Fisheries in Large Marine Ecosystems: Descriptions and Diagnoses

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Abstract

We present a rationale for the description and diagnosis of fisheries at the level of Large Marine Ecosystems (LMEs), which is relatively new, and encompasses a series of concepts and indicators different from those typically used to describe fisheries at the stock level. We then document how catch data, which are usually available on a smaller scale, are mapped by the Sea Around Us Project (see www.seaaroundus.org) on a worldwide grid of half-degree lat.-long. cells. The time series of catches thus obtained for over 180,000 half-degree cells can be regrouped on any larger scale, here that of LMEs. This yields catch time series by species (groups) and LME, which began in 1950 when the FAO started collecting global fisheries statistics, and ends in 2004 with the last update of these datasets. The catch data by species, multiplied by ex-vessel price data and then summed, yield the value of the fishery for each LME, here presented as time series by higher (i.e., commercial) groups. Also, these catch data can be used to evaluate the primary production required (PPR) to sustain fisheries catches. PPR, when related to observed primary production, provides another index for assessing the impact of the countries fishing in LMEs. The mean trophic level of species caught by fisheries (or 'Marine Trophic Index') is also used, in conjunction with a related indicator, the Fishing-in-Balance Index (FiB), to assess changes in the species composition of the fisheries in LMEs. Also, newly conceived 'Stock-Catch Status Plots' are presented which document graphically, for each LME, both the increase in the number of stocks that moved from the fully exploited to the overexploited and collapsed stages, and the relative biomass of fish extracted from stocks in these various stages. Finally, original time series of estimated catch data are presented for the six LMEs of the coast of North Siberia, Arctic Alaska and Arctic Canada (all entirely contained within FAO Statistical Area 18), for which even crude catch estimates were previously unavailable. Altogether these descriptors of fisheries and ecosystem states over the last 50+ years allow a diagnosis of the fisheries of each LME, and inferences on global trends, as LMEs are the source of 80% of the global marine catch.

Introduction

Fisheries have been seen traditionally as local affairs, largely defined by the range of the vessel exploiting a given resource (Pauly & Pitcher 2000). The need for countries to manage all fisheries within their Exclusive Economic Zones (EEZ), a consequence of the United Nations Convention on the Law of the Sea (UNCLOS), led to attempts to derive indicators for marine fisheries and ecosystems at the national level (see e.g., Prescott-Allen 2001). Also, it was realized that, given the large scale migrations of some exploited stocks, and of distant-water fleets (Bonfil *et al.* 1998), an even better integration of fisheries could be achieved at the level of Large Marine Ecosystems (LMEs)(Sherman *et al.* 2003, Sherman & Hempel, this vol.).

However, no national or international jurisdiction reports, at the LME level, for catches and other quantities from which fisheries sustainability indicators could be derived were available. Indeed, if the fisheries of LMEs are to be assessed, and if comparisons of the fisheries in, and of their impact on LMEs, are to be performed, then the fisheries within LMEs must be documented for this explicit purpose, mainly by assembling data sets from national and other sources.

The Sea Around Us Project was created in 1999 with the explicit purpose of assessing the impact of fisheries on marine ecosystems and of developing policies which can mitigate this impact (Pauly 2007). Thus, we set ourselves, from the very beginning, the task of assembling data on all the fisheries that impacted on a 'place', i.e., any area of the sea, since whatever one's definition of an 'ecosystem' is, it must include reference to a place. Indeed, the concept of place has a profound implication on our ability to implement ecosystem based management of fisheries (Pauly 1997; Sumaila 2005).

When dealing with the fisheries of places such as LMEs, the physical and other features that are relevant to the fisheries must also be expressed at the LME scale. The Sea Around Us website provides such statistics, which are used in the LME-specific accounts in this volume. These are:

1) The percentage of global coral reef area in a given LME (rather than the area itself, which is highly variable between authors), based on a global map produced by the World Conservation Monitoring Centre (www.unep-wcmc.org);
2) The percentage of seamounts in a given LME (rather than their number, for the same reason), based on a global map of Kitchingman & Lai (2004);
3) The percentage of the area of a given LME that is part of a Marine Protected Area (MPA), based on an MPA database documented in Wood *et al*. (in press).

Other fisheries-relevant information, not used here, but available through the 'Biodiversity' option on our website (www.seaaroundus.org), are fish species by LME (from www.fishbase.org), and of marine mammals and other marine organisms, to be consolidated in SeaLifeBase (www.sealifebase.org). Additionally, the 'Ecosystem' option allows access to maps of primary production (see Sherman & Hempel, this vol. for details), major estuaries (Alder 2003), ecosystem models, and other features of LMEs.

However, the major exhibit of the website, and the major product of the Sea Around Us Project are time series of fisheries catches by LME. They were obtained using a method developed by Watson *et al.* (2004), which relies on splitting the world oceans into more than 180,000 spatial cells of ½ degree lat.-long., and mapping onto these cells, by species and higher taxa, all catches that are extracted from such cells. The catches in these spatial cells can then be regrouped into higher spatial aggregates, for example, the EEZs of maritime countries or, as is relevant here, the LMEs that have been so far defined in the world's oceans (Watson *et al* 2004).

As these aggregates of spatial cells can then be combined with other data, for example, the price of the fish caught therein, or their trophic level, one can straightforwardly derive other time series, e.g., of indicators of the value, or the state of fisheries in any area. In the following, we present how the primary (i.e., 'catch') time series were obtained, along with a set of four derived time series included in this volume for all (except some of the Arctic) LMEs. As these time series are presented through graphs (the tabular data are available from www.seaaroundus.org); each section below refers to the graph that presents one of these time series. A final section is devoted to the newly derived catch graphs for the six Arctic LMEs that are entirely within FAO Statistical Area 18, and which are the sole fisheries-related exhibit presented for these LMEs.

