Large Marine Ecosystems of the World
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Mapping Fisheries onto Marine Ecosystems for Regional, Oceanic and Global Integrations

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ABSTRACT

Research on ecosystem-based fisheries management, marine biodiversity conservation, and other marine fields requires appropriate maps of the major natural regions of the oceans, and their ecosystems. A global ocean classification system proposed by T. Platt and S. Sathyendranath and implemented by A.R. Longhurst, defined largely by physical parameters that subdivide the oceans into four 'biomes' and 57 'biogeochemical provinces' (BGCPs), is merged with the system of 64 Large Marine Ecosystems (LMEs) identified by K. Sherman and colleagues as transboundary geographic coastal and watershed units. This arrangement enhances each of the systems, and renders them mutually compatible. LMEs are ecologically defined to serve as a framework for the assessment and management of coastal fisheries and environments including watersheds, while the BGCPs have physical definitions, including borders defined by natural features, and extend over open ocean regions. The combined mapping will, for example, allow the computation of GIS-derived properties such as temperature, primary production, and their analysis in relation to fishery abundance data for any study area in the combined system. A further useful aspect of the integration is that it allows for the quantification, even within the EEZs of various countries, of the distribution of marine features (e.g. primary production, coral reef areas) so far not straightforwardly associated with different coastal states. Applications to shelf, coral reef and oceanic fisheries, and to the mapping of marine biodiversity are briefly discussed.

INTRODUCTION

There is broad consensus in the scientific community that fisheries management should be ecosystem-based, but very little agreement as to what this means (NRC 1999). Also, there is a need to analyze biodiversity data at larger scales than have generally been done so far, as demonstrated by e.g., Sala *et al.* (2000), for terrestrial and freshwater biomes. Clearly, when dealing with such complex issues, the first task, as in all science-based approaches to a problem, is to define the object(s) of concern, and to develop a consistent method to show how these objects are interrelated. Here, the objects are the marine ecosystems within which fisheries and biodiversity are to be analyzed, and marine life in general, is embedded.

Fortunately, reaching a consensus on the classification of marine ecosystems may be relatively easy, given the compatibility, originally noted in Pauly *et al.* (2000), of two classification schemes proposed in recent years. Both of these integrate an enormous amount of empirical data, and are sensitive to previous analyses of marine ecology. The two schemes are: (1) the global system of 57 'biogeochemical provinces' (BGCPs) developed by Platt and Sathyendranath (1988, 1993), Platt *et al.* (1991, 1992), Sathyendranath *et al.* (1989), Sathyendranath and Platt (1993), implemented by Longhurst (1995, 1998), and defined at scales appropriate for understanding physical forcing of ocean primary production and related processes; and (2) the 64 coastal Large Marine Ecosystems (LMEs), incrementally defined by Sherman and co-workers (Sherman and Alexander, 1986, 1989; Sherman *et al.* 1990, 1993; Sherman and Duda 2001; IOC 2002), whose ecologically-based definition, size, coastal locations and ecologically-based definitions make them particularly suitable for addressing management issues, notably those pertaining to fisheries on continental shelves, and coastal area management (Sherman and Duda 1999a; 1999b, Duda and Sherman 2002).

After reviewing selected features of these two schemes, we describe how the 64 Large Marine Ecosystems (LMEs) relate to the 4 biomes and their 57 biogeochemical sub-provinces (BGCPs). The joint classification which then emerges is presented in the form of a spatial hierarchy, and is presented as maps, each emphasizing a key feature of the classification. Overall, the integrated scheme allows for explicit consideration of different scales, as discussed e.g. by Levin (1990).

THE BIOMES

In this outline of geographic areas, the four biomes are the largest units. In Figure 16-1 biomes are defined by the dominant oceanographic process that determine the vertical density structure of the water column, which is what principally constrains the vertical flux of nutrients from the interior of the ocean. In the **Polar biome**, vertical density structure is largely determined by the flux of fresh or low-salinity water derived from ice-melt each spring and which forms a prominent halocline in polar and sub-polar oceans. In oceanographic terms, this occurs in each hemisphere polewards of the Oceanic Polar Front, whose location in each ocean is determined by the characteristic circulation of each. Though looming large on Mercator maps, the

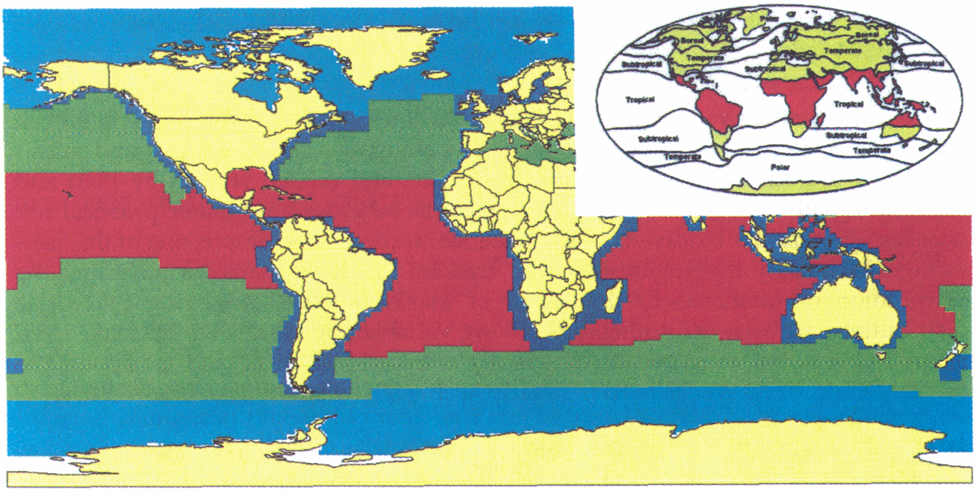

Figure 16-1. Map of the 4 world ocean's biomes: Polar (aqua), Westerlies (green), Trade Winds (red) and Coastal Boundary (blue). Biomes are the largest category in the proposed classification of the world oceans. Note its overall similarity to a conventional map of the atmospheric climate (inset, adapted from Anon. 1991)

