Supplementary Materials for

Still catching attention:
Sea Around Us reconstructed global catch data, their spatial expression and public accessibility

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Contents

Introduction 2
The rationale for catch data reconstruction 2
Catch reconstruction: definitions, sources, methodology and challenges 3
  Methods and definitions 4
  Foreign catches 12
  Catch composition 13
Reconstructed global tuna catch data 14
Catch reconstruction database 17
  Structure of the database 18
Foreign fishing access database 19
Taxon distributions 20
  Filter 1: FAO Areas 21
  Filter 2: Latitudinal range 23
  Filter 3: Range-limiting polygon 24
  Filter 4: Depth range 25
  Filter 5: Habitat preference 26
  Filter 6: Equatorial submergence 30
  Completed taxon probability distributions 31
Spatial allocation 33
  How each data layer is conceptually unique and how it is handled 35
  An overview of the algorithm 38
Conclusion 39
Acknowledgments 40
References 40

Introduction

The following sections [adapted from contributions in 1] describe the databases and methods developed and used by the *Sea Around Us* for global fisheries studies and engagement [e.g., 2].

The rationale for catch data reconstruction

Fishing must generate a catch, whether it is done by West African artisanal fishers supplying a teeming rural market or by the huge trawler fleets in Alaska that supply international seafood markets. There is no point fishing if not for generating a catch. Indeed, the catch of a fishery and its monetary value both define that fishery and provide the metric by which to assess its importance relative to other fisheries and other sectors of the overall economy. Hence, changes in the magnitude and species composition of catches obviously can and should be used - along with other information (e.g., on the growth, mortality, etc. of the fish that are exploited) - for inferences on the status of fisheries.

The key role of catch data is the reason why the Food and Agriculture Organization of the United Nations (FAO) proceeded, soon after it was founded in 1945, to issue occasional compendia of the world's fishery statistics, as part of the United Nations' attempt to "quantify the world" [3]. These compendia turned, in 1950, into the much-appreciated FAO *Yearbook of Fisheries Catch and Landings*, based on annual data submissions by its member countries, vetted and harmonized by FAO staff. Contrary to the situation prevailing for major food crops (rice, wheat, maize, etc.), for which we have numerous international databases, the contents of the Yearbooks (now available online; see www.fao.org) have been, to this day, the only global database on wild caught 'fish' (i.e., including invertebrates and other marine groups such as, e.g., edible algae). As such, it is widely cited as the major source for inferences on the status of fisheries in the world [4].

However, in many countries, particularly in the developing world, the government's role in monitoring their fisheries seems to end with the annual ritual of filling-in catch report forms and sending them to FAO. For others, mainly developed countries, collecting catch data from fishing ports and markets is only a start, and the bulk of their fishery-related research is in the form of 'stock assessments' and surveys.

Stock assessments, which are usually performed annually, are, however, extremely expensive, ranging from an estimated 50,000 USD per stock (assuming 6 expert-months for analyzing existing data) to millions of USD when fisheries-independent data are required [5]. This is the reason, beside a worldwide scarcity of stock assessment domain expertise, why only a very small percentage of the over 200 maritime countries and associated island territories perform regular stock assessments, which, moreover, deal only with the most abundant or most valuable species they exploit. For some countries or territories, this may be one species, a dozen, or about two hundreds, as in the USA. In all cases, however, this is only a small fraction of the number of species that are exploited, if only as unintended 'by-catch' which may be retained or discarded.

Therefore, FAO always encouraged the development of methods allowing inferences on the state of fisheries without, or with limited stock assessments [see e.g., 6, 7, 8]. This was obviously driven by the need, given FAO's global mandate, to inform policy makers about the state of fisheries in all countries of the world, including those without access to stock assessment expertise and the costly research vessels required to collect fisheries-independent data.

Inherently, this implies that sufficient attention should be given to reliable catch data collection throughout the world, and notably to devising cost-effective systems for the acquisition of accurate fisheries catch data, along with ancillary data on fishing effort, and their economic equivalent, catch value and fishing cost. Such combinations of data permit first order assessments of fisheries and their underlying stocks. Yet often, catch data seem to be entirely missing from certain areas of countries or territories, particularly for the informal sector, i.e., small-scale fisheries. In such cases, catch statistics can be 'reconstructed' from other data, and Pauly [9] provides the rationale, and Zeller, Booth [10] the method [updated in 11] for such reconstructions.

The major impediment to applying the rationale and methods of 'reconstruction' is that colleagues initially do not trust themselves to make the assumptions required to reconstruct unseen quantities such as historic catches, or to trust themselves to have 'knowledge' about the likely level of catches in the absence of 'properly' collected data. Yet it is only by making bold assumptions that we can obtain the historic catches required for comparisons with recent catch estimates, and thus infer major trends in fisheries.

Catch reconstruction: definitions, sources, methodology and challenges

It is now well-established that official fisheries catch data, for perfectly legitimate reasons, have historically missed or under-reported certain sectors (e.g., the subsistence, or the recreational sectors) as well as fisheries discards. Nowadays, however, when fisheries are viewed and managed in the context of the ecosystems in which they are embedded [12], less than full accounting for (or estimation of) all withdrawals and catch-associated mortality from marine ecosystems is insufficient.

What is covered here are reconstructions of catches in the waters within the Exclusive Economic Zones (EEZ, Figure 1 in main text) that countries have claimed since they could do this under the United Nations Convention on the Law of the Sea (UNCLOS), or which they could claim under UNCLOS rules, but have not (such as some countries around the Mediterranean). Countries that have not formally claimed an EEZ were assigned EEZ-equivalent areas based on the fundamental principles of EEZs as outlined in UNCLOS (i.e., 200 nm and/or mid-line rules). Note that we:

a) Treat disputed zones (i.e., EEZ areas claimed by more than one country) as being 'owned' by each claimant with respect to their fisheries catches, including the extravagant claims by one single country on the large swaths of the open South China Sea; and
b) Treat EEZ areas prior to each country's year of EEZ declaration as 'EEZ-equivalent waters'.

These catch reconstructions, therefore deal with catches made in about 40% of the world ocean space (within EEZs), while the industrial catches taken in the high seas (mainly tuna and other large pelagic fishes), which cover the remaining 60%, are dealt with in the subsequent section.

Methods and definitions

The country-by-country fisheries catch data reconstructions are based on the rational outlined above and described in Pauly [9], and operationalized by Zeller, Booth [10] with improvements in Zeller, Harper [11]. The former contribution asserted (i) there is no fishery with 'no data' because fisheries, as social activities throw a shadow unto the other sectors of the economy in which they are embedded, and (ii) it is always worse to put a value of 'zero' (often the result of 'no data' entries which numerically turn into a 'zero') for the catch of a poorly documented fishery than to estimate its catch, even roughly, because subsequent users of one's statistics will interpret the zeroes as 'no catches', rather than 'catches unknown'.

Zeller, Booth [10] developed a six-step approach for implementing these concepts:

1) Identification, sourcing and comparison of baseline reported catch times series, i.e., a) FAO (or other international reporting entities) reported landings data by FAO statistical areas, taxon and year; and b) national data series by area, taxon and year. We define 'landings' as 'live weight of retained catch', i.e., what FAO terms 'nominal catch';
2) Identification of sectors (e.g., subsistence, recreational), time periods, species, gears etc., not covered by (1), i.e., missing data components. This is conducted via extensive literature searches and consultations with local experts;
3) Sourcing of available alternative information sources on missing data identified in (2), via extensive searches of the literature (peer-reviewed and grey, both online and in hard copies) and consultations with local experts. Information sources include social science studies (anthropology, economics, etc.), reports, colonial archives, data sets and expert knowledge;
4) Development of data 'anchor points' in time for each missing data component, and expansion of anchor point data to country-wide catch estimates;
5) Interpolation for time periods between data anchor points, either linearly or assumption-based for commercial fisheries, and generally via per capita (or per-fisher) catch rates for non-commercial sectors; and
6) Estimation of total catch times series, combining reported catches (1) and interpolated, country-wide expanded missing data series (5).

Since these 6 points were originally proposed, a 7th point has come to the fore which cannot be ignored [11]:

7) Quantifying the uncertainty associated with each reconstruction.

Here, we expand on each of these seven reconstruction steps, based on the experience accumulated during the last decade, when completing or guiding the reconstructions for every country in the world (see also Figure 2 in main text):

Step 1: Identification, sourcing and comparison of existing, reported catch times series

Implicit in this first step is that the spatial entity be identified and named that is to be reported on (e.g., EEZ of Germany in the Baltic Sea), something that is not always obvious.

For most countries, the baseline data are the statistics reported by member countries to FAO (and of whose existence a surprisingly large number of colleagues, especially in developing countries, are not aware). Whenever available, we also use data reported nationally for a first-order comparison with FAO data, which often assists in identifying catches likely taken in areas beyond national jurisdiction, i.e., either in EEZs of other countries or in high seas waters. The reason for this is that many national datasets do not include catches by national distant-water fleets fishing and/or landing catches elsewhere, or differentiate between these. As FAO assembles and harmonizes data from various sources, this first-order comparison enabled catches 'taken elsewhere' to be identified and separated from truly domestic (national EEZ) fisheries (see below for the spatial layering of reconstructed datasets).

We treat all countries recognized in 2010 [or acting like internationally recognized independent countries with regards to fisheries, e.g., the divided island of Cyprus; 13] by the international community as having existed from 1950-2010. This was necessary, given our emphasis on 'places', i.e., on time-series of catches taken from specific ecosystems. This also applies to island and other territories, many of which were colonies, and which have changed status and borders since 1950.

For several countries, the baseline was provided by other international bodies. In the case of EU countries, the baseline data originated from the International Council for the Exploration of the Sea (ICES), which maintains fisheries statistics by smaller statistical areas, as required given the Common Fisheries Policy of the EU, which largely ignores EEZs. A similar area is the Antarctic continent and surrounding islands, whose fisheries are managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), where catches (including discards, a unique feature of CCAMLR) are available by relatively small statistical areas [see e.g., 14].