Graph 1 - Reported landings by species, per LME

The method used by the Sea Around Us Project to map catches onto ½ degree lat.-long. spatial cells has been described by Watson *et al.* (2003, 2004, 2005) in some detail. Here, we summarize it in 5 steps:

1) Assemble the 'catch' data to be mapped. Data were sourced from FISTAT, the database of the United Nations Food and Agriculture Organization (FAO; www.fao.org), the STATLANT database and selected reports of the International Council for the Exploration of the Sea's (ICES, www.ices.int/fish/statlant.htm), the Northwest Atlantic Fisheries Organization (NAFO; www.nafo.ca/), FAO Regional bodies (Southeast Atlantic, Mediterranean and Black Sea (GFCM), Eastern Central Atlantic (CECAF) and RECOFI), Cuban fisheries catch data (Baisre *et al.* 2003); Estonian fisheries catch data (Ojaveer 1999), 'nationally disaggregated' catch data for the components of the former USSR (Zeller & Rizzo *in press*) and the former Yugoslavia (Rizzo & Zeller *in press*), Guam, and the Commonwealth of the Northern Mariana Islands (Zeller *et al.* 2007), American Samoa (Zeller *et al.* 2006), and, for the Antarctic, from the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR; www.ccamlr.org). These data consist of marine finfish, brackishwater and diadromous finfish, and marine invertebrates. They exclude marine mammals, and reptiles (i.e., sea turtles), algae, and invertebrates harvested for purposes other than food (e.g., corals harvested as construction material). All freshwater organisms are excluded, as are fish and invertebrates produced in mariculture operations. The latter is not always clear-cut, due to the similarity between sea ranching and capture fisheries, and it may be the cause for some of the large recent 'catch' increases in some LMEs, notably those along the Chinese coast. Another cause of catch mis-estimation (although one with reversed sign) is discarded by-catch (Zeller & Pauly 2005), and Illegal, Unregulated and Unreported (IUU) fishing, which is generally not accounted for by our sources of 'catch' data. For this reason, we nearly always refer to 'reported landings'. Thus, when encountering 'catches', readers should be aware that these are not really catches, i.e., landings + discards + IUU, etc. Finally, in the case of some countries for which the FAO database does not provide catches, or reports without correcting the unrealistic figures submitted by member countries, the Sea Around Us Project has attempted to reconstruct or correct the catch, using concepts initially presented by Pauly (1998). However, for the analyses presented in this volume, this concerned only the following areas: China (Watson & Pauly 2001); Cuba, Estonia and US flag territories in the Pacific (see references above), and the seven Arctic LMEs in FAO area 18, for which we provide preliminary catch time series, to replace the landings of zero that FAO often reports for this area (see below). For all other countries, we stress again, the catches reported here originated from FAO and other official sources.

2) Create, for each taxon (species, genera, families and orders) for which at least one country reports landings, a distribution range map, constrained by an external polygon, based on the known depth and latitudinal range, and within which account is taken of the habitat preference of this taxon (Watson *et al*. 2004, Close *et al.* 2006). These range maps rely heavily on data extracted from FishBase (www.fishbase.org) for fish, and from various sources, all consolidated in SeaLifeBase (www.sealifebase.org) for invertebrates. The range maps were all revised for the catch allocation used here (see Close *at al.* 2006; www.seaaroundus.org). Also, a new procedure, which we call 'demersal creep', was implemented which accounts (only in demersal taxa, generally caught by trawling) for the fact that when exploitation is light (and catches low), only the

near-shore part of the distribution is fished, with the fraction of the distribution range covered increasing ratchet-like when catches increase, up to the entire distribution being covered when the catch reaches its maximum (and remaining there when catches subsequently decrease).

3) Combine the landings reported by various countries and species (or higher taxa) with the corresponding distribution range maps, and allocate these landings to spatial cells, subject to fishing access status (does country A fish in the EEZ of country B?), and other constraints (Watson *et al.* 2004). The procedure used here considers where countries have been fishing, which can be in their own waters (or EEZ, since the early 1980s), in the waters (EEZ) of countries to which they have legal access (as documented by access agreements), or to which they have traditional or illegal access (as documented by other sources). The allocation procedure thus uses a large database of access agreements, which grew from a smaller database called FARISIS (FAO 1999), which was kindly made available by FAO to the Sea Around Us Project. Published or online reports of countries observed fishing in the waters of other countries, even without any known access agreements, were also considered and incorporated in the access agreement database.
4) When under these rules the landings of a given taxon reported by a given country cannot be allocated to its own waters (because that taxon does not occur there), or to the waters of other countries (because no access agreement is known, nor is it known to fish there traditionally or illegally), the case is investigated until resolution is found.
5) Once the landings by species is allocated to ½ degree lat.-long. spatial cells and the landings reported by different countries are thus reassigned to the ecosystem(s) from which they originated, a procedure is implemented which attempts to reduce the fraction of the reported landing assigned to the 'miscellaneous fish' category. These miscellaneous fish, particularly abundant in reports from tropical developing countries and from China, make it extremely difficult to understand what happens to the underlying stocks. The procedure used for this, which relies on a set of simple heuristics, does not affect total catch levels. Rather, it only reassigns fish from the 'miscellaneous fish' category to some of the identified taxa already reported by either the country itself or its neighbors. As presently implemented, these rules disaggregate > 50 % of the reported 'miscellaneous fish' landings of the world (R. Watson, Sea Around Us Project, August 2007, unpublished data).

These steps, though they typically do not modify the reported landings by FAO statistical areas, produce a radically different view of landings at the level of the EEZ of individual countries. Thus, in the Mauritanian EEZ, for example, which is a component of the Canary Current LME, the landings derived from this procedure are much higher than suggested by looking at the FAO data for Mauritania because we 'put back' into the Mauritanian EEZ fish that was landed in other countries, but which was caught in Mauritanian waters (Watson *et al.* 2005). Another feature of Mauritanian landings (and of landings elsewhere in the world) is that since 2007, they do not include the ex-USSR, even for the period from 1950-1991, when its fleets were active through the oceans. This is so because we have retroactively re-assigned ex-USSR catches to its components maritime republics (Estonia, Georgia, Latvia, Lithuania, Russian Federation and Ukraine), based on their relative reported landings in the first years of the post-dissolution period, and rules about who tended to fish where (Zeller & Rizzo). Thus, we show Russian, Estonian, etc. catches from 1950 onward. However, their sum, it must be stressed, still adds up to the FAO catch for the ex-USSR. An analogous procedure was used for the relevant components of the former Yugoslavia, i.e., Croatia, Slovenia and Montenegro (Rizzo & Zeller).

