

ECOLOGICAL GEOGRAPHY AS FRAMEWORK FOR A TRANSITION TOWARD RESPONSIBLE FISHING

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ABSTRACT

Meeting the widely expressed requirement that fisheries should somehow be managed on an “ecosystem basis” implies that fisheries-relevant ecological processes, and the fisheries themselves, should be documented in the form of maps. This allows recovery, in intuitive fashion, of at least some of the many dimensions of the complex ecosystems in which the fisheries are embedded.

The implied transition, in fisheries science, from bi-variate time series, to maps as major heuristic devices has a number of implications – some obvious, some less so – of which a number are here discussed and illustrated. Among the issues covered are: (i) the requirement for a consensus taxonomy of large marine ecosystems; (ii) the need to construct fisheries catch maps in the absence of positive records of what was caught where; (iii) the proper identification of one’s audience; and (iv) the mapping of marine protected areas and reserves.

The seriousness of the fisheries crisis is emphasized in the process, and the case is made that fisheries, if ever they are going to achieve some measure of sustainability – however defined – will ultimately have to be limited not only through the amount of effort they can effectively deploy, but also limited in space, leading to a change to the defaults under which fisheries operate, currently set such that ALL aquatic wildlife can be exploited, if under some restrictions.

INTRODUCTION

[1] Fisheries worldwide are in serious trouble. There is perhaps no need to document this, but we shall still present a single graph, a time series of global marine catches, with and without the catches from China and of Peruvian anchoveta, which jointly mask the clear declining trend evident in the rest of the world’s fisheries and species (Figure 1).

[2] This crisis has many aspects and proposed solutions, and one of the latter is the widely expressed requirement that fisheries management should somehow be put on an ecosystem basis – even though what this means is not yet very clear (NRC, 1999).

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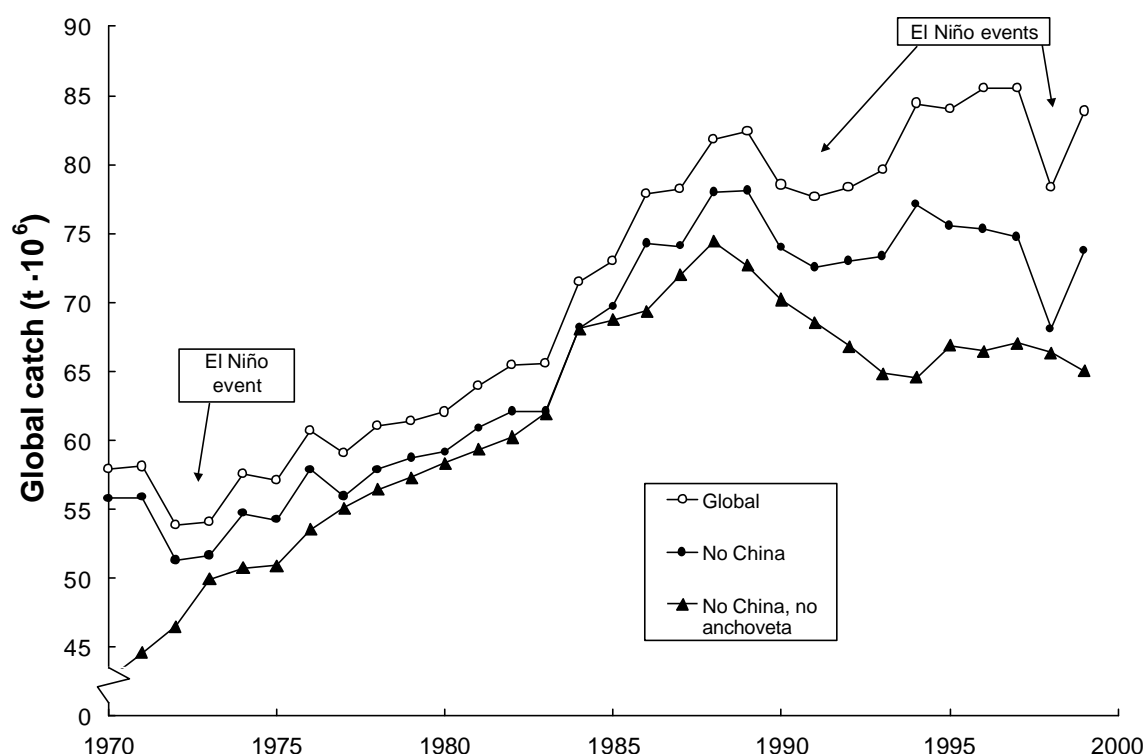


Figure 1. Trend in world marine fisheries catches, as reported by FAO, with and without (i) the catches from China (incl. Hong Kong and Macau, but excl. Taiwan) from Statistical Area 61 (Northwestern Pacific), which are massively over-reported (Watson *et al.*, in press), and (ii) the catches of Peruvian anchoveta, whose fluctuations largely reflect El Niño events. Removal of these two series unmasks a strong declining trend for the rest of the world's fisheries, confirming the perception of widespread fisheries failures.

[3] The most common exhibits, in fisheries science, so far, have usually been time series of key variables, e.g. catch, fishing mortality, or spawning biomass. Such time series are usually hard to assemble, and their value increases with time (i.e. with the number of generations they encompass). Hence the enormous value (both in terms of the costs they embody, and of the insights they led to) of the recruitment time series assembled by R.A. Myers and collaborators (e.g. Myers *et al.*, 1999).

[4] Indeed, the bivariate plots representing time series serve among fisheries scientists as key heuristic device: we work hard to assemble them, show them to colleagues (see Figure 1), and jointly ponder on their features, such as the amount of contrast they do or do not incorporate (Hilborn and Walters, 1992). Also, a huge number of methods have been developed to analyse such plots, ranging from time-series analysis (Chatfield, 1984) and other statistical methods (regression, etc.) to simulation models, e.g., ECOSIM (see Walters *et al.*, 1997), designed to produce (i.e. predict) time series.

[5] However, fisheries, embedded as they are in natural ecosystems, and relying as they do on natural fluxes of these systems, depend on the features of places. Thus, while we emphasize the variability of fisheries in time, we tend to lose track of their variability in space (Samb and Pauly, 2000). Indeed, we hardly use maps to discuss fisheries (except for tunas, see below). Maps, clearly, will be an important part of ecosystem-based management – though obviously it will not be all.

[6] Maps were crucial to the emergence of the modern world, as they catalogued the countries newly discovered by the European powers, and the best routes to their riches. The emergence of physical oceanography as a discipline of its own was also mediated by maps; indeed they are the currency that Commodore Matthew Maury (1806-1873), one of the founders of physical

oceanography, used to 'pay' for the current, wind and depth observations that mariners sent him. Even our humble science of fisheries used maps to represent some of its newly acquired knowledge (Garstang, 1909; Figure 2). Why we later neglected the device so successfully used by this and other pioneers of fisheries science to summarize their knowledge on the biology of North Sea or other fish need not be pursued here. What we can do, however, is to point out that the availability of powerful, PC-based Geographical Information System (GIS) technology makes it possible for maps to return to the central role that maps had formerly in summarizing knowledge in intuitive fashion, and hence this contribution.

[7] A number of issues will have to be sorted out, however, before fisheries maps become a routine tool in fisheries sciences, viz:

- ecosystem taxonomy and classification;
- fisheries catch maps and related issues of scale;
- using maps to reach new audiences; and
- maps and space-based fisheries management.