When FAO data are used, care is taken to maintain their assignment to different FAO statistical areas for each country. The point here is that, because they are very broad, the FAO statistical areas often distinguish between strongly different spatial entities, for example the Caribbean Sea from the coast of the Eastern Central Pacific in the case of Panama, Costa Rica, Nicaragua, Honduras and Guatemala.

Step 2: Identification of missing sectors, taxa and gear

This step is where the contribution of local co-authors and experts is highly beneficial. Four sectors potentially occur in and are defined by the *Sea Around Us* for the marine fisheries of a given coastal country, with the distinction between large-scale and small-scale being the most important point [15]:

Industrial sector: consisting of relatively large motorized vessels, requiring large sums for their construction, maintenance and operation, fishing either domestically, in the waters of other countries and/or the high seas, and landing a catch that is overwhelmingly sold commercially (as opposed to being consumed and/or given away by the crew). However, irrespective of vessel size, all fishing gears that are dragged or towed across the seafloor or intensively through the water column (e.g., bottom- and mid-water trawls) are here considered industrial, following Martín [16], as are large pirogues [e.g., from Senegal, 17] and 'baby trawlers' [in the Philippines, 18] capable of long-distance fishing, i.e., in the EEZ of neighboring countries. Thus, the industrial sector can also be considered *large-scale* and *commercial* in nature;

Artisanal sector: consisting of small-scale (hand lines, gillnets etc.) and fixed gears (weirs, traps, etc.) whose catch is predominantly sold commercially (notwithstanding a small fraction of this catch being consumed or given away by the crew). Our definition of artisanal (also applies to the other two small-scale sectors, see below) fisheries relies also on adjacency: they are assumed to operate only in domestic waters (i.e., in their country's EEZ). Within their EEZ, they are further limited to a coastal area to a maximum of 50 km from the coast or to 200 m depth, whichever comes first. This is the area that we call the *Inshore Fishing Area* [IFA, 19]. Note that the definition of an IFA assumes the existence of a small-scale fishery, and thus unpopulated islands [e.g., Kerguelen, 20], although they may have fisheries in their EEZ (which by our definition are industrial), have no IFA. The artisanal sector is thus defined as *small-scale* and *commercial*. The other small-scale sectors we recognize are subsistence and recreational fisheries, which overlap in many countries.

Subsistence sector: consisting of fisheries that often are conducted by women for consumption by one's family. However, we also count as subsistence catch the fraction of the catch of mainly artisanal boats that is given away to the crews' families or the local community, as occurs, e.g., in Red Sea fisheries [21, 22]. We also recognize that true subsistence fisheries may also contain a fraction of catch that is sold, although the main driver for going fishing is sustenance, not commerce. The subsistence sector is thus defined as *small-scale* and *non-commercial*.

Recreational sector: consisting of fisheries conducted mainly for pleasure, although a fraction of the catch may end up being sold or consumed by the recreational fishers and their families and friends [23]. Unless data exist on catch and release mortalities in a given country, catch from recreational catch-and-release fisheries are not estimated. Often, fisheries that started out as subsistence (e.g., in the 1950s) changed progressively into recreational fisheries as economic development increased in a given country and its cash economy grew. The recreational sector is thus defined as *small-scale* and *non-commercial*.

Finally, for all countries and territories, we account for major discards, here treated as 'catch type' (and contrasted to 'catch type' being retained landings) and which mainly originate from industrial fisheries. Discarded fish and invertebrates are generally assumed to be dead, except for the U.S. fisheries where the fraction of fish and invertebrates reportedly surviving is generally available on a per species basis [24]. Due to a distinct lack of global coverage of information, we do not account for so-called under-water discards, or net-mortality of fishing gears [e.g., 25]. We also do not address mortality caused by ghost-fishing of abandoned or lost fishing gear [26-28], even though it can be substantial, e.g., about 4% of trap-caught crabs worldwide [29].

Furthermore, the *Sea Around Us* excludes from consideration all catches of marine mammals, reptiles, corals, sponges and marine plants (the bulk of the plant material is not primarily used for human consumption, but rather for cosmetic or pharmaceutical use). In addition, we do not estimate catches made for the aquarium trade, which can be substantial in some areas in terms of number of individuals, but relatively small in overall tonnage, as most aquarium fish are small or juvenile specimens [30]. Note that at least one regional organization (the Secretariat of the Pacific Community, SPC) is coordinating the tracking of catches and exports of Pacific island countries involved in this trade [31]. Finally, we do not explicitly address catches destined for the Live Reef Fish Trade [LRFT, 32], although, given that these fisheries are often part of normal commercial operations, the catch tonnages of the LRFT is assumed to be addressed in our estimates of commercial catches. Our subsequent estimates of landed value of catches using the global ex-vessel fish price database [33, 34] will therefore undervalue the catch of any taxa destined directly to the LRFT. All the data omissions indicated above are additional factors why our reconstructed total catches are a conservative metric of the impacts of fishing on the world's marine ecosystems and/or of the value of fisheries catches.

For any country or territory, we check whether catches originating from the above fishing sectors are included in the reported baseline of catch data, notably by examining their taxonomic composition, and any metadata, from, e.g., the FAO 'Yearbooks' [e.g., 35].

The absence from the baseline data of a taxon known to be caught in a country or territory (e.g., cockles gleaned by women on the shore of an estuary) can also be used to identify a fishery that has been overlooked in the official data collection scheme, as can the absence of reef fishes in the coastal data of a Pacific Island state [11]. Note, however, that, to avoid double counting, tuna and other large pelagic fishes, unless known to be caught by a local small-scale fishery (and thus not likely to have been reported to a Regional Fisheries Management Organization or RFMO in the past), are not included in this reconstruction step, as industrial large pelagic catches are reconstructed using a separate global approach, see following section.

Finally, if gears are identified in national data, but catch data from a gear known to exist in a given country are not included, then it can be assumed that its catch has been missed, as documented for weirs in the Persian Gulf [36, 37].

Step 3: Sourcing of available alternative information sources for missing data

The major initial source of information for catch reconstructions are publications and websites of governments and specifically their Department of Fisheries or equivalent agency, both online and in hard copies. Contrary to what could be expected, it is sometimes not the agency responsible for fisheries, or the scientists most knowledgeable about the fisheries which supplies the catch statistics to FAO, but other agencies or government entities, e.g., some statistical office or agency, with the result that much of the granularity of the original data (i.e., taxonomic resolution, catch by sector, by species or by gear) is lost even before it reaches Rome. Furthermore, the data request forms (spreadsheets) sent by FAO each year to each country do not explicitly encourage improvements or changes in taxonomic composition on the spreadsheets (although the accompanying instruction forms do suggest to add other taxa if data are available), as the spreadsheets contain the country's previous years' data in the same composition as submitted in earlier years, and the spreadsheet itself does not actively suggest or invite better resolution data to be added. This may suggest to the often time pressed government officials tasked with completing the FAO data questionnaires that they could simply add the most recent year's data in the same taxonomic composition as previous years. This can lead to pooling of detailed data at the national level into the taxonomic categories inherited through earlier (sometimes decades old) FAO reporting schemes [e.g., Bermuda, 38]. Thus, by getting back to the original data, much of the original granularity can be regained during reconstructions [e.g., Bermuda, 39]. A second major source of information on national catches are international research organizations such as, e.g., FAO, ICES, or SPC, or RFMOs such as, e.g., NAFO, IOTC or CCAMLR, or current or past regional fisheries development and/or management projects (many of them launched and supported by FAO), such as the BOBLME Project. All these organizations and projects issue reports and publications describing - sometimes in considerable details - the fisheries of their member countries. Another source of information is obviously the academic literature, now widely accessible through Google Scholar.

A good source of information for earlier decades (especially the 1950s and 1960s) for countries that formerly were part of colonial empires (especially British or French) are the colonial archives in London (British Colonial Office) and the 'Archives Nationales d'Outre-Mer', in Aix-en-Provence, and the publications of ORSTOM, for the former French colonies. A further good source of information and data are also non-fisheries sources, including household-, consumption- and/or nutritional-surveys, which can be of great use for estimating unreported subsistence catches. We found the Aquatic Sciences and Fisheries Abstracts (ASFA) and university library services (and especially its experienced librarians) invaluable for tracking and acquiring such older documents.

Our global network of local collaborators is also crucial in this respect, as they have access to key data sets, publications and local knowledge not available elsewhere, often in languages other than English.

Figure S1 shows a plot of the publications used for and cited in 110 of the approximately 270 country/territory catch reconstructions against their date of publication. Although overall, recent publications predominate, older publications firmly anchor the 1950s catch estimates of many reconstructions. Note also that the data in Figure S1 imply the use of, on average, around 35 publications per reconstruction (not counting online web-sources and personal communications, including orally provided information, e.g., via interviews or meetings, cited within the text of catch reconstruction reports). The reconstruction reports themselves should be consulted for fine-grained source information on specific countries or territories. Every reconstruction we undertook is thoroughly documented and published, either in the peer-reviewed scientific literature [e.g., 11, 17, 40, 41, 42], or as detailed technical reports in the publicly accessible and search-engine indexed

Fisheries Centre Research Reports series [e.g., 43, 44-46], or the *Fisheries Centre Working Paper* series [e.g., 47, 48], or as reports issued by regional organizations [e.g., 49].

We use this opportunity to mention the issue of language, as it is still far too common in the scientific community to behave as if something that is not published in English does not exist, thus adding to the widespread misperception that "there are no data." We take this language bias very seriously in the *Sea Around Us*, which, besides team members who read Chinese, also has or had others who speak Arabic, Danish, Filipino/Tagalog, French, German, Hindi, Japanese, Portuguese, Russian, Spanish, Swedish and Turkish. To deal with languages none of us master, we hired research assistants who spoke, e.g., Korean or Malay/Indonesian, and/or relied on our multilingual network of colleagues and friends throughout the world, e.g., for Greek or Thai. While it is true that English has now become the undisputed language of science [50], other languages are used by billions of people, and one cannot assemble knowledge about the fisheries of the world without the willingness and capacity to explore the literature in languages other than English.