Polar biome occupies only about 6 percent of the ocean's surface. Between the Polar fronts and the Subtropical Convergence in each ocean lies the **Westerlies biome**. Here, large seasonal differences in mixed-layer depth are forced by seasonality in surface irradiance and wind stress. Biological processes consequently may have sufficiently strong seasonality so that a spring bloom characterizes the plankton calendar. Across the equatorial regions, between the boreal and austral Subtropical convergences lies the **Trade-wind biome**. Here, the conjunction between low values for the Coriolis parameter, a strong density gradient across the permanent pycnocline and weak seasonality in both wind stress and surface irradiance result in relatively uniform levels of primary production throughout the year. Upper continental slopes, continental shelves and marginal seas comprise the **Coastal Boundary biome**. This is constrained between the coastline itself and (usually) the oceanographic front characteristically found at the shelf-edge. The single generalization that characterizes this biome is that nutrient flux in the water column is forced by a great variety of processes, including, for example: coastal upwelling, tidal friction, and fresh-water outflow from river mouths. In the partitions discussed above, subdivision of this biome into provinces was not carried as far as might be useful for some purposes. One of the objectives of the present study is to do just that, to clarify the linkages among biogeochemical provinces and Large Marine Ecosystems.

The boundaries between the biomes vary seasonally and between years, as can readily be inferred from satellite images. Dynamic boundaries that respond to this variability are discussed for primary production and related studies by Platt and Sathyendranath, (1999). However, such dynamic schemes are neither practical nor necessarily useful for biodiversity and fisheries studies. For example, one of the tasks facing biodiversity investigations is the creation of global maps documenting the distribution of hundreds of thousands of marine species. Requiring that these distributions are assigned to habitats having variable boundaries would make even simple, first-order assignments of species extremely difficult and postpone the delivery of products whose need is already keenly felt by students of biodiversity.

Thus, in the case of fishes, of which about 15,000 species are marine, the assignment within FishBase (see www.fishbase.org) of species to climate type (as defined in Figure 16-1, inset), required us to distinguish tropical from non-tropical species (see Pauly 1998), and this task alone required several person-months to complete. Moreover, there are numerous types of floral or faunal assemblages whose location does not vary, though their habitat is part of, or affected by a surrounding or overlying pelagic ecosystem. Thus, the reef fishes of the Galapagos do not change their location when an El Niño event strikes the archipelago. Rather, it is their abundance which is affected (Grove 1985, Grove and Lavenberg 1997). A similar argument applies to benthic communities, whose boundaries will tend to reflect the long-term average location of the boundaries of the overlying pelagic systems, rather than tracking their changing location (Ekman 1967).

The ecosystem classification scheme presented here is thus deliberately fixed in space. On the other hand, we anticipate that its use by various authors will quickly lead to the identification and quantification of changes in species compositions, thus reintroducing the dynamic element required at various spatial and temporal scales (Levin 1990).

Oceanographic conditions within the four biomes are obviously not uniform, and each can be subdivided further using the same set of principles as those that determined the biomes themselves. For example, in both the westerlies and trades biomes there are definable ocean regions where heavy tropical rainfall or excessive continental fresh water runoff lead to the existence of a quasi-permanent low salinity 'barrier- layer' occupying the upper portion of the thermally-stratified surface layer. This has important biological consequences and suggests that these regions should be recognized as individual partitions. Using such methods, based on close examination of regional physical oceanography, the four primary biomes can be further partitioned into 57 provinces, the BGCPs discussed above. Figure 16-2 illustrates these BGCPs, as defined by Longhurst *et al.* (1995). This schema has been used to stratify the world ocean in two studies, pertaining to the global distribution of primary production (Longhurst *et al.* 1995, Platt and Sathyendranath 1999, Pauly 1999) and tuna catches (Fonteneau 1998).

BIOGEOCHEMICAL PROVINCES

The next largest units in the hierarchy are the 57 Biogeochemical Provinces (BGCPs), based on Platt and Sathyendranath (1988) who proposed this recognition of natural regions of the ocean, each region having characteristic physical forcing to which there is a characteristic response of the pelagic ecosystem. These regions are dynamic biogeochemical provinces because their boundaries respond to annual and seasonal changes in physical forcing and are 'biogeochemical' because, within each, the biota respond to those characteristic geochemical processes which determine nutrient delivery to the euphotic zone. The concept has been used to partition both global and basin-scale analyses of primary productivity, though the 'dynamic' boundary aspect of the system remains to be exploited. So far, most applications of the partition have assumed that boundaries between provinces were fixed at locations representing average conditions.

The central principle in locating boundaries between provinces is that of the critical depth model of Sverdrup (1953), which remains the most useful formulation to relate phytoplankton growth to surface illumination, and to the vertical density structure of the water column. It successfully predicts, for example, the timing of the North Atlantic spring bloom. A proposed partition of the North Atlantic into 18 BGCPs (Platt *et al.* 1995) was followed by a partition of all oceans and adjacent seas into 57 provinces (Figure 16-2, Longhurst *et al.* 1995, Longhurst 1998).