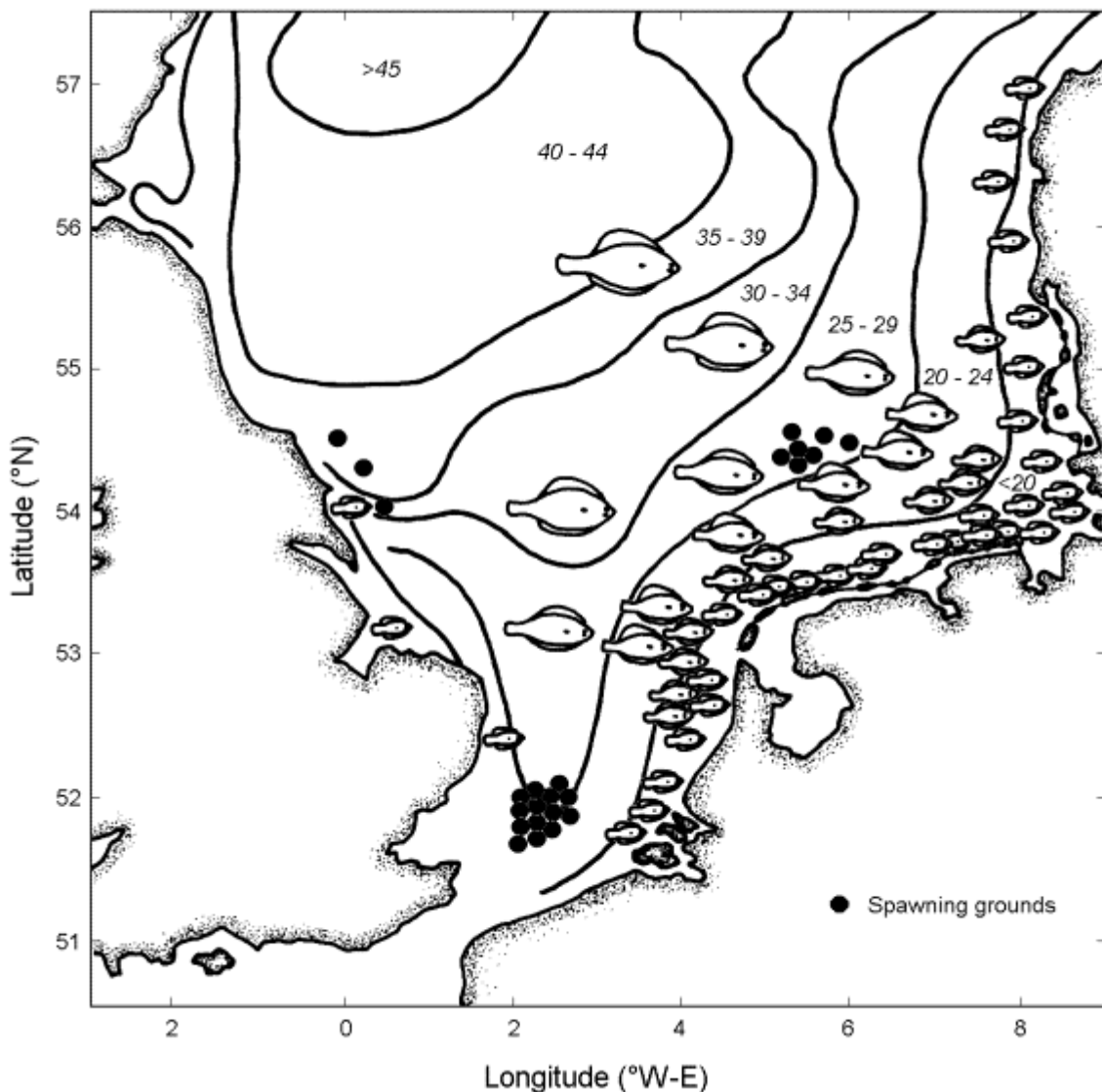


Figure 2. Schematic representation of the distribution of plaice (*Pleuronectes platessa*) in the North Sea, illustrating the key aspects of its life history (modified from Garstang, 1909). Contrast this information-rich map with the text that would be required to convey the same amount of information.

ECOSYSTEM TAXONOMY AND CLASSIFICATION

[8] Using fisheries maps for putting fisheries in an ecosystem context assumes that some agreement exists as to the definition and location of marine ecosystems. Indeed, without a prior definition of ecosystem boundaries, there is a real danger that the fisheries to be studied will themselves be used to pragmatically define the boundaries of ecosystems, as happened earlier with traditional biogeography, in which the distribution of the diverse groups mapped by specialists led to the definition of taxa-specific geographies, all mutually incompatible (see Ekman, 1967). Moreover, these taxa-specific geographies ended up being useless, even to those who had proposed them, due to the circularity of their definition. Thus, if the distribution of species within a given taxon defines a system of, say 'provinces,' then features of these provinces diverging from what would be suggested (given the underlying physical structure of the ocean) will be not be identified, nor any resulting improvement to the system of provinces.

[9] The way out of this circularity is, of course, to use predefined ecosystem definitions (and boundaries), independent of (but hopefully with deep affinities to) the taxa or processes (here: fisheries) that are being mapped. There are at present three broad taxonomies-*cum*-classification systems representing the world ocean at scales below that defined by entire oceans, or their major basins, namely:

- The system of 18 Statistical Areas used by FAO to report global fisheries catches.
- The Large Marine Ecosystems defined by K. Sherman and collaborators.
- The system of four Biomes and 57 Biogeochemical Provinces described by Longhurst (1998) and presented in Box 1.

Box 1. Biogeographical provinces

Until recently, a 'geography of the sea' did not exist that was suitable for describing, in standardized fashion, the distribution of all marine organisms, despite a history of oceanographic research starting with the *Challenger* Expedition (1872 to 1876). Numerous maps did exist in which this or that oceanographic parameter, or the distribution of a few organisms had been used to draw a map of some sort (see, e.g., Ekman, 1967). However, no tests were conducted of the ability of these maps to predict distributions other than those from which they were derived: circularity reigned supreme.

Reasons for this are easy to imagine, from the excessive preoccupation of various specialists with their favorite taxonomic groups, to the absence, before the computer revolution, of analytic tools that were up to the task. However, the real reason is probably that developing a truly synoptic vision of the ocean was impossible before the advent of satellite-based oceanography.

Satellites cannot 'see' very deep into the sea. However, what satellites do see is the very stuff that generates fundamental differences between ocean provinces: sea surface temperatures and their seasonal fluctuations, and pigments such as chlorophyll, and their fluctuations. Marine systems differ from terrestrial systems in that their productivity is essentially a function of nutrient inputs to the illuminated layers. This gives a structuring role to the physical processes that enrich surface waters with nutrients from deeper layers, such as wind-induced mixing, fronts, upwellings, etc. (Longhurst, 1995). Thus, the location, duration and amplitude of deep nutrient inputs into different oceanic regions – as reflected in their chlorophyll standing stocks – largely define the upper trophic level biomasses and fluxes that can be maintained in these regions. This is the reason why satellite images reflect fundamental features of the ocean, while maps based on the distribution of various organisms – even 'indicator' organisms – can only reflect second-order phenomena.

T. Platt, S. Sathyadranath and A.R. Longhurst are among the first to have realized this, and thus their stratification of the ocean, and the estimates of global primary production based thereon, are far superior to earlier attempts. The system of biomes and biogeochemical provinces defined in the process was further refined in a book by Longhurst (1998), the review of which (Pauly, 1999) provides the basis for this box.

One interesting aspect of this stratification (or classification) is that the biogeochemical provinces (BGCP) in the 'coastal biome' thus defined largely overlap with the Large Marine Ecosystems (LME) of Sherman and collaborators (Pauly *et al.*, 2000; see Figures 4 and 5a&b). This correspondence should make it possible to integrate in a common framework the vast amount of geo-referenced information on marine biological processes that is now available, and to finally make widely available to practitioners the data that so many of them still claim we do not have.

[10] The FAO's system of statistical areas is at present the only device routinely used for breaking global catches into geographic space (Figure 3 – at end of paper). These 18 FAO areas are rather large, and have boundaries based largely on political considerations. Therefore, they can not be used directly to put fisheries onto an ecosystem context; however, they do provide some constraints for the rule-based construction of fisheries maps described in Box 2.

[11] Initially, Large Marine Ecosystems (LMEs) were only what the three words in their name imply, namely marine ecosystems defined such as to cover a large area (200 000 km² or more). Gradually, however, and mainly due to the work of K. Sherman and collaborators, LMEs became restricted to an explicit list of 50 coastal entities (Figure 4 – at end of paper), with a dozen recently added (see www.edc.uri.edu/lme/default.htm), broadly defined by physical features (presence of shelves, coastal currents, fronts, etc.), and documented in a growing number of books (listed in www.edc.uri.edu/lme/publications.htm).

[12] One major conservation-oriented non-governmental organization (NGO), the World Conservation Union (IUCN), has endorsed the concept, with the intention of using it for reporting on marine biodiversity. Similarly, FishBase, the global database of fish, has linked all species of marine fishes in the world (about 15 000 species) with the LME in which they occur (see Table 1).

[13] One important features of LMEs is that, while covering only 18% of the world's oceans, they accounted for 75% of the world's fisheries catches in 1999. These figures, based on the 50 LMEs listed in Sherman and Duda (1999) will increase when recalculated based on the 62 LME in Figure 4 (at end of paper).

