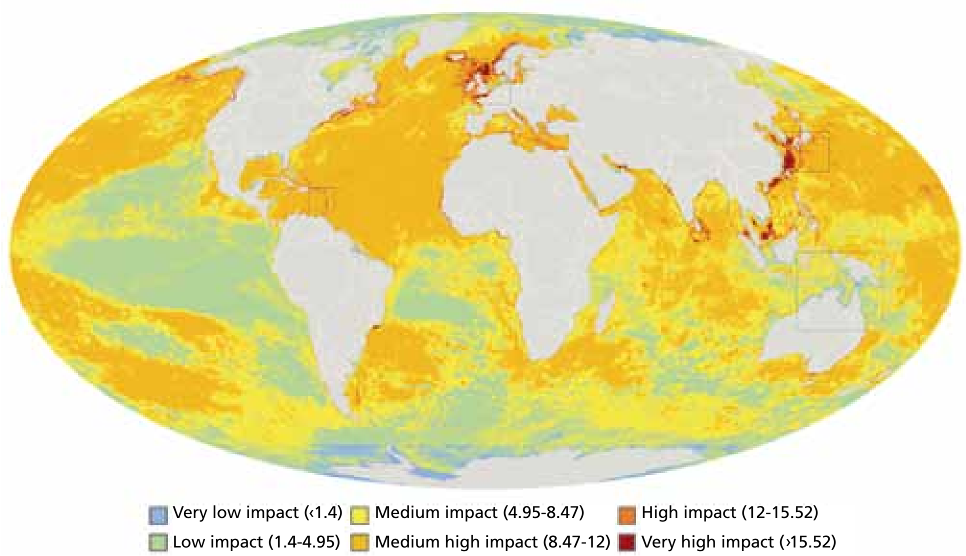
The Global International Waters Assessment (UNEP, 2006b) is a holistic and globally comparable assessment of transboundary aquatic resources in the majority of the world's international river basins and their adjacent seas, particularly in developing regions. Complex interactions between mankind and aquatic resources were studied within four specific major concerns: freshwater shortage, pollution, overfishing and habitat modification. Of importance to the EAA is that the GIWA project divided the continents and shallow-water seas of the world into 66 natural regions consisting of one or more international river basins and their adjacent Large Marine Ecosystems. Therefore there is a linkage between land and water. Another advantage is that the 66 natural regions are contiguous.

The GIWA Report presents the severity of 22 environmental and socio-economic water-related issues in all the studied regions. The global synopsis not only describes the current and future state of aquatic systems and their resources but also discusses the root causes and driving forces that create adverse environmental pressures, and draws policy related conclusions. The availability of the spatial data is unclear; however attribute data for each of the 66 regions and a global overview should be available. An important use would be to evaluate estimates of aquaculture potential against the water-related situations found within the 66 GIWA regions.

Global map of human impacts on marine ecosystems

The management and conservation of the world's oceans require synthesis of spatial data on the distribution and intensity of human activities and the overlap of their

FIGURE 3.3
Global Map of Human Impacts to Marine Ecosystems



Source: Halpern *et al*. (2008).

impacts on marine ecosystems. An ecosystem-specific, multiscale spatial model to synthesize 17 global datasets of anthropogenic drivers of ecological change for 20 marine ecosystems was developed by Halpern *et al.* (2008). Their analysis indicates that no area is unaffected by human influence and that a large fraction (41 percent) is strongly affected by multiple drivers. However, large areas of relatively little human impact remain, particularly near the poles (Figure 3.3).

From an EEA perspective the analytical process and resulting maps provide flexible tools for regional and global efforts to allocate conservation resources; to implement ecosystem-based management; and to inform marine spatial planning, education, and basic research that pertain to mariculture and possibly to brackishwater culture environments. Maps that show inorganic and organic pollution as well as nutrient inputs are among the most potentially useful for mariculture. From a GIS viewpoint the data layers are set out (www.nceas.ucsb.edu/globalmarine/impacts) and the ecosystems data are downloadable in a number of GIS formats. (www.nceas.ucsb.edu/globalmarine/ecosystems).

Marine and coastal ecosystems and human well-being

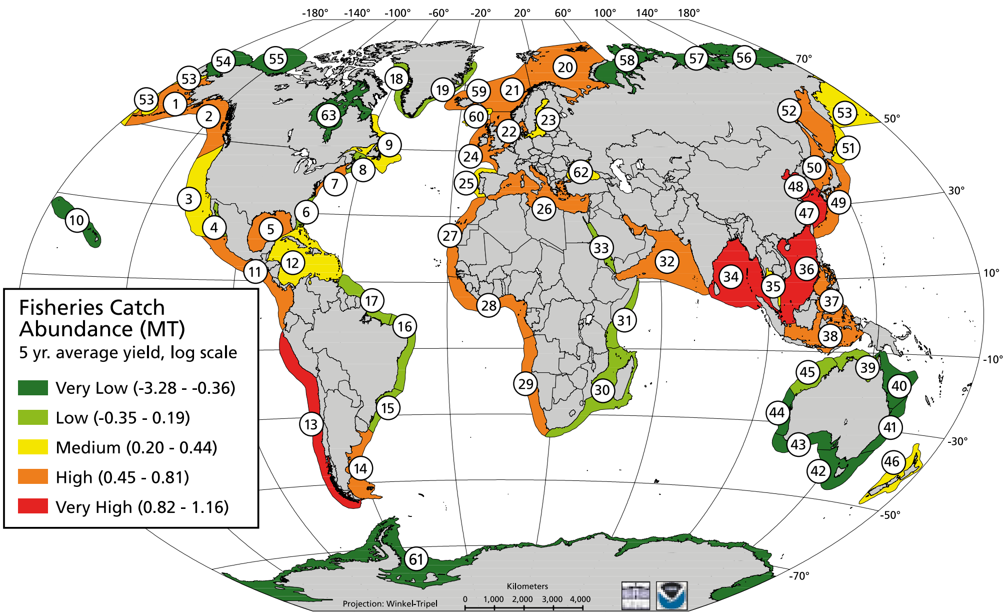
The Marine and Coastal Ecosystems and Human Well-being report (UNEP, 2006a) is a synthesis of the findings from the reports of the Millennium Ecosystem Assessment (MA) working groups (conditions and trends, scenarios, response and sub-global assessments) concerning marine and coastal ecosystems. The Millennium Ecosystem Assessment is an international initiative that began in 2001 under the auspices of the United Nations. The MA establishes a collaborative and scientific approach to assess ecosystems, the services they provide, and how changes in these services will impact upon human well-being. UNEP-WCMC and UNEP's Division of Early Warning and Assessment (DEWA) have coordinated the synthesis of this report in recognition that the loss of marine and coastal services has impacts on human well-being. The aim was to contribute to the dissemination of the information contained within the MA to decision-makers and a wide range of stakeholders of marine and coastal ecosystems through seven key messages. In addition it is envisaged the information contained within this synthesis report will contribute to larger international efforts such as the Global International Waters Assessment (GIWA), Global Biodiversity Outlook (GBO), the Global Marine Assessment (GMA), Global Environmental Outlook (GEO), the Regional Seas, and the Convention on Biological Diversity (CBD).

From an EAA viewpoint, this report is useful for examining issues relating to coastal and marine aquaculture. From a GIS viewpoint, it appears that there are no spatial data directly available; however, the Millennium Assessment itself may contain the data including the map of global coastal ecosystems.

Large marine ecosystems (LMEs)

Large marine ecosystems are regions of ocean space encompassing coastal areas from river basins and estuaries to the seaward boundaries of continental shelves and the outer margins of the major current systems. They are relatively large regions in the order of 200 000 km^2 or greater, characterized by distinct: bathymetry, hydrography, productivity, and trophically dependent populations (Sherman and Hempel, 2008). On a global scale, the 64 LMEs produce 95 percent of the world's annual marine fishery biomass yields. Within their waters, however, most of the global ocean pollution, overexploitation, and coastal habitat alteration occur. For 33 of the 63 LMEs, studies have been conducted of the principal driving forces affecting changes in biomass yields, these have been peer-reviewed and published in ten volumes (www.lme.noaa.gov). Based on lessons learned from these LME case studies, a five module strategy has been developed to provide science-based information for the monitoring, assessment, and management of LMEs. The modules are focused on LME: (1) productivity, (2) fish and fisheries, (3) pollution and health, (4) socioeconomics, and (5) governance (www.lme.noaa.gov).Of interest as background and for orientation are the poster maps (www.edc.uri.edu/lme/maps.htm). Additionally, there are downloadable GIS data that include LME boundaries (2003) as lines and polygons and related data such as countries and coastlines (www.edc.uri.edu/lme/gisdata.htm). Obviously, these ecosystem spatial definitions, their attribute data and their relation to various uses such as fisheries (Figure 3.4) are of prime interest for the development and management of mariculture in the EAA context.

FIGURE 3.4
Fisheries Catch Abundance in Large Marine Ecosystems: 2000-2004



1. East Bering Sea
2. Gulf of Alaska
3. California Current
4. Gulf of California
5. Gulf of Mexico
6. Southeast U.S. Continental Shelf
7. Northeast U.S. Continental Shelf
8. Scotian Shelf
9. Newfoundland-Labrador Shelf
10. Insular Pacific-Hawaiian
11. Pacific Central-American
12. Caribbean Sea
13. Humboldt Current
14. Patagonian Shelf
15. South Brazil Shelf
16. East Brazil Shelf
17. North Brazil Shelf
18. West Greenland Shelf
19. East Greenland Shelf
20. Barents Sea
21. Norwegian Sea
22. North Sea
23. Baltic Sea
24. Celtic-Biscay Shelf
25. Iberian Coastal
26. Mediterranean
27. Canary Current
28. Guinea Current
29. Benguela Current
30. Agulhas Current
31. Somali Coastal Current
32. Arabian Sea
33. Red Sea
34. Bay of Bengal
35. Gulf of Thailand
36. South China Sea
37. Sulu-Celebes Sea
38. Indonesian Sea
39. North Australia
40. Northeast Australia
41. East-Central Australia
42. Southeast Australia
43. Southwest Australia
44. West-Central Australia
45. Northwest Australia
46. New Zealand Shelf
47. East China Sea
48. Yellow Sea
49. Kuroshio Current
50. Sea of Japan/East Sea
51. Oyashio Current
52. Sea of Okhotsk
53. West Bering Sea
54. Chukchi Sea
55. Beaufort Sea
56. East Siberian Sea
57. Laptev Sea
58. Kara Sea
59. Iceland Shelf
60. Faroe Plateau
61. Antarctic
62. Black Sea
63. Hudson Bay

Source: Sherman and Hempel (2008).

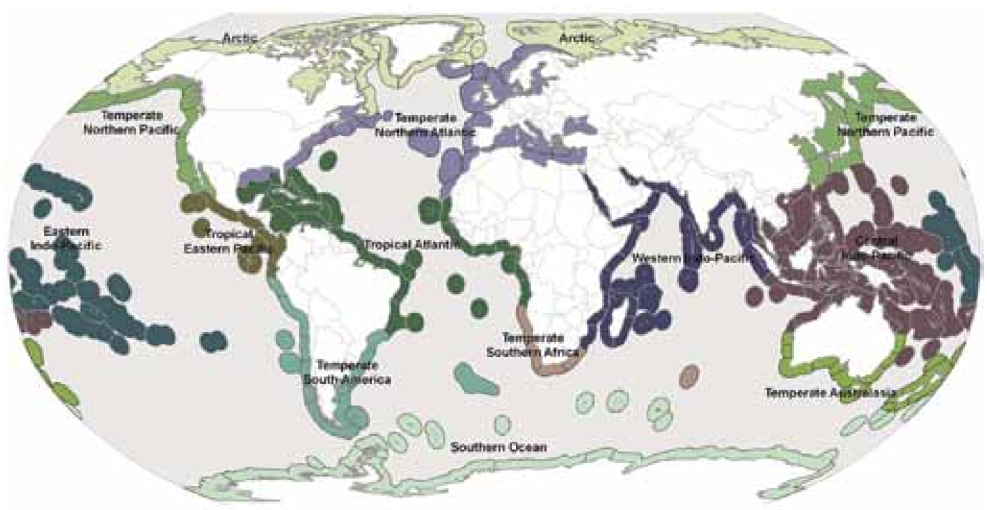
Marine Ecoregions of the World (MEOW)

The conservation and sustainable use of marine resources is a highlighted goal in a growing number of national and international policy agendas. Efforts to assess progress, as well as to strategically plan and prioritize new marine conservation measures, have been hampered by the lack of a detailed, comprehensive biogeographic system to classify the oceans. Spalding *et al.* (2007) describe a global system for coastal and shelf areas: the Marine Ecoregions of the World is a nested system of 12 realms, 62 provinces, and 232 ecoregions covering all coastal and shelf waters of the world shallower than 200 m. The map extends to 370 km (200 nm) offshore, or to the 200-m isobath where this lies further offshore (Figure 3.5).

Spalding *et al.* (op cit.) conclude that the MEOW classification provides a critical tool for marine conservation planning. It will enable gap analyses and assessments of representativeness in a global framework. It provides a level of detail that will support linkage to practical conservation interventions at the field level. Clearly, this classification will be useful to the EAA and particularly to GIS for Open Ocean

Aquaculture (OOA) because the MEOW corresponds closely to the EEZ areas of the world in which OOA will develop thus providing both an administrative and ecological context for that development. The MEOW shapefile is available at http://conserveonline.org/workspaces/ecoregional.shapefile.

FIGURE 3.5
Final biogeographic framework: Realms and provinces. Biogeographic realms with ecoregion boundaries outlined



Source: Spalding *et al*. (2007).

Eutrophication and hypoxia in coastal areas: A global assessment of the state of Knowledge

Eutrophication -the overenrichment of waters by nutrients- threatens and degrades many coastal ecosystems around the world. The two most acute symptoms of eutrophication are hypoxia (or oxygen depletion) and harmful algal blooms, which among other things can destroy aquatic life in affected areas.

Of the 415 areas around the world identified as experiencing some form of eutrophication by Selman *et al*. (2008), 169 are hypoxic and only 13 systems are classified as “systems in recovery.”

Mapping and research into the extent of eutrophication and its threats to human health and ecosystem services are improving, but there is still insufficient information in many regions of the world to establish the actual extent of eutrophication or identify the sources of nutrients.

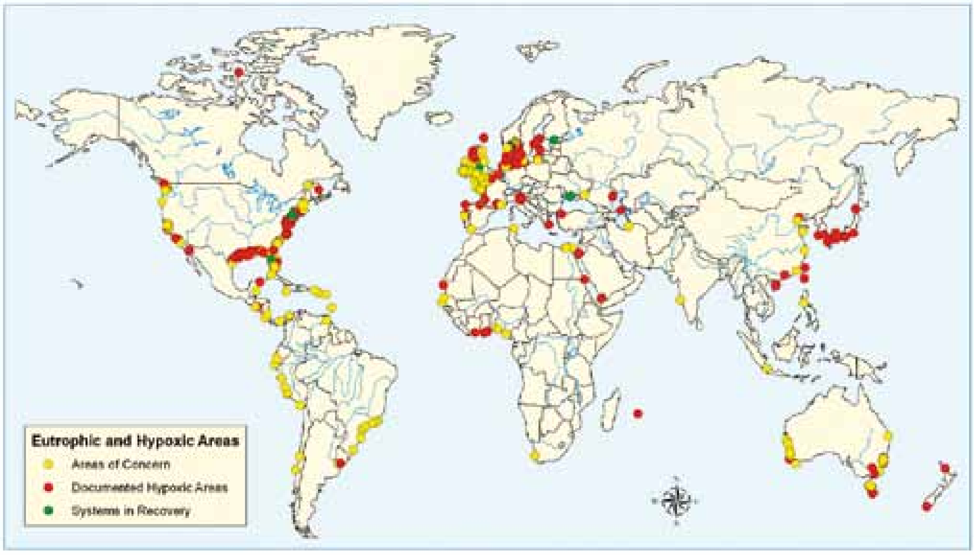
From the viewpoint of the EAA, euthrophication may be positive for certain aquaculture systems (e.g. nitrogen enrichment benefiting filter feeders through plankton production); however, it may also involve risks as from hypoxia.