After examination of 26,000 archived chlorophyll profiles to determine Gaussian parameters describing the regional/seasonal characteristic profiles, surface chlorophyll from 43,000 grid-points from monthly Coastal Zone Colour Scanner images, and about 23,000 monthly mean mixed-layer depths, together with other oceanographic variables, a two-level partition was created to adequately represent regional differences in the expression of the Sverdrup model. The first partition is into the 4 biomes, following the usage of this term by terrestrial ecologists to mean a region of relatively uniform dominant vegetation type, with its associated flora and fauna: grassland, tundra, steppe, humid forest and so on (Golley 1993). Secondly, these biomes are each partitioned into a number of regional entities, the biogeochemical provinces. It is at this geographic areal level that the LME's exist.

Table 16-1. Countries Participating in GEF/Large Marine Ecosystem Projects

Approved GEF Projects

LME	Countries
Gulf of Guinea (6)	Benin, Cameroon, Côte d'Ivoire, Ghana, Nigeria, Togo[a]
Yellow Sea (2)	China, Korea
Patagonia Shelf/Maritime Front (2)	Argentina, Uruguay
Baltic (9)	Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, Sweden
Benguela Current (3)	Angola,[b] Namibia, South Africa[b]
South China Sea (7)	Cambodia, China, Indonesia, Malaysia, Philippines, Thailand, Vietnam
Black Sea (6)	Bulgaria, Georgia, Romania, Russian Federation, Turkey,[b] Ukraine
Mediterranean (19)	Albania, Algeria, Bosnia-Herzegovina, Croatia, Egypt,[b] France, Greece, Israel, Italy, Lebanon, Libya, Morocco,[b] Slovenia, Spain, Syria, Tunisia, Turkey, Yugoslavia, Portugal
Red Sea (7)	Djibouti, Egypt, Jordan, Saudi Arabia, Somalia, Sudan, Yemen
Western Pacific Warm Water Pool-SIDS (13)	Cook Islands, Micronesia, Fuji, Kiribati, Marshall Islands, Nauru, Niue, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu
	Total number of countries: 72[c]

GEF Projects in the Preparation Stage

LME	Countries
Canary Current (7)	Cape Verde, Gambia, Guinea,[b] Guinea-Bissau,[b] Mauritania, Morocco, Senegal
Bay of Bengal (8)	Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka, Thailand
Humboldt Current (2)	Chile, Peru
Guinea Current (16)	Angola, Benin, Cameroon, Congo, Democratic Republic of the Congo, Côte d'Ivoire, Gabon, Ghana, Equatorial Guinea, Guinea, Guinea-Bissau, Liberia, Nigeria, Sao Tome and Principe, Sierra Leone, Togo
Gulf of Mexico (3)	Cuba,[b] Mexico,[b] United States
Agulhus/Somali Currents (8)	Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, South Africa, Tanzania
Caribbean LME (23)	Antigua and Barbuda, The Bahamas, Barbados, Belize, Columbia, Costa Rica, Cuba, Grenada, Dominica, Dominican Republic, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, Venezuela
	Total number of countries: 54[c]

[a]The six countries participating in the Gulf of Guinea project also appear in a GEF/LME project in the preparatory phase
[b]Countries that are participating in more than one GEF/LME project
[c]Adjusted for multiple listings

LARGE MARINE ECOSYSTEMS

The term 'Large Marine Ecosystem' (LME) is used to distinguish regions of ocean space encompassing coastal areas out to the seaward boundary of continental shelves and the outer margins of coastal current systems. As such, LMEs are regions of the order of 200,000 km^2 or greater, characterized by distinct bathymetry, hydrography, productivity and trophic patterns (Sherman *et al.* 1991; 1996; 1999a; 1999b; Sherman 1994; Sherman and Duda 1999a; 1999a; 1999b; 1999c; IOC 2002). The 64 LMEs are the source of more than 90 percent of the world's annual marine fisheries yields. Also, most of the global ocean pollution, overexploitation, and coastal habitat alteration occur within these 64 LMEs. They provide, therefore, a convenient framework for addressing issues of natural resources management. Moreover, given that most of them border developing countries, LMEs also provide a framework for addressing issues related to economic development.

Also, as part of the collaboration between the Sea Around Us Project (details at www. saup.fisheries.ubc.ca) and the FishBase project (Froese and Pauly 1999), the world's marine fishes (about 15,000 species; see above) have been assigned to BGCPs and LMEs, if somewhat tentatively in a few cases. We note that this work, which relied on a large number of local ichthyofaunal lists, required about 12 person-months to complete. However, it would have required much longer had it been necessary first to compile a global list of fish species, and to assign them directly to the BGCP, without prior assignment to FAO areas, countries, and oceanic islands, as is provided by FishBase (Froese and Pauly 1999; www.fishbase.org). This point is even more important with regard to invertebrate groups, whose global distribution will have to be mapped, in the long term, in a manner compatible to that used for fishes. This should, for example, be an important component of the Ocean Biogeographic Information System currently under consideration in the USA.