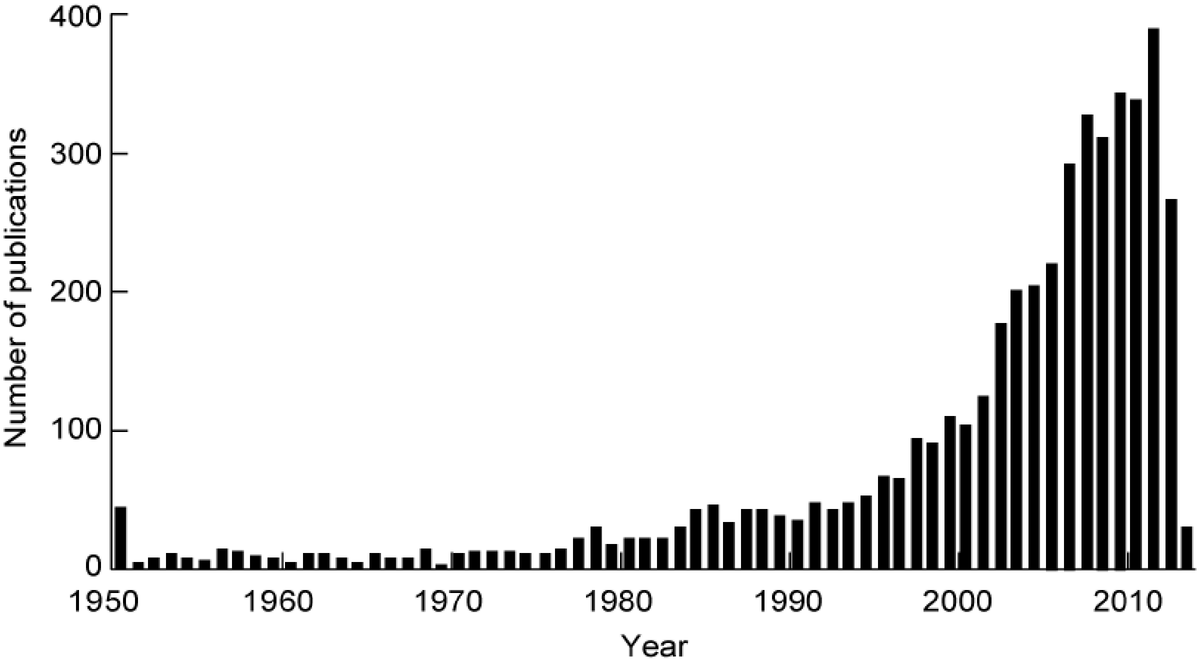

Figure S1. Number of publications (scientific and grey literature) and their publication dates used for 110 of the 270 country/territory catch reconstructions conducted globally. A total of 4,000 publications (excluding personal communications and online sources) were consulted for the 110 reconstruction, resulting in an average of 36 publications being used per reconstruction. The slightly elevated number for 1950 is due to pooling of material dated pre-1950 (as far back as the early 20th century and late 19th century) that was used conservatively to inform 1950 anchor point information.

Step 4: Development and expansion of 'anchor points'

'Anchor' points are catch estimates usually pertaining to a single year and sector, and often to an area not exactly matching the limits of the EEZ or IFA in question. Thus, an anchor point pertaining to a fraction of the coastline of a given country may need to be expanded to the country as a whole, using fisher or population density, or relative IFA or shelf area as raising factor, as appropriate given the local condition. In all cases, we are aware that case studies underlying or providing the anchor point data may had a case-selection bias (e.g., representing an exceptionally good area or community for study, compared to other areas in the same country), and thus use any raising factors very conservatively. Hence, in many instances, we may actually be underestimating any raised catches.

Step 5: Interpolation for time periods between anchor points

Fisheries, as a social activity involving multiple actors, are very difficult to govern; particularly, fishing effort is difficult to reduce, at least in the short term. Thus, if anchor points are available for years separated by multi-year intervals, it will be usually more reasonable to assume that the underlying fishing activity went on in the intervening years with no data. Strangely enough, this 'continuity' assumption we take as default is something that some colleagues are reluctant to make, which is the reason why the catches of, e.g., small-scale fisheries monitored intermittingly often have jagged time-series of reported catches. Exceptions to such continuity assumptions are obvious major environmental impacts such as hurricanes or tsunamis, e.g., cyclones Ofa and Val in 1990-1991 in Samoa [51], or hurricane Hugo in 1989 in Montserrat [52], and major socio-political disturbances, such as military conflicts, e.g., the 1989-2003 Liberian civil war [53], which we explicitly consider with regards to raising factors and the structure of time series. In such cases, our reconstructions mark the event through a temporary change (e.g., decline) in the catch time-series (documented in the text of each catch reconstruction), if only to give pointers for future research on the relationship between fishery catches and natural catastrophes or conflicts. As an aside, we note here that the absence of such a signal (e.g., a reduction in catch for a year or two) in the officially reported catch statistics in countries having experienced a major event of this sort (e.g., Cyclone Nargis in 2008 in Myanmar) is often a sign that their official catch data are highly questionable or manufactured, without reference to what occurs on the ground [see also 54]. Overall, our reconstructions assume - when no information to the contrary is available - that commercial catches (i.e., industrial and artisanal) between anchor points can be linearly interpolated, while for non-commercial catches (i.e., subsistence and recreational), we generally use population trends or number of fishers over time to interpolate between anchor points (via *per capita* rates).

Radical and rapid effort reductions (or even their attempts) as a result of an intentional policy decision and actual implementation do not occur widely. One of the few exceptions that comes to mind is the trawl ban of 1980 in Western Indonesia, whose very partial implementation is discussed in Pauly and Budimartono [55]. The ban had little or no impact on official Indonesian fisheries statistics for Central and Western Indonesia, another indication that they, also, may have little to do with the realities on the ground. FAO [56, pp. 10-11] hints at this being widespread in the Western Central Pacific and the Eastern Indian Ocean (incidentally the only FAO areas where reported catches appear to keep on increasing) when they note that "*while some countries (i.e., the Russian Federation, India and Malaysia) have reported decreases in some years, marine catches submitted to FAO by Myanmar, Vietnam, Indonesia and China show continuous growth, i.e., in some cases resulting in an* *astonishing* (emphasis added) *decadal increase (e.g., Myanmar up 121 percent, and Vietnam up 47 percent)*" which should be taken as a carefully worded statement to the effect that the officially reported data are highly questionable or made up.

Step 6: Estimation of total catch times series by combining (1) and (5)

A reconstruction is completed when the estimated catch time-series derived through steps 2-5 are combined and harmonized with the reported catch of Step 1. Generally, this will result in an increase of the overall catch. The step of harmonizing reconstructed unreported catches with the reported baselines obviously goes hand-in-hand with documenting the entire procedure, which is done via a text that is formally published in the scientific literature, or pending publication, is made available online as either a contribution in the *Fisheries Centre Research Reports* series or as a *Fisheries Center Working Paper*. These documents should be consulted by anyone intending to work with our data. We invite feedback on any of these studies in order to continually improve a country's data. Both the data as well as the documentation associated with each reconstruction are available at www.seaaroundus.org.

Several reconstructions were performed earlier in the mid- to late 2000s, when official data (i.e., FAO statistics or national data) were not available to 2010 [e.g., 10, 57, 58]. These cases were subsequently updated to 2010 through focused updates [e.g., 59] or simple forward carry procedures [e.g., 11], in line with each country's individual reconstruction approach to estimating missing catch data. Thus, all reconstructions were brought to 2010 to ensure identical time coverage. Future datasets will progressively combine systematic forward carries with in-depth country data updates.

Step 7: Quantifying the uncertainty in (6)

On several occasions, after having submitted reconstructions to peer-reviewed journals, we were surprised by the vehemence with which reviewers insisted on a quantification of the uncertainty involved in our reconstructions. Our surprise was due to the fact that catch data, in fisheries research, are never associated with a measure of uncertainty, at least not in the form of anything resembling confidence intervals. We pointed out that the issue at hand was not one of statistical 'precision' (i.e., whether, upon re-estimation, we could expect to produce similar results), but about 'accuracy', i.e., attempting to eliminate a systematic bias, a type of error which statistical theory does not really address.

However, this is an ultimately frustrating argument, as is the argument that officially reported catch data, despite being themselves sampled data, e.g., from commercial market sampling [e.g., Syria, 60] or landings site sampling [e.g., Mozambique, 61, 62], with unknown but potentially substantial margins of uncertainty, are never expected or thought to require measures of uncertainty. We are not aware of any official reported catch dataset that includes estimates of uncertainty. Nevertheless, we apply to all reconstructions the procedure in Zeller, Harper [11] for quantifying their uncertainly, which is inspired from the 'pedigrees' of Funtowicz and Ravetz [63] and the approach used by the Intergovernmental Panel on Climate Change to quantify the uncertainty in its assessments [64].

This procedure consist of the authors of the reconstructions attributing a 'score' to each catch estimate by fisheries sector (industrial, artisanal, etc., as well as discards) in each of three periods (1950-1969, 1970-1989 and 1990-2010) expressing their evaluation of the quality of the time series and underlying data and information sources as well as assumptions made, i.e., (1) 'very low', (2) 'low', (3) 'high' and (4) 'very high' (Table S1). Note the deliberate absence of a 'medium' score, to avoid the non-choice that this easy option would represent. Each of these scores corresponds to a percent range of uncertainty adapted from Monte-Carlo simulations in Ainsworth and Pitcher [65] and Tesfamichael and Pitcher [66]. The overall score for the reconstructed total catch of a sector and/or period can then be computed from the mean of the scores for each sectors, weighted by their catch, and similarly for the relative uncertainty. Alternatively, the percent uncertainty for each sector and period can be used for a full Monte Carlo analysis. Note that we do not view these measure of uncertainty as strict 'confidence intervals' in any statistical sense, but rather as 'uncertainty ranges' of our reconstructed data sets.