From the viewpoint of GIS in support of the EAA, a map in the report locates documented areas of hypoxia, areas of concern, and locations in recovery (Figure 3.6); however, these are only indicative of the actual locations and area expanses affected. The spatial data and attributes may be obtained from the World Resources Institute on request.

In dead water – Merging of climate change with pollution, over-harvest, and infestations in the world’s fishing grounds.

This UNEP report, titled as above, deals with the multiple and combined impacts of pollution; alien infestations; over-exploitation and climate change on the seas and oceans (Nellemann, Hain, and Alder, 2008). The worst concentration of cumulative impacts of climate change with existing pressures of over-harvest, bottom trawling,

FIGURE 3.6
World hypoxic and eutrophic areas



Source: Selman *et al*. (2008).

invasive species, coastal development and pollution appear to be concentrated in 10–15 percent of the oceans concurrent with today's most important fishing grounds. The summary of the UNEP report synthesizes the issues and presents useful facts on the state of marine environments (www.grida.no/publications/rr/in-dead-water).

Global maps in the main report of particular interest include fish catch tonnes/km^2, tropical cyclone frequency, human development within 75 km of the coast, and marine invasive hotspots all of which have some relevance to the EAA. Presumably, the underlying spatial data could be obtained for spatial analyses in support of the EAA.

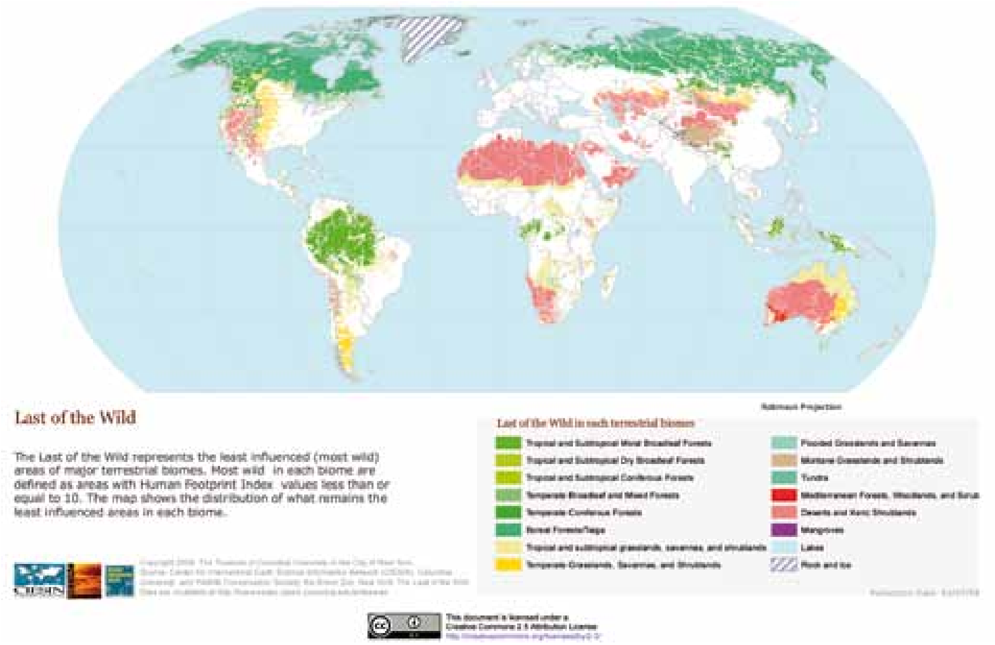
3.3 TERRESTRIAL ECOSYSTEMS

Last of the Wild, Version 2

Human influence is a global driver of ecological processes on the planet, on a par with climatic trends, geological forces, and astronomical variations. The Wildlife Conservation Society (WCS) and the Center for International Earth Science Information Network (CIESIN) at Columbia University have joined together to systematically map and measure the human influence on the Earth's land surface today. The Last of The Wild, Version Two (Figure 3.7) depicts human influence on terrestrial ecosystems using datasets compiled on or around 2000 (http://sedac.ciesin.columbia.edu/wildareas).

The Human Influence Index and Human Footprint are produced through an overlay of a number of global data layers that represent the location of various factors presumed to exert an influence on ecosystems: human population distribution, urban areas, roads, navigable rivers, and various agricultural land uses. The combined influence of these factors yields the Human Influence Index. The Human Influence Index (HII), in turn, is normalized by global biomes to create the Human Footprint (HF) dataset. HF values range from 1 to 100. The Last of the Wild data collection includes the Human Influence Index (HII) grids, Human Footprint grids, and The Last of the Wild vector data (http://sedac.ciesin.columbia.edu/wildareas/downloads.jsp#last). The datasets are available at global and continental scales. Global data are available in a geographic coordinate system at 30 arc-second grid cell size and Interrupted Goode Homolosine Projection (IGHP) at 1km grid cell size. Continental-level data is available only in geographic coordinate system (GCS). Data are also available in ASCII (.asc) and ArcInfo Grids. The Last of the Wild vector data are available only in shapefile format. Details of how to use each format are in the readme.doc document included when zipfiles are downloaded. These data are especially relevant for the EAA because they can be used to infer expectations of environmental impacts on aquaculture that are not tied to administrative boundaries. From a GIS viewpoint the datasets are particularly valuable because of their ready availability and high resolution.

FIGURE 3.7
Last of the wild, Version 2



Source: Center for International Earth Science Information Network (CIESIN), Columbia University and Wildlife Conservation Society, the Bronx Zoo, New York, 2008

Pilot Analysis of Global Ecosystems (PAGE) – Agroecosystems

This analysis determines the extent of agricultural land use and assesses the status of agroecosystems on a global basis (Wood, Sebastian and Scherr, 2001) (Figure 3.8).

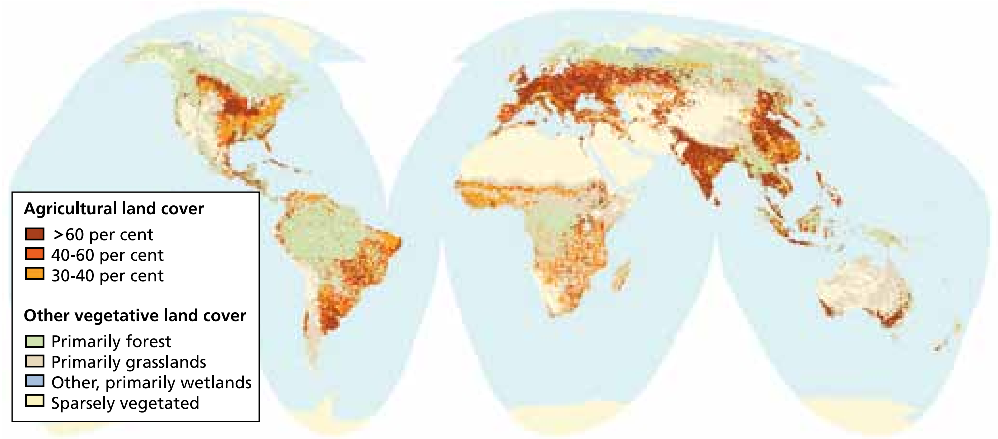
The report is the most comprehensive mapping of global agriculture to that date; however, with a publication in 2001, the material is now somewhat dated. The mapping is mainly global, but would be useful to place existing aquaculture and aquaculture potential in the context of agroecosystems. The study also shows ways to better understand and monitor changes in the capacity of the systems to provide sustainable goods and services.

From an EAA and GIS perspective, the Global Agroecosystems dataset has a resolution of about 9.2 km at the equator that is relatively coarse resolution.These data characterize agroecosystems in 17 classes, defined as “a biological and natural resource system managed by humans for the primary purpose of producing food as well as other socially valuable nonfood products and environmental services” (Wood, Sebastian and Scherr, op cit.).

WWF terrestrial ecoregions of the world

Terrestrial ecoregions of the world (www.worldwildlife.org/science/ecoregions/item1267.html), described by Olson *et al.* (2001) is an earlier spatial counterpart to the Freshwater Ecoregions of the World. The ecoregions approach is useful because ecoregions are likely to reflect the distribution of species and communities more

FIGURE 3.8
Global extent of agriculture



Note: Other vegetative land cover might contain as much as 30 percent agricultural land, but the actual amount cannot be determined using the GLCCD dataset. The satellite-derived estimate of agricultural extent is likely to under-represent some types of agricultutal land cover including:extensive dryland arable farming, pastures, irrigatec areas, and permanent crops - particularly in forest margins. Since the satellite interpretation was performed on a regional basis, the nature and extent of this under-reporting varies among regions.

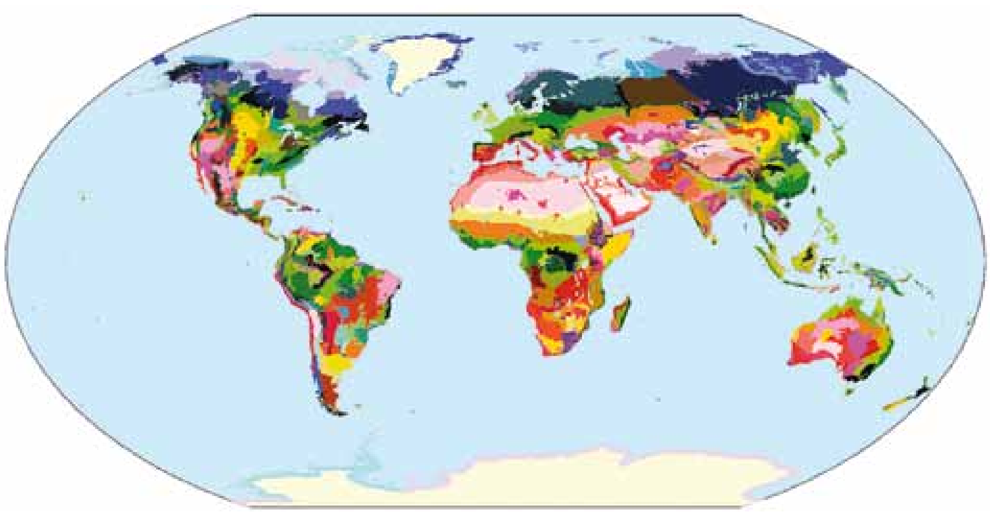
Source: IFPRI reinterpretation of GLCCD, 1996; USGS EDC, 1999a.

accurately than do units based on global and regional models derived from gross biophysical features, such as rainfall, temperature, or vegetation structure.

The terrestrial world is sub-divided into 14 biomes and eight biogeographic realms. Nested within these are 867 ecoregions (Figure 3.9).

The ecoregions map has been used as a biogeographic framework to highlight those areas of the world that are most distinctive or have high representation value and are therefore worthy of greater attention. Ecoregions were ranked by the distinctiveness of their biodiversity features, i.e. species endemism, the rarity of higher taxa, species richness, unusual ecological or evolutionary phenomena and global rarity of their habitat type. This ranking is important for spatial planning in support of the EAA in order to identify high value ecosystems. A spatial database is downloadable (www.worldwildlife.org/science/data/item6373.html).

FIGURE 3.9
Terrestrial ecoregions of the world



Source: Olson *et al*. (2001).

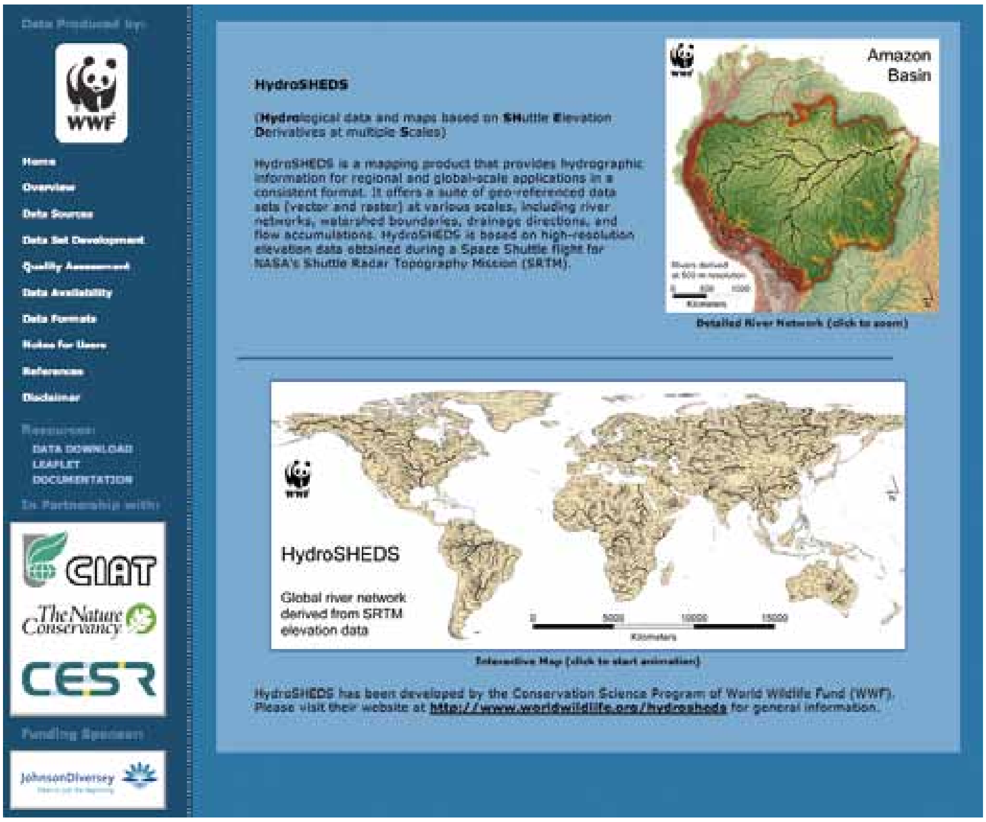
HydroSHEDS

Hydrological data and maps based on shuttle elevation derivatives at multiple scales (HydroSHEDS) are an innovative product that provide hydrographic information in a consistent and comprehensive format for regional and global-scale applications. They were developed by WWF's Conservation Science Program and collaborators. HydroSHEDS offers a suite of geo-referenced data sets, including stream networks, watershed boundaries, drainage directions, and ancillary data layers such as flow accumulations, distances, and river topology information. The goal of developing HydroSHEDS was to generate key data layers to support regional and global watershed analyses, hydrological modeling, and freshwater conservation planning at a quality, resolution and extent that had previously been unachievable. Available resolutions range from 3 arc-second (approx. 90 meters at the equator) to 5 minute (approx. 10 km at the equator) with seamless near-global extent.

From the most basic level, HydroSHEDS will support the EAA by allowing creation of digital river and watershed maps.

These maps can then be coupled with a variety of other geo-spatial datasets or applied in computer simulations, such as hydrologic models, in order to estimate flow regimes important for aquaculture and to assess dangers to aquaculture from flows of poor quality water, or from flows that are inadequate or excessive. From a GIS viewpoint, a variety of data can be interactively selected and downloaded for any area of interest as shown in the global map below (Figure 3.10) (http://hydrosheds.cr.usgs.gov).

FIGURE 3.10
Hydrological data and maps based on shuttle elevation derivatives at multiple scales (HydroSHEDS)



Source: Lehner, Verdin and Jarvis (2008).