Various development agencies, notably the Global Environment Facility (GEF), the United Nations Development Programme, the UN Environment Programme, the UN Industrial Development Organization, and the World Bank have endorsed the LME concept as framework for several of their international assistance projects, for example in the Gulf of Guinea, the Yellow Sea, and the Benguela Current, with additional projects forthcoming (Sherman and Duda 1999). Table 16-1 shows the numbers of countries currently represented in transboundary LME projects being funded by or in preparation for the GEF. Given this considerable amount of interest, it is fortunate that a number of BGCPs, in the coastal domain, are nearly congruent with the 64 LMEs. Thus, Figure 16-3 illustrates the areal congruities between 19

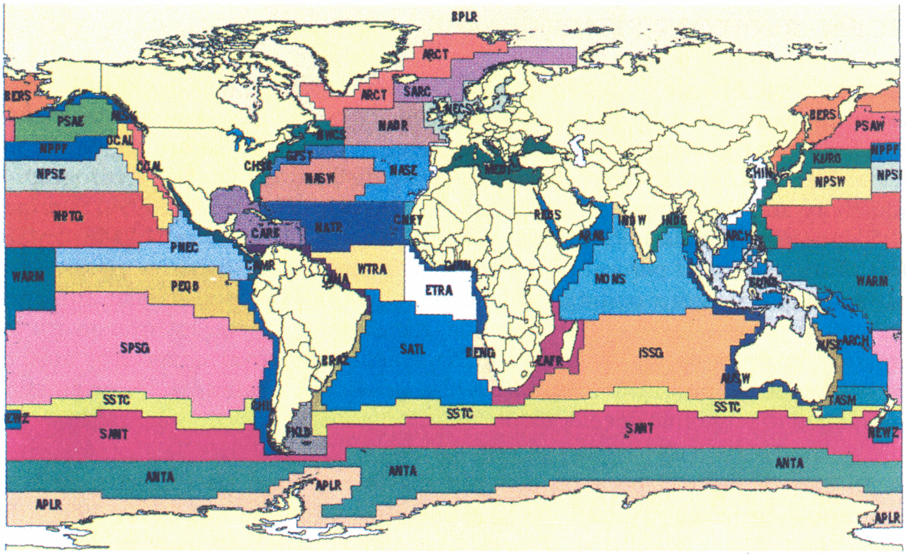

Figure 16-2. Map of the world ocean's 57 biogeochemical provinces, the second level in our proposed classification of the world oceans. (The borders of a few disjunct provinces, notably ARCH, were simplified; detailed file available from http://saup.fisheries.ubc.ca/lme/lme.asp).

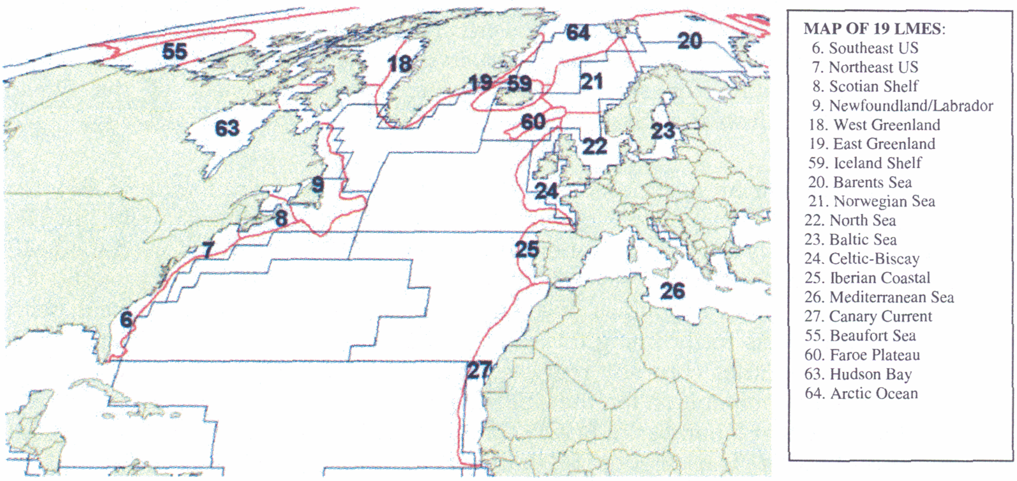

Figure 16-3. Map shows areal congruities between Coastal Biome biogeochemical provinces (BGCPs designated by straight lines) and the numbered Large Marine Ecosystems outlined in red (LMEs numbers are from the LME map, next page). Map by Adrian Kitchingman, UBC.