Table S1. Scoring system for deriving uncertainty ranges for the quality of time series data of reconstructed catches.

Score		**+/-%**[a]	**Corresponding IPCC criteria**[b]
4	Very high	10	High agreement & robust evidence
3	High	20	High agreement & medium evidence **or** medium agreement & robust evidence
2	Low	30	High agreement & limited evidence **or** medium agreement & medium evidence **or** low agreement & robust evidence.
1	Very low	50	Less than high agreement & less than robust evidence

[a] Percentage uncertainty derived from Monte-Carlo simulations [65, 66].

[b] "Confidence increases" (and hence percentage ranges are reduced) "when there are multiple, consistent independent lines of high-quality evidence" [64].

Foreign catches

Foreign catches are catches taken by industrial vessels of a fishing country in the EEZ, or EEZ-equivalent waters of another coastal country. By definition, all foreign fishing in the waters of another country is deemed to be industrial in nature. As the high seas legally belong to no one (or to everybody, which is here equivalent), there can be no 'foreign' catches in the high seas.

Prior to UNCLOS, and the declaration of EEZs by maritime countries, foreign catches were illegal only if conducted within the territorial waters of such countries (generally, but not always 12 nm) without explicit permission from the host country. Since the declarations of EEZs by the overwhelming majority of maritime countries, foreign catches are considered illegal if conducted within the (usually 200 nm) EEZ and without access ‘agreement’ with the coastal state (except in the EU, whose waters are managed by a ‘Common Fisheries Policy’ which implies a multilateral ‘access agreement’).

Such ‘agreements’ can be tacit and based on historic rights, or more commonly explicit and involving compensatory payment for the coastal state. The *Sea Around Us* has created a database of such access and agreements, which is used to allocate the catches of distant-water fleets to the waters where they were taken (see below). Our website presents and regularly updates, for each EEZ in question, the relevant access information used for spatial allocation. Many catch reconstructions, in addition to identifying the catch of domestic fleets, often at least mention the foreign countries fishing in the waters of the country they cover (information we use in our access database), while other reconstructions explicitly quantify these catches [particularly in West Africa, 67, 68].

This information is then harmonized with (a) the catches deemed to have been taken outside a country’s EEZ, as derived in Step 1 above, and (b) the landings of countries reported by FAO as fishing outside the FAO areas in which they are located (e.g., Spain, located in FAO Area 27 [Northeast Atlantic] reporting catches from Area 51 [Western Indian Ocean], Figure 1), which always identifies these catches as distant-water landings, and thus allows estimation of the catch by foreign fisheries in a given area and even EEZ. Conservative estimates of discards are then added to these foreign landings, derived from the discarding rates of both the domestic and foreign fisheries operating in the countries and/or FAO areas in question [e.g., 69]. Ultimately, the total catch thus extracted from a given area (i.e., a chunk of EEZ or EEZ-equivalent waters, or high seas waters within a given FAO area) is then computed as the sum of three data layers as described below under ‘*catch reconstruction database*’.

In line with INTERPOL and UNDOC, we believe that illegal fishing is a crime [70]; here we define it as foreign fishing within the EEZ waters of another country without a formal permission to access. We do not treat domestic fisheries’ violations of ‘fishing regulations’ as ‘illegal’. In general, our reconstruction method cannot readily distinguish between legal and illegal foreign fishing (because we do not necessarily know about all access agreements). Thus by default, our data only pertain to ‘reported’ versus ‘unreported’ catches, irrespective of legal status of foreign fleets in a host country. However, for around 2 dozen countries where the number of illegally operating vessels could be inferred [e.g., West Africa; 17, 71-73], the fleet size could be multiplied by appropriate catch per unit of effort rates, leading to an estimate of illegal catch, which was then harmonized with other Layer 2 data.

Catch composition

The taxonomy of catches is what allows catches to be mapped in an ecosystem setting, as different taxa have different distribution ranges and habitat preferences (see ‘*taxon distributions*’ below). Also, temporal changes in the relative contribution of different taxa in the catch data also indicate changes in fishing operations and/or in dominance patterns in exploited ecosystems. Thus, various ecosystem state indicators can be derived from catch composition data, e.g., the 'mean temperature of the catch' which tracks global warming [74], 'stock-status plots' which can provide a first-order assessment of the status of stocks [75] and the 'marine trophic index', which reveals instances of "fishing down marine food webs" [76-78, 79; see also www.fishingdown.org, 80].

Most national statistical systems in the word manage to present at least some of their catch in taxonomically disaggregated form (i.e., by species), but many report a large fraction of their catch as over-aggregated, uninformative categories such as 'other fish' or 'miscellaneous marine fishes' or 'marine fishes nei' (nei is defined as 'not elsewhere included'). Interestingly, many official national datasets have better taxonomic resolution than the data reported to FAO by national authorities [see e.g., 38]. It is highly likely that this is largely the result of the design of the data request forms that FAO distributes to countries each year, which do not seem to actively encourage the most detailed national taxonomic resolution data whenever possible, despite such suggestions being included in the documentation FAO sends with the data request files. We have attempted to reduce the contribution of such over-aggregated groups to the total catch of a reconstruction, by using a variety of approaches. The species and higher taxa in the catch of a given country or territory can thus belong to either one three groups:

1) Species or higher taxa that were already included in the baseline reported data;
2) Species or higher taxa into which over-aggregated catches have been subdivided using two or more sets of composition data, such that the changing composition data reflect at least some of the observed changes of fishing operations and/or in the underlying ecosystem; or
3) Species or higher taxa into which over-aggregated catches have been subdivided using only one set of catch composition data, and which therefore cannot be expected to reflect changes in catch compositions due to changes in fishing operations and/or changes in the underlying ecosystem. This score is also applied in cases where no local/national information on the taxonomic composition was available, and thus a taxonomic resolution from neighbouring countries was applied.

In upcoming versions of the *Sea Around Us* catch database we hope to be able to label each taxon of every country with (1), (2) or (3), such that (3) and perhaps also (2) are NOT used to compute indicators such as outlined above (they would falsely suggest an absence of change) – although we fear that this may still occur.

Reconstructed global tuna catch data

Despite tuna fisheries being among the most valuable in the world [81], as well as the considerable interest by civil society in the management of large pelagics, there are, to date, no truly global and fully comprehensive spatial datasets or 'atlas' presenting the historical industrial catches of these taxa for all species and regions of the world back to 1950, although the FAO Atlas of Tuna and Billfishes does present sizeable subsets of data on this topic[1].

Here, we present the methods used to produce the comprehensive global 'atlas' of industrial large pelagics fisheries as first described by Le Manach, Chavance [82]. To produce this global dataset, we assembled various existing tuna datasets (Table S2), and harmonized them using a rule-based approach.

Table S2. Overview of the various data sources used for the creation of a comprehensive global catch dataset of industrially caught tuna and other large pelagic fishes.

Ocean	RFMO	Sources of data		Spatial resolution 'tuna cells'	Countries/gears/species
		Nominal catch	Spatial data		
Atlantic	ICCAT	website	website	1°x1°, 5°x5°, 5°x10°, 10°x10°, 10°x20°, 20°x20°	114/48/142
Indian	IOTC	website	website	1°x1°, 5°x5°, 10°x10°, 10°x20°, 20°x20°	57/35/45
Eastern Pacific	IATTC	website	FAO Atlas of tuna and billfish catches	5°x5°	28/11/19
Western Pacific	WCPFC	website	website	5°x5°	41/9/9
Southern	CCSBT	CCSBT staff	website	5°x5°	11/8/1

For each ocean, the nominal catch data were spatialized according to reported proportions in the spatial data. For example, if France reported 100 tonnes of yellowfin tuna in 1983 using longlines in the nominal dataset, but there were 85 tonnes of yellowfin tuna reported spatially in 1983 by France using longlines, in four separate statistical 'tuna cells' (potentially of varying spatial size, Table S2), the nominal 100 tonnes for France were split up into those four spatial 'tuna cells' according to their reported proportion of total catch in the spatial dataset. This matching of the nominal and spatial records was done over a series of successive refinements, with the first being the best-case scenario, in which there were matching records for year, country, gear and species. The last refinement was the worst-case scenario, in which there were no matching records except for the year of catch. For example, if France reported 100 tonnes of yellowfin tuna caught in 1983 using longlines, but there were no spatial records for any country catching yellowfin tuna in 1983, the nominal 100 tonnes for France were split up into spatial 'tuna cells' according to their reported proportion of total catch of any species and gear in 1983. After each successive refinement, the matched and non-matched records were stored separately, so that at each new refinement, only the previous step's non-matched records were used. The matched database was added to at the end of

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[1] The Food and Agriculture Organization of the United Nations (FAO) publishes a Tuna and Billfish Atlas (www.fao.org/figis/geoserver/tunaatlas), but it includes only data on 12 species of tuna and billfishes (i.e., albacore, Atlantic bluefin tuna, Atlantic white marlin, bigeye tuna, black marlin, blue marlin, Pacific bluefin tuna, skipjack tuna, southern bluefin tuna, striped marlin, swordfish, and yellowfin tuna). For reasons of confidentiality of commercial interests, this dataset at present lacks longline data for the eastern Pacific area after 1962, managed by the IATTC, although some data for the earlier period have been published in aggregated form elsewhere.

each step. The end result was a catch baseline database containing all matched and spatialized catch records, which sum up to the original nominal catch.