[14] The most rigorous division of the world ocean, at least in terms of biological oceanography is, however, the system described by Longhurst (1998), based on Platt and Sathyendranath (1988), Sathyendranath et al. (1995), and Longhurst (1995). (See Box 1 and Figures 5a&b – at end of

Box 2. Construction of fisheries maps (by R. Watson)

The records used for constructing detailed catch maps (here: by ½ degree lat./log. cells) for an ocean basin (or worldwide for global maps) for a given year are based either (1) exclusively on FAO statistics on the countries fishing in that basin, or on the FAO global statistics, or (2) on FAO statistics complemented with time series of discards, estimates of illegal catches, etc., or (3) statistics that substitute for those of FAO, e.g. ICES statistics in the Northeastern Atlantic, complemented as in (2) or not (A in Figure 6a).

These are processed as a set of database records by first dis-aggregating the statistics for the generalized group into records at lower taxonomic levels (B in Figure 6a), as necessary for many countries where the reported catch composition is very aggregated, such as China, and using a catch composition interpolated from that of immediate neighbours with detailed statistics, here Taiwan and South Korea). Then, each taxon represented in a landing record is looked up in a database of species-specific spatial distributions that identifies the subset of spatial cells of the world's oceans from which the catch record in question could originate.

The country reporting (fishing) is then looked up in (a) a database of fishing access agreements (updated from Anon. 1998), and (b) a database identifying the Exclusive Economic Zones of the world's countries (see Table 1), which jointly identify the spatial cells that are available for that country to fish in (including the EEZ of other countries for which arrangements exist). The FAO area that the statistic was reported from is also used to identify a set of spatial cells from which the catch may originate. These sets of spatial cells are then compared and if there are no overlapping cells the landing is not allocated and an 'error report' is logged (see 'no' in Figure 6b). Otherwise, the reported landing is assigned among overlapping cells in proportion to their areas. Thus, landing rates (t/km²/year) are accumulated in each cell as each record is processed (currently, we are able to allocate over 95% of the world catch to cells; the remainder reflects error reports whose resolution we expect to contribute to cleaning up the underlying databases. In this way, a grid map of landing rates is built up as each landing record is processed (D in Figures 6a&b).

Though each record is processed for the taxonomic level it is reported at (after dis-aggregation), the results can be reassembled into larger groups as required, e.g. for statistical models (E in Figures 6a&b). Alternatively, the taxon- and cell-specific catch records can be multiplied by its corresponding market price, yielding maps of catch value, a new product for which the *Sea Around Us Project* envisages a large range of uses.

paper). At the highest level, this hierarchical classification is based on a division of the world ocean into four biomes. In the Polar biome, covering only 6% of the world ocean, vertical density structure is very largely determined by low-salinity water derived from ice-melt each spring. In the Westerlies biome, between the Polar fronts and the Subtropical Convergence, large seasonal differences in mixed-layer depth are forced by seasonality in surface irradiance and wind stress, inducing strong seasonality of biological processes, characteristically including a spring bloom of phytoplankton. The Trade-wind biome lies across the equatorial regions, between the boreal and austral Subtropical convergences, where 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. Finally, the Coastal Boundary biome is composed of the continental shelves and the adjacent slopes, i.e. from the coastlines to the oceanographic front usually found at the shelf-edge (Pauly *et al.*, 2000).

[15] Next, the biomes are subdivided into 57 biogeochemical provinces (BGCP), defined by satellite imagery and physical oceanography. Each BGCP is characterized by a distinct regime of physically-driven water mixing, leading to a distinct pattern of (seasonal) supply of nutrients to the euphotic zone, and hence primary production (Longhurst *et al.*, 1995, Longhurst, 1998; see also Table 1).

[16] In this scheme, the BGCP comprising coastal biomes largely overlap with the area covered by the LME mentioned above, and hence the suggestion of a consensus system in Pauly *et al.* (2000), currently being implemented through a collaboration between members of various teams represented by the authors of the consensus statement.

[17] A further advantage of the consensus approach implied by the structure provided by LME/BGCP is that it leads to emphasizing benthic-pelagic coupling, as a single set of ecosystems is proposed for the neritic (shelf) areas of the world. This is appropriate, as it counters the misguided tendency to separate the pelagic and benthic realms, which leads to ecosystems representations that are exceedingly 'open,' and in which benthic-pelagic coupling must be explicitly represented (and thus quantified). Rather, benthic-pelagic coupling should be allowed to appear as an emergent property of neritic food webs, as will occur when one's ecosystem representation includes predators feeding both on benthic and pelagic organisms, and detritus (e.g., marine snow) that is consumed both while sinking, and after it has sedimented. Conversely, there is no need for benthic-pelagic coupling in representations of open ocean systems, where the pelagic (sub)system is largely independent of benthic processes, and can be modelled as such; see e.g. Kitchell *et al.*, 1999.

[18] Another reason to be wary of uncoupling the benthic and pelagic components of neritic systems is that fishing itself tends to turn ecosystems dominated by benthic organism (in terms of biomass or species numbers) into systems dominated by (small) pelagics and planktonic organisms. This feature, initially documented as a response to the stress generated by the combined effects of pollution and overfishing in the North American Great Lakes, has now been shown capable of being induced by fishing alone – at least in principle (see Parsons, 1996). Broadly speaking, this would be due to trophic cascades, wherein less piscivores => more small pelagics => less zooplankton => more phytoplankton. Such indirect effects are very hard to identify in practice, given the contribution of terrigenous fertilizers in regions plagued by algal blooms, such as the Northern Gulf of Mexico (Turner and Rabalais, 1994), or the Inner Gulf of Thailand (Piyakarnchana, 1999). However, the possibility that such effects can occur provides a good additional reason for constructing models of neritic systems that integrate the entire water column, and not only their benthic or pelagic components.

CONSTRUCTION OF CATCH MAPS AND ISSUES OF SCALE

[19] The scope of fisheries science, and of the related components of marine biology, has traditionally been defined by the scale of the fisheries studied (Pauly and Pitcher, 2000), which may range from a few square kilometres or even less (e.g. in the case of fisheries for sessile invertebrates) to thousands of square kilometres in the case of high sea fisheries. However, basin-level analyses are rare, except for tuna fisheries (for which, incidentally, mapping is frequently used; see below).

[20] Over 75% of fisheries landings (in value) are consumed in countries other than those owning the Exclusive Economic Zone (EEZ) in which these landings were realized (based on FAO, 2000). In contrast, only 4-5% of the rice grown in the world is traded internationally (Maclean, 1997). This, by itself, provides a rather good reason why global fisheries maps are appropriate to our times – not to mention the need to quantify the global impacts of fisheries on marine ecosystems.

[21] One objection frequently heard relating to the feasibility of large-scale fisheries maps is the absence of suitable data, widely understood to consist of positive records of where some fishing unit may have caught, at a certain time, a certain quantity of fish (as plotted in tuna atlases (Fonteneau, 1995; see Table 1 for FAO atlas). Such records, usually supplied by the industry, or costly observer programmes, are indeed rather scarce, and, when available, are either presented at very coarse scales (e.g. in 5° scale for the FAO tuna atlas, to mask small-scale patterns with the high concentrations so dear to the industry), or pertain to small areas, and the catch of a limited set of gear. Constructing global fisheries maps from such data, i.e. from the ‘bottom-up,’ does indeed seem unfeasible. However, such ‘positive’ records are not required to construct fisheries catch maps. These can also be constructed from the geographic range of the exploited taxa, and constraints on which parts of that range led to the reported catches, i.e. from ‘negative’ records as it were. The procedure used for this is presented in Box 2 and Figures 6a & 6b, while Table 1 indicates sources of information on the key databases used in the process.