3.4 SUMMARY AND CONCLUSIONS

The first objective of this chapter was to provide mainly at global levels, an overview from a spatial viewpoint of various assessments and issues concerning the state of marine, coastal and terrestrial ecosystems. The second objective was to indicate how the ecosystems data are relevant to the EAA and in particular to spatial analyses in support of the EAA. One measure of relevance is provided by taking the global viewpoint: Each country can view its own issues in terms of those common to other countries and regions. Hopefully, this viewpoint would engender activities aimed at resolving shared problems among countries within regions. Compilations and definitions of ecoregions and ecosystems relevant to the EAA and to spatial planning tools for the EAA have been organized according to their coverage, i.e. ecosystems including both land and water, aquatic ecosystems and terrestrial ecosystems.

All of studies identified can be useful to the EAA in a qualitative way by raising the awareness of aquaculture planners and practitioners to issues and considerations that must be taken into account for the further development of aquaculture and for the mitigation of the potential impacts of aquaculture on the environment. An important additional benefit is that many of these are spatially explicit at global, regional and country levels. A few studies incorporate indices that are useful in assessing environmental impacts on aquaculture at the country level. Finally, many studies (or projects) offer readily available spatial and attribute data (or the possibility to acquire the data on request) of potential use to GIS, remote sensing and mapping in support of the EAA. The global datasets are a temporary substitute for country-level spatial data until higher resolution datasets can be developed. The usefulness of some of these datasets for spatial planning for the EAA has been demonstrated by their use in other chapters in this review and elsewhere. As shown by the many approaches to defining ecoregions and ecosystems, the criteria are many and the methods and data are oftentimes complex. Thus, although these data are "ready made", a considerable expenditure of time to study and evaluate the approaches used and the actual relevance with regard to resolution and quality of the data will be required in order to use them effectively and responsibly for the EAA, or for GIS in support of the EAA.

4. Spatial data to support the ecosystem approach to aquaculture

Spatial data are indispensable for GIS to support the implementation of the EAA. Data needs, in turn, can be viewed in relation to the major uses for which the data are to be used within ecosystems. The major uses directly bearing on ecosystems are to:

- Estimate the potential impact of aquaculture on the environment including the natural, economic and social realms of ecosystems.
- Estimate the impact of natural and man-induced changes in the environment and ecosystems and their associated economic and social consequences for aquaculture.

These do not preclude other more specialized uses of spatial data for aquaculture that are implicit in the EAA. For example,

- Objectively identify optimal locations and use of natural resources.
- Identify and resolve conflicting uses of space and natural resources.
- Quantify production levels and match these to markets, infrastructure and socio-economic divers.

Implementing these tasks at the relevant scales, in turn, depends on the availability of several kinds of spatial and attribute data:

1. Ecosystems already defined and mapped.
2. Ecosystem parameters already defined, but not yet spatially integrated and mapped
3. Data to define aquaculture potential (e.g. environment, culture systems and (bioeconomic models).
4. Locations and characteristics of aquaculture (inventory, and for verification of estimates of potential).
5. Real-time data to support decisions on day to day aquaculture operations

Regarding the first of these data needs, ecosystems pre-defined globally, regionally and nationally, allows aquaculture to be placed in its proper ecological context, depending on the scale by which various kinds of aquaculture are located. Spatially defined ecosystems at the global scale most relevant to the EAA and GIS in support of the EAA have been described in Chapter 3. Regarding the remainder of the data needs, there will be many instances, especially at sub-national levels, where spatially defined data needed for ecosystems level work are of too coarse a resolution, or none will be available. In these instances additional spatial data will be needed to enhance already existing ecosystem data to meet the needs of aquaculture development and management.

The purpose of this chapter is to provide an overview of sources that can satisfy data needs mainly at global and national levels. The sources are the focus and the kinds of data are only generally indicated. This is because one source can contain data that could contribute to the various kinds of data needs enumerated above. Unfortunately, with the exception of GISFish, there is no comprehensive catalogue of spatial data targeted specifically to aquaculture at a global level; however, there are many Web sites that are of use directly or that offer links to useful data of various types. Of course, our sources are not exhaustive. New sources are rapidly becoming available as, among others, satellite resolution increases and coverage expands in time and space and as the practical applications of spatial analyses become more common.

Sources to satisfy GIS for EAA data needs can be loosely categorized in the following ways:

- earth browsers (e.g. Google Earth, World Wind, Microsoft Virtual Earth) with georeferenced satellite image backdrops as well as various kinds of infrastructure layers that are the digital substitute for printed maps;
- portals as data catalogues (e.g. GISFish, FAO GeoNetwork; Ocean Portal);
- general data sources (e.g. Global Lakes and Wetlands Database; Africa Water Resources Database) to define ecosystems; and
- specialized data sources (e.g. Natural Disaster Hotspots and Risks; IPCC Data Distribution Centre; World Database on Protected Areas).

The sources are summarized in Table 4.1 and each covered in the following sections.

TABLE 4.1
Summary of Internet sites to acquire global spatial data to define ecosystems and their attributes

Internet site	*Technical description and scale	Uniform Resource Locator (URL)
Earth browsers		
Internet site	Technical description and scale	Uniform Resource Locator (URL)
Google Earth	Most land areas are covered in satellite imagery with a resolution of about 15 m per pixel. However, Google is actively replacing this base imagery with 2.5m SPOT Image imagery and several higher resolution datasets	http://earth.google.com
World Wind	World Wind allows any user to zoom from satellite altitude into any place on Earth, leveraging high resolution LandSat imagery and SRTM elevation data to experience Earth in visually rich 3D. Baseline resolutions: 500 m (Blue Marble Next Generation); 15 m (Landsat imagery; except for polar areas).	http://worldwind.arc.nasa.gov/download.html
Bing Maps (Microsoft Virtual Earth)	Bing Maps Platform (previously Microsoft Virtual Earth) is a geospatial mapping platform produced by Microsoft. It allows developers to create applications that layer location-relevant data on top of the Bing Maps map imagery. This includes imagery taken from satellite sensors, aerial cameras as well as Streetside imagery, 3D city models and terrain.	www.microsoft.com/maps
Portals		
GISFish	Wide range of data sources at different scales and resolutions	www.fao.org/fishery/gisfish/id/1134
Ocean Portal	Intended to assist users in locating web based data and information sources as well as to promote exchange of information and experience between users	www.iode.org/index.php
Conservation GeoPortal	It does not actually store maps and data, but rather the descriptions and links to those data resources	www.conservationmaps.org/Portal/ptk
Global Change Master Directory	Directory holds more than 22,000 data set descriptions	http://gcmd.nasa.gov/Aboutus/index.html
UN Atlas of the Oceans	Entry point to maps, statistics and online databases	www.oceansatlas.org
TerraLook	Images include recent high-resolution ASTER images, and Landsat images from three historical periods going back to the early '70s	http://terralook.cr.usgs.gov
General data sources useful to define ecosystems		
Global Administrative Unit Layers (GAUL)	Provides reliable spatial information on administrative units for all countries in the world providing a contribution to the standardization of the spatial dataset representing administrative units. - Vector format	www.foodsecinfoaction.org/News/news_06_06.htm www.fao.org/geonetwork/srv/en/metadata.show?id=12691&currTab=simple
FAO GeoNetwork: GIS Gateway – Thematic Spatial Databases and Information Systems	Wide range of data sources at different scales and resolutions. Spatial from FAO, other UN Agencies, NGO's and other institutions	www.fao.org/geonetwork/srv/en/main.home

* Note: See Glossary in Chapter 11.

TABLE 4.1 Cont.
Summary of Internet sites to acquire global spatial data to define ecosystems and their attributes

Internet site	Technical description and scale	Uniform Resource Locator (URL)
Global Lakes and Wetlands Database	Global scale (1:1 to 1:3 million resolution)	www.worldwildlife.org/science/data/GLWD_Data_Documentation.pdf www.worldwildlife.org/science/data/item1877.html
Watersheds of the World: A Special Collection of River Basin Data	Provides maps of land cover, population density and biodiversity for 154 basins and sub-basins around the world. It further contains 20 global maps portraying relevant water resources issues. As such, it is a crucial reference for anyone working on water management worldwide	http://earthtrends.wri.org/maps_spatial/watersheds/global.php http://multimedia.wri.org/watersheds_2003/index.html
African Water Resources Database	28 thematic data layers drawn from over 25 data sources, resulting in 156 unique datasets. Vector: 1:65 000 to 1:5 000 000 for a range of point, line and polygon features; Grid data 1 to 5 kilometres, with some 15 to 30 meter localized or 500 meter continental imagery.	www.fao.org/docrep/010/a1170e/a1170e00.htm
The Harmonized World Soil Database	30 arc-second raster database with over 15 000 different soil mapping units that combines existing regional and national updates of soil information worldwide	www.fao.org/nr/water/news/soil-db.html
Specialized data sources		
Ecosystems Based Management Tools Network – Data Clearinghouse	EBM tools include data collection and management tools; data processing tools; conceptual modeling tools; modelling and analysis tools; scenario visualization tools; decision support tools; project management tools; stakeholder communication and engagement tools; and monitoring and assessment tools.	www.ebmtools.org/data.html
World Database on Protected Areas	Most comprehensive global spatial dataset on marine and terrestrial protected areas available.	www.wdpa.org www.wdpa.org/AnnualRelease.aspx
Gridded Population of the World, Version 3	Consists of estimates of human population for the years 1990, 1995, and 2000 by grid cells that are approximately 5 km at the equator.	http://sedac.ciesin.columbia.edu/gpw/global.jsp
LandScan World Population Grids	Worldwide population database compiled on approximately 1 km^2 latitude/longitude grid	www.ornl.gov/sci/landscan/landscanCommon/landscan_data-avail.html
Natural Disaster Hot Spots – Global Risk Analysis	The data zip archive includes an ASCII text file of the raster data set (*.asc), detailed metadata (*.htm), and projection information (*.prj).	www.ldeo.columbia.edu/chrr/research/hotspots/coredata.html

TABLE 4.1 Cont.

Summary of Internet sites to acquire global spatial data to define ecosystems and their attributes

Internet site	Technical description and scale	Uniform Resource Locator (URL)
Data Distribution Centre (DDC) of the Intergovernmental Panel on Climate Change (IPCC)	The DDC provides climate, socio-economic and environmental data, both from the past and also in scenarios projected into the future.	www.ipcc-data.org
	GIS Climate Change Scenarios. Currently the datasets can be downloaded in a GIS shapefile format	www.gisclimatechange.org/faqPage.do
Worldclim	WorldClim is a set of global climate layers (climate grids) with a spatial resolution of one square kilometre.	http://www.worldclim.org
	IPPC 3rd Assessment data and future climate projections.	www.worldclim.org/futdown.htm
Climpag	Climpag contains methodologies, tools for a better understanding and analysis of the effect of the variability of weather and climate on agriculture as well as data and maps. The Global climate grids are provided as comma separated value (csv) in .5°x.5° resolution.	www.fao.org/nr/climpag
Shellfish Reefs at Risk	Global assessment of the distribution and condition of bivalve shellfish reefs that occur in temperate and subtropical estuaries. Presumably, the underlying spatial data could be obtained on request from the Nature Conservancy.	http://conserveonline.org/library/shellfish-reefs-at-risk-report/@@view.html

4.1 EARTH BROWSERS

Data accessed via stand-alone web browsers can be useful for mapping aquaculture (e.g. for use in FAOs National Aquaculture Sector Overview (NASO) inventory of aquaculture (www.fao.org/fishery/naso/search/en) and as a source of many important layers in an aquaculture management information system such as waterbodies, roads, and population centers, when imported into a GIS (Figure 4.1). Among the most useful of the earth browsers are Google Earth (http://earth.google.com), MSN Virtual Earth (http://virtualearth.msn.com) and World Wind (http://nasa-world-wind.en.softonic.com).

FIGURE 4.1
A variety of aquaculture installations near Calbuco, Chile from Google Earth

Source: Google Earth (March 2010).

An advantage of some earth browsers is the ability to link directly to images from inside GIS software (e.g. Manifold GIS and Microsoft Virtual Earth) and to capture images as Keyhole Markup Language (KML) files for import to GIS (e.g. Google Earth). Limitations of the earth browsers include imagery or other layers that may be out of date or of unknown date, resolution too coarse to be of use for some kinds of aquaculture applications such as inventories or lack of complete coverage in cloud-prone areas of the world. Nevertheless, they should be the first stop in a spatial data search where base maps and specialized layers are lacking.

4.2 PORTALS

Portals are access points, usually to the Internet, that consolidate links to various kinds of specialized information and data.

GISFish

GISFish is a "one stop" site from which to obtain the global experience on GIS, remote sensing and mapping as applied to fisheries and aquaculture (www.fao.org/fishery/gisfish). In October 2009 it was expanded to include marine fisheries. An important observation here is that GISFish itself provides a direct entry route into GIS, remote sensing and mapping for the EAA because of its dual emphasis on aquaculture and spatial analyses. GISFish sets out the issues in fisheries and aquaculture, and demonstrates the benefits of using GIS, remote sensing and mapping to resolve them. The global experience provided by GISFish of most relevance to the EAA is captured in Issues, Publications, and, Data and Tools. Within GISFish there is a category called "Data Sources" that provides links to more than 40 sources of special interest to aquaculture. An analysis of the relevance of the material in GISFish to the EAA is in Chapter 6.

Ocean Portal
Ocean Portal is a high-level directory dealing very broadly with Ocean Data and Information related Web sites including data center data catalogs and broad categories of ocean data as starting points. (www.iode.org/index.php?Itemid=65&id=24&option=com_content&task=view). Its objective is to help scientists and other ocean experts in locating such data and information. In this regard, it is a portal from which to begin widely searching. For example, a search on the keyword "GIS" within the Ocean Portal revealed 209 links in the Data Resources category.

Conservation GeoPortal
The Conservation GeoPortal is a collaborative effort by and for the conservation community to facilitate the discovery and publishing of GIS data and maps, to support conservation decision-making and education (www.conservationmaps.org/Portal/ptk).It is primarily a data catalog, intended to provide a comprehensive listing of GIS datasets and map services relevant to biodiversity conservation. The Conservation GeoPortal does not actually store maps and data, but rather the descriptions and links to those resources. From an EAA and GIS perspective, this appears to be a new initiative with few actual links so far available.

Global Change Master Directory (GCMD)
The GCMD goal is to enable users to locate and obtain access to Earth science datasets and services relevant to global change and Earth science research. The GCMD database holds more than 25 000 descriptions of Earth science datasets and services covering all aspects of Earth and environmental sciences (http://gcmd.nasa.gov/Aboutus/index.html). From the EAA perspective, the GCMD is a portal through which to search for relevant studies and GIS data. The most promising categories include Earth Surface, Oceans, Climate Indicators and Human Dimensions.

UN Atlas of the Oceans
The UN Atlas of the Oceans is an Internet portal providing information relevant to the sustainable development of the oceans (www.oceansatlas.org/index.jsp). It is designed for policy-makers who need to become familiar with ocean issues and for scientists, students and resource managers who need access to databases and approaches to sustainability. The UN Atlas can also provide the ocean industry and stakeholders with pertinent information on a range of ocean matters.

TerraLook
TerraLook is an example of a portal dedicated to satellite remotely sensed imagery (available at http://asterweb.jpl.nasa.gov/TerraLook.asp). It includes a free tool and satellite data provided by NASA and the US Geological Survey. TerraLook provides time series of geo-referenced jpeg images plus image processing/GIS software. It is intended to provide easy access to satellite images for users with little or no prior experience, though it also proves useful for experienced users who want a quick image. The data includes global coverage layers of "best available" Landsat images from about 1975, 1990, 2000 (and, soon for 2005). ASTER data are also available, and access is provided to the entire ASTER archive of about 2 million images going back to 2000. While full

ASTER datasets cost about US$ 100 per scene, these jpeg images are completely free. The open source tool supports basic image processing and GIS functions.