The catches thus assigned to the various sized 'tuna cells' (1º x 1º to 20º x 20º; Table S2) were then spatially re-allocated to the standard 0.5° x 0.5° degree cells used by the *Sea Around Us* following the procedure described below (see '*spatial allocation*'). All artisanal catches (i.e., any gear other than industrial scale longlines, purse-seines, and pole-and-lines, as well as 'offshore gillnets') were reallocated to the EEZs of origin of the fleet, and harmonized with the country reconstructed data.

Finally, a review of the literature was performed for each ocean to collect estimates of discards. Due to the limited amount of country- and fleet-specific data that this search yielded, it was decided that discard percentages should be averaged across the entire time-period and applied to the region of origin of the fleet (e.g., East Asia or Western Europe), rather than the actual country of origin of the fleet. Similarly to the spatial assignment step described above, successive refinements were then performed to add discards to all reported catch.

The end result of the entire process is the first harmonized and spatially complete database of global industrial large pelagic fisheries, including an estimate of discards. Until now, only regional (RFMO) or incomplete (e.g., the FAO Atlas of Tuna and Billfish Catches) databases existed, thus providing a truncated picture of these highly interconnected, global fisheries. Therefore, the interest of this new database lies in its ability to show the development of the various fisheries within and between each ocean basin (i.e., a clear advantage of scaling up), despite its preliminary nature.

Several points should be noted for improvement, and the total catch is still thought to be incomplete, and can be improved upon in future iterations:

- The IATTC (Inter-American Tropical Tuna Commission) posed some data problems by not releasing the spatialized longline catch data that were indicated for release in 2014. We hope that spatialized IATTC data will become available in the future, which will then improve the mapping of tuna catches in the northeast Pacific;
- The ICCAT nominal catch database contains some qualitative geographic information (i.e., 'sub-areas'), which are apparently not geographically defined. Thus, we could not use them to refine our coarse spatial assignment. If these sub-areas were to become geographically defined, it would allow us to improve the spatial assignment of the nominal catch to specific sub-areas rather than to the entire ICCAT area;
- The FAD vs. free school breakdown we used could be improved, using the actual spatial and annual breakdown from the spatialized database rather than applying only the annual breakdown. This gear distinction is made only by the IOTC (Indian Ocean Tuna Commission) and ICCAT. We did not differentiate between these two targeting methods, and our stopgap measure resulted in the same spatial allocation for both FAD and free-school catches. This can certainly be improved upon;
- Discard rates used here only account for a subset of the literature, and we encountered some initial difficulties in harmonizing these data. Feedback from worldwide experts could allow

us to refine these rates, by integrating a rule-based approach by gear and country to our discard estimation; and

- Finally, we also imagine that other global databases such as FishBase (www.fishbase.org) could be used to refine our spatial distribution of the catch by, e.g., restricting species to certain areas.

Thus, these spatial large pelagics data should be viewed as a first-order version, and we hope that it will trigger some interest in the community, ultimately resulting in the involvement of experts to improve the assumptions and resultant data.

Catch reconstruction database

The catch reconstruction database comprises all of the catch reconstruction data for 1950 to 2010 by fishing country, taxon name, year of catch, fishing sector (industrial, artisanal, subsistence, recreational), catch type (landings, discards), reporting status (reported, unreported), catch amount (in t), input data source (national data, FAO data, reconstructed data) and spatial location of catch such as which Exclusive Economic Zone (EEZ), FAO area, or other area designation (if applicable, e.g., ICES area, CCAMLR area).[2] The database is further sub-divided into three different data layers, which include a layer with the catch taken by a fishing country in its own EEZ or EEZ-equivalent waters (called ‘Layer 1’), the non-tuna catch by each fishing country in other EEZs and/or the high seas (‘Layer 2’), and the catch of all tuna and large pelagic species caught by each fishing country’s industrial fleet (‘Layer 3’). The basic structure of Layers 1 and 2 are identical, while Layer 3 differs slightly in structure due to the nature of the large pelagic input data sets that were reconstructed separately [see previous section and 82]. The process of integration of data from individual reconstructions [Gabon, 83, e.g., Bahamas, 84] into the global catch reconstruction database includes a data verification process, and the allocation of each record to one of the layers based on the taxon, sector, and the area where the taxon was caught.

After initial, detailed review of each country/territory reconstruction dataset and associated technical report by senior *Sea Around Us* research staff, the reconstruction dataset for each EEZ is further verified for accuracy and is formatted to fit the structure of the final database. For example, the total *reported landings* presented in the reconstruction dataset of each country/territory (which represent the catches landed *and* deemed reported to national authorities from within the own EEZ of that country/territory) are compared with the reported data as presented by the FAO on behalf of the respective country/territory in the FAO statistical area that contains the EEZ in question. Any ‘surplus’ of FAO data are then considered to have been caught outside the EEZ of the given country/territory, and thus are treated as part of Layer 2 data. When any issue with the reconstructed catch data is identified, the issue is raised with the *Sea Around Us* catch reconstruction team and the original authors of the reconstruction for further checking and refining of the input data. Additional data verification steps include harmonization of scientific taxon

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[2] ICES: International Council for the Exploration of the Sea; CCAMLR: Convention for the Conservation of Antarctic Marine Living Resources.

names in the reconstruction data with the official, globally recognized and standardized taxon names via the global taxonomic authorities of FishBase (www.fishbase.org) and SeaLifeBase [www.sealifebase.org; see 85]. Fishing country names and EEZ names are also checked and standardized against the *Sea Around Us* spatial databases, and database codes assigned to all parameters. The fishing country and EEZ names allow us to link the catch data to the foreign fishing access database, which contains the information on which fishing country can access the EEZ or EEZ-equivalent waters of another country (see '*foreign fishing access database*' below).

Based on the location where each taxon was deemed to have been caught, each catch record is assigned to a different data Layer. This includes a cross-checking process between the various reconstruction input datasets. For example, if information and data sources used for the reconstruction for country A reported on the presence and the landings of another country (Country B) in the EEZ of country A, this catch of country B is checked against the data in Layer 2 of country B, as provided through country B reconstruction and FAO data. Emphasis is placed on avoiding double counting of catches.

Structure of the database

As indicated above, the catch reconstruction database contains the catch data assigned to one of three layers:

Layer 1

This layer contains all the catches taken by a country within that country's own EEZ. It contains industrial, artisanal, subsistence and recreational sector catches, sub-divided by catch type (landed vs. discarded catch) and reporting status (reported vs. unreported). However, this layer excludes all industrial catches of large pelagics (see Table S3 for the list of reported taxa excluded here), which are moved to Layer 3 for later harmonization with the '*Reconstructed Global Tuna Data*' as described above.

Table S3: Tuna and other large pelagic taxa (n = 29) initially moved from country reconstruction datasets to layer 3 for harmonization with the reconstructed global tuna data.

Common name	TaxonName
Albacore	*Thunnus alalunga*
Atlantic bluefin tuna	*Thunnus thynnus*
Atlantic bonito	*Sarda sarda*
Atlantic sailfish	*Istiophorus albicans*
Atlantic white marlin	*Tetrapturus albidus*
Bigeye tuna	*Thunnus obesus*
Billfishes	Istiophoridae
Black marlin	*Makaira indica*
Black skipjack	*Euthynnus lineatus*
Blackfin tuna	*Thunnus atlanticus*
Blue marlin	*Makaira nigricans*
Bullet tuna	*Auxis rochei rochei*
Indo-Pacific blue marlin	*Makaira mazara*
Indo-Pacific sailfish	*Istiophorus platypterus*

Kawakawa	*Euthynnus affinis*
Little tunny	*Euthynnus alletteratus*
Longbill spearfish	*Tetrapturus pfluegeri*
Longtail tuna	*Thunnus tonggol*
Mediterranean spearfish	*Tetrapturus belone*
Pacific bluefin tuna	*Thunnus orientalis*
Shortbill spearfish	*Tetrapturus angustirostris*
Skipjack tuna	*Katsuwonus pelamis*
Slender tuna	*Allothunnus fallai*
Southern bluefin tuna	*Thunnus maccoyii*
Striped marlin	*Kajikia audax*
Swordfish	*Xiphias gladius*
Tuna	*Thunnus* spp.
Wahoo	*Acanthocybium solandri*
Yellowfin tuna	*Thunnus albacares*

Layer 2

This layer contains data derived either directly from the reconstruction datasets and associated technical reports (i.e., catches listed as being taken outside the country's own EEZ), or indirectly by subtracting the reconstructed catch identified as reported landings in a country's own EEZ (excluding the taxa listed in Table S3) from the data reported by FAO on behalf of that country (also excluding the taxa listed in Table S3) in the relevant FAO (or other statistical) area (i.e., the 'home' FAO area of a given fishing country). Also, Layer 2 includes catches by a given fishing country in all non-home FAO areas; we refer to these catches as being taken by the given country's Distant-Water Fleets. This layer includes only industrial fishing sector catches, as we define all fleets or gears that can operate outside of a given country's own EEZ waters as industrial (i.e., large-scale) in nature. The few documented cases where so-called 'artisanal', 'semi-artisanal' or 'semi-industrial' fleets fish in neighboring EEZs, e.g., for Senegal's large pirogues [17], we internally re-label these catches as belonging to the industrial sector.

Layer 3

This layer initially included 29 specific large pelagic taxa (Table S3) whose reconstructed industrial catch data were moved to this layer to permit harmonization with the independently and globally reconstructed industrial large pelagic dataset, as described in the previous section. The global large pelagic dataset combined taxonomically more diverse large pelagic catch datasets, and added bycatch and discards associated with the global industrial tuna and large pelagic fisheries. Thus, the final harmonized large pelagic dataset (harmonized Layer 3) contains around 140 taxa and their associated catch.