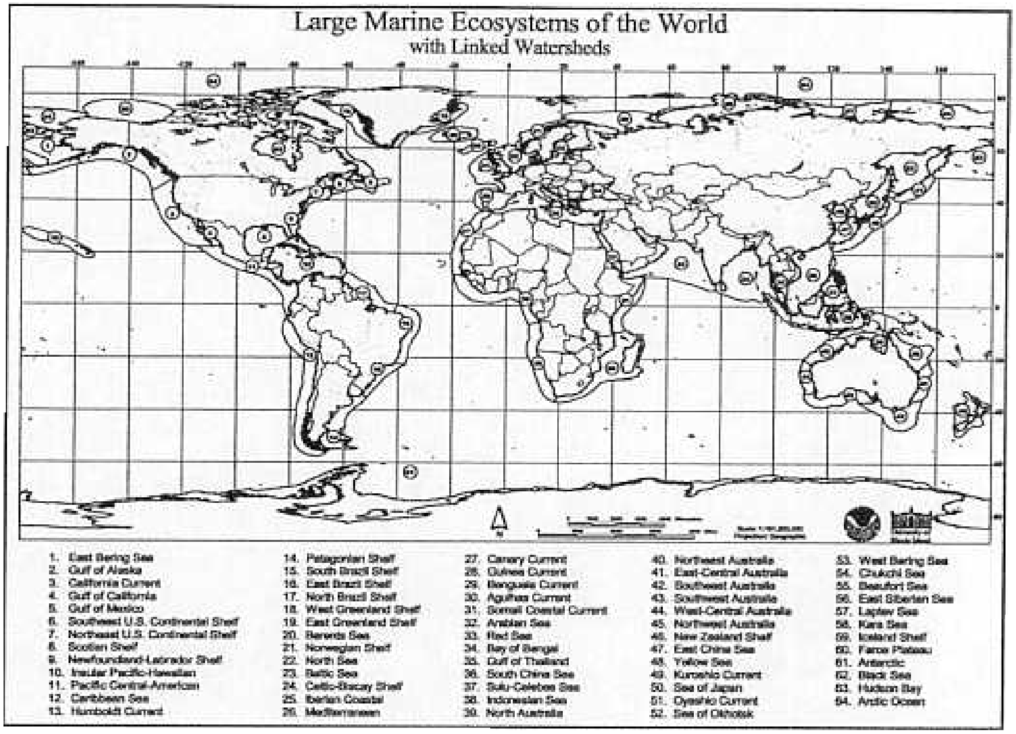

Figure 16-4. Map of the 64 Large Marine Ecosystems of the World

LMEs and the BGCPs of the same regions. A map for the global oceans, depicting the boundaries of all 64 LMEs is shown in Figure 16-4 and at www.lme.noaa.gov and www.edc.uri.edu/lme.

This mapping provides, we believe, the elements that had been lacking within each of the systems thus rendered compatible. Coastal BGCPs often overlap with LMEs that are, by definition, science-based units for fisheries and coastal area assessment and management. The LMEs obtain, via their incorporation into the scheme of biomes and BCGPs as discussed above, borders (here implemented in steps of half-degree cells), that allow GIS-based computation of system properties, such as mean depth, temperature, primary production (Figure 16-5), and other ecosystem attributes.

Another consideration is that our scheme for including access to LMEs together with BGCPs and biome level assessments can be used as an ecological complement to the coarse stratification scheme used by the Food and Agriculture Organization of the United Nations (FAO) to present global marine fisheries data, and which relies on 18 FAO statistical areas (7 for the Atlantic Ocean, 3 for the Indian Ocean and 8 for the Pacific Ocean). Table 16-2 lists examples of ecosystem data products available or soon to be available online.

Table 16-2. Ecosystem data products available or soon to be available on the University of British Columbia (UBC) (www.saup.fisheries.ubc.ca) and University of Rhode Island (URI) (www.edc.uri.edu/lme) websites:

- The bathymetry of the LME areas;
- The percentage of the world's ocean space for each LME
- The percentage of the world's coral reef area within the LME;
- The percentage of the world's gazetted seamounts within the LME;
- Productivity in $gC/M^2/yr$ as SeaWifs derived median values;
- Hot link to lists of fish found in the LME as recorded in FishBase;
- Hot link to Lindeman pyramid (trophic levels) of species in LMEs;
- Access to graphs showing multidecadal trends in catch composition (currently 12 groups: anchovies, herring-like, perch-like, tuna & billfishes, cod-like, salmon/smelt, flatfishes, Scorpionfishes, sharks & rays, crustaceans, molluscs, and 'others') for LMEs from 1950 to 2000;
- Images of selected oceanographic features within LMEs including SST and temperature profiles.
- The 64 LMEs, along with selected summary data, are depicted at websites www.lme.noaa.gov and at www.edc.uri.edu/lme.

To facilitate comparisons between catch data stratified by these two schemes, we have split the five circumpolar BCGPs into ocean-specific provinces. This procedure enables 'closure' of the Atlantic, Indian and Pacific oceans and thus allows direct comparisons, at least at ocean-level scale, between catch data stratified within the scheme proposed here, and that used by FAO for its global catch database. In this context, we have assigned the catches in the global FAO data set to BGCPs and LMEs using locally-derived data sets. Among other things, this allows for rapidly arraying fisheries catches and related ecological data for comparative analyses.