Table 1. Databases (on-line or CD-ROM) used for the construction of fisheries catch maps

Data type	Organization	URL
Fisheries landings	FAO	www.fao.org/fi/statist/FISOFT/FISHPLUS.asp
Tuna and billfish landings by 5° cells	FAO	www.fao.org/fi/atlas/tunabill/english/home.htm
Taxonomy for all species, and ranges for many	FishBase	www.fishbase.org
Distribution of commercial fish and invertebrates	FAO	www.fao.org/fi/sidp/default.htm
Physical ocean data (depths, temp. etc.)	NOAA	www.ngdc.noaa.gov/mgg/global/global.htm
Seasonal patterns by biogeochemical provinces	DFO, Canada	www.mar.dfo-mpo.gc.ca/science/ocean/BedfordBasin/Papers/Longhurst1998/Provinces/EcologicalGeographyOfTheSea.htm
Primary productivity	JRC of the EU	www.me.sai.jrc.it/me-website/contents/shared_utilities/frames/index_windows.htm
Coral reefs	ReefBase	www.reefbase.org
Seamounts	NOAA	www.ngdc.noaa.gov/mgg/global/global.htm
Sea ice extent	Univ Colorado	nsidc.org/index.html
Exclusive economic zones	Veridan Information Solutions	http://www.maritimeboundaries.com/main.htm
Fishing agreements	FAO	(see FAO, 1998) <i>Contact FAO</i>

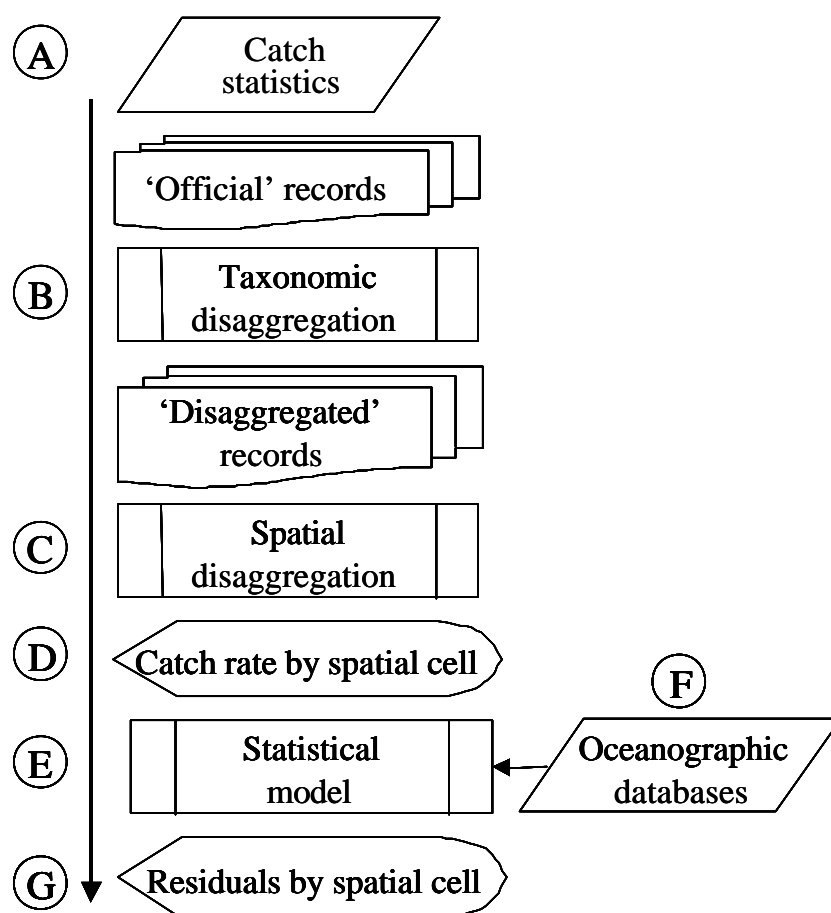


Figure 6a. Schematic representation of algorithm for construction of catch maps in the absence of positive, georeferenced catch records: the algorithm is initiated (in A) with global catch statistics from FAO, or from regional or national sources; its output are cells to which catches have been assigned (see also Figure 5b and Box 2).

[22] This approach works straightforwardly at larger scales (FAO areas, biomes, ocean basins, or global), but not at smaller scales, wholly comprised within the geographic range of a number of resources species, where positive knowledge on fleet operations is required. Issues of scale also show up when dealing with the definition of an ecosystem. Indeed, such issues are implicit in its definition as an ‘area where a set of species interact in characteristic fashion, and generate among them biomass flows that are stronger than the flows linking that its area to adjacent ones’ (Pauly and Froese, 2001). This definition applies to the large scale inherent in the LMEs and BGCPs presented above, but also the small scale (a few hundred metres), where organisms interact to form the food webs that characterize coral reefs, or small lagoon or estuarine systems.

Using maps to reach new audiences

[23] It is not the fishing industry that is asking for fisheries management to be put on an ecosystem basis, but politicians, pressed by conservation-orientated NGOs, themselves expressing public unease about the way marine ecosystems, and especially their more charismatic components (marine mammals, turtles, birds) are being affected by fishing.

[24] Thus, progress in putting fisheries on a ecosystem basis will have to be reported to that audience – quite a change for fisheries scientists accustomed to generate Total Allowable Catches (TACs), communicated to high-level bureaucrats by their superiors, fought by industry representatives, then applied or not to contain a fishery on the ground.

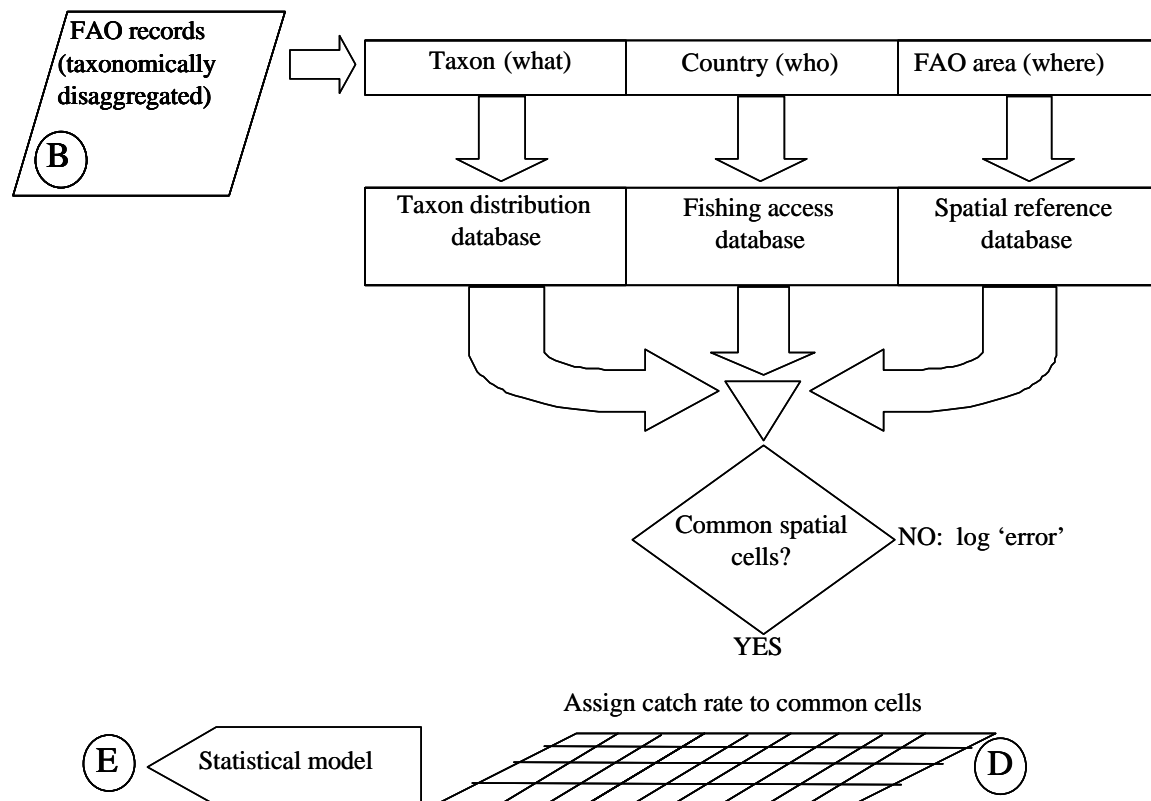


Figure 6b. Schematic representation of algorithm for construction of catch maps in the absence of positive records. A catch record (from FAO database or other source) is evaluated via three criteria (what taxon, by which country, in which FAO area), and can be assigned only when one or more cells meet these criteria. Over 95% of the world catches from FAO can be straightforwardly assigned in this fashion, the remainder providing pointers to corrections of the assignment rules (see also Figure 6a and Box 2).

[25] It may be argued that the public at large will not understand the message conveyed by maps of fisheries and their ecosystem impacts. Yet, everyday, a large part of the population, in most countries of the world, watch television weather programmes, and understand the sophisticated weather maps presented therein, although they are based on millions of data points analysed in quasi-real time by supercomputers, and combine dynamic displays of temperature, atmospheric pressure, cloud cover, risk of precipitation, etc. The public has been able to learn the 'language' of weather maps because (a) it matters, and (b) visual displays presented in intuitive fashion can convey far more information than a text that is read or heard (Tufte, 1983).