Our procedure was recently tested independently by Gascuel (2007), who found that our approach approximates well the values that would have been generated by Mauritania, were it to also report the landings by all the distant water fleets operating in its EEZ.

Figure 1 shows the landings, by species for all LMEs in the world. Since this graph is normalized to show the 11 most abundant species (with the remainder pooled into 'mixed group'), and not many species are globally important, this graph exhibits more 'mixed group' landings (as 12th category) than typically occur in any specific LME. Also, it will be noted that LMEs account for the overwhelming part of the world catch, i.e., between 76% (1990) and 91% (1968) of global catch. However, the average contribution of LME catches appears to have slightly declined over time, from around 89-90% in the early decades to around 78-81% for recent time periods. Indeed, the only major group not caught primarily in LMEs is represented by large pelagic fishes, primarily tunas.

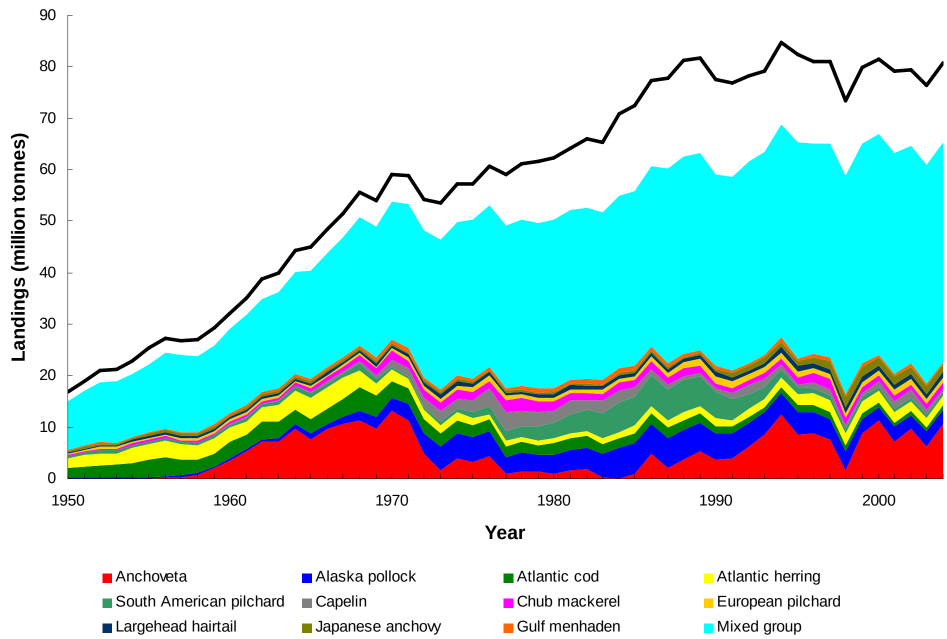


Figure 1. Landings by species in all LMEs (colored time series), and in the world ocean (black line). As this graph individually identifies only the 11 species with the highest global catch (with the remainder pooled into 'mixed group'), this graph exhibits more 'mixed group' landings (as 12th category) than reported from any specific LME. The only major group not caught primarily in LMEs is large pelagic fishes, primarily tunas. Our website (www.seaaroundus.org) also presents catches by 'Commercial groups' (as used in Figure 2), 'Functional Groups, as used in Ecopath models (see www.ecopath.org), 'Country fishing', and 'Gear', based on Watson *et al.* (2006).

In addition to the catch by species, the website of the Sea Around Us Project presents, for all but the six Arctic LMEs located fully in FAO Area 18 (see section 'Catch graphs for Arctic LMEs in FAO Statistical Area 18' below), catches by 'Commercial groups' (as used in 'Graph 2', see below), 'Functional groups, as used in Ecopath models (see www.ecopath.org), 'Country fishing' (not to be mistaken for the PPR by, or footprint of countries, see Graph 3 below), and 'Gear', based on Watson *et al.* (2006a, 2006b).

Graph 2 - Value of reported landings by major commercial groups, per LME

Fishing is an economic operation and the ex-vessel value of the landings has to cover all fixed and variable costs of fishing and still generate a profit, except when fisheries are subsidized (Sumaila & Pauly 2006). To be able to evaluate the ex-vessel value of fisheries worldwide, a database of ex-vessel fish price data was constructed, based on 1) observed prices in different countries at different times for different species; and 2) inferred prices, based on observed prices and an averaging algorithm which took taxonomic affinity, adjacency of countries and time into account (Sumaila *et al.* 2007). As observed prices were available for the most important commercial species, the inferred prices have little influence on the total value of landings from any LME fishery.

The year-, species- and time-specific prices in the database were then adjusted for inflation to year 2000 real prices in US$, using consumer price index (CPI) data from the World Bank, and multiplied by the spatially allocated landings for the corresponding years and species (groups). This yielded time series of the value of fisheries landings in year 2000 inflation adjusted prices, which can be compared in time and space (Sumaila *et al.* 2007), and which, in the aggregate, match, for example, estimates of the ex-vessel values of fisheries catches produced by the OECD.

Here we present graphs of reported landing value by 'Commercial groups', to facilitate comparison between LMEs which may not share species. This may also facilitate their interpretation by readers who do not know biological details on the various species caught in different LMEs, but know market categories. Again, we stress that all values presented here are based on real 2000 prices, i.e., deflated nominal prices (Sumaila *et al* 2007). Figure 2 shows the value by major commercial groups of reported landings in all LMEs of the world. As might be seen, LMEs account for most of the value of marine fisheries catches in the world with values ranging from 71-90% of global landings value. However, this is a slightly smaller fraction than for catch biomass, as many of the offshore fishing grounds for extremely valuable tunas are not included in LMEs.