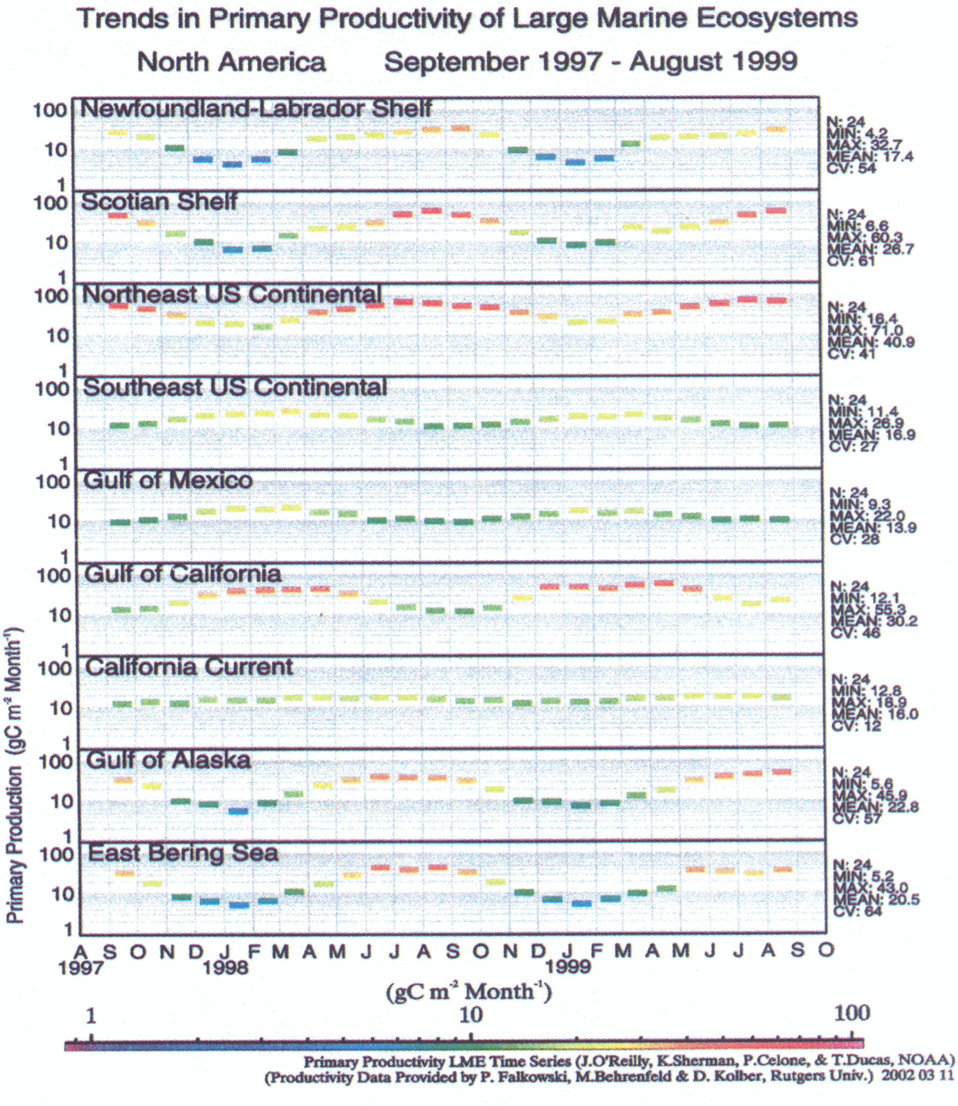

Figure 16-5. Trends in Primary Productivity of the Large Marine Ecosystems of North America, September 1997 - August 1999. Productivity data are based on SeaWiFS data and the Behrenfeld & Falkowski 1997 model. Primary productivity estimates were provided by P. Falkowski, M. Behrenfeld and D. Kolber, Rutgers University.

Table 16-3. Hierarchical relationships among the global ocean Biomes and Provinces, and the 64 LMEs that are merged with the biogeochemical coastal provinces.

<table>
<tr><th colspan="6">----POLAR BIOME----</th></tr>
<tr><td colspan="2">BOREAL PROVINCES
Hudson Bay LME
Beaufort Sea LME
Barents Sea LME
Kara Sea LME
Laptev Sea LME
East Siberian Sea LME
Chukchi Sea LME
Arctic Ocean LME</td><td colspan="2">PACIFIC POLAR PROVINCES
Eastern Bering Sea LME
Western Bering Sea LME</td><td colspan="2">ANTARCTIC POLAR PROVINCES
Antarctic LME</td></tr>
<tr><th colspan="6">----WESTERLIES BIOME----</th></tr>
<tr><th colspan="3">ATLANTIC PROVINCES</th><th colspan="3">PACIFIC PROVINCES</th></tr>
<tr><td colspan="3">Mediterranean Sea LME
Canary Current LME
Guinea Current LME
Benguela Current LME</td><td colspan="3">Kuroshio Current LME
Oyashio Current LME
Gulf of Alaska LME</td></tr>
<tr><th colspan="6">----TRADE WINDS BIOME----</th></tr>
<tr><th colspan="3">ATLANTIC PROVINCES</th><th colspan="3">PACIFIC PROVINCES</th></tr>
<tr><td colspan="3">Caribbean Sea LME
Gulf of Mexico LME</td><td colspan="3">Insular Pacific Hawaiian LME</td></tr>
<tr><th colspan="6">----COASTAL BIOME----</th></tr>
<tr><th colspan="6">NW ATLANTIC SHELVES PROVINCES</th></tr>
<tr><td colspan="3">Scotian Shelf LME
Newfoundland-Labrador Shelf LME</td><td colspan="3">NE US Continental Shelf LME
SE US Continental Shelf LME</td></tr>
<tr><th colspan="6">NE ATLANTIC SHELVES PROVINCES</th></tr>
<tr><td colspan="3">West Greenland Shelf LME
East Greenland Shelf LME
Iceland Shelf LME
Faroe Plateau LME
Black Sea LME</td><td colspan="3">North Sea LME
Norwegian Sea LME
Celtic-Biscay LME
Baltic Sea LME
Iberian Coastal LME</td></tr>
<tr><th colspan="6">SW ATLANTIC SHELVES PROVINCES</th></tr>
<tr><td colspan="3">East Brazil Shelf LME
Patagonian Shelf LME</td><td colspan="3">North Brazil Shelf LME
South Brazil Shelf LME</td></tr>
<tr><th colspan="6">AUSTRALIAN SHELVES PROVINCES</th></tr>
<tr><td colspan="3">West-Central Australian Shelf
Northwest Australian Shelf
Northeast Australian Shelf
North Australian Shelf LME</td><td colspan="3">East Central Australian Shelf
Southeast Australian Shelf
Southwest Australian Shelf</td></tr>
<tr><th colspan="6">PACIFIC COASTAL PROVINCES</th></tr>
<tr><td colspan="3">Gulf of California LME
California Current LME
Humboldt Current LME
Indonesian Seas LME
Sea of Japan LME
New Zealand LME</td><td colspan="3">Sulu-Celebes Sea LME
Pacific Central American Coastal LME
Sea of Okhotsk LME
Yellow Sea LME
East China Sea LME
South China Sea LME
Gulf of Thailand LME</td></tr>
<tr><th colspan="6">INDIAN OCEAN PROVINCES</th></tr>
<tr><td colspan="3">Bay of Bengal LME
Arabian Sea LME</td><td colspan="3">Somali Current LME
Agulhas Current LME
Red Sea LME</td></tr>
</table>