[26] Thus, engaging the public and our political representatives in debates about the state of fisheries resources, and about alternative approaches to their utilization and long-term-sustainability, should be possible, if we use the proper format for conveying that information. We believe that maps provide that format, and we have documented this with maps illustrating the decline of piscivorous fishes in the North Atlantic (see Box 3).

[27] It is our belief that without such engagement with the public, the fisheries sector, including the fisheries science that studies it, and the largely captive regulatory agencies that 'manage' the resources, will not be able to halt the decline illustrated by the biomass maps described in Box 3.

Maps and space-based fisheries management

[28] What is striking when examining the catch or biomass maps (Figure 7) above is all show the same trend, at least for the North Atlantic, the only ocean basin we have so far examined in some detail. This is not surprising, given that we did not include local components in the algorithms used to generate these maps. The point, though, is that at the scale we were working (with about 21 000 pixels of ½ degree latitude and longitude), there were no marine reserve, or

other refugia [with biomass trends different from the general downward trend for the North Atlantic as a whole] to consider.

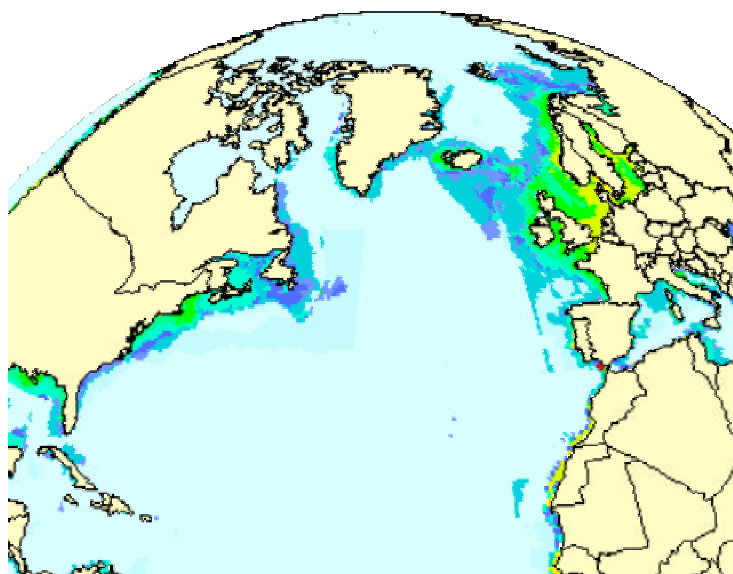


Figure 7. Catch map for the North Atlantic (here: 1990s), constructed as explained in Box 2 and Figures 6a&b, with redder (darker) shades indicating higher catch rates, in $t/km^2/year$. Colour versions of this and similar maps for other periods and areas are available on-line; see Box 3.

[29] Or put differently: there are – at the scale of our pixels, appropriate to represent the distribution ranges of all but small intertidal species – no areas of the North Atlantic where fishes are not exposed to nets and other gear designed for, and extremely effective, at catching them. The deleterious effects of the sort default setting implied here (i.e. that fish can be exploited anywhere, unless regulations state otherwise, rather than the converse) are discussed by Walters (1998).

[30] Put as a map, contrasting areas with fishing (say red) vs. areas without any fishing, this would imply a single colour for the entire the North Atlantic, without any green, or other shades (Figure 8). We are confident that, as for the weather maps presented above, the meaning of this monochromatic map will be widely understood by lay audiences.

[31] Figure 8 would be less dire had it been designed to illustrate the extent of protection for coral reefs and other sensitive coastal systems (e.g. kelp beds). For these, the idea of area-based protection is well accepted, and a number of (mainly small) marine reserves have been created.

[32] Here, high-resolution maps are understood as playing the key role in defining the terms of the debate between different stakeholder groups, namely local residents, small-scale fishers, dive-resort operators, environmental NGOs, etc. In contrast, it may take a while for the management of commercial fisheries to rely on area-based protection as its key tool. When this happens, maps will be there to help us see where we are, and where we should be going.

Acknowledgments

[33] We thank Mr A. Gelchu for shape files of fish distribution; Dr U.R. Sumaila for estimating the fraction of the world's fish catch value that is exported; and our colleagues at FAO for fruitful exchanges. We also thank the Pew Charitable Trusts for their support of the *Sea Around Us Project*.

Box 3. Examples of fisheries 'weather' maps for the North Atlantic (by V. Christensen)

The North Atlantic is one of the best studied marine areas of the world, which is not surprising, since the marine sciences emerged largely along its shores, from 150 to 100 years ago. As a consequence, and contrary to the stubborn beliefs, by various colleagues, in a widespread 'lack of data,' abundant data sets exist which can be used to evaluate the impact of fisheries on North Atlantic ecosystem, one of the goals of the *Sea Around Us Project* (SAUP; see www.fisheries.ubc.ca/projects/SAUP and Pauly and Pitcher, 2000). However, these datasets do not have the form required for analysis. [Note though, that this is always true: it is the analytical process itself which determine the format data should have.]

After opting to present the SAUP analyses in form of 'weather maps,' a two-step approach was used for their construction:

1. Construction of mass-balance food web models for all major shelf areas, and a representative subset of oceanic areas to quantify biomasses at different trophic levels, and for different periods.
2. Extension, using a statistical model, of the biomass estimates in (1) to the entire North Atlantic, and the period from 1950 to 2000.

Item (1) relied on 17 models constructed by a vast number of authors, most associated with national research institutions in the countries concerned (for details, see contributions in Guénette *et al.*, 2001). Importantly, these models included data-rich representations of the North Sea in 1880, and the Newfoundland shelf in 1900, both implying higher biomass of predatory fishes than in the corresponding 1980s models, and several other model pairs, contrasting present biomass with those in the 1970s or 1960s.

The fish biomasses in these models, all constructed using the ECOPATH with ECOSIM software (EwE), were put on a spatial basis using the Ecospace routine of EwE (Walters *et al.*, 1999), using the same ½ degree spatial cells also used to construct catch maps (see Box 2).

Item (2) then consisted of identifying a General Linear Model of the form

$$\text{Biomass}_{t yc} = f(\text{catch}_{yc}; \text{year and physical attribute of } \frac{1}{2} \text{ cell}) \quad \dots 1)$$

wherein the subscripts are t = trophic level, y = year, and c = catch in each ½ degree cell (mapped as presented in Box 2), and where the (bio-)physical attribute (assumed invariable in time) of each cell include mean depth and temperature, primary production, ice cover and other properties (see Christensen *et al.*, 2001, for details).

Examples of the maps thus generated, which indicate a strong decline of predatory fish biomass from 1950 to the present, indicative of 'fishing down marine food webs' (Pauly *et al.*, 1998, 2001) are available on-line (www.fisheries.ubc.ca/projects/SAUP). These maps highlight processes that are rather worrisome and none of the persons (both specialists and laypersons) to whom they have been shown has failed to perceive their analogy to weather maps, and to very bad weather developing over the North Atlantic.