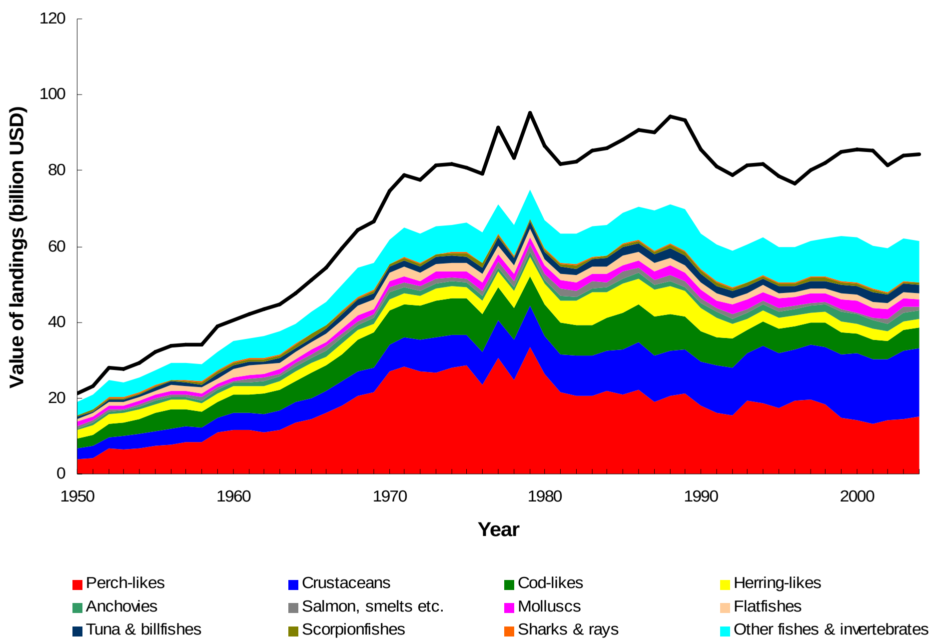


Figure 2. Ex-vessel value of reported landings in all LMEs of the world, by 'Commercial groups' (colored time series), with the value of the global marine catch also added (black line). All values presented are based on real 2000 prices, i.e., deflated prices (Sumaila *et al.* 2007).

Graph 3 – Primary production required to sustain fisheries within LMEs

Footprint analysis consists essentially of expressing all human activities in terms of the land area required for generating products that are consumed by us, or for absorbing the waste generated in the course of supplying these products. Numerous conversion tables exist which allow footprint analysis, for example for producing crops, or absorbing carbon emissions, and these are being used to account for the human impact on ecosystems in standardized fashion (Wackernagel & Rees 1996). Also important to the footprint concept is that, generally, they are expressed in relative terms, i.e., in terms of the surface area of a country. Thus, a country which has a footprint exceeding its surface area relies on resources from other countries. The footprint concept, and conversion tables which are used to implement it, are, however, tied to land areas. There has been to date no published application of this concept to LMEs.

Here, we present extensions of the footprint concept to LMEs. However, the productivity of a given area of ocean is determined by the local primary production, which can vary tremendously over small distances, depending on local mixing processes (Longhurst 2007). Thus we shall not consider the surface area of LMEs, but their average primary production as reference for footprint analysis; hence the concept of Primary Production Required (PPR) (Christensen & Pauly 1993) used here.

The Primary Production Required (PPR) by fisheries landings is a function of the trophic level of the fishes that are caught. Thus, far more primary production is required to produce one tonne of a high-level trophic fish, for example tuna, than a tonne of a low level- trophic fish, for example sardine. This is because the transfer efficiency between trophic levels in the ocean is relatively low, estimated at 10 % on the average (Pauly & Christensen 1995). Thus, to calculate the primary production that was required to produce a given tonnage of fish, we need the average trophic level of the fish in question, an assumption about trophic efficiency (here 10%) and the equation $PPR = landings \cdot 10^{(TL-1)}$ (Christensen and Pauly 1995).

The landings data used to estimate footprints are those presented above. PPR is calculated separately for each species (or group of species) for the fleets of all countries operating in the LME in question, expressed in terms of the primary production in that LME. The combined footprint of different countries fishing in a given LME area can thus be assessed. To facilitate comparisons between LMEs, the 'maximum fraction' (of PPR, in terms of primary production in each LME) is also shown. It is computed as the mean of values for the five years with the highest PPR value.

The primary production data used here refer to the average from October 1997 to September 1998 and will not be representative of observed primary production in specific years, nor of the average primary production from 1950 to 2004 in each LME. While this may cause some errors, there is no reason to believe it should cause any systematic bias, and we consider it warranted to use the PPR measure for comparisons between LMEs. Thus the low level of relative PPR in Australian LMEs compared with the high values in the north Atlantic is likely not an artifact, nor will the relative contribution of various countries' fleets to the overall footprint within a given LME be an artifact.

On the other hand, extremely high values of PPR (above a fraction of 0.5) point at serious problems, including:

1) The assumptions and data used for implementing the method itself (i.e., the use of one year's worth of SeaWifs global remote sensing data as a proxy for primary production for all years from 1950 to 2004, everywhere);
2) Over-reported landings;

3) Extensive range extension in periods of peak abundance, e.g., in Japanese sardine (Watanabe *et al.* 1996), or migration of targeted species, especially feeding migrations, extending beyond the limits of an LME;
4) High reported landings from exploitation of accumulated biomass, rather than exploitation of annual surplus production.

Which of these problems is likely to apply is indicated in the LME-specific chapters. By way of generalization, however, we may mention here that (2) tends to occur in East Asian LMEs (Watson & Pauly 2001), (3) in the Kuroshio LME, and some of the smaller LMEs of the North Atlantic, and (4) with regard to Atlantic cod in the Northwest Atlantic in the earlier periods. The problem in (1), on the other hand, occurs throughout the world. However, it is not likely to be the cause of the geographic pattern just mentioned.