LMEs lend themselves to Ecopath modeling

The ECOPATH with ECOSIM and ECOSPACE modeling approach has been reviewed in several contributions (Christensen and Pauly 1992; Walters *et al.* 1997, 1999; Pauly Christensen and Walters 2000), and there is no need here to present its working or outputs. ECOPATH models exist for numerous parts of the world (details in www.ecopath.org), including the North Atlantic. Currently, well over 100 models have been published, and more than 1800 people in nearly 100 countries have registered as users of the ECOPATH software system. However, the ecosystem model coverage of various ocean basins is still spotty at best, hence precluding simple raising of flows and rates from ecosystem to basin scales. Thus, a stratification scheme is required, based on the geographic structure outlined above, which can be used to scale models from the sampling area of the field data used to parameterize the models to the wider area that is assumed represented by these same models. The strata for the Atlantic, Pacific, Indian Ocean and Polar regions are presented in Table 16-3.

LMEs are seen here as providing the key level for ecosystem model construction. For each LME, an Ecopath model can be constructed to describe the ecosystem resources and their utilization, and to ensure that the total fisheries catch of each LME is used as output constraint (just as their primary production will be used as input constraint). In addition, our stratification scheme can accommodate any number of additional ECOPATH models for each LME. This can be done so as to simultaneously address the issue of parameter uncertainty, as briefly described below.

The LME ECOPATH models require information on abundance, production and consumption rates and diets for all ecosystem groupings. Such information can be obtained from the following sources:

- Abundance, production and consumption rates, and diets of marine mammals are available from the Sea Around Us database for all (117) species of marine mammals (see also Pauly *et al.* 1998b, Trites and Pauly 1998);
- Fishery catches: available from the spatially structured catch database generated as described above, and covering all species groups;
- Occurrence, biology and ecology of marine fishes: available from FishBase (www.fishbase.org), and available at the LME-level. The relevant FishBase search routine was designed for optimizing extraction of Ecopath-relevant information, and is a result of the ongoing cooperation between FishBase and Sea Around Us projects;
- For marine invertebrates: only limited information (beyond the catches in the FAO database) is available from electronic databases, but a variety of

publications provide extensive information. Production rates can be estimated from the well-founded empirical relationships of Brey (1999), now included in Ecopath;

- Primary production estimates: establishment of a global database aimed at supplying fine grid-level satellite-based estimates of primary production is presently underway through a cooperation between the Space Applications Institute, EC Joint Research Centre, Ispra, Italy, and several authors of the present contribution.

The origin of each set of data (5 rate or state variables for each of the often 20-40 functional groups in a model, plus a diet matrix) can be described and a related confidence interval assigned to each of the input parameters. Confidence intervals can also be estimated, as 'posterior distributions' for the output parameters of models. In addition a module of Ecopath is designed to describe the 'pedigree' of Ecopath models, i.e. the degree to which the models are rooted in locally sampled and reliable data (described in more detail by Christensen and Walters 2000). This module estimates, based on the pedigree of its input data, an overall quality index for each model, which in turn can serve as a weighting factor, as required when dealing with discrepancies (e.g. between local vs. LME-wide catches), i.e., when raising one or several model(s) to the LME level. The LME-level Ecopath models will make up the backbone for our approach for addressing province, basin and global issues related to abundance, productivity, interactions and impacts for ecosystem resources e.g., by trophic levels. Being based on the best available estimates of productivity and utilization of the upper trophic levels, and on productivity for the primary producers, the models are constrained from the top as well as from below.

Where possible the LME-level models will be supplemented with additional models. The procedure for this is:

- New models are assigned to strata, based on the proportion of area covered falling within each of the depth strata < 10 m, 10-50 m, 50-200 m, 200-1000 m, and > 1000 m;
- For each new model, the confidence intervals of input and output parameters are estimated along with the pedigree index of the model;
- The LME-level model is assigned to depth strata using weights based on the relative primary productivity in each of the depth strata;
- Within each of the depth strata productivity, abundance, etc., are raised to the LME level using the quality index of the models as weighting factors for the associated confidence intervals.

With this structure in place, it will be easy to add new models as they become available, and it is feasible to assign confidence intervals to all estimates derived from the analysis.

EXCLUSIVE ECONOMIC ZONES

Exclusive Economic Zones (EEZs) are not science-based and are the most political of the units for which the interrelational database could supply information. Allocating freshwater species and their catches to countries is straightforward, as the international borders of countries are usually well defined. This is more difficult in the marine realm, where the fishes and invertebrates caught off the coast of a given country may be caught outside its territorial waters. The International Law of the Sea provides, at least in principle, a solution to this, in form of Exclusive Economic Zones, usually reaching 200 nautical miles into the open ocean, and linking countries with much of the productive areas, i.e., the shelves, adjacent to their coasts. However, not all countries have an EEZ accepted by all their neighbors, and in certain areas, such as the South China Sea, the same rocky outcrops are claimed by up to half a dozen countries (McManus 1992). It cannot be expected that this and similar situations in other parts of the world will be resolved soon and we cannot expect therefore, that official maps of the EEZ will appear that could be used for assigning fisheries catches to the countries of the world.