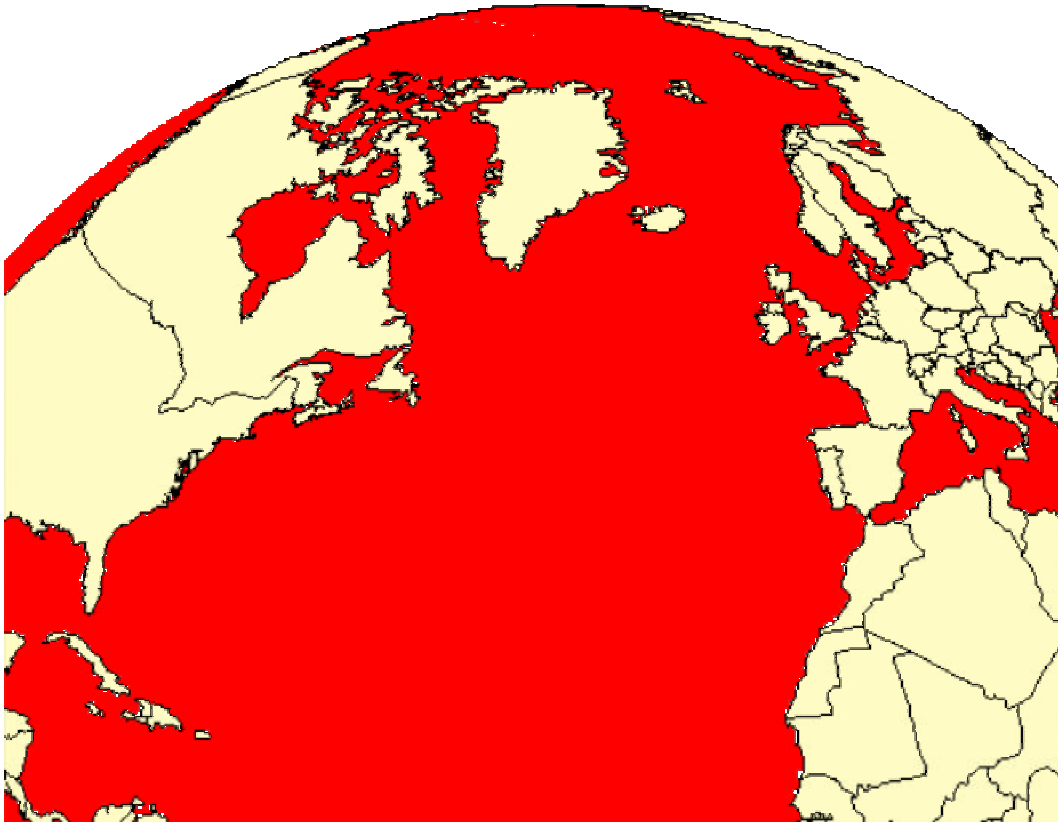
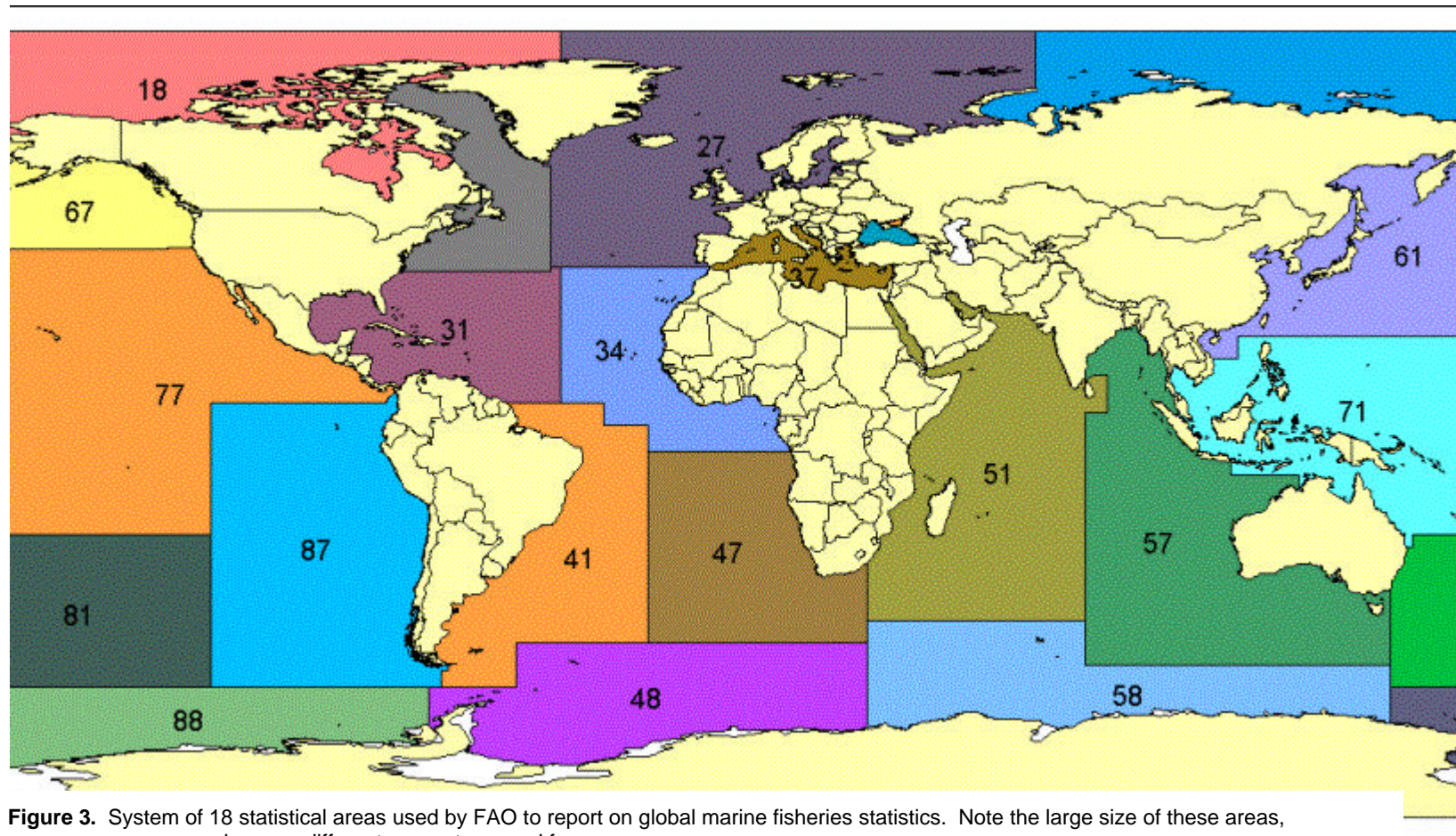


Figure 8. Map of the North Atlantic, with red (dark) identifying those areas where fishing is allowed, and fish killed, and green (light) the areas where no fishing is permitted, thus allowing the resource to recover. Unfortunately, there are no green areas to be seen at the scale of $\frac{1}{2}$ degree cells.
[The authors welcome corrections that would identify recently created refugia]

REFERENCES

- Anon. 1991. *Bartolomew Illustrated World Atlas*. Edinburgh: HarperCollin.,
- Chatfield, C. 1984. *The analysis of time series: an introduction*. London: Chapman & Hall. 286 p.
- Christensen, V., Guénette, S., Heymans, S., Walters, C.J., Watson, R., Zeller, D., & Pauly, D. 2001. Trends in the abundance of high-trophic level fishes in the North Atlantic, 1950 to 2000. In: S. Guénette, V. Christensen, T. Pitcher and D. Pauly (eds). *Fisheries Impacts on North Atlantic Ecosystems: Models and Analyses*. Fisheries Centre Research Reports 9(4) [in press].
- Ekman, S. 1967. *Zoogeography of the sea*. London: Sidgwick & Jackson. 417 p.
- FAO. 1998. FAO's fisheries agreements register (FARISIS). Committee on Fisheries, 23rd Session, Rome, Italy, 15-19 February 1999. (COFI/99/Inf.9 E) 4 p.
- FAO. 2000. Fisheries Trade Flow (1995-1997). *FAO Fisheries Circular*, No.961. 330 p.
- Fonteneau, A. 1998. *Atlas of tropical tuna fisheries*. Paris: Edition ORSTOM.
- Froese, R., & Pauly, D. (eds). *FishBase 2000: Concepts, Design and Data Sources*. Los Baños, Philippines. 344 p.
- Garstang, W. 1909. The distribution of the plaice in the North Sea, Skagerrak and Kattegat, according to size, age and frequency. *Rapp. Counc. int. Explor. Mer.*, **1**: 136-138.
- Guénette, S., Christensen, V., Pitcher, T., & Pauly, D. (eds) 2001. *Fisheries Impacts on North Atlantic Ecosystems: Models and Analyses*. Fisheries Centre Research Reports 9(4) [in press].
- Hilborn, R., & Walters, C.J. 1992. *Quantitative fisheries stock assessment: choice, dynamics and uncertainty*. New York, NY: Chapman & Hall. 570 p.
- Kitchell, J.F., Boggs, C.H., He Xi, & Walters, C.J. 1999. Keystone predators in the Central Pacific. p.665-684, in: *Ecosystem Approaches for Fisheries Management*. Alaska Sea Grant College Program. AK-SG-9901.
- Longhurst, A.R. 1995. Seasonal cycles of pelagic production and consumption. *Progr. Oceanogr.*, **36**: 77-167.
- Longhurst, A.R. 1998. *Ecological Geography of the Sea*. San Diego, CA: Academic Press. 398 p.
- Longhurst, A.R., Sathyendranath, S.A., Platt, T., & Caverhill, C.M. 1995. An estimate of global primary production in the ocean from satellite radiometer data. *J. Plankt. Res.*, **17**: 1245-1271.
- Maclean, J. (ed). *Rice Almanac*. Los Baños, Philippines: IRRI. 181 p.
- Myers, R.A., Bowen, K.G., & Barrowman, N.J. 1999. The maximum reproductive rate of fish at low population sizes. *Can. J. Fish. Aquat. Sci.*, **56**: 2404-2419.
- NRC [National Research Council]. 1999. *Sustaining marine fisheries*. Washington, DC: National Academy Press. 164 p.
- Parsons, T.R. 1996. The impact of industrial fisheries on the trophic structure of marine ecosystems. p.352-357, in: G.A. Polis and K.D. Winnemiller (eds). *Food webs: integration of patterns and dynamics*. New York, NY: Chapman & Hall.
- Pauly, D. 1999. Review of A. Longhurst's "Ecological Geography of the Sea." *TREE*, **14**(3): 118.
- Pauly, D., & Froese, R. 2001. Fish Stocks. p. 801-814 (vol. 2) in: S. Levin (ed). *Encyclopedia of Biodiversity*. San Diego, CA: Academic Press.
- Pauly, D., & Pitcher, T.J. 2000. Assessment and mitigation of fisheries impacts on marine ecosystems: a multidisciplinary approach for basin-scale inferences, applied to the North Atlantic. p.1-12, in: D. Pauly, and T.J. Pitcher (eds). *Methods for Evaluating the Impacts of Fisheries on North Atlantic Ecosystems*. Fisheries Centre Research Reports 8(2). [Available online at www.fisheries.ubc.ca/projects/SAUP]

- Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., & Torres, F.C., Jr. 1998. Fishing down marine food webs. *Science*, **279**: 860-863.
- Pauly, D., Christensen, V., Froese, R., Longhurst, A., Platt, T., Sathyendranath, S., Sherman, K., & Watson, R.. 2000. Mapping fisheries onto marine ecosystems: a proposal for a consensus approach for regional, oceanic and global integration . p.13- 22, in: D. Pauly, and T.J. Pitcher (eds). *Methods for Evaluating the Impacts of Fisheries on North Atlantic Ecosystems*. Fisheries Centre Research Reports 8(2). [Available online at www.fisheries.ubc.ca/projects/SAUP]
- Pauly, D., Palomares, M.L., Froese, R., Sa-a, P., Vakily, M., Preikshot, D., & Wallace, S. 2001. Fishing down Canadian aquatic food webs. *Can. J. Fish. Aquat. Sci.*, **58**: 51-62.
- Pitcher, T., Alder, J., & Pauly, D. (eds). 2001. *Fisheries Impacts on North Atlantic Ecosystems: Evaluations and Policy Exploration*. Fisheries Centre Research Reports 9(5) [in press].
- Piyakarnchana, T. 1999. Changing state and health of the Gulf of Thailand Large Marine Ecosystem. p.240-250, in: K. Sherman and Qisheng Tang (eds). *Large Marine Ecosystems: Assessment, Sustainability and Management*. Malden, UK: Blackwell Science.
- Platt, T., & Sathyendranath, S.A. 1988. Oceanic primary production: estimation by remote sensing at local and regional scales. *Science*, **241**: 1613-1620.
- Samb, B., & Pauly, D. 2000. On 'variability' as a sampling artefact: the case of *Sardinella* in north-western Africa. *Fish and Fisheries*, **1**: 206-210.
- Sathyendranath, S.A., Longhurst, A.R., Caverhill, C.M., & Platt, T. 1995. Regionally and seasonally differentiated primary production in the North Atlantic. *Deep-Sea Res.*, **42**: 1773-1802.
- Sherman, K., & Duda, A.M. 1999. An ecosystem approach to global assessment and management of coastal waters. *Marine Ecology Progress Series*, **190**: 271-287.
- Tufte, E.R. 1983. *The visual display of quantitative information*. Cheshire, CT: Graphic press. 197 p.
- Turner, R.E., & Rabalais, N.N. 1994. Coastal eutrophication near the Mississippi river delta. *Nature*, **368**: 619-621.
- Walters, C.J. 1998. Designing fisheries management systems that do not depend upon accurate stock assessments. p.279-288, in: T.J. Pitcher, D. Pauly and P. Hart (eds) *Reinventing Fisheries Management*. Fish and Fisheries 23. Dordrecht, the Netherlands: Kluwer Academic.
- Walters, C.J., Christensen, V., & Pauly, D. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. *Rev. Fish Biol. Fish.*, **7**(2): 139-172.
- Walters, C.J, Pauly, D., & Christensen, V. 1998. ECOSPACE: prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. *Ecosystems*, **2**: 539-554.
- Watson, R., Pang, L., & Pauly, D. in press. Two studies on the marine fisheries of China. *FAO Fisheries Technical Paper* [in press]



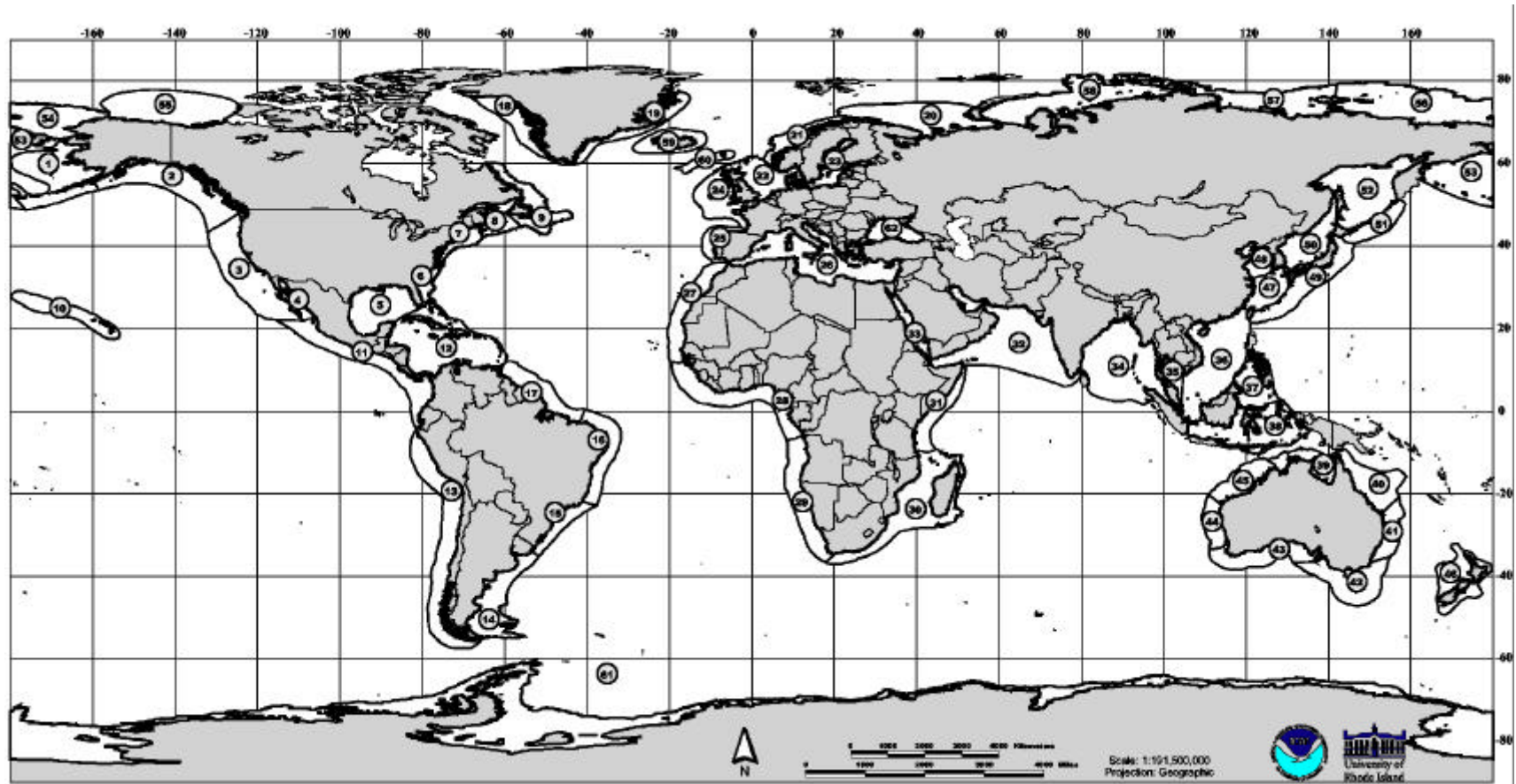


Figure 4. System of Large Marine Ecosystems (LMEs) identified by K. Sherman and collaborators. This maps includes 12 recently defined LMEs (notably around Australia; see Table 1).