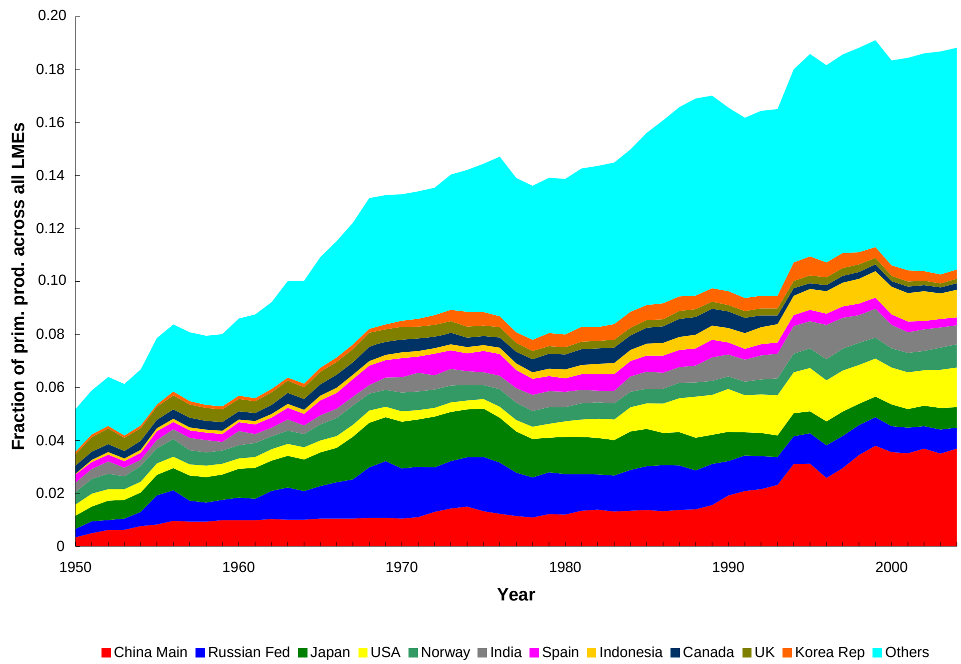


Figure 3. Primary Production Required (PPR; Pauly & Christensen 1995) to sustain fisheries in the 57 most important LMEs of the world, an expression of their 'footprint' (Wackernagel & Rees 1996). PPR is calculated separately for each species (or group of species) caught by the fleets of all countries operating in a LME (or here: in 57 of 64 LMEs). The 'maximum fraction' (of PPR, in terms of primary production in each LME) is computed as the mean of values for the five years with the highest PPR value.

Figure 3 shows the fraction of primary production required to sustain the landings reported by countries fishing within 57 LMEs of the world, as fractions of their combined primary production. (The Arctic LMEs exclusive to FAO Area 18 are not included here, due to their small catches and variable ice-free zones). The fraction of primary production required has increased steadily over the years, in line with increasing reported landings, and is approaching 20%. In recent years, the countries with the largest footprint in all LMEs combined were China, USA and Indonesia, with China outpacing all others (even with correction of over-reporting of landings, Watson & Pauly 2001).

Graph 4 – The Marine Trophic Index and the FiB index, by LME

When a fishery begins in a given area, it usually targets the largest among the accessible fish, which are also intrinsically most vulnerable to fishing (Cheung *et al*. 2007). Once these are depleted, the fisheries then turn to less desirable, smaller fish. This pattern has been repeated innumerable times in the history of humankind (Jackson *et al.* 2001) and also since the 1950s, when landing statistics began to be collected systematically and globally by FAO.

With a trophic level assigned to each of the species in the FAO landings data set, Pauly *et al* (1998) were able to identify a worldwide decline in the trophic level of fish landings. This phenomenon, now widely known as 'fishing down marine food webs', has been since shown to be ubiquitous when investigated on a smaller scale, e.g., in countries such as Greece (Stergiou & Koulouris 2000) or subdivisions of large countries, e.g. India (Bhathal 2005). This ubiquity of fishing down is one of the reasons why the Convention on Biological Diversity (CBD) adopted the mean trophic level of fisheries catch, which it renamed Marine Trophic Index (MTI) as one of eight biodiversity indicators for "immediate testing" (CBD 2004, Pauly & Watson 2005).

Diagnosing fishing down the food web from the mean trophic level of landings is problematic, however. Landings reflect abundances only crudely. Also, a fishery that has overexploited its resource base, e.g., on the inner shelf, will tend to move to the outer shelf and beyond (Morato *et al.* 2006). There, it accesses hitherto unexploited stocks of demersal or pelagic fish, and the MTI calculated for the whole shelf, which may have declined at first, increases again, especially if the 'new' landings are high. Thus, at the scale of an LME, a trend reversal of the MTI may occur when the fisheries expand geographically. This is the reason why the diagnosis as to whether fishing down occurs or not, performed for many of the LMEs in this volume, generally depends on the species composition of the landings, which may indicate whether a geographic expansion of the fishery has taken place.

To facilitate this evaluation, a time series of the Fishing-in-Balance (FiB) index is also presented for each LME. Pauly *et al.* (2000) defined the FiB index such that its value remains the same when a downward trend in mean trophic level is compensated for by an increase in the volume of 'catch', as should happen given the pyramidal nature of ecosystems and the transfer efficiency of about 10% between trophic levels alluded to above.

The FIB index will decline, obviously, when both the MTI and landings decline, as now happens, unfortunately, in many LMEs. On the other hand, the FIB index will increase if landings increases more than compensate for a declining MTI. In such cases (and obviously also in the case when landings increases and the MTI is stable or increases), the FiB index increases indicate that a geographic expansion of the fishery has taken place, i.e., that another part of an ecosystem is being exploited (Bhathal & Pauly *in press*). Note that the absolute value of the FiB index can be applied to assess the change of the FiB index from any baseline we like. It is here standardized to have a value of zero in 1950.

Figure 4 presents the trophic level and FIB index for all LMEs combined, but with Peruvian anchoveta (*Engraulis ringens*) and large pelagic fishes (large tunas and billfishes) excluded. The very localized fishery for Peruvian anchoveta, a low trophic level species, is the largest single-species fishery in the world, and it exhibits extreme fluctuations in landings (see Figure 1, top, and Chapter XVII-56 Humboldt Current LME), which mask the comparatively more subtle patterns in trophic level changes by the rest of the world's fisheries. The reason for excluding large tunas and billfishes is that much of their catch is taken in pelagic waters outside of the currently defined LMEs. Thus, the inclusion of these landings from only part of their stock-exploitation ranges would artificially inflate trophic level patterns, especially in recent decades, where the tuna fisheries expanded tremendously (Pauly and Palomares 2005). The trend in mean trophic level for all LMEs combined (Figure 4, top) indicates a decline in the MTI from a peak in the 1950s to a low in the mid 1980s. This is attributed to 'fishing down marine food webs' (Pauly et al. 1998, Pauly and Watson 2005), attenuated by an offshore expansion of the fisheries (Figure 4, bottom, and see Morato *et al.* 2006). In the mid 1980s, the continued offshore expansion, combined with declining inshore catches led to a trend reversal in the MTI, i.e., to the fishing down effect being completely occulted. Analyses at smaller scales (i.e., as documented in the LME-specific chapters, or in smaller-scale studies, see above) confirm this.