Nevertheless, various scholars and institutions have published EEZ maps of various parts of the world (see e.g. Mahon 1987 for the Caribbean), based on the rules for definition of EEZ established by the Law of the Sea Convention (Charney and Alexander 1993). We propose that such maps can be used to derive a coherent single map for the EEZ of the world, especially if care is taken to incorporate into such a map the delimitations so far agreed through bilateral or multilateral treaties (as compiled, e.g., in Charney and Alexander 1993). The advantage of such a map is that, unlike the map of LMEs and provinces mentioned above, it will enable the assignment of fish and other species, and of fisheries catch statistics to countries. This will enable comparisons of various features of the use and productivity of various countries' EEZ, with enough degrees of freedom for multivariate analyses, as are now routinely performed for the land-based resources. It is clear, of course, that such a designation will be unofficial and for scientific purposes only, and that it will have no bearing, implicit or explicit, on the status of any EEZ disputes between sovereign states.

Global distribution of coral reef systems can be quantified

Coral reefs, though presently under threat throughout much of their range (Buddemeier and Smith 1999), support important fisheries wherever they occur (Munro 1996). However, quantifying these catches in reliable fashion has proven particularly difficult. One reason is that most countries with coral reefs had administrative infrastructures that precluded detailed monitoring of their fisheries. As suggested by Smith (1978), who performed the first analysis of this type, global assessment of present and potential fisheries yields from coral reefs would be much improved by comparative studies wherein the coral reef fish and invertebrate catches from various EEZs would be matched against the surface area of coral reefs within these same EEZs.

However, while it is possible to assign to coral reefs, at least roughly, a fraction of the catches of each country with reefs in the global FAO fisheries catch database, a matching set of coral reef area per country is not available, despite various global reviews of coral reef distribution (see e.g. Wells 1988; Polunin and Roberts 1996).

The model of Kleypas et al. (1999) can be used, however, to estimate expected coral reef area for any part of the world ocean with a well defined depth, temperature and light regime, and thus can be used to predict coral reef areas within each of the EEZ defined above. We anticipate, once this model becomes widely available, that plots of coral reef fish and/or invertebrate catches vs. reef area will allow us to identify countries with problematic catch data, and/or estimated coral reef areas, and thus to gradually improve the underlying databases and models. Much progress is, however, being made toward making global maps of coral reef distribution (and that of other critical habitats) available by the World Conservation Monitoring Centre (http://www.unep-wcmc.org/marine/data/coral_mangrove/marine.maps.main.html).

Spatial expression of fisheries catch data

Fisheries catches are usually not reported on a per-area basis (e.g. as $t{\cdot}km^2 \cdot year^{-1}$), though the areas from which they are derived are often specified. Maps of catch per area are rare, and indeed exist only for local studies, often pertaining to single-species fisheries. Thus, one additional reason for the hierarchical system proposed above is that it would allow, and make worthwhile, consistent, basin-scale and ocean-wide mapping of catches onto the ecosystems from which they originate. We have initiated the emergence of such global maps through a procedure described in Watson *et al.* (2002) in which fisheries data reported by countries to FAO for taxa of differing levels of identification (ranging from species to 'miscellaneous marine fishes') for the large FAO statistical areas could be assigned to spatial cells measuring one half degree of latitude by one half degree of longitude
(see http://saup.fisheries.ubc.ca/lme/CatchAllocate.htm)

A database of the global distribution of commercial fisheries species was developed using information from a variety of sources including the FAO, FishBase, and experts on various resource species or groups. Some distributions were specific; others provided depth or latitudinal limits, or simple presence/absence data. A rule-based spatial disaggregation process was used which determined the intersection set of spatial cells within the broad statistical area for which the statistics were provided to FAO, the global distribution of the reported species, and the cells to which the reporting nation had access through fishing agreements. The reported catch tonnage was then proportioned within this set of cells.

CONCLUSIONS

The ecosystem classification proposed here is not meant as a panacea that will solve all our biogeographical problems, or all spatial problems of fisheries. It should not be necessary to stress this; however, it is likely that some readers will think we believe it. We don't. However, we know that no telephone registry would ever emerge, if regular debates were held as to the optimal way to arrange the letters in the alphabet. The ecosystem classification proposed here has been implemented globally by FishBase, which assigns all marine fish species so far described to their LME(s). It will also be used to give a geographic structure to an unofficial, 'spatialized' version of the FAO database of global fisheries catches (see above), thus complementing the atlas of tuna catches compiled by Fonteneau (1998), and allowing both to be related to estimates of primary production for example, mapped in similar fashion by Longhurst *et al.* (1995) and by O'Reilly and Zetlin (1998). Moreover, this classification is fully compatible with the LME approach of Sherman and co-workers, which has led to an extensive documentation of management issues at the LME scale (see references in Sherman and Duda 1999), and a number of field projects designed to address these issues, funded by various international granting agencies (Table 16-1). The merger of offshore biogeochemical biomes and provinces with the more coastal and ecologically defined LMEs provides a hierarchical framework for moving up from LMEs to global scale changes in ecosystem states, and scaling down from open-water pelagic seas to coastal LMEs. It is now possible with the GIS framework to better account for impacts on marine ecosystems of water mass and current perturbations, movements of highly migratory species (whales, tunas, billfish, turtles), changes in coastal pelagic and demersal species biodiversity and biomass yields, the spatial advances in eutrophication, and the frequency and extent of pollution events. Thus, we invite colleagues to join us in expressing their results using the classification and definitions proposed here. To support this collaboration, we will supply, via the Internet, tables presenting the details of the classification by half-degree cells.

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