Foreign fishing access database

The foreign fishing access database, which originally built on a fishing agreements database by the FAO [86], contains both observed foreign fishing records, and fishing agreements and treaties that were signed by fishing countries and the host countries in whose EEZs the foreign fleets were permitted to fish. In addition, the database also has start and end year of agreements and/or the observed access. The type of access is also specified, as ‘unilateral’, ‘reciprocal’, ‘assumed unilateral’, or ‘assumed reciprocal’. Also, the type of agreement is recorded in the database and the agreement can be classified into bilateral agreements such as partnership, multilateral agreements such as international conventions or agreements with regional fisheries organizations, private, licensing or exploratory agreements. Additional information contained in this database relates to the type of taxa likely targeted by foreign fleets (e.g., tuna vs. demersal taxa), as well as any available data on access fees paid [87, 88] or quotas included in the agreements.

This database is used in conjunction with the catch reconstruction database and the taxon distribution database [see below, 85] in the spatial allocation process (see ‘*Spatial allocation*‘ section below) that assigns catches to the global *Sea Around Us* ½ x ½ degree cell system.

Taxon distributions

Ecosystem-based fisheries management [EBFM, 12, 89] must include a sense of place, where fisheries interact with the animals of specific ecosystems. To be useful to researchers, managers and policy makers attempting to implement EBFM schemes, the *Sea Around Us* presents biodiversity and fisheries data in spatial form on a grid of about 180,000 half degree latitude and longitude cells which can be regrouped into larger entities, e.g., the EEZs of maritime countries, or the system of Large Marine Ecosystems (LME) initiated by NOAA [90], and now used by practitioners throughout the world [e.g., 91].

However, presently not all the marine biodiversity of the world can be mapped in this manner; thus, while FishBase (www.fishbase.org) includes all marine fishes described so far (more than 15,000 spp.), so little is known about the distribution of the majority of these species that they cannot be readily mapped in their entirety. The situation is even worse for marine invertebrates, despite huge efforts (see www.sealifebase.org).

We define as ‘commercial’ all marine fish or invertebrate species that are either reported in the catch statistics of at least one of the member countries of the FAO, or are listed as part of commercial and non-commercial catches (retained as well as discarded) in country-specific catch reconstructions. For most species occurring in the landings statistics of FAO, there were enough data in FishBase for at least tentatively mapping their distribution ranges. Similarly, most species of commercial invertebrates had enough information in SeaLifeBase for their approximate distribution range to be mapped.

Here, we summarize the procedure used by Palomares, Cheung [85] for creating and/or updating distribution probability ranges [updated and improved from 92] for all ‘commercial’ species (currently over 2,500 for the 1950-2010 time period), and which consist of a set of rigorously applied filters that will markedly improve the accuracy of the *Sea Around Us* biodiversity and catch maps.

The ‘filters’ used here are presented in the order that they are applied. Prior to applying the ‘filters’, the identity and nomenclature of each species is verified using FishBase or SeaLifeBase, two internationally authoritative online encyclopedias covering the fishes of the world, and marine non-fish animals, respectively, and their scientific and English common names corrected if necessary. This information is then standardized throughout all *Sea Around Us* databases. Following the creation of all species-level distributions as described here, taxon distributions for higher taxonomic grouping, such as genus, family etc. are generated by combining each taxon-level's contributing components, e.g., for the genus *Gadus*, all distributions of species within this genus are combined.

Note that the procedures presented here explicitly avoid the use of temperature and primary productivity to define or refine distribution ranges for any species, even though these strongly shape the distribution of marine fishes and invertebrates [93, 94]. This was done in order to allow for subsequent analyses of distribution ranges to be legitimately performed using these variables, i.e., to avoid circularity when used for climate change analyses [74, 95-97].

Filter 1: FAO Areas

The FAO has divided the world's oceans into 19 areas for catch reporting purposes (Figure 1 in main text). Information on the occurrence of commercial species within these areas is available primarily through (a) FAO publications and the FAO website (www.fao.org); and (b) FishBase and SeaLifeBase. Figure S2A and S3A illustrate the occurrence by FAO area of Florida pompano (*Trachinotus carolinus*) and silver hake (*Merluccius bilinearis*), i.e., examples representing pelagic and demersal species, respectively.

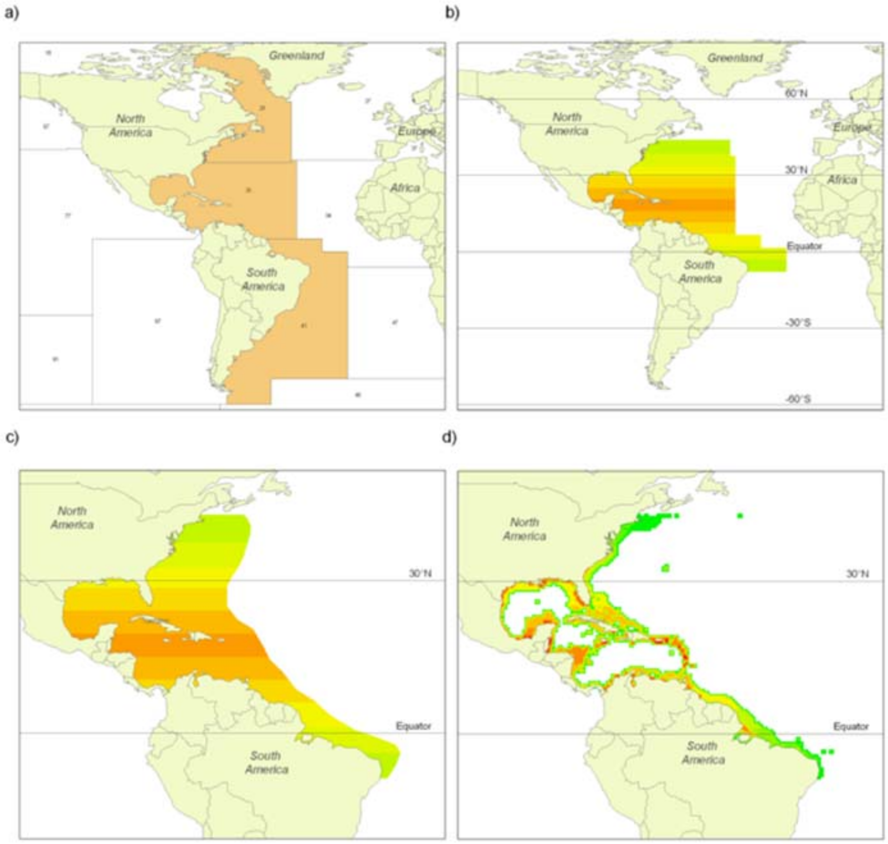

Figure S2. Partial results obtained following the application of the filters used for deriving a species distribution range map for the Florida pompano (*Trachinotus carolinus*): (**A**) illustrates the Florida pompano's presence in FAO areas 21, 31 and 41; (**B**) illustrates the result of overlaying the latitudinal range (43°N to 9°S) over the map in A; (**C**) shows the result of overlaying the (expert-reviewed) range-limiting polygon over B; and (**D**) illustrates the relative abundance of the Florida pompano resulting from the application of the depth range, habitat preference and equatorial submergence filters on the map in C.

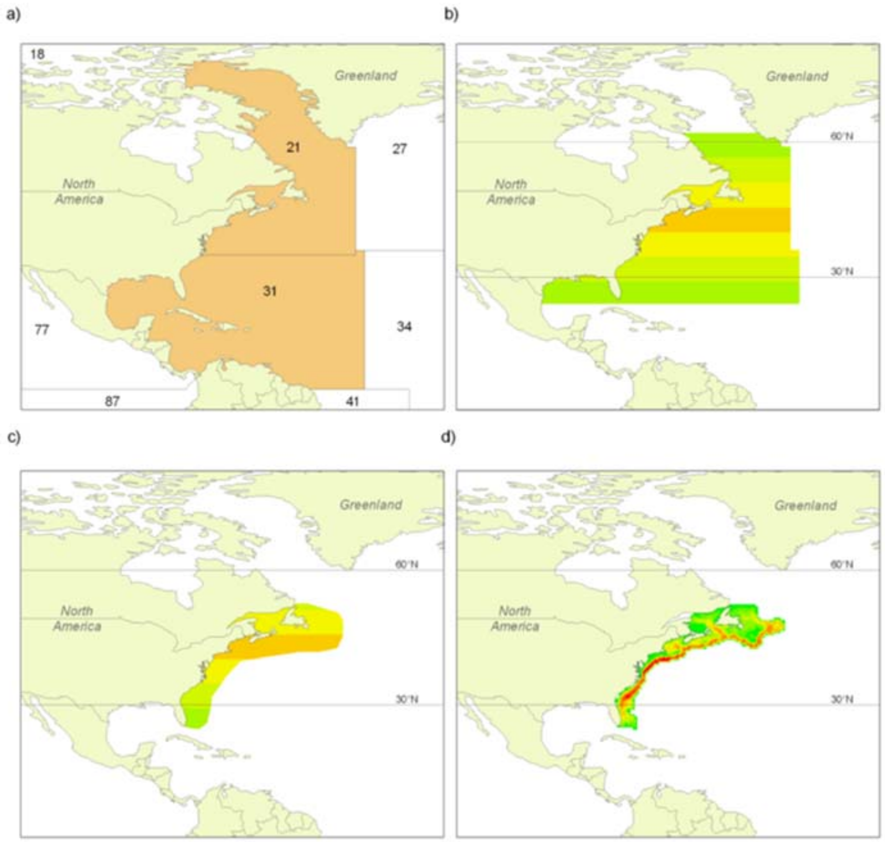

Figure S3. Partial results obtained following the application of the filters used for deriving a species distribution range map for the silver hake (*Merluccius bilinearis*): (**A**) illustrates the silver hake's presence in FAO areas 21 and 31; (**B**) illustrates the result of applying the FAO and latitudinal range (55°N to 24°N); (**C**) shows the result of overlaying the (expert-reviewed) range-limiting polygon over B; and (**D**) illustrates the silver hake's relative abundance resulting from the application of the depth range, habitat preference and equatorial submergence filters on the map in C.