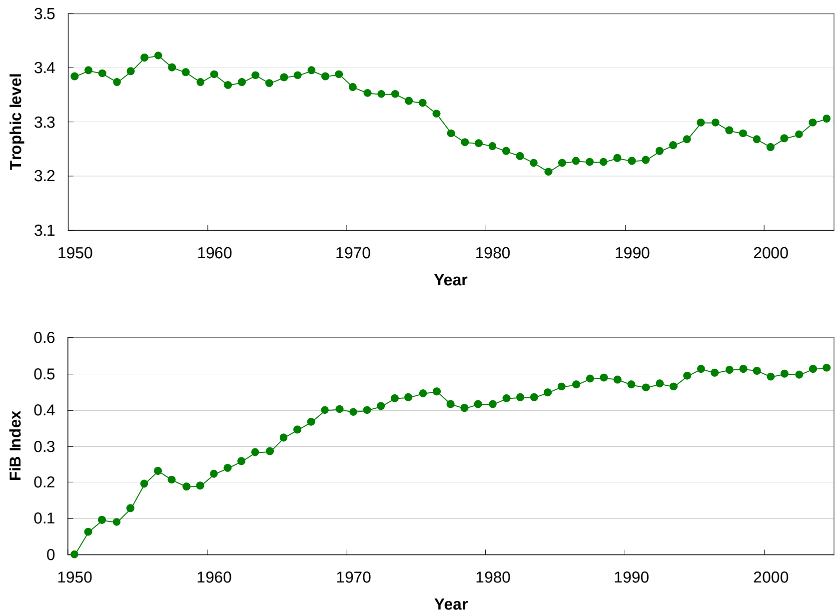


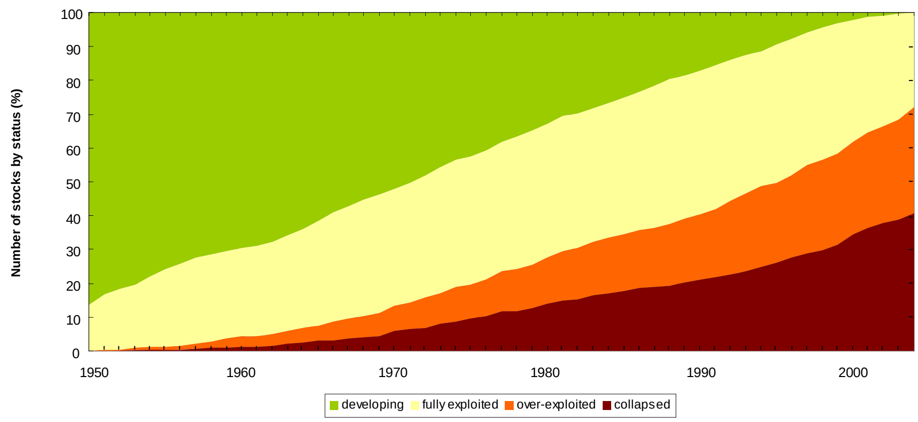
Figure 4. Two indicators based on the trophic levels (TL) of exploited fish, used to characterize the fisheries in the LMEs of the world. Top: trend of mean TL, indicating 'fishing down marine food webs', recently masked by offshore expansion of the fisheries (Pauly *et al.* 1998, Pauly & Watson 2005). Bottom: corresponding trend of the Fishing-in-Balance (FiB) index, which is defined such that its increase in the face of stagnating or increasing MTI suggests a geographic expansion of the fisheries (see text and Bhatal & Pauly, *in press*).

Graph 5 – Stock-Catch Status Plots, by LME

These graphs have their origin in the work of Granger & Garcia (1996), who fitted time series of landings of the most important species in the FAO database with high-order polynomials, and evaluated from their slopes whether the fisheries were in their 'developing', 'fully utilized' or 'senescent' phases. Froese & Kesner-Reyes (2002) simplified these graphs by defining for any time series, five phases relative to the maximum reported landing in that time series, representing a 'stock'. They are:

- **Undeveloped**: Year of landing is before the year of maximum landing, and landing is less than 10% of the overall maximum;

- **Developing**: Year of landing is before the year of maximum landing, and landing is between 10 and 50 % of the overall maximum;
- **Fully exploited**: Landing is greater than 50% of maximum year's landing;
- **Overexploited**: Year of landing is after year of maximum landing, and landing is between 10 and 50% of the overall maximum; and
- **Collapsed**: Year of landing is after the year of maximum landing, and landing is below 10% of the overall maximum.



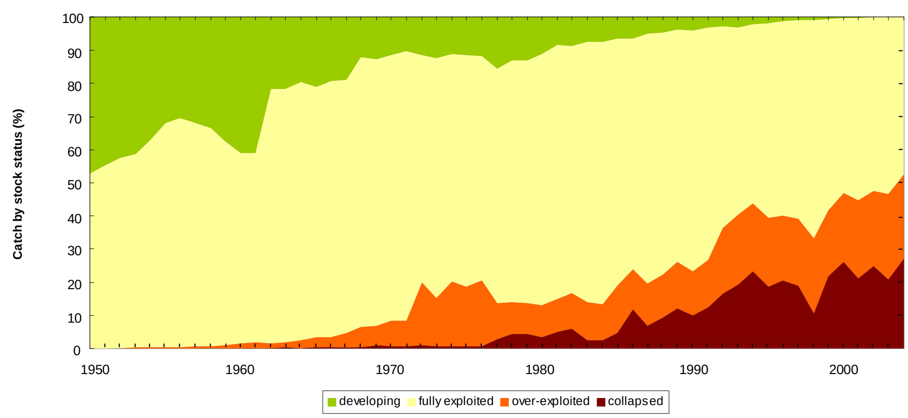


Figure 5. A newly proposed type of paired 'Stock-Catch-Status Plots' (here presented for all LMEs in the world), wherein the status of stocks, i.e., species with a time series of landings in an LME, is assessed, based on Froese & Kesner-Reyes (2002), using the following criteria (all referring to the maximum catch in the series): Developing (catches < 50 %); Fully exploited (catches >= 50%); Overexploited (catches between 50% and 10%); Collapsed (catches < 10%). Top: Percentage of stocks of a given status, by year, showing a rapid increase of the number of overexploited and collapsed stocks. Bottom: Percentage of catches extracted from stocks of a given status, by year, showing a slower increase of the percentage of catches that originate from overexploited and collapsed stocks. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded.