There are several advantages of TerraLook with respect to spatial analyses. One is the global coverage both spatially and temporally, thus allowing for change analysis. Another is that the data are already georeferenced and freely downloadable, but also can be manipulated by the associated tools. Finally, where other spatial data are scarce, TerraLook data could be used to make base maps.

4.3 GENERAL DATA SOURCES

General data sources have been created by various organizations for a broad variety of users, but the data may be used directly or modified for EAA spatial analyses, for example, to define ecosystems.

Global Administrative Unit Layers (GAUL)

Indispensable to any spatial effort in support of the EAA are geodata on administrative boundaries at all levels. Among the general uses are defining responsibilities for regulation of aquaculture. From a GIS viewpoint administrative boundaries provide a geographic basis for analysis of social and economic data in relation to ecosystem boundaries.

The Global Administrative Unit Layers (GAUL) is an initiative implemented by FAO within the EC-FAO Food Security Programme funded by the European Commission. The GAUL aims at compiling and disseminating the most reliable spatial information on administrative units for all the countries in the world, providing a contribution to the standardization of the spatial dataset representing administrative units. The GAUL always maintains global layers with a unified coding system at country, first (e.g. regions) and second administrative levels (e.g. districts). In addition, when the data is available, it provides layers on a country by country basis down to third, fourth and lower administrative levels.

Technical aspects of the GAUL are described by the EC-FAO Food Security Programme (FAO, 2008). The GAUL is updated annually and the most recent data (2009) are available via the FAO GeoNetwork (below) at www.fao.org/geonetwork/srv/en/metadata.show?id=12691&currTab=simple.

The GAUL dataset is for the benefit of the United Nations and other authorized international and national institutions/agencies.

FAO GeoNetwork

The GeoNetwork's purpose is:

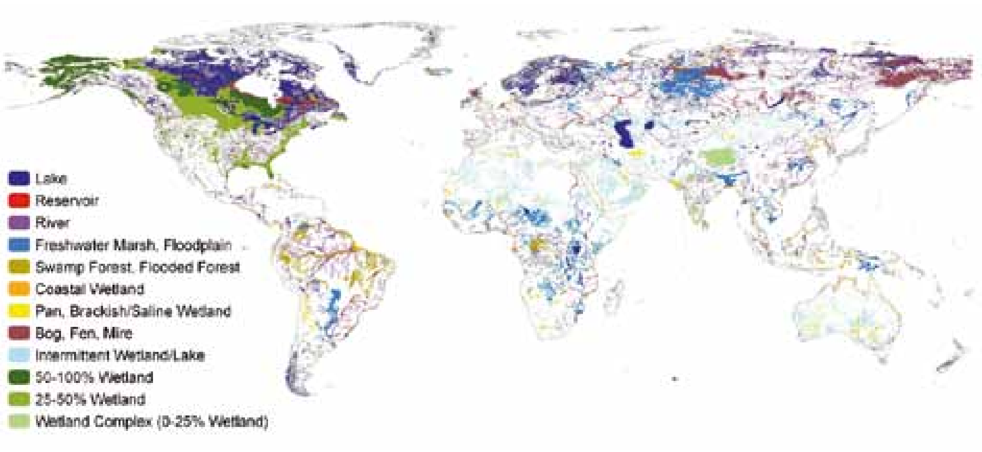
- to improve access to and integrated use of spatial data and information
- to support decision making
- to promote multidisciplinary approaches to sustainable development
- to enhance understanding of the benefits of geographic information

Of special interest are the “Data Collection”section where a number of core products of relevance to the EAA are available for download such as international boundaries, hydrosheds, global population density, and exclusive economic zones; and the “GIS Gateway”to access Thematic Spatial Databases and Information Systems” from different Departments at FAO (www.fao.org/geonetwork/srv/en/main.home).

Global Lakes and Wetlands Database (GLWD)

According to Lehner and Doll (2004), the GLWD lakes and reservoirs database covers a total of approximately 2.7 million km^2 or 2.0 percent of the global land surface area (except Antarctica and glaciated Greenland), while wetlands are estimated to reach about 8-10 million km^2, or 6.2–7.6 percent of the Earths surface (Figure 4.2). An extrapolation of GLWD data suggests that the total number of global lakes may reach or exceed 1.5 million for lakes ≥ 10 ha, and 15 million for lakes ≥ 1 ha. With these numbers, lakes may cover about 3.2 million km^2, or 2.4 percent of the total global terrestrial surface.

FIGURE 4.2
Global lakes and wetlands



Source: Lehner and Doll (2004).

The GLWD has been created drawing upon a variety of existing maps, data and information. The combination of best available sources for lakes and wetlands on a global scale (1:1 to 1:3 million resolution), and the application of GIS functionality enabled the generation of a database which focuses in three coordinated levels on (1) large lakes and reservoirs, (2) smaller waterbodies, and (3) wetlands.

Level 1 (GLWD-1) comprises the shoreline polygons of the 3 067 largest lakes (area ≥ 50 km^2) and 654 largest reservoirs (storage capacity ≥ 0.5 km^3) worldwide, and includes extensive attribute data.

Level 2 (GLWD-2) comprises the shoreline polygons of permanent open waterbodies with a surface area ≥ 0.1 km^2 excluding the waterbodies contained in GLWD-1.

The approx. 250 000 polygons of GLWD-2 are attributed as lakes, reservoirs and rivers. Level 3 (GLWD-3) comprises lakes, reservoirs, rivers and different wetland types in the form of a global raster map at about 1 km resolution at the equator. GLWD-2 and GLWD-3 do not provide detailed descriptive attributes such as names or volumes.

The importance of the GLWD to the EAA is obvious: The waterbodies it contains represent the areas where aquaculture is already developed, or in which aquaculture has varying potential for development in inland waterbodies having surface areas greater than 100 ha. In other words, the GLWD provides a spatial framework in which to base a global inventory of aquaculture and on which to base comparative estimates of aquaculture potential at a global scale.

For GIS in support of the EAA, the GLWD is available for download as three separate ArcView layers (two polygon shapefiles and one grid; www.worldwildlife.org/science/data/item1877.html).

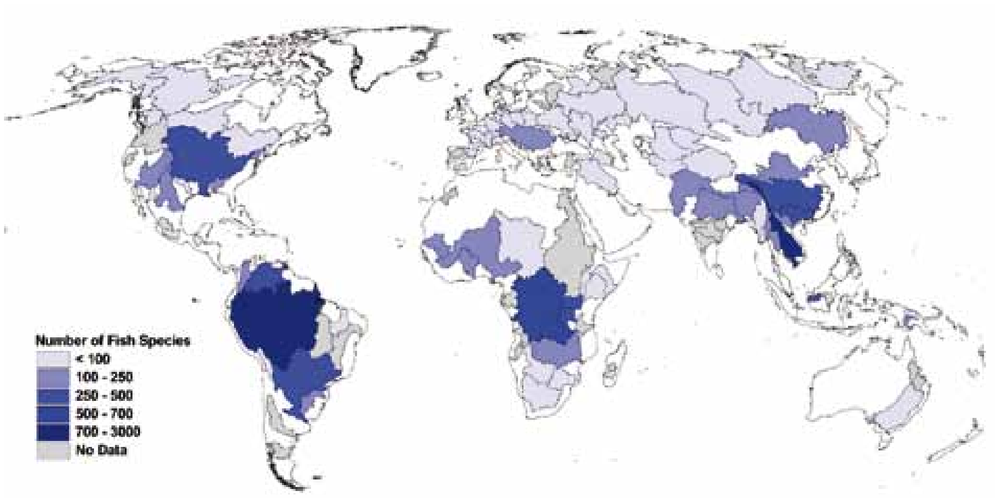
An example of the application of the GLWD data to a practical problem is provided in Chapter 5. Here freshwater surface area estimates by country are used to estimate the intensity of use of freshwaters for aquaculture.

Watersheds of the world: A special collection of river basin data

Watersheds of the World provides maps of land cover, population density and biodiversity for 154 river basins and sub-basins around the world (http://earthtrends.

wri.org/maps_spatial/watersheds/global.php). It lists indicators and variables for each of these basins and, where appropriate, provides links and references to relevant information. It further contains 20 global maps portraying relevant water resources issues or related resources (e.g. freshwater fishes, Figure 4.3). As such, it is a valuable reference for water management worldwide.

FIGURE 4.3
Freshwater fish species richness by basin



Source: World Resources Institute, 2003.

List of twenty downloadable global maps relating to Watersheds of the World
Primary Watersheds Map
Freshwater Fish Species Richness by Basin
Endemic Freshwater Fish Species by Basin
Endemic Bird Areas by Basin
Wetland Area by Basin
Cropland Area by Basin
Grassland, Savanna and Shrubland Area by Basin
Forest Cover by Basin
Remaining Original Forest Cover by Basin
Dryland Area by Basin
Urban and Industrial Area by Basin
Protected Area by Basin
Average Population Density by Basin
Degree of River Fragmentation and Flow Regulation by Basin
Annual Renewable Water Supply per Person by Basin for 1995 and Projections for 2025
Environmental Water Scarcity Index by Basin
Large Dams under Construction by Basin
Ramsar Sites by Basin
Virtual Water Flows
Selected Basins with IUCN and IWMI Projects

This map collection is designed to provide easy access to essential data and information at the basin level to support and promote the integrated management of water resources, and to increase the participation of stakeholders in the decision-making processes. Its ultimate goal is to promote resource management that allows for socially equitable economic development, and the sustainability of healthy ecosystems and their dependent species. Clearly, the objectives of this data collection parallel those of the EAA and many of the maps could be considered as constraints or as factors aiding the development and management of aquaculture. Additionally, many of the maps are indicative of the environmental issues pertaining at basin level.Technical notes and sources on the maps are available for download (http://earthtrends.wri.org/maps_spatial/watersheds/notes.php) as are the maps themselves (www.iucn.org/about/work/programmes/water/wp_resources/wp_resources_eatlas/wp_resources_eatlas_download.cfm), but no download site for GIS data is provided. The GIS data can be obtained as a CD-ROM with a request made to the same Uniform Resource Locator (URL).

FAO African Water Resource Database (AWRD)

The African Water Resource Database (AWRD) data archive possibly represents the most comprehensive archive of water management and base resource mapping data ever compiled for Africa and that is available in the public domain (Jenness *et al.*, 2007a;b). The AWRD is a set of data and custom-designed tools, combined in a GIS analytical framework, aimed at facilitating responsible inland aquatic resource management with a specific focus on inland fisheries and aquaculture.The AWRD data archive includes an extensive collection of datasets covering the African continent including 28 thematic data layers drawn from over 25 data sources, resulting in 156 unique datasets. The core data layers include: various depictions of surface waterbodies; multiple watershed models; aquatic species; rivers; political boundaries; population density; soils; satellite imagery; and many other physiographic and climatological data types. The AWRD archival data have been specifically formatted to allow their direct utilization within any GIS software package conforming to Open-GIS standards.

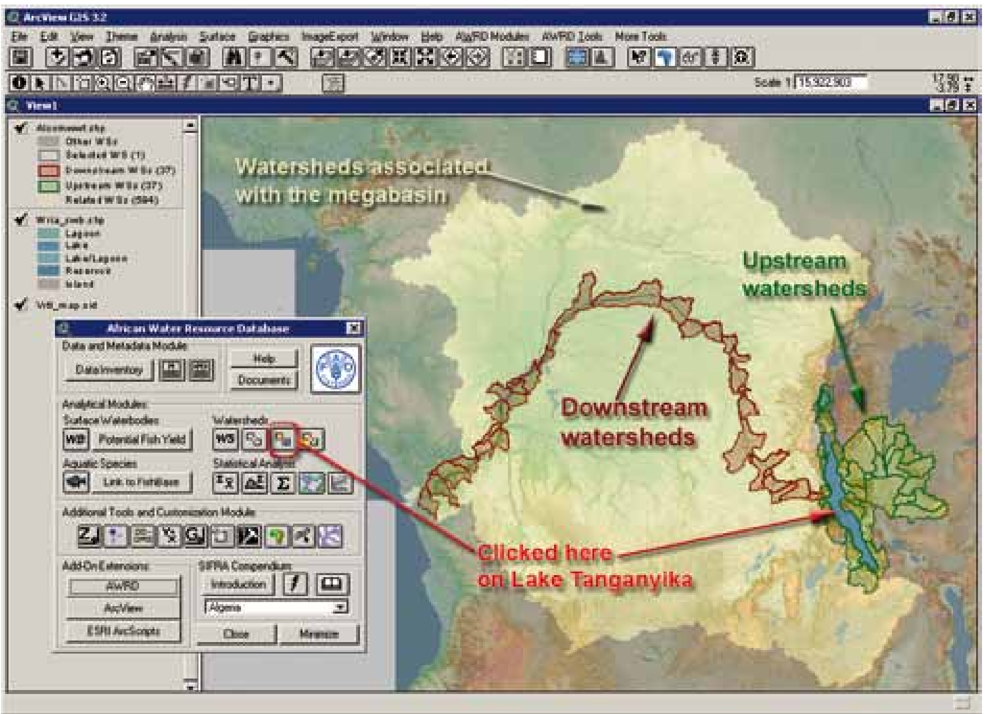
To display and analyse the AWRD archive, the AWRD also contains a large assortment of new custom applications and tools programmed to run under version 3 of the ArcView GIS software (ArcView 3.x). There are six analytical modules within the AWRD interface: 1) the Data and Metadata Module; 2) the Surface Waterbodies Module; 3) the Watershed Module; 4); the Aquatic Species Module; 5) the Statistical Analysis Module; and lastly, 6) the Additional Tools and Customization Module. Many of these tools come with simple and advanced options and allow the user to perform analyses on their own data.

The case studies presented in the AWRD publications (Jenness *et al.*, 2007a;b) illustrate how the AWRD archive and tools can be used to address key inland aquatic resource management issues such as the status of fishery resources and transboundary movements of aquatic species.

The Watersheds Module and related analytical tools represent perhaps the most comprehensive and intensive programming effort undertaken within the AWRD interface. This module offers a wide variety of tools specifically designed to analyse and visualize watersheds. The identification of "upstream watersheds" using the AWRD Watershed Module enables the spatial delineation of factors that directly or indirectly affect fishery potential. This tool can be of great value for assessing pollution from runoff of "upstream" watersheds into aquaculture ponds or residuals from aquaculture ponds into "downstream" watersheds. Analysis of invasive and introduced aquatic species is another area where this tool has great value because such introductions can have impacts both upstream and downstream within a hydrological system. Figure 4.4 shows upstream and downstream watersheds for Lake Tanganyika.

From an EAA perspective, the AWRD is a ready-made data package and analytical tool kit to define ecosystems and resolve issues in the context of freshwater aquaculture. Additionally, it is an already constituted tool for building spatial analytical capacities in support of the EAA.

FIGURE 4.4
Visualization of the flow regime associated with Lake Tanganyika



Source: Jenness *et al*. (2007a;b).

The Harmonized World Soil Database

The Harmonized World Soil Database (version 1.1, 2009) is a 30 arc-second raster database with over 15 000 different soil mapping units that combines existing regional and national updates of soil information worldwide (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009).The resulting raster database consists of 21 600 rows and 43 200 columns, which are linked to harmonized soil property data. The use of a standardized structure allows for the linkage of the attribute data with the raster map to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry).

4.4 SPECIALIZED DATA SOURCES

Specialized data sources are those that can be used to create GIS layers within spatially defined ecosystems. One example of specialized data sources pertaining to GIS, remote sensing and mapping for marine aquaculture development and management at Economic Exclusive Zone (EEZ) scales are those listed by Kapetsky and Aguilar (2007). However, the data covered in this section are mainly available globally.