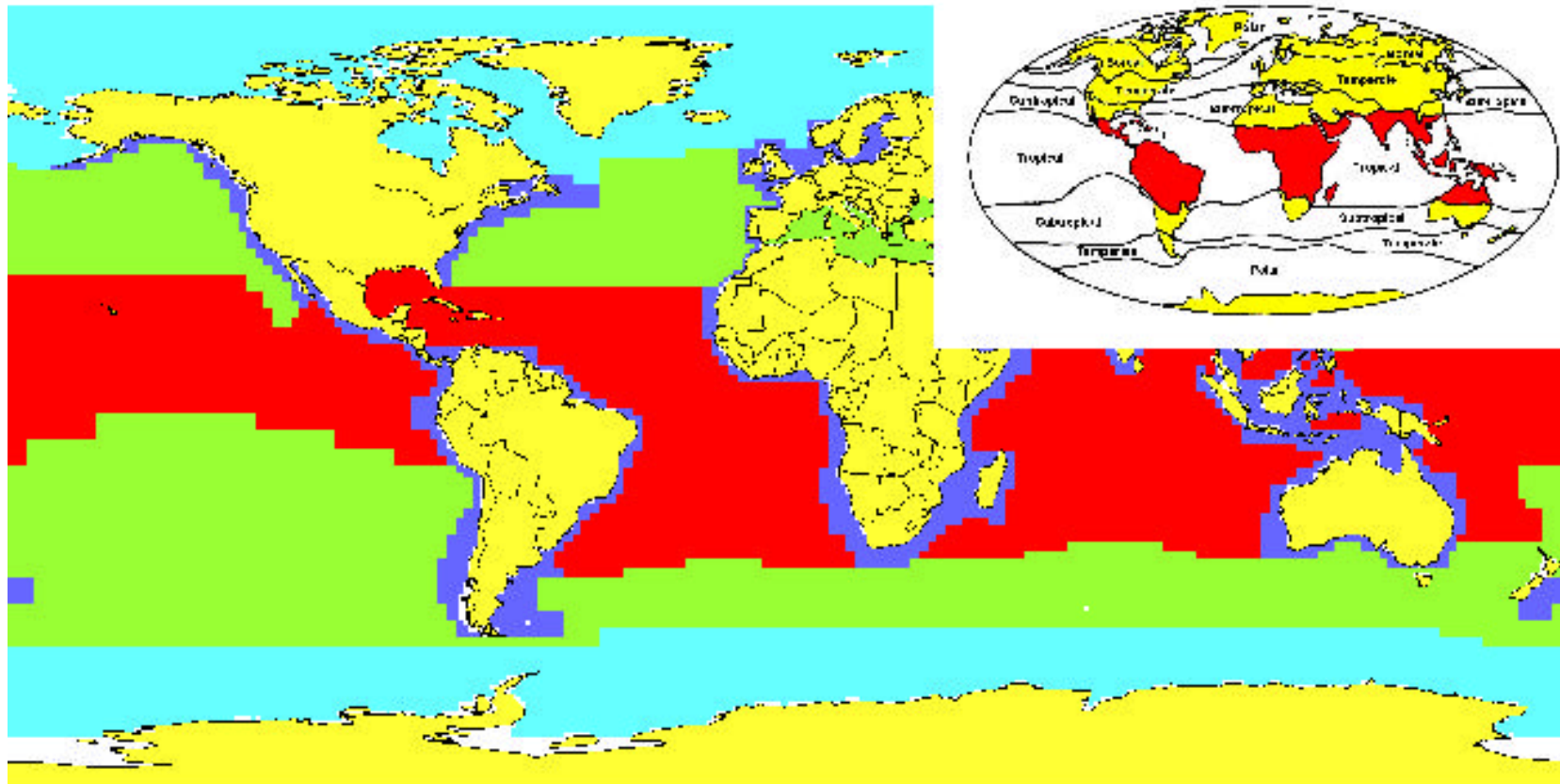


Figure 5a. The four 'biomes' in the global ocean stratification of A.R. Longhurst and colleagues (Polar, Westerlies, Trade-Winds, and Coastal Boundary). Note their overall match with a global climate map (insert, from Anon., 1991).

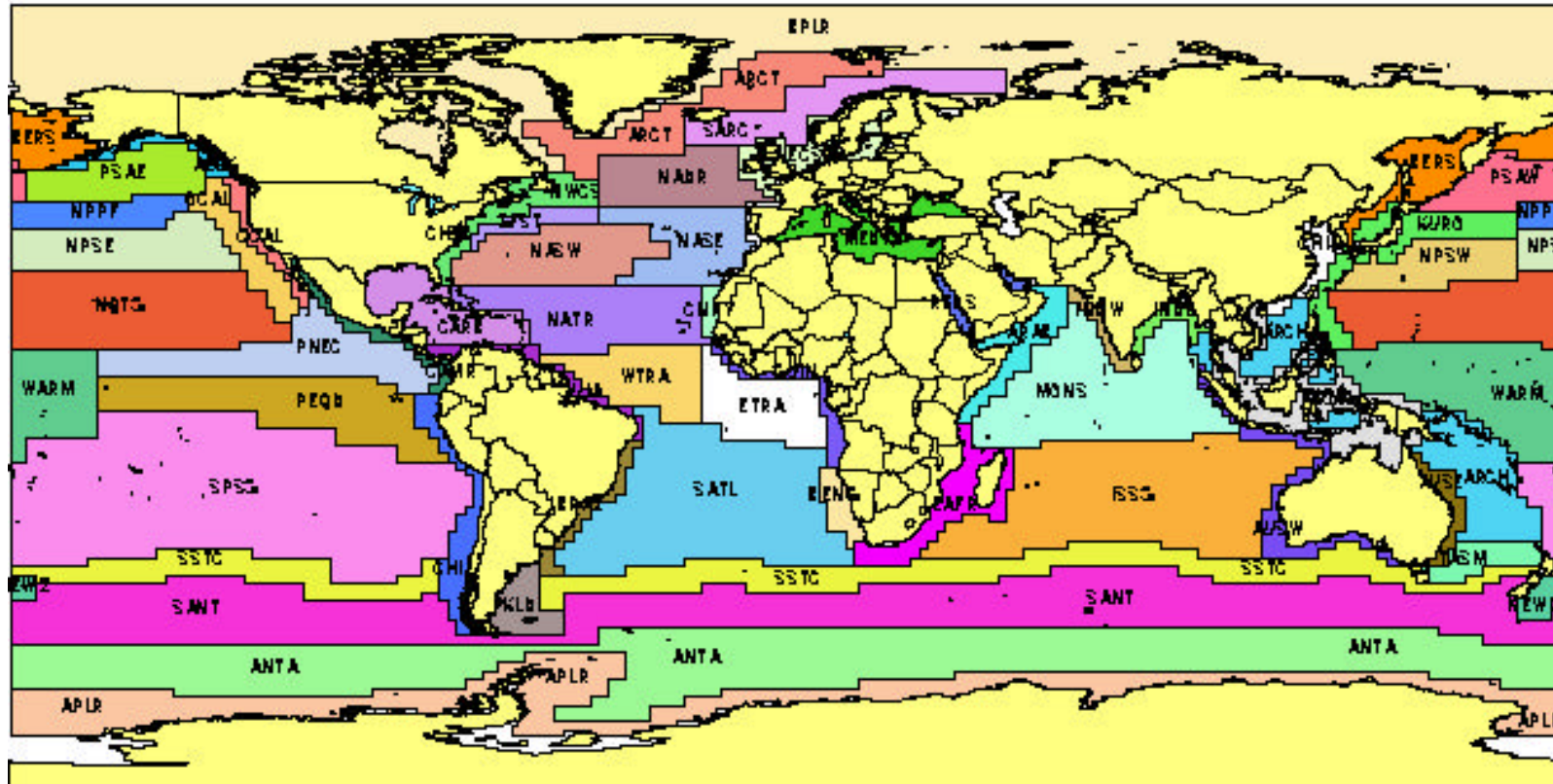


Figure 5b. Biogeochemical provinces (BGCP) in the system of A.R. Longhurst and collaborators. Note that each BGCP fits into one of the four biomes in Fig. 5a, thus allowing for a nested hierarchy of comparable ecosystems.