The fisheries in a given area can then be diagnosed by plotting time series of the fraction of 'stocks' in any of these categories (Froese & Kesner-Reyes, 2002). Such graphs were used in a paper by Froese & Pauly (2004) documenting the state of the North Sea LME. This method of diagnosis suggests that the number of collapsed stocks (as defined in Figure 5) is increasing alarmingly throughout the world, as can be seen in the LME-specific 'Stock-Catch Status Plots' included in this book. Here, a 'stock' is defined as a time series of one species, genus or family for which the first and last reported landings are at least 10 years apart, for which there are at least 5 years of consecutive catches and for which the catch in a given LME is at least 1000 tonnes.

Here, we propose a variant of what may be called ‘stock number by status plots’: a ‘catch by status plot’, defined such that it documents, for a series of years, the fraction of the reported landings biomass that is derived from stocks in various phases of development (as opposed to the number of such stocks). As might be seen in Figure 5, such a plot of relative ‘catch’ by status (lower panel) is quite different from the stock number by status plots (upper panel). We call the combination of these two plots ‘Stock-Catch-Status Plots’ (Figure 5).

Figure 5 illustrates the dual nature of the newly derived Stock-Catch Status Plots, for all LMEs in the world combined. It illustrates that, overall, 70 % of global stocks within LMEs are deemed overexploited or collapsed, and only 30% fully exploited (Figure 5, top). However, the latter stocks still provide 50% of the globally reported landings biomass, with the remainder produced by overexploited and collapsed (Figure 5, bottom). This confirms the common observation that fisheries tend to affect biodiversity even more strongly than they affect biomass.

Catch graphs for Arctic LMEs in FAO Statistical Area 18

The Arctic, generally defined as the area within the 10^{o} Celsius summer isotherm, has about four million human inhabitants. FAO Statistical Area 18, ranging from Novaya Zemlya in the west to the Hudson Bay in the east, is comprised of the Siberian coast (Russia), the Arctic coast of Alaska (USA), the Arctic coast of Canada, and parts of the northern coast of Greenland, or about two-third of what is generally defined as the Arctic. FAO Area 18 is also an area with extremely low fish catches. However, landings are not as low as the FAO data from that area would have it, and the negligible (often zero) catches officially reported from this area are mainly the result of Russia, the USA and Canada not reporting adequately on the small-scale fisheries in their section of the Arctic. This obviously affects the seven LMEs presently defined for this area, i.e., from west to east, the Kara, Laptev, East Siberian, Chukchi and Beaufort Seas, Hudson Bay, and the large Arctic LME (soon to be differentiated into [Canadian] Arctic Archipelago, Baffin Bay/Davis Strait as ‘new’ Arctic LMEs). Six of these seven LMEs are located entirely within FAO Area 18, while the Arctic LME has substantial coverage also in FAO Areas 21 (NW Atlantic) and 27 (NE Atlantic).

Thus, to complete our coverage of the world’s LMEs, and to produce a baseline against which future fisheries development in the Arctic can be assessed, the Sea Around Us Project undertook a reconstruction of catch time series for FAO Area 18. We present here key results from this work on northern Siberia (Pauly & Swartz *2007*) and Arctic Canada (Booth & Watts *2007*), and from an ongoing study on Arctic Alaska (S. Booth and D. Zeller, Sea Around Us Project, unpublished data). These results are summarized, for the Arctic LMEs, in Table 1 and Figure 6, and are presented individually in their respective chapters.

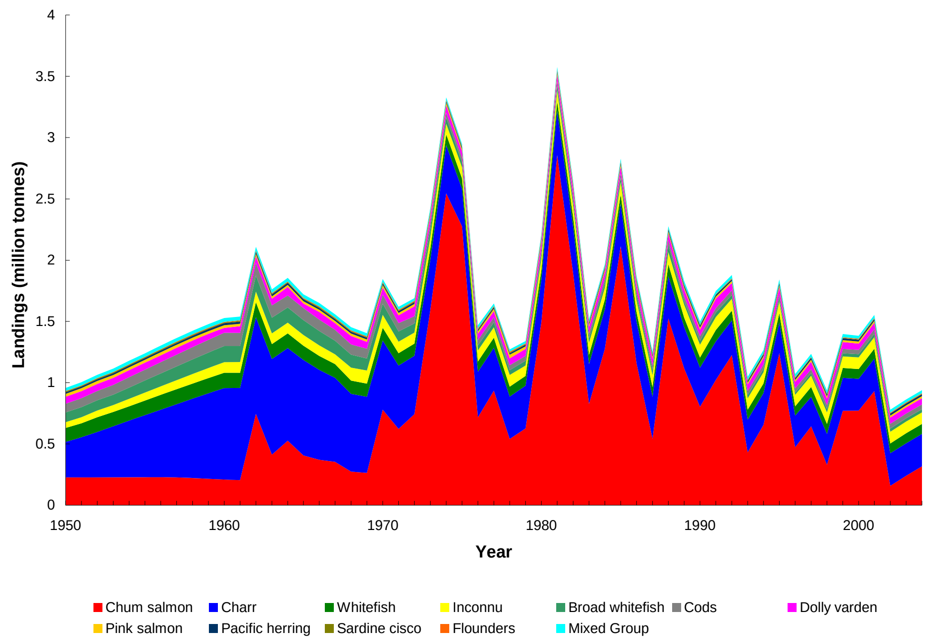


Figure 6. Estimated catches from the six LMEs fully comprised within FAO Statistical Area 18, and based on Pauly & Swartz (*2007*), Booth & Watts (*2007*) and Booth & Zeller (unpubl. data). These conservative estimates of (small-scale fisheries) catches are considerably higher than reported by FAO for the same area, an extreme case of the tendency, by FAO member countries, of underreporting the catches of their small-scale fisheries (see also Zeller *et al.* 2006, 2007).