Filter 2: Latitudinal range

The second filter applied in this process is the latitudinal range. Charles Darwin, after reviewing literature on the distribution of marine organisms, concluded that *"latitude is a more important element than longitude"* [see 98, p. 125, for the sources of this quote]. This does not mean, however, that longitude and other factors do not play a role in determining a taxon's distribution.

The latitudinal range of a species is defined as the space between its northernmost and southernmost latitudes of occurrence. This range can be found in FishBase for most fishes and in SeaLifeBase for many invertebrates. For fishes and invertebrates for which this information was lacking, latitudes were inferred from the latitudinal range of the EEZs of countries where they are reported to occur as endemic or native species, and/or from occurrence records on the Ocean Biogeographic Information System website (OBIS; www.iobis.org). Note, however, that recent occurrence records (from the 1980s onwards) and known range extensions were not used to determine 'normal' latitudinal ranges, as they tend to be affected by global warming [95].

A species will not have the same probability of occurrence, or relative abundance throughout its latitudinal range; it can be assumed to be most abundant at the center of its range [99]. Defining the center of the latitudinal distribution range is done using the following assumptions:

a) For distributions confined to a hemisphere, a symmetrical triangular probability distribution is applied, which estimates the center of the latitudinal range as the average of the range, i.e., [northernmost + southernmost latitude] / 2;
b) For distributions straddling the equator, the range is broken into three parts – the outer two thirds and the inner or middle third. If the equator falls within one of the outer thirds of the latitudinal range, then abundance is assumed to be the same as in (a). If, however, the equator falls in the middle third of the range, then abundance is assumed to be flat in the middle third and decreasing to the poles for the remainder of the range.

Figures S2B and S3B illustrate the result of the FAO and latitudinal filters combined. Both the Florida pompano and the silver hake follow symmetrical triangular distributions as mentioned in (a) above.

Filter 3: Range-limiting polygon

Range-limiting polygons help confine species in areas where they are known to occur, while preventing their occurrence in other areas where they could occur (because of environmental conditions), but do not. Distribution polygons for a vast number of species of commercial fish and invertebrates can be found in various publications, notably from FAO (e.g., species catalogues, species identification sheets, guides to the commercial species of various countries or regions), and in online resources, some of which were obtained from model predictions, e.g., Aquamaps [100, see www.aquamaps.org]. Such polygons are mostly based on observed species occurrences, which may or may not be representative of the actual distribution range of the species.

Occurrence records assume that the observer correctly identified the species being reported, which adds a level of uncertainty to the validity of distribution polygons. More often than not, experts are required to review and validate a polygon before it is published, e.g., in an FAO species catalogue. This review process is also important, notably for polygons that are automatically generated via model predictions such as Aquamaps. Note that for commercially important endemic species, this review process can be skipped as the polygon is restricted to the only known habitat and country where such species occur.

For species without published polygons, range maps are generated using the filter process described here and compared with the native distribution generated in Aquamaps. Differences between these two 'model-generated' maps are verified using data from the scientific literature and OBIS/GBIF (i.e., reported occurrences, notably from scientific surveys). Note that FAO statistics, in which countries report a given species in their catch, can be used as occurrence records, the only exception occurring when the species was caught by the country's Distant-Water Fleet, as defined above.

Polygons are drawn based on the verified map (i.e., stripped of unverified occurrences). Additionally, faunistic work covering the high-latitude end of continents and/or semi-enclosed coastal seas with depauperate faunas (e.g., Hudson Bay, or the Baltic Sea) were used to avoid, where appropriate, distributions reaching into these extreme habitats. The results of this step, i.e., the information gathered from the verification of occurrences, are also provided to FishBase and SeaLifeBase to address data gaps.

All polygons, whether available from a publication or newly drawn, were digitized with ESRI's ArcGIS, and were later used for inferences on equatorial submergence (see below). Figures S3C and S4C illustrate the result of the combination of the first three filters, i.e., FAO, latitude and range-limiting polygons. These parameters and polygons will be revised periodically, as our knowledge of the species in question increases.

Note that because this mapping process only deals with commercially-caught species, the distribution ranges for higher level taxa (genera, families, etc.) were usually generated using the combination of range polygons from the taxa included in the higher-level taxon. Thus, the range polygons for genera were built using the range polygons of the commercial species that fall within them, but in the case of genera (but not family or higher) this species-level pooling was augmented by genus–specific distribution information from FishBase and SeaLifeBase. Family-level polygons were generated from genus-level polygons, and so on. Latitude ranges, depth ranges and habitat preferences were expanded in the same manner. While this procedure will not produce the true distribution of the genera and families in question, which usually consists of more species than are reported in catch statistics, it is likely that the generic names in the catch statistics often refer to the very commercial species that are used to generate the distribution ranges, as these taxa are frequently more abundant than the ones that are never reported in official catch statistics.

Filter 4: Depth range

Similar to the latitudinal range, the 'depth range', i.e., "[the] *depth (in m) reported for juveniles and adults (but not larvae) from the most shallow to the deepest* [waters]", is available from FishBase for most fish species and SeaLifeBase for many commercial invertebrates, along with their common depth, defined as the "[the] *depth range (in m) where juveniles and adults are most often found. This range may be calculated as the depth range within which approximately 95% of the biomass occurs*" [101]. Given this, and based on Alverson, Pruter [102], Pauly and Chua [103], and Zeller and Pauly [104], among others, the abundance of a species within the water column is assumed to follow a scalene triangular distribution, where maximum abundance occurs at the top one-third of its depth range.

Filter 5: Habitat preference

Habitat preference is an important factor affecting the distribution of marine species. Thus, the aim of this filter is to enhance the prediction of the probability that a species occurs in an area, based on its association with different habitats. Two assumptions are made here:

- That, other things being equal, the relative abundance of a species in a spatial ½ degree cell is determined by a fraction derived from the number of habitats that a species associates with in that same cell, and by how far the association effect will extend from that habitat; and
- That the extent of this association is assumed to be a function of a species' maximum size (maximum length) and habitat 'versatility'. Thus, a large species that inhabits a wide range of habitats is more likely to occur far from the habitat(s) with which it is associated while smaller species tend to have low habitat versatility [105].

The maximum length and versatility of a species are classified into three categories, and it is assumed that a species can associate with one or more categories with different degrees of membership (0 to 1). A higher membership value means a higher 'probability' that the species is associated with that particularly category. The membership values are defined by a pre-specified membership function for each of the length and versatility categories (Figure S4). For example, the striped bass (*Morone saxatilis*) has a maximum length of 200 cm (total length). Based on the pre-defined membership function presented in Figure S4a, the striped bass has a large body size with a membership of 1. Note that there are maximum length estimates for all the exploited species used by the *Sea Around Us*, derived from FishBase and SeaLifeBase.

The ability of a species to inhabit different habitat types, here referred to as 'versatility', is defined as the ratio between the number of habitats with which a species is associated to the total number of habitats as defined in Table S4. These habitats are categorized as 'biophysical' (i.e., coral reef, estuary, sea grass, seamount, other habitats), 'depth-related' (shelf/slope/abyssal), and 'distance from coast' (inshore/offshore). As species are generally specialized towards 'biophysical' habitats, this filter only takes those five habitats into consideration. Taking our example again, FishBase lists the following for the striped bass: "*Inhabit coastal waters and are commonly found in bays but may enter rivers in the spring to spawn*" [106]. This associates the striped bass with estuaries and 'other habitats' (i.e., when it enters rivers to spawn). Given that the total number of defined biophysical habitats is five, and the striped bass is associated with two of those, then the versatility of striped bass is estimated to be 0.4 (i.e., 2/5). Finally, based on the defined membership functions shown in Figure S4b, the versatility of striped bass is classified as 'low' to 'moderate', with a membership of approximately 0.4 and 0.6, respectively.

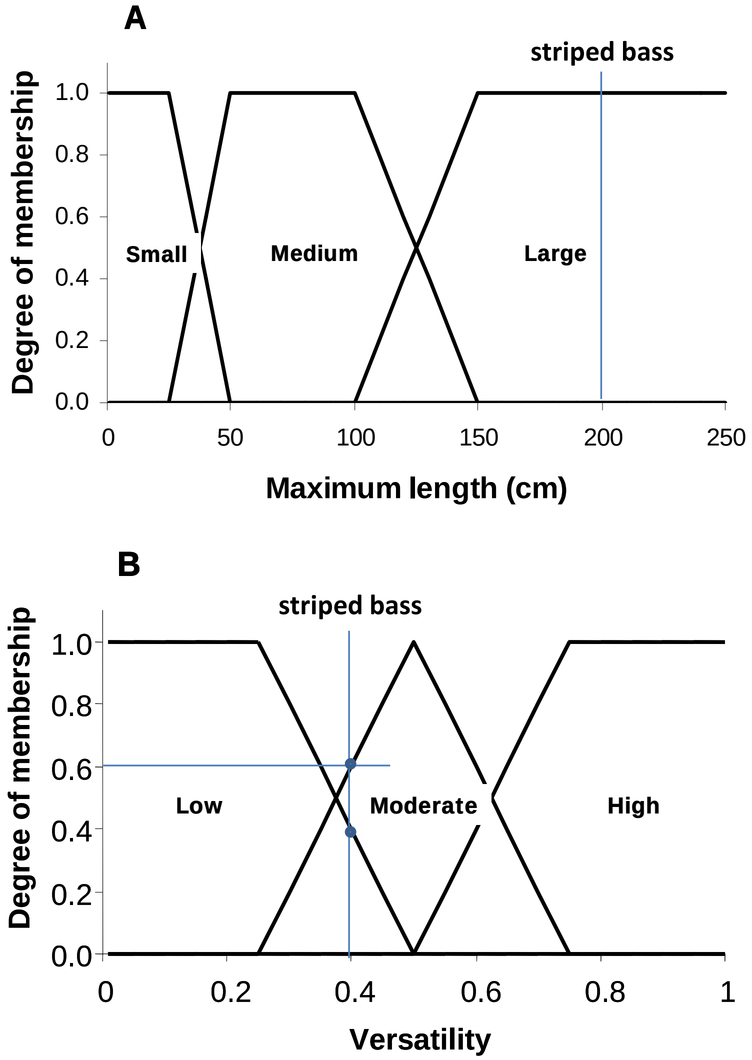

Figure S4. Fuzzy membership functions for the three categories of (a) maximum length and (b) taxon's versatility. Habitat versatility is defined as the ratio of the number of habitat types in which a taxon occurs to the total number of defined habitat types**.**