Ecosystems Based Management Tools Network – Data Clearinghouse

A portal with mainly data of interest to the United States of America and Canada (www.ebmtools.org/data.html). The tools, all of which are applicable to some extent globally, are covered in some detail in Chapter 7.

World Database on Protected Areas

The World Database on Protected Areas (WDPA) is compiled from multiple sources and is the most comprehensive global dataset on marine and terrestrial protected areas available (www.wdpa.org) It is a joint venture of UNEP and IUCN, produced by UNEP-WCMC and the IUCN World Commission on Protected Areas (IUCN-WCPA) in association with governments and collaborating NGOs.The WDPA stores key information about protected areas such as name, designation or convention, total area (including marine area), date of establishment, legal status and IUCN Protected Areas Management Category. It also stores the spatial boundary and/or location (where available) for each protected area in a GIS. The online WDPA allows users to search by protected area name, country, and international programme or convention (Figure 4.5).

FIGURE 4.5
Interactive map showing query function, a part of the World Database on Protected Areas

Source: UNEP-WCMC, 2009.

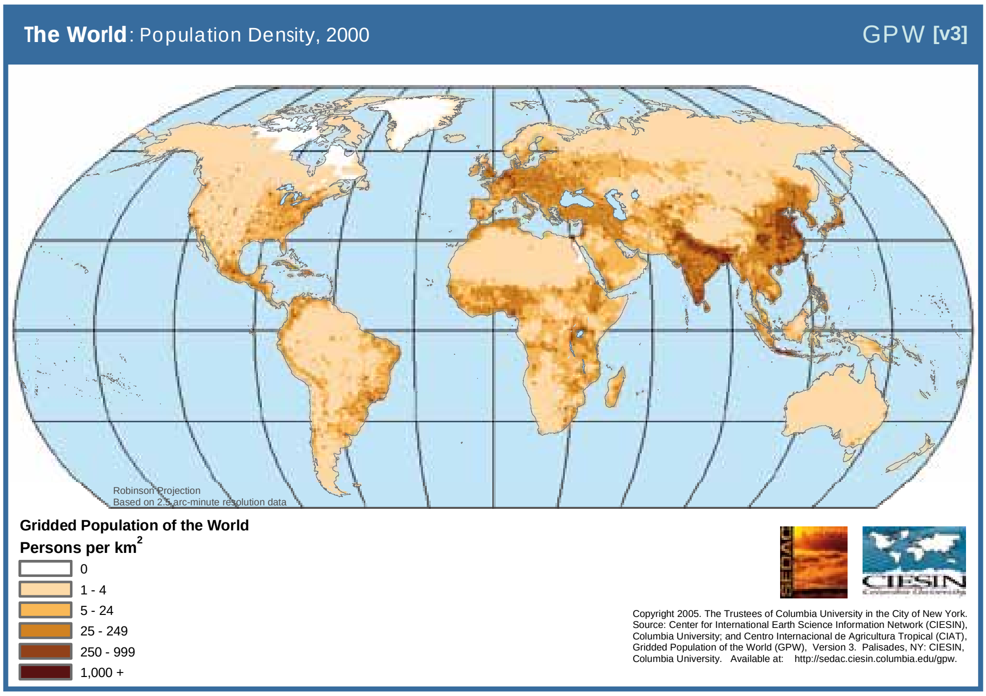
From an EAA perspective the WDPA provides indications of no-go areas with regard to aquaculture development. From a GIS viewpoint, spatial data on protected areas can be downloaded and can serve as a constraint layer on estimates of aquaculture potential. The WDPA is in the course of being redesigned into a web-enabled spatial database platform with custom data editing, downloading and analysis facilities. The data are updated annually and the most recent data set (2009) is available at www.wdpa.org/AnnualRelease.aspx

Gridded Population of the World, Version 3

The Gridded Population of the World (GPWv3) (CIESIN, 2005) consists of estimates of human population for the years 1990, 1995, and 2000 by grid cells that are approximately 5 km at the equator, and some associated datasets dated circa 2000 (Figure 4.6). The data products include population count grids (raw counts), population density grids (per square km), land area grids (actual area net of ice and water), mean administrative unit area grids, centroids, a national identifier grid, national boundaries, and coastlines. These products vary in GIS-compatible data formats and geographic extents (global, continent [Antarctica not included], and country levels).

A proportional allocation gridding algorithm, utilizing more than 300 000 national and sub-national administrative units, is used to assign population values to grid cells.

FIGURE 4.6
Global population density in 2000



Source: CIESIN (2005).

LandScan Worldwide Population Grids

The LandScanTM Dataset comprises a worldwide population database compiled on an approximately 1 km^2 latitude/longitude grid. Thus, the LandScan data are at a higher resolution than the Grided Population of the World data described above and for that reason more applicable to national and sub-national levels for the EAA. For the LandScan datasets, census counts (at sub-national level) were apportioned to each grid cell based on likelihood coefficients, which are based on proximity to roads, slope, land cover, nighttime lights, and other information.The LandScan Dataset files are available via the internet in ESRI grid format by continent and for the world, and in ESRI raster binary format for the world.

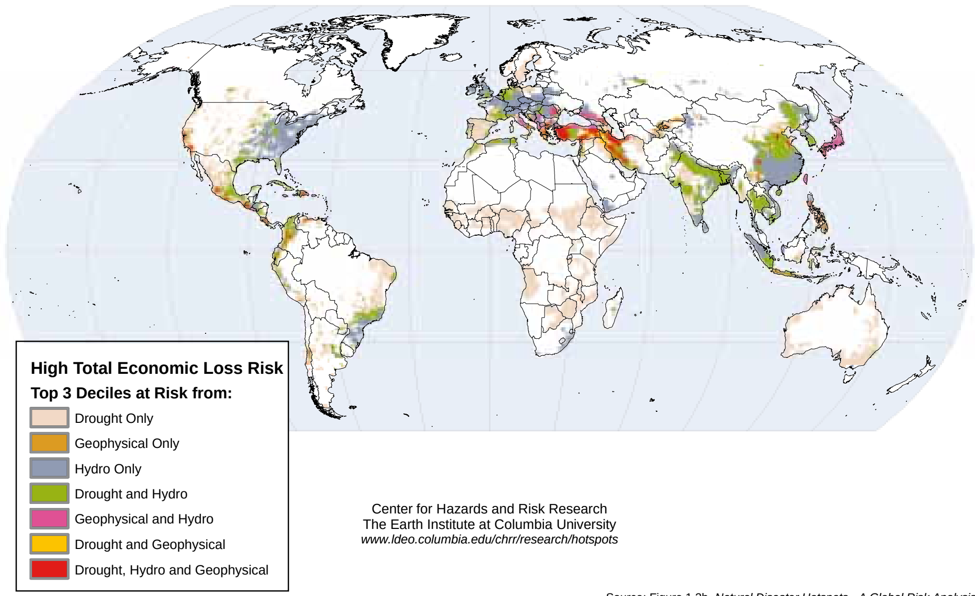
LandScan datasets are released annually, with each new release superseding the previous. LandScan dataset licenses are available free of charge for U.S. Federal Government, for United Nations Humanitarian efforts, and educational research use.

Natural Disaster Hotspots; Global Risk Analysis

This is a set of global geospatial data on six major natural hazards and associated risks of mortality and economic loss provided by the Center for Hazards and Risk Research at Columbia University, United States of America. (Dilly *et al.* (2005) have assessed the global risks of two disaster-related outcomes: mortality and economic losses. They estimated risk levels by combining hazard exposure with historical vulnerability for two indicators of elements at risk—gridded population and Gross Domestic Product (GDP) per unit area—for the six major natural hazards of: earthquakes, volcanoes, landslides, floods, drought, and cyclones. By calculating relative risks for each grid cell rather than for countries as a whole, they have been able to estimate risk levels at sub-national scales.

These datasets are especially valuable for the EAA because risks to aquaculture can be inferred both as environmental impacts and in economic terms on grid cells of approximately 5 km width at the equator (Figure 4.7). For GIS in support of the EAA, these data provide additional layers with which to assess natural environmental impacts that are readily available for download as gridded datasets (www.ldeo.columbia.edu/chrr/research/hotspots/coredata.html) and that can be previewed as maps (Figure 4.6) (www.ldeo.columbia.edu/chrr/research/hotspots/maps.html).

FIGURE 4.7
Global distribution of highest risk disaster hotspots by hazzard type
Total Economic Loss Risks



Source: Dilly *et al.* (2005).

The Data Distribution Centre (DDC) of the Intergovernmental Panel on Climate Change (IPCC)

The DDC offers access to baseline and scenario data for representing the evolution of climatic, socio-economic, and other environmental conditions. (www.ipcc-data.org/). The data are provided by co-operating modelling and analysis centres. The DDC also provides technical guidelines on the selection and use of different types of data and scenarios in research and assessment. The DDC is designed primarily for climate change researchers, but materials available from the site may also be of interest to educators, governmental and non-governmental organisations, and the general public.

Analysis of climate impacts, adaptation, and vulnerability involves a set of activities designed to identify the effects of climate variability and change, to evaluate and communicate uncertainties, and to examine possible adaptive responses. Methods for analysis of impacts, adaptation, and vulnerability have evolved over the past decade, and a large array of methods and tools are now available for use in specific sectors, at different scales of analysis, and in contrasting environmental and socio-economic contexts. Most assessments of the impacts of future climate change are based on the results of impact models that rely on quantitative climatic and non-climatic data and scenarios. The identification, selection, and application of baseline and scenario data are crucial steps in the analytical process. The great diversity of the data required and the need to maintain consistency between different scenario elements can pose substantial challenges to researchers. The IPCC DDC seeks to provide access to such data and scenarios and to offer guidance on their application.

Several other centers provide global climate change model outputs among which is the US National Center for Climate Research that makes available outputs in GIS formats. This center uses the Community Climate System Model (CCSM). The CCSM is a coupled climate model for simulating the earth's climate system.

Composed of four separate models simultaneously simulating the earth's atmosphere, ocean, land surface and sea-ice, and one central coupler component, the CCSM allows researchers to conduct fundamental research into the earth's past, present and future climate states. A GIS-oriented Frequently Asked Questions (FAQ) is available (www.gisclimatechange.org/faqPage.do) and data are available for download after initial registration and login.

WORLDCLIM

WorldClim is a set of global climate layers (climate grids) with a spatial resolution of one square kilometre. The climate elements considered are monthly precipitation and mean, minimum, and maximum temperature. The data can be used for mapping and spatial modeling in a GIS or other computer program. The data are described by Hijmans *et al.* (2005). The attraction of these data for spatial analyses in support of the EAA is their high resolution for such tasks as estimating changes in future temperature-based growth rates of cultured organisms and effects of water availability on inland aquaculture. Download possibilities include IPPC 3rd Assessment data (www.worldclim.org/futdown.htm). Future climate projections, calibrated and statistically downscaled using the WorldClim data for 'current' conditions and projected future climate by climate model (e.g. CCCMA), emission scenario (e.g. the a2a model emission scenario), year (e.g. 2050) and spatial resolution (e.g. approximately 1 km at the equator) are available at www.worldclim.org/futdown.htm. All data are in generic grid format.

Climpag

Climpag is aimed at bringing together the various aspects and interactions between weather, climate and agriculture in the general context of food security. As per FAO basic texts, the word agriculture includes crops and grasslands, livestock husbandry, forestry and fisheries.

Climpag contains methodologies, tools for a better understanding and analysis of the effect of the variability of weather and climate on agriculture as well as data and maps (www.fao.org/nr/climpag).

Perhaps of greatest interest are:

- Rainfall maps. These maps indicate respectively: the monthly total rainfall amount (in millimeters), and the monthly rainfall percentage of normals (in percentage).
- Global climate grids. These grids are based on Koeppen climatologies and the climatic net primary production maps of FAO are based on different periods and precipitation datasets. All data are provided as comma separated value (csv) in .5°x.5° resolution. Furthermore some derived information like temperature of the coldest and warmest months, Martonnes aridity index and Gorczynskis continentality index are provided (www.fao.org/nr/climpag/globgrids/KC_commondata_en.asp).
- WebLocClim. This Local Monthly Climate Estimator was developed to provide an estimate of climatic conditions at locations for which no observations are available. To achieve this, the programme uses the 28 800 stations of FAOCLIM 2.0, the global agroclimatic database maintained by the Agrometeorology Group of FAO (www.fao.org/nr/climpag/locclim/locclim_en.asp).

Climpag and WorldClim are different so they could be considered as being complementary, Climpag is a portal on climate (variability) and agriculture with all methodologies, data, tools, and examples related to these whilst WorldClim provides climate datasets. Another big difference is that in Climpag you can download real-time data (monthly at country level) and maps (e.g. Rainfall for Africa).

Shellfish reefs at risk

This is the first global assessment of the distribution and condition of bivalve shellfish reefs that occur in temperate and subtropical estuaries (Beck *et al.*, 2009). The assessment is focused primarily on biogenic reefs formed by oysters within their native ranges, but also includes observations about mussels that form beds and provide other ecosystem services. Quantitative and qualitative data were compiled about these reef forming species from published literature as well as from expert surveys, direct observations and from derived condition estimates for oyster reefs in 144 estuaries and 40 ecoregions around the world .

There are several implications for the EAA from these data, one of which would be reef areas to avoid for aquaculture development, but also areas near which to develop reef re-stocking shellfish culture installations. Presumably, the underlying spatial data could be obtained on request from the Nature Conservancy (http://conserveonline.org).

4.5 SUMMARY AND CONCLUSIONS

The purpose of this chapter was to provide an overview of sources that can satisfy spatial data needs for the implementation of the EAA. The list of sources is not exhaustive and most sources pertain to global and national level spatial data. Nevertheless, these sources are indicative of the kinds of data that, at higher resolutions, would be required to support the EAA at levels below the national level. Data sources were assembled in four categories (1) Earth browsers, (2) Portals (3) Generalized data, and (4) Specialized data. Specifically, spatial data are required to define ecosystems where no such definitions already exists at a useful scale, or to enhance already existing ecosystem data with data specific to the needs of aquaculture. The fundamental tasks that rely on spatial data are to estimate the potential impact of aquaculture on the environment and ecosystems and to estimate the impact on aquaculture of natural and man-induced changes to the environment in an ecosystems specific context. Real time management of aquaculture operations is another task relying in part on remote sensing data.

It is fair to conclude that there are huge quantities of spatial data freely available that could be important for use in spatial analyses in support of the EAA. Many of these datasets could be useful at national and sub-national levels. But like the ecoregions and ecosystems already defined (Chapter 3), considerable effort will be required to determine quality and applicability relative to resolution, and spatial and temporal coverage at national and sub-national levels. One of the early and essential steps of implementing spatial analyses in support of the EAA at national levels will be to inventory and evaluate relevant spatial data at a range of resolutions.

5. The geography of aquaculture in relation to environments and potential impacts

5.1 INTRODUCTION, OBJECTIVES AND OVERVIEW

According to FAO (www.fao.org/fishery/topic/14894/en) major environmental impacts of aquaculture have been associated mainly with high-input high-output intensive production systems (e.g. culture of salmonids in raceways and cages) the effects of which included discharge of suspended solids, nutrient and organic enrichment of recipient waters resulting in build-up of anoxic sediments, changes in benthic communities (alteration of seabed fauna and flora communities) and the eutrophication of lakes. Large-scale shrimp culture has resulted in physical degradation of coastal habitats, for example, through conversion of mangrove forests and destruction of wetlands, salinization of agricultural and drinking water supplies, and land subsidence due to groundwater abstraction. However, misapplication of husbandry and disease management chemicals, collection of seed from the wild (bycatch of non-target species occurring in the collection of wild seed) and use of fishery resources as feed inputs, are also causing concern. Mollusc culture has been held responsible for local anoxia of bottom sediments and increased siltation. Additionally, the environmental costs of aquaculture have been examined by Bartley *et al.* (2007) and a regional evaluation of environmental impact assessment and monitoring in aquaculture covering Africa, Asia-Pacific, Europe and North America, and Latin America) was made by FAO (2009). But to date there has been no globally comprehensive and comparable assessment of aquaculture's impact on the environment nor of environmental impacts on aquaculture.