Because the catches in Figure 6 are usually not destined for commercial markets, and relatively small, we abstain here from presenting their ex-vessel value, and indeed, from deriving any catch-based indicators (MTI, PPR, etc). Consequently, the LME-specific accounts do not include graphs illustrating catch-based indicators, either.

Table 1: Estimated average annual catches (1950-2004) and major taxa for LMEs within FAO Statistical Area 18, arranged from west to east.

LME	Average catch (tonnes·year^{-1})	Major taxa
Kara Sea	7,239	*Coregonus sardinella*, *C. lavaretus*, *C. nasus*
Laptev Sea	3,667	*Coregonus sardinella, C. autumnalis, C. muksun*
East Siberian Sea	2,717	*Coregonus nasus, C. sardinella, C. autumnalis*
Chuckchi Sea	1,727	*Oncorhynchus keta*, *Coregonus* spp., *Stenodus leucichthys*
Beaufort Sea	127	*Coregonus* spp., *Stenodus leucichthys, Clupea pallasii*
(Canadian) Arctic Sea[1]	1,066	*Salvelinus alpinus*, Gadidae, *Salmo salar*
Hudson Bay	484	*Salvelinus alpinus,* Gadidae, *Salmo salar*

[1] These data apply only to that part of the currently defined Arctic LME that comprises the (Canadian) Arctic Archipelago, and are not included in Figure 6. These data exclude the much higher catches from the Arctic LME areas within FAO areas 21 (Baffin Bay, Davis Strait) and 27 (NE Atlantic waters).

Discussion

Traditionally, the local and sectoral focus of fisheries science, monitoring and management has precluded the development and use of indicators at large spatial scales. With the advent of ecosystem-based concerns and concepts such as the Large Marine Ecosystems (Sherman *et al.* 2003), it has become evident that such indicators will be needed for better integration of fisheries in ecosystem-based management approaches.

However, existing national and international institutions, due to their historic sectoral, local and national focus, are not in a position to report fisheries information, i.e., catches, their values and associated indicators at an ecosystem level, such as LMEs. In contrast, the Sea Around Us Project was specifically established to assess the impacts of fisheries at an ecosystem level. We therefore developed tools and concepts to present available fisheries data via ½ degree lat.-long. spatial cells, allowing consideration of various spatial scales, such as LMEs. It is this 'place'-based, rather than sector-based approach which allows us to document fisheries impacts at the scale of LMEs. We have also derived a standard set of indicators and graphical representations, presented here on a global scale (i.e., for all currently defined LMEs combined). They are presented in LME-specific format in the various chapters of this book, and as well, through our website (www.seaaroundus.org).

The five types of graphs presented here allow comprehensive overviews of the general status of fisheries and ecosystem of each LME, as they account for the characteristics of fisheries, biology and ecology of the exploited species and ecosystem. Catch and catch values indicate status and trends of the fisheries, e.g., through changes in species composition and catches. These relate strongly to the status of stocks in the LME, as indicated by the Stock-Catch Status Plots developed here. Changes in fisheries and stock status have direct impacts on the ecosystem which can be indicated by the MTI and FiB. These also determine the footprint of fisheries – an indicator of sustainability, as shown here through the Primary Production Required by fisheries within LMEs.

All of these indicators require accurate and complete catch data. Such catch data, however, are not available for all LMEs. The methods we use for re-expressing FAO's global reported landings dataset on a spatial basis, here through LMEs, cannot compensate for these limitations. Rather, it makes them visible, and emphasizes the need for catch reconstruction at the national level (*sensu* Zeller *et al.* 2006, 2007), from which LME catch time series can then be derived. This was here specifically illustrated by reconstructed catch time series from Northern Siberia (Russian Federation), Arctic Alaska (USA), and parts of Arctic Canada, with the help of which the fisheries of six arctic LMEs could be characterized for the first time. In the next years, the Sea Around Us Project, working in close collaboration with national scientists, will radically expand its coverage of countries with reconstructed catches, to overcome the data problems highlighted in the LME-specific chapters. Also, we will expand our list of indicators, and include several that do not rely on catch trends, but on biomass (or catch/effort) trends, which are far more informative.

The LME framework, populated with relevant and current catch and related fisheries data, is set to provide the information needed to develop policies for ecosystem-based fisheries management. It provides a neutral platform for jurisdictions (national and sub-national) to come together to discuss resource management issues as a single ecological unit and look at the consequences of policies, irrespective of boundaries. This information will also provide guidance on information gaps (e.g., spatial effort data) and areas for research (e.g., large scale fisheries-independent biomass estimation), so that ecosystem based management of fisheries and marine areas can be strengthened in many of the world's coastal regions.

The LME system can also enhance the global assessments of marine areas and resources. Until now, large-scale assessments have primarily focused on ocean basins (Pauly *et al.* 2005) or FAO Statistical Areas (Pauly *et al.* 1998, Alder *et al. 2007*). However, these are large areas, and the important differences needed for developing policy can be lost in such a large scale management unit. Assessments based on LMEs can give much better resolution. LME units also lend themselves to ecosystem modeling software such as Ecopath with Ecosim (EwE), which can be used to simulate developments scenarios (Christensen & Walters 2004). Recent experience with EwE and FAO Statistical Areas as modelling units has highlighted that these areas are too large for meaningful treatment (Alder et al. 2007). For example, FAO area 21 includes the Barents Sea and the North Sea, which are strongly divergent ecosystems in terms of structure and fisheries (Alder *et al*. 2007). LMEs do not have this problem. Also, they can be interfaced with other spatial entities, e.g., 'ecoregions' (Spalding *et al.* 2007), i.e., with smaller scale systems defined in terms of their biodiversity.

Thus, the present volume presents globally, and for the first time, comprehensive fisheries data and indicators assembled at a large spatial ecosystem scale, namely for all 64 currently defined Large Marine Ecosystems.

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