Central to an ecosystem approach to the management of aquaculture is the need to optimize benefits while minimizing impacts. With regard to the environmental impacts of aquaculture, it is necessary to establish their magnitude and locations in order to plan for the appropriate ameliorative interventions. Specifically, for this review, it is essential to ascertain in which countries and in which environments spatial planning tools could contribute most to the EAA and to design the appropriate training and technical assistance. For the same reason it is necessary to establish the effects of the environment on aquaculture. Accordingly, the objectives of this chapter are to:

- estimate the relative intensity of use that aquaculture makes of the freshwater, brackishwater and marine environments at the country level, and from a global perspective, in a comprehensive and comparative manner; and
- estimate the relative intensity of the impact of the environment on aquaculture, also at a country and global level in a comprehensive and comparative manner.

As an overview of the chapter, the aquaculture production data used from FAO FishStat Plus (FAO, 2007) and the base year is 2005. Although these data are not the most recent, they are complete for all countries with significant aquaculture production and the 2005 production data do not differ significantly from the 2007 country level production data as shown by a correlation coefficient of 0.99. The environmental/aquaculture impact analyses are based on the assumption that the quantity of aquaculture production is directly related to the potential impact of aquaculture on the environment and by inference on ecosystems. As detailed below, this assumption is strengthened by relating production to specific environments and by considering production in each environment in terms of its expanse. The analysis of aquaculture's impacts is comprehensive because it includes all countries with aquaculture production and it is comparative because all countries have been treated in the same way by using a common data base.

In order to provide a point of comparison, the country level overall aquaculture production and by main environments (brackishwater, freshwater and marine)[1] is established. Then, the relative intensity of use of the environments by aquaculture is estimated by expressing brackishwater and mariculture production as a function of the shoreline length of each country. The intensity of use of the freshwater environment is estimated by expressing freshwater aquaculture production as a function of total freshwater surface area in each country. Countries which make relatively intensive use of one, two and three environments for aquaculture are identified. A different approach is taken to estimate the potential environmental impacts on aquaculutre, The Environmental Performance Index (EPI) is employed. The intensity of environmental impacts on aquaculture is estimated by placing a heavy weighting on a country's ecosystem vitality as measured by its EPI index. Finally, the countries in which the use of the environments for aquaculture is most intensive are compared with the countries in which the environmental impacts on aquaculture are most heavy.

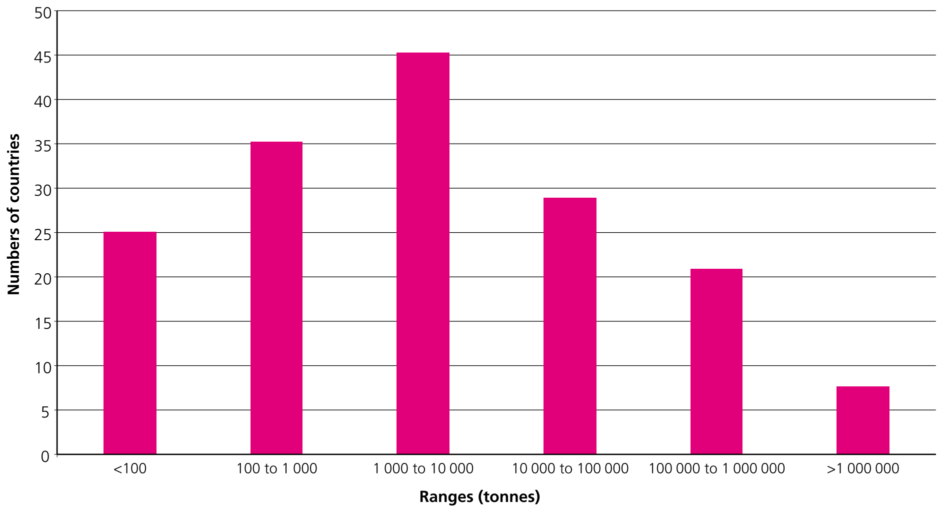
5.2 IMPORTANCE OF AQUACULTURE BY TOTAL PRODUCTION

In 2005 there were 163 countries listed by FAO FishStat Plus (FAO, 2007) with at least one tonne of aquaculture production. Total production was nearly 63 million tonnes.

Most countries produce from 1 000 to 10 000 tonnes and the majority of countries are relatively small producers (Figure 5.1).

World aquaculture is dominated by China with 69 percent of the global total and by a

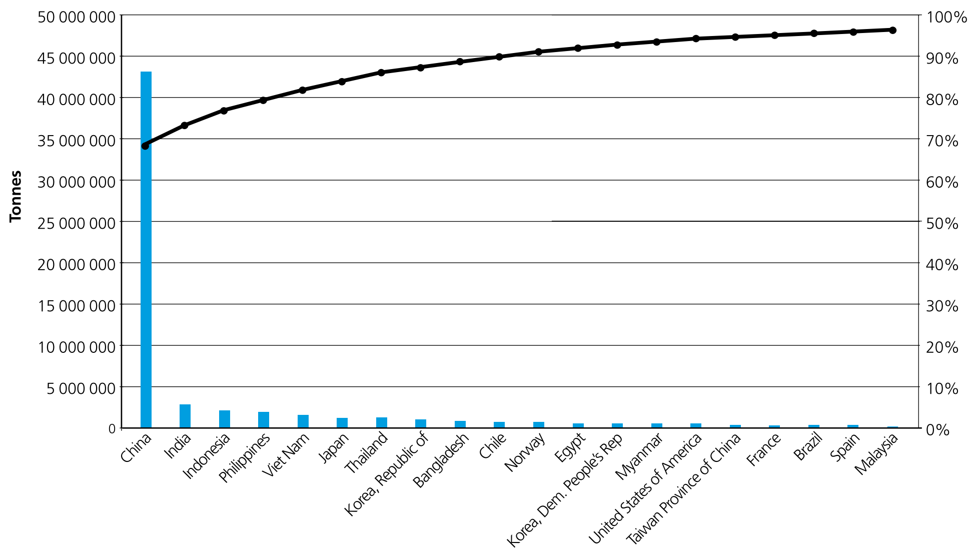
FIGURE 5.1
Ranges of total aquaculture production by country in 2005



relatively small number of additional countries. Production of the top 20 countries together accounts for 96 percent of the global total leaving 143 countries to produce the remaining 4 percent (Figure 5.2). Given this situation, on the face of it, it would seem that with the potential impact of aquaculture equated to quantity of annual production, only a relatively small number of countries are impacting the environment through aquaculture.

[1] 1 Main envioronments classified according to FAO FishStat Plus (FAO, 2007).

FIGURE 5.2
The top 20 countries in aquaculture production and cumulative production in 2005

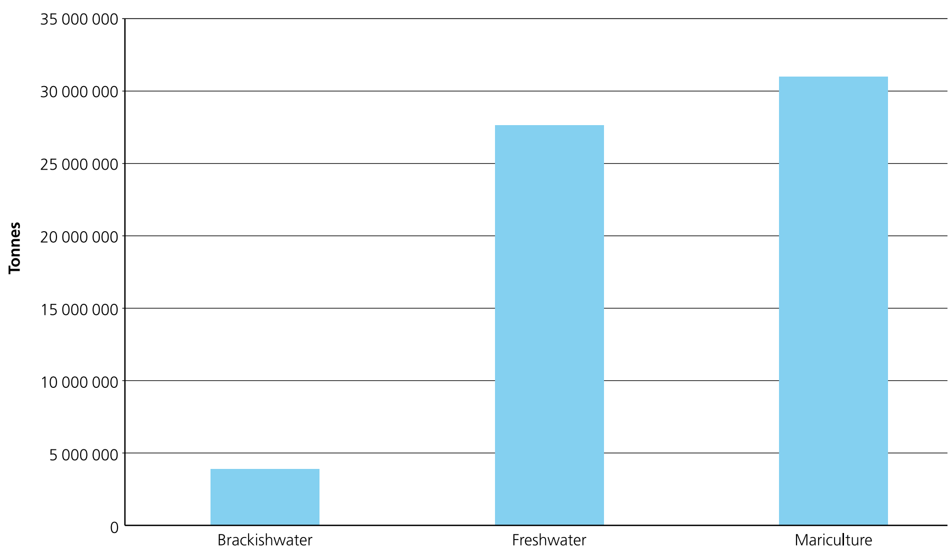


5.3 IMPORTANCE OF AQUACULTURE BY ENVIRONMENT

Considered by environment, mariculture production from a total of 87 countries dominates aquaculture with 50 percent of the total produced (Figure 5.3). Nearly all of mariculture is located in sheltered areas in close proximity to the coastline. Therefore, it follows that coastal marine ecosystems, including bays and the outer portions of estuaries, are much more influenced environmentally by mariculture than is the open ocean.

Brackishwater aquaculture from a total of 57 countries accounts for only 6 percent of total production. Brackishwater aquaculture is practiced within the coastal shoreline in estuaries, fjords, coastal lagoons, and associated systems such as mangroves and marshes. Thus, when considered globally, the impact of brackishwater aquaculture on the environment is much less than that of mariculture because of its much lower production. Freshwater aquaculture accounts for 44 percent of the total and is dealt with separately in section 5.6.

FIGURE 5.3
Aquaculture total production in 2005 by environment

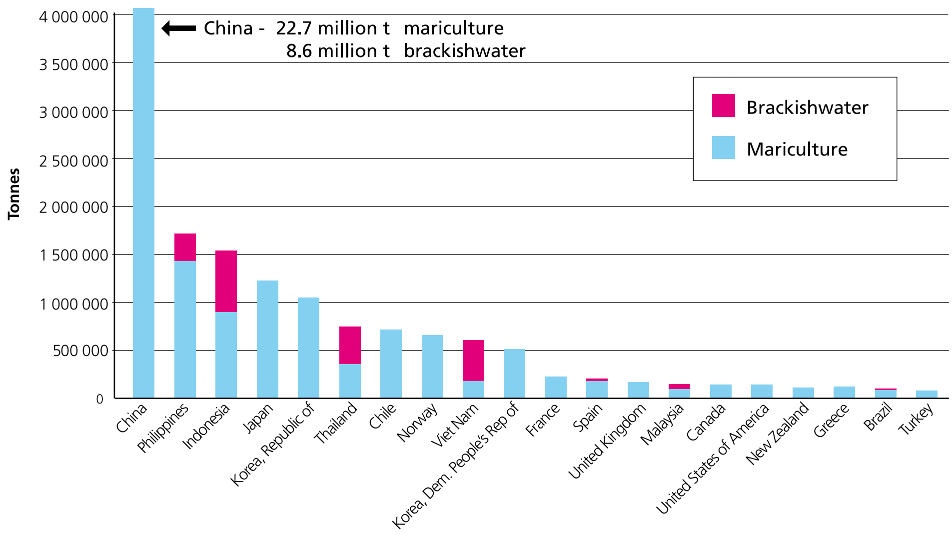


5.4 IMPACTS OF AQUACULTURE IN MARINE AND BRACKISHWATER ENVIRONMENTS BASED ON ANNUAL PRODUCTION

Of the 87 countries with mariculture production and of the 57 countries with brackishwater production, there are 34 countries with both mariculture production and brackishwater production. Therefore, aquaculture in these countries impacts both the near shore marine environment and the brackishwater environment. There are 53 countries with mariculture production, but with no brackishwater production. Aquaculture in these countries presumably impacts only the near shore marine environment. Conversely, there are 23 countries with brackishwater production, but no mariculture production. Aquaculture in these countries impacts only the brackishwater environment. In total, aquaculture in 110 countries impacts the near shore marine environment, the brackishwater environment, or both.

In production terms, about 56 percent of total aquaculture output from the 110 countries is generated at or near the coastline (50 percent marine + 6 percent brackishwater). Thus, on the face of it, coastal ecosystems, in both brackishwater and marine environments, are relatively heavily used by aquaculture among countries which are the most productive in these environments. In this regard, China produced nearly equal amounts in mariculture and brackishwater culture, 22.7 and 23.5 million tonnes, respectively, equivalent to 67 percent of the total world mariculture and brackishwater production together. An additional 19 countries, together with China, account for 97 percent of the global production (Figure 5.4). Not all of these countries declare both marine and brackishwater production. Among the top 20 countries, seven do not report brackishwater production and two report brackishwater production, but no marine production (Figure 5.4). This situation, in which marine and brackishwater production are concentrated in coastal areas, gives ample reason for considering mariculture together with brackishwater culture in terms of environmental impacts, and eventually in terms of the ecosystems in which they reside.

FIGURE 5.4
Top 20 countries in mariculture plus brackishwater production in 2005

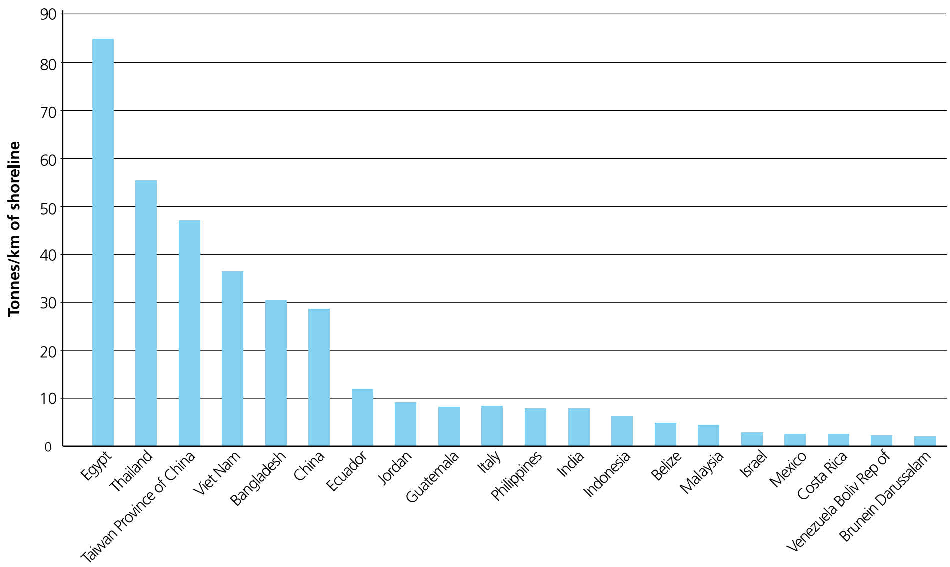


5.5 IMPACTS OF AQUACULTURE ON MARINE AND BRACKISHWATER ENVIRONMENTS BASED ON ANNUAL PRODUCTION AND LENGTH OF SHORELINE

This situation, that both mariculture and brackishwater culture affect the coastal environment, the former near shore and the latter within the shoreline, provides a new way to assess the relative spatial impact of aquaculture on coastal ecosystems at a country level. The basic assumption that allows this new approach is that both mariculture and brackishwater aquaculture are proximate to the coast and therefore their main impacts are on coastal ecosystems.

The approach made here is to introduce shoreline length as a spatial parameter. Shoreline length was obtained from the World Fact Book (www.cia.gov/library/publications/the-world-factbook/fields/2060.html?countryName=World&countryCode=xx&regionCode=oc&#xx) The consideration of aquaculture production relative to shoreline length provides an indication of the relative intensity of use made of coastal ecosystems by aquaculture as measured in terms of tonnes per kilometre of shoreline. Relative intensity of use can then be interpreted as a measure of the environmental impact of aquaculture. An important benefit of this approach is that the results are both comprehensive and comparative globally among all aquaculture producing countries. Of the 57 countries reporting brackishwater aquaculture in 2005, there are 24 that have an intensity of use of the coastal environment of at least 1 tonne per kilometre of shoreline. Of those, there are seven countries that range from 12 to 85 tonnes per kilometre of shoreline. Egypt ranks highest and other important countries among the top 20 are Thailand and the Taiwan Province of China (Figure 5.5).

FIGURE 5.5
Top 20 countries in intensity of brackishwater aquaculture in 2005 (tonnes per kilometre of shoreline)



It is noteworthy that China ranks sixth when considered in this way and conversely, other countries that are relatively unimportant in overall production gain in importance (e.g. Jordan, Belize).

In comparison with brackishwater culture relative to shoreline length, there are 55 countries with a mariculture output of at least 1 tonne per kilometre of shoreline. Of these, China has an exceptionally high output of 726 tonnes per kilometre of shoreline. Among the top 20, after China, outputs range from 126 to 9 tonnes per kilometre of shoreline. (Figure 5.6). As with brackishwater production, several territories and countries that otherwise would not be important emerge when production is considered as a function of length of shoreline (e.g. Faeroe Islands, Israel, Ireland). The environmental impacts of mariculture and brackishwater culture come together on the coast. A measure of the environmental impact of these two culture categories, expressed in terms of intensity, is apparent by adding mariculture and brackishwater production, each in terms of tonnes per kilometre of shoreline. China is by far the world leader in this category with 784 tonnes per kilometre of shoreline (Figure 5.7). Clusters of countries using the coastal environment for aquaculture either intensively or moderately intensively are in Asia, western Europe, and Latin America (Figure 5.8).

FIGURE 5.6
Top 20 countries in intensity of mariculture production in 2005 (tonnes per kilometre of shoreline)

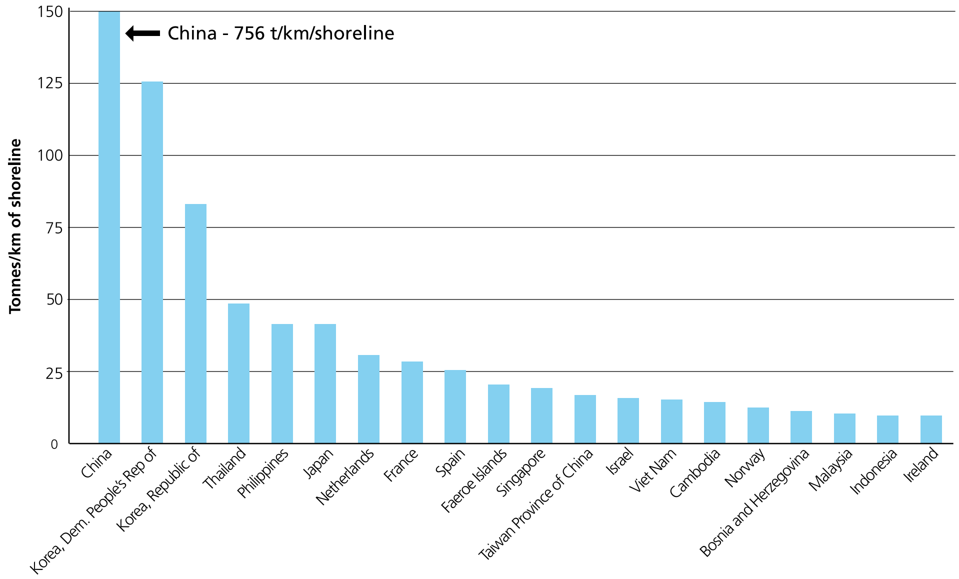
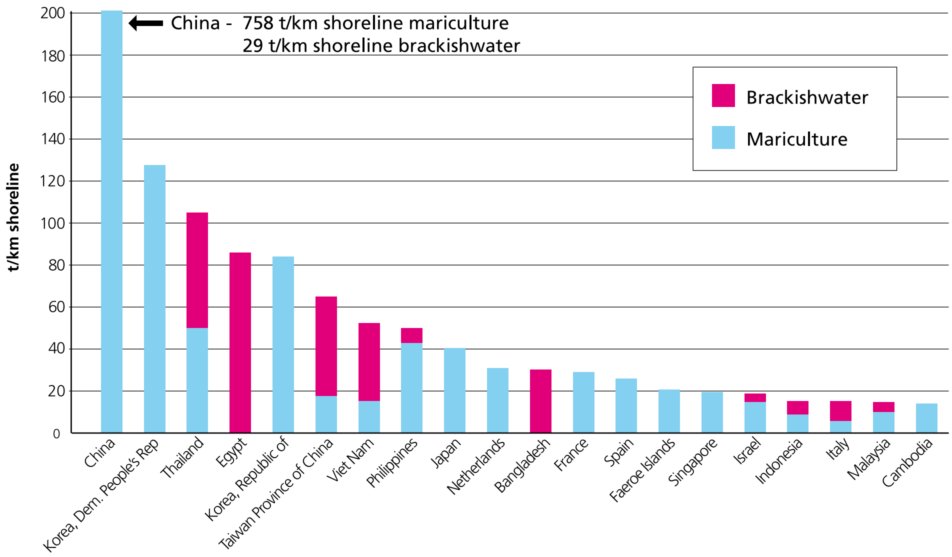


FIGURE 5.7
Top 20 countries in intensity of use of the coast for aquaculture in 2005 (mariculture + brackishwater production per kilometre of shoreline)

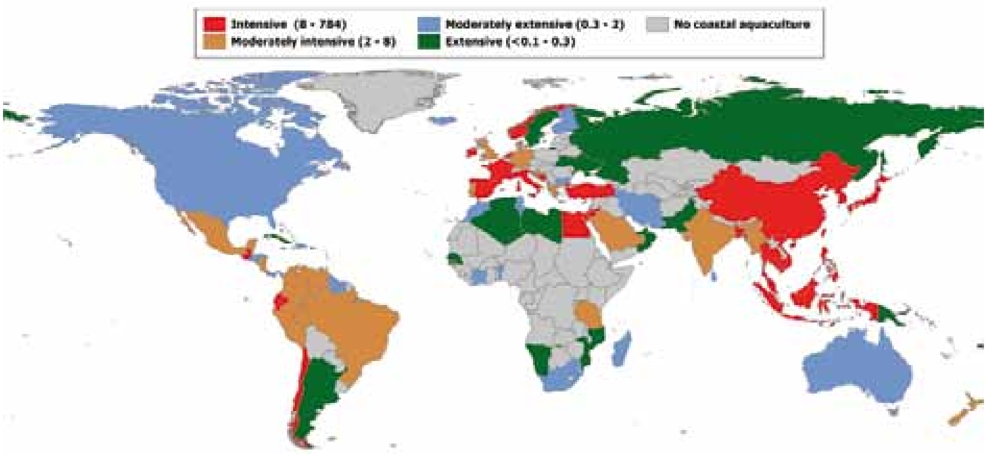


5.6 POTENTIAL IMPACTS OF AQUACULTURE USE ON FRESHWATER ENVIRONMENTS BASED ON PRODUCTION BY COUNTRY

Freshwater aquaculture from a total of 143 countries accounts for 46 percent of total aquaculture production (Figure 5.3). It is carried out in a wide variety of natural ecosystems such as rivers and lakes, plus in artificial ecosystems having variable environmental controls on the culture environment such as in reservoirs, ponds, raceways and silos as well as in closed systems. In contrast to much of mariculture and brackishwater aquaculture, freshwater aquaculture may combine species from several trophic levels within the same culture system.

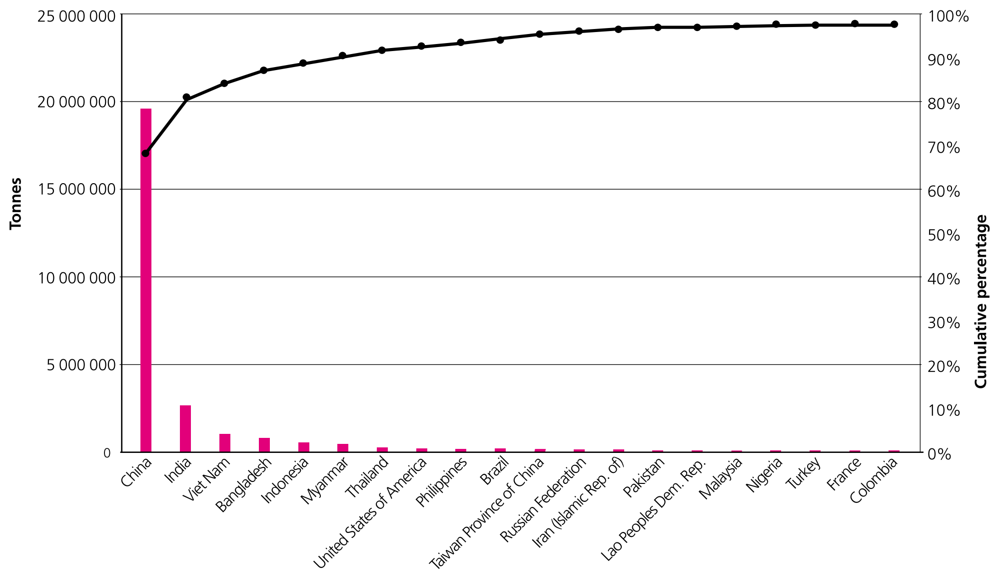
Freshwater aquaculture is based on animals that are fed or on those that partially or

FIGURE 5.8
Use of the coastal environment for aquaculture in 2005 (tonnes per kilometre of shoreline)



completely extract their feed from the environment (phyto- and zooplankton in the water column, benthic plants and animals). Therefore, the potential impact of aquaculture on freshwater ecosystems can be highly variable depending on the species, culture system and associated levels of inputs and outputs as well as on the location within the ecosystem. The top 20 countries in freshwater production account for 98 percent of global production (Figure 5.9). China, with 72 percent of global production, dwarfs the output of the next most important countries, India and Viet Nam.

FIGURE 5.9
The top 20 countries in freshwater aquaculture production and cumulative production in 2005



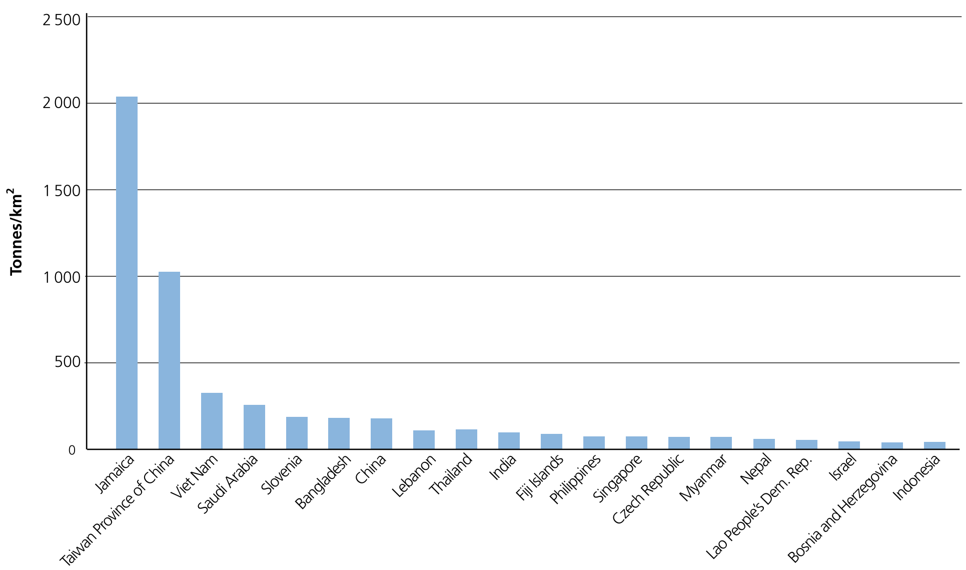
5.7 POTENTIAL IMPACTS OF AQUACULTURE USE ON THE FRESHWATER ENVIRONMENT BASED ON PRODUCTION BY COUNTRY

As with mariculture and brackishwater culture, freshwater aquaculture production can be considered here in spatial terms. Production is carried out in a wide variety of natural ecosystems such as rivers and lakes and in artificial ecosystems with differing amounts of control on the culture environment such as reservoirs, ponds, raceways and silos. In this section, the combined surface areas of lakes, reservoirs and rivers are used as the spatial indicator of the total freshwater area of a country. The data have been derived by clipping Levels 1 and 2 of the Global Lakes and Wetlands Database (GLWD) (Lehner and Doll, 2004) with country boundaries based on Global Administrative Unit Layers (FAO, 2008). The GLWD is described in more detail in Chapter 4.

The basic assumption for this analysis is that the total freshwater surface area of a country, as estimated using the GLWD, is a measure of freshwater area in which aquaculture is, or can be developed. It follows then that production as a function of total freshwater surface area is a measure of the intensity of use of the freshwater environment for aquaculture. For example, at one extreme countries with relatively large expanses of freshwater and relatively low aquaculture production would be low intensity users of freshwater for aquaculture.

When aquaculture production is considered as a function of freshwater surface area, a far different picture from production per country emerges. Using this approach, Jamaica and Taiwan Province of China are by far the most intensive users of freshwaters for aquaculture with 2 032 tonnes/km^2 of freshwater surface (tonnes/km^2) and 1 025 tonnes/km^2, respectively and China drops to sixth place with 176 tonnes/km^2 (Figure 5.10). Clusters of intensive and moderately intensive use of the freshwater environment for aquaculture are in Asia, Europe, the Middle East, northwestern Latin America and North America (Figure 5.11).

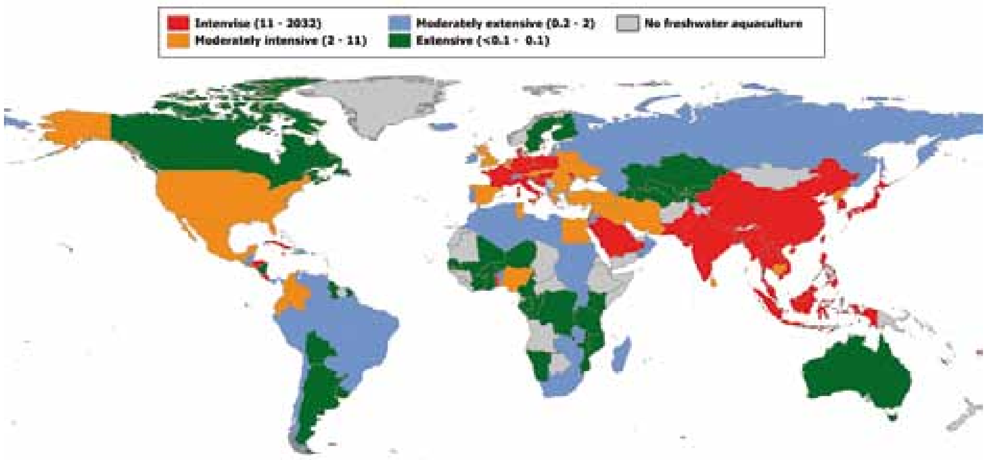
FIGURE 5.10
Top 20 countries in intensity of use of the freshwater area for aquaculture production in 2005 as tonnes/km^2 of freshwater surface area



5.8 COMPARISONS OF THE USE OF ECOSYSTEMS BY AQUACULTURE AMONG COUNTRIES

The objective in this section is to estimate the intensity of use of the marine, brackishwater and freshwater environments for aquaculture in spatial terms. The discussion requirements are that the estimates are comprehensive in the sense of including all aquaculture countries and comparable among them, but straightforward in interpretation. As was stated previously, intensity of use of the coastal environment was calculated as mariculture and brackishwater annual production per kilometer of shoreline length.. In contrast, intensity of use of freshwater environments for aquaculture was calculated annual freshwater production per country as a function of freshwater surface area. The linear and area-wise estimates of

FIGURE 5.11
Intensity of use of the freshwater environment for aquaculture production in 2005 as tonnes/km^2 of freshwater surface area



intensity of use are not additive. Additionally, because the data are highly skewed, means and standard deviations of production would provide biased pictures of intensity of use. The problems of additivity and skewness have been resolved by casting the data into quartiles.

Countries that make the most intensive use of inland, coastal and marine ecosystems for aquaculture are of the most interest here. That is, those that potentially make the most impact on the environment. The degree of aquaculture intensity has been classified as follows:

- Intensive – 4th quartile (76th to 100th percentile)
- Moderately intensive – 3rd quartile (51th to 75th percentile)
- Moderately extensive – 2nd quartile (26th to 50th percentile)
- Extensive – 1st quartile (0 to 25th percentile)

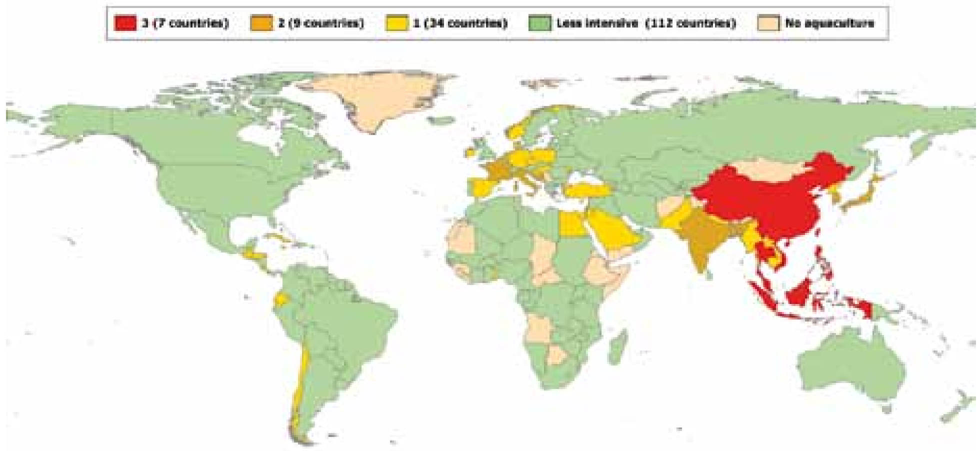
The use of the terms “intensive” and “extensive”are not meant to imply the very specific definitions assigned to them in FAO Glossary of Aquaculture (www.fao.org/fi/glossary/aquaculture/default.asp). Rather these terms as used herein simply to provide an alternative, comparative quantitative meaning to quartiles as mathematical terms.

In overview, there are 36 countries in the relatively intensive freshwater aquaculture category, 22 countries with relatively intensive mariculture, and 15 in the relatively intensive brackishwater category. Viewed another way, of the 163 countries that reported aquaculture production in 2005, there are 50 that make relatively intensive use of ecosystems in at least one of the three main environments. Among those 50 countries, there are seven countries that make intensive use of ecosystems for aquaculture in all three environments, nine countries that use ecosystems intensively in two of three environments, and the reminder, 34, make intensive use of only one of the three environments (Figure 5.12) in which aquaculture is relatively intensive).

5.9 POTENTIAL ENVIRONMENTAL IMPACTS ON AQUACULTURE BASED ON ECOSYSTEM VITALITY

Just as aquaculture impacts the environment and the ecosystems within it, so do natural events and human activities impact aquaculture. The purpose of this section is to rank countries in a comprehensive and comparable way as to their actual or potential environmental impacts on aquaculture. The approach is to use a ready-made indicator as a starting point, the Environmental Performance Index 2008 that was described in Chapter 3 (page 43).

FIGURE 5.12
Numbers of environments used intensively for aquaculture among freshwater, brackishwater and marine environments



The 2008 Environmental Performance Index (EPI) (overview available at http://sedac.ciesin.columbia.edu/es/epi/papers/2008EPIPolicymakerSummary.pdf) ranks 149 countries on 25 indicators relating to six established policy categories: Environmental Health, Air Pollution, Water Resources, Biodiversity and Habitat, Productive Natural Resources, and Climate Change. The EPI identifies broadly-accepted targets for environmental performance and it measures how close each country comes to these goals.

The EPI builds on measures relevant to the goals of reducing environmental stresses on human health, which is called the Environmental Health objective. More importantly from an aquaculture viewpoint, it also includes measures relevant to the goal of reducing the loss or degradation of ecosystems and natural resources. This is called the Ecosystem Vitality objective.

For the purpose of estimating environmental impacts on aquaculture, the default weight on Environmental Vitality, bearing directly on factors that can environmentally impact aquaculture (Figure 5.13) (http://epi.yale.edu/chart/new_weighting/RankingsModule_2), was increased from the 50 percent to 90 percent. Accordingly, the weight on Environmental Health, bearing only indirectly on aquaculture, was reduced from 50 percent to 10 percent (Figure 5.13).

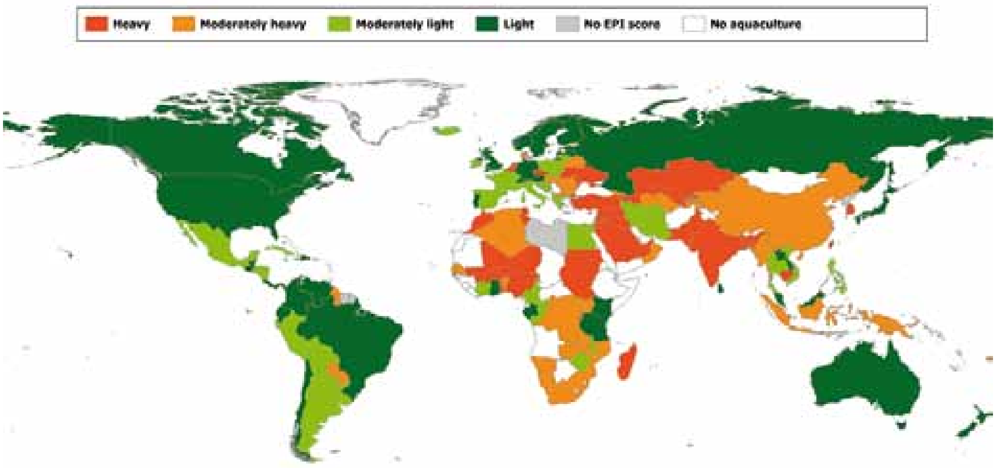
The assumption is that environmental impacts on aquaculture vary inversely with the EPIs estimates of ecosystem vitality when Ecosystem Vitality is weighted at 90 percent. In other words, countries with high re-weighted EPI scores impact aquaculture relatively lightly and those with low scores actually or potentially impact aquaculture relatively heavily. Actual impacts could be in those countries where aquaculture production is presently important and potential impacts would be in countries where aquaculture is presently little developed. The procedure uses quartiles to cast the EPI scores into four relative impact categories with respect to environmental impacts on aquaculture: heavy, moderately heavy, moderately light, and light. Of the 163 aquaculture countries, it is possible to derive re-weighted EPI scores available for 132 of them.

The geographic distribution of environmental impacts on aquaculture at the country level is shown in Figure 5.14. Countries actually or potentially with heavily or moderately heavy impacts on aquaculture are mainly in Asia and Africa, Eastern Europe and the Middle East. The countries and territories for which there are no EPI scores are mainly those in which the intensity of aquaculture production is low. The exceptions are the Democratic Republic of Korea, Singapore and the Faeroe Islands.

FIGURE 5.13
EPI categories heavily weighted on Ecosystem Vitality to estimate environmental impacts on aquaculture at the country level

Source: Socio-economic data and applications center (2009).

FIGURE 5.14
Environmental impacts on aquaculture based on a 90 percent weight on Ecosystem Vitality in the Environmental Performance Index



5.10 ENVIRONMENTAL IMPACTS ON AQUACULTURE IN RELATION TO THE INTENSITY OF AQUACULTURE PRODUCTION

Successful aquaculture development and management depend on anticipating and mitigating environmental problems both from- and on aquaculture. The objective of this section is to define the relationship between those countries in which aquaculture is most intensively practiced (Section 5.8, Figure 5.11) and those for which the impact of the environment on aquaculture has been estimated using the re-weighted Ecosystem Vitality category of the EPI (Section 5.9, Figure 5.14). For this purpose, the countries where aquaculture is most intensively practiced in each environment (4th quartile countries – Figure 5.11) have been assigned the re-weighted EPI scores in the four impact categories.

TABLE 5.1
Summary by numbers of countries where aquaculture potentially/heavily impacts the environment coincident with potential environmental impacts on aquaculture

Number of environments potentially heavily impacted by aquaculture	Total number of countries*	Potential environmental impact on aquaculture			
		Heavy	Moderately heavy	Moderately light	Light
3	7	1	2	3	1
2	9	3	2	3	1
1	31	10	5	8	8
Total	47	14	9	14	10

*There are three countries in this group without an environmental impact score Democratic People's Republic of Korea, Singapore and the Faeroe Islands

Among countries in which aquaculture is intensively practiced in three environments, there is one country, Malaysia, where the environmental impact on aquaculture is relatively light, three countries where it is moderately light, Thailand, Viet Nam and the Philippines, and two countries where it is moderately heavy, China and Indonesia, and one country, Taiwan Province of China, where it is heavy (Table 5.1). Among countries where aquaculture is practiced intensively in two environments, the environmental impact on aquaculture is evenly distributed among the categories, but there are three countries, the Republic of Korea, India, and Bangladesh, where the environmental impact on aquaculture is in the heavy category (Table 5.1). Looking at the countries where aquaculture is intensively practiced in only one environment the impact of the environment on aquaculture is relatively evenly distributed between heavy and light. There are ten countries in which the environmental impact on aquaculture is heavy (Table 5.1).

5.11 SUMMARY AND CONCLUSIONS

Aquaculture's impact on the marine, brackishwater and freshwater environments was estimated based on the assumption that the quantity of production in each of those environments is directly related to the intensity of impact on those environments. By inference, the potential impact of aquaculture on the three environments could be extended to the ecosystems associated with those environments. This assumption was used to make a globally comprehensive and comparable analysis of the intensity of the use of the freshwater, brackishwater and marine environments by aquaculture at the country level. Also, the converse, the environmental impact on aquaculture, was estimated at the country level using the Environmental Performance Index with a 90 percent weight on Ecosystem Vitality. These results support the main objective of this chapter that was to identify the countries in which GIS, remote sensing and mapping could be most usefully deployed in support of the EAA. As a first priority those are the countries in which aquaculture's impact on ecosystems is most intensive and in which environmental impacts on aquaculture are most heavy.

There are several considerations relating to these estimates. The first is that they are indicative. They provide a starting point for further investigations at national and sub-national levels and they should be verified by in-country data. The second is that capabilities and capacities to support spatial planning for the EAA vary among countries. Thus, some of those countries identified as intensively using environments for aquaculture, or in which aquaculture may be heavily impacted by the environment, may already be dealing effectively with these issues. A partial measure of how effective countries have been in dealing with such impacts is contained in the evaluation of environmental impacts assessment and monitoring by FAO (2009). One strategy to advance the use of spatial planning tools for aquaculture would be to enlist the support of the most capable and advanced countries to help those that are less advantaged.

From a geographic perspective the results can be summarized in the following ways:

- Of the 163 countries that reported aquaculture production in 2005, there were seven countries that made intensive use of ecosystems for aquaculture in all three environments, nine countries that used ecosystems intensively in two of the three environments, and the reminder, 34 that made intensive use of only one of the three environments (Figure 5.12).
- The potential environmental impacts of mariculture and brackishwater aquaculture mainly affect on coastal ecosystems. Clusters of countries intensively and moderately intensively using the coastal environment for aquaculture are in Asia, west Europe, and Latin America (Figure. 5.8).
- Clusters of countries intensively and moderately intensively using the freshwater environment for aquaculture are in Asia, Europe, the Middle East, north-western Latin America and North America (Figure. 5.11).
- Countries in which environmental impacts on aquaculture are actually or potentially heavy or moderately heavy are mainly in Asia and Africa, Eastern Europe and the Middle East (Figure 5.14).
- Among the countries intensively using at least one of the three environments for aquaculture, the environmental impacts on aquaculture are fairly evenly distributed in the range from heavy to light impacts (Table 5.1).
- These estimates of the potential impact of aquaculture on environments and of environmental impacts on aquaculture are indicative, but nevertheless provide useful starting points to gauge in which regions and which countries GIS support of the EAA could be most usefully deployed.

Before an EAA GIS-based plan can be implemented at country level, the extent to which GIS is already being used in support of the EAA has to be established as well as the capacity to expand GIS activities in support of the EAA. The assessment of GIS applications in aquaculture (Chapter 8) casts some light on this, but direct contact with each fisheries – aquaculture entity in each country is required to better substantiate activities and capacities.

These results call attention to the need for improved ways to comprehensively comparatively assess aquaculture's impact on the environment and the environment's impact on aquaculture. Refinement of the estimates by the three major environments within the countries is possible using FAO FishStat Plus (FAO, 2007) data in several ways, firstly by separating extractive and fed aquaculture that impact the environment separately. Secondly, culture methods and environments are often unique for a species (e.g. cages for Atlantic salmon in brackish and temperate marine waters) so that specific kinds of impacts can be inferred. The assumption is that countries producing the same species and using the same culture systems share the same or similar environmental problems and could benefit from the same kinds of GIS, remote sensing and mapping interventions. However, this approach does not satisfy the need to know the "where" of the impacts. This can be accomplished only by comprehensive inventories of aquaculture.

At watershed, aquaculture zone and farm scales there is no substitute for a spatial inventory of aquaculture with at least attributes that include species, culture systems, and production being recorded, in order to estimate impacts on the environment and ecosystems. Countries need to make this activity a priority in their implementation of the EAA. For a relatively inexpensive initiative, the benefits can be great. Thailand already provides one example of such an implementation as mentioned in the Workshop

Report of this document and also available on the Internet (http://gis.fisheries.go.th/WWW/index.jsp). An excellent starting point for a spatial inventory of aquaculture with attributes that include species, culture systems, and production are the FAO National Aquaculture Sector Overviews (NASOs) (www.fao.org/fishery/collection/naso/en). Figure 5.15 illustrates one of the NASO maps being constructed for Italy as an example.

FIGURE 5.15
NASO map for Italy showing location of farms by administrative units along with their characteristics (March 2010)

Source: Aquaculture Service (FIRA) under the ownership of FAO and is part of the National Aquaculture Sector Overview map collection.

The National Aquaculture Sector Overview (NASO) collection provides a general overview of the aquaculture sector of FAO member countries. The NASOs contain summarized information on the history of aquaculture; human resources involved in the sector; farming systems distribution and characteristics; main cultured species contributing to national production; production statistics; description of the main domestic markets and trade; promotion and management of the sector; and development trends and issues at the national level. The information provided in the NASOs has been primarily provided by experts on aquaculture and by national authorities and, supplemented by graphs created by FAO to illustrate reported production statistics. Ninety eight NASOs have been published on the FAO Web site so far. NASO is part of FAO Fisheries and Aquaculture Department regular programme and it was decided to update the online documents every four to five years.

The NASO initiative offers a good starting point for implementing GIS in support of the EAA and finances should be allocated to accelerate the effort especially among the countries which have been identified herein as most intensively using the environments for aquaculture and in which aquaculture is most heavily impacted by the environment.