Table S4. Habitat categories used, and for which global maps are available in the *Sea Around Us*, with some of the terms typically associated with them (in FishBase, SeaLifeBase and other sources)

Categories	Specifications of global map	Terms often used
Estuary	Alder [107]	Estuaries, mangroves, river mouth
Coral	UNEP-WCMC [108]	Coral reef, coral, atoll, reef slope
Sea grass	Not yet available*	Sea grass bed
Seamounts	Kitchingman and Lai [109]	Seamounts
Other habitats	–	Muddy/sandy/rocky bottom
Continental shelf	NOAA [110]	Continental shelf, shelf
Continental slope	NOAA (2004)	Continental slope, upper/lower slope
Abyssal	NOAA (2004)	Away from shelf and slope
Inshore	NOAA (2004)	Shore, inshore, coastal, along shoreline
Offshore	NOAA (2004)	Offshore, oceanic

* The *Sea Around Us* is currently developing a global map of sea grass, which will be applied when available.

Determining habitat association

Qualitative descriptions relating the commonness of (or the preference of) a species to particular habitats (as defined in Table S4) are given weighting factors as enumerated in Table S5. Such descriptions are available from FishBase for most fishes and in SeaLifeBase for most commercially important invertebrates. Going back to our example, we thus know that the striped bass occurs in (and thus prefers) brackish water (i.e., estuaries), but enters freshwater (i.e., 'other habitats') to spawn. Given the weighting system in Table S5, estuaries is assigned a weight of 0.75 (usually occurs in) and 'other habitats' is given a weight of 0.5 (assuming a seasonal spawning period).

Table S5. Common descriptions of relative abundance of species in habitats where they occur and their assigned weighting factors. The weighting factor for ‘other habitats’ is assumed to be 0.1 when no information further information is available.

Description	Weighting factor
Absent/rare	0.00
Occasionally, sometimes	0.25
Often, regularly, seasonally*	0.50
Usually, abundant in, prefer	0.75
Always, mostly, only occurs	1.00

* If a species occurs in a habitat, but no indication of relative abundance is available, a default score of 0.5 is assumed.

Maximum distance of habitat effect

Maximum distance of habitat effect (maximum effective distance) refers to the maximum distance from the nearest perimeter of the habitat which ‘attracts’ a species to a particular habitat. This is defined by the maximum length and habitat versatility of the species using the heuristic rule matrix in Table S6. Taking our example for the striped bass, with a ‘large’ maximum length (membership=1) and ‘low’ to ‘moderate’ versatility (membership values of 0.4 and 0.6), points to a ‘farthest’ maximum effective distance in Table S6. The degree of membership assigned to maximum effective distance is equal to the minimum membership value of the two predicates[3], in this example, 1 vs. 0.4 = 0.4 and 1 vs. 0.6 = 0.6. When the same conclusion is reached from different rules, the final degree of membership equals the average membership value (in this example, (0.4+0.6)/2=0.50).

The maximum effective distance from the associated habitat can be estimated from the 'centroid value' of each conclusion category, weighted by the degree of membership. The centroid values for ‘near’, ‘far’ and ‘farthest’ maximum effective distances were defined as 1 km, 50 km and 100 km, respectively. In our example, we obtained membership values of 0.4 for near (1 km) and 0.6 for farthest (100 km) maximum effective distance, respectively. This gives an estimate of (0.4*1 + 0*50 + 0.6*100)/(0.4 + 0 + 0.6) = 60.4 km (see Figure S5).

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[3] Predicate logic: a generic term for systems of abstract thought applied in fuzzy logic. In this example, the first-order logic predicate is “IF maximum weight is large”, and the second-order logic predicate is “AND versatility is moderate”. The resulting function, i.e., the conclusion category based on the predefined rules matrix in Table S6, is “THEN maximum effective distance is farthest.

Table S6. Heuristic rules that define the maximum effective distance from the habitat in which a species occurs. The columns and rules in bold characters represent the predicates (categories of maximum body size and versatility), while those in italics represent the resulting categories of maximum effective distance.

Versatility	**Maximum body size**		
	Small	**Medium**	**Large**
Low	*Near*	*Near*	*Near*
Moderate	*Far*	*Far*	*Farthest*
High	*Far*	*Farthest*	*Farthest*

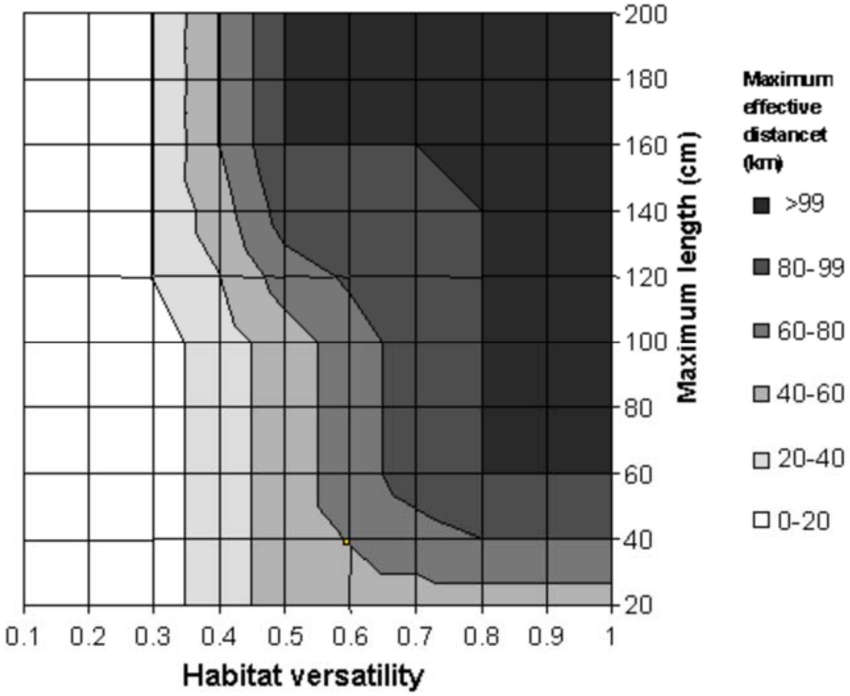

Figure S5. Maximum effective distance for striped bass (*Morone saxatilis*) estimated from the habitat versatility and maximum length of that species (see text).

Estimating relative abundance in a spatial cell

Several assumptions are made to simplify the computations. First, it is assumed that the habitat always occurs in the center of a cell and is circular in shape. Second, species density (per unit area) is assumed to be the same across any habitat type; and that density declines linearly from the habitat perimeter to its maximum effective distance. Given these assumptions, the total relative abundance of a species in a cell equals the sum of abundance on and around its associated habitat, expressed as:

$$B'T = (\alpha j + \alpha j{+}1 \cdot (1 - \alpha j)) \cdot (1 - A) \qquad \ldots 1)$$

where *B'T* is the final abundance, *αj* is the density away from the habitat from cell *j*, and *A* is the habitat area of the cell. The relative abundance resulting from the different habitat types is the sum of relative abundance, and is weighted by their importance to the species.

Although these assumptions on the relationship between maximum length, habitat versatility and maximum distance from the habitat may render uncertain predicted distributions at a fine spatial scale, this routine provides an explicit and consistent way to incorporate habitat considerations into distribution ranges.

Filter 6: Equatorial submergence

Ekman [94] gives the current definition of equatorial submergence: "*animals which in higher latitudes live in shallow water seek in more southern regions archibenthal or purely abyssal waters […]. Cold-water animals must seek colder, deeper water layers in regions with warm surface water if they are to inhabit such regions at all.*" Equatorial submergence, indeed, is caused by the same physiological constraints which also determine the 'normal' latitudinal range of species, as described above, and its shift due to global warming, i.e., respiratory constraints fish and aquatic invertebrates experience at temperatures higher than that which they have evolved to prefer [111, 112].

Modifying the distribution ranges to account for equatorial submergence requires accounting for two constraints: (1) data scarcity; and (2) uneven distribution of environmental variables (temperature, light, food, etc.) with depth. FishBase and SeaLifeBase notwithstanding, there is little information on the depth distribution of most commercial species. However, in most cases, the following four data points are available for each species: the shallow end of the depth range ($D_{shallow}$), its deep end (D_{deep}) of the depth range, the poleward limit of the latitudinal range (L_{high}), and its lower latitude limit (L_{low}). If it is assumed that equatorial submergence is to occur, then it is logical to also assume that $D_{shallow}$ corresponds to L_{high}, and that D_{deep} corresponds to L_{low}.

Also, we further mitigate data scarcity by assuming the shape of the function linking latitude and equatorial submergence. Here, two parabolas (P) are used (Figure 5), one for the shallow limits of the depth distribution ($P_{shallow}$), and one for the deeper limits (P_{deep}), with the assumption that both $P_{shallow}$ and P_{deep} are symmetrical about the Equator. In addition, maximum depths are assumed not to change poleward of 60^0 N and 60^0 S. The uneven distribution of the temperature gradient can be mimicked by constraining $P_{shallow}$ to be less concave than P_{deep} by setting the geometric mean (D_{gm}) of $D_{shallow}$ and D_{deep} as the deepest depth that $P_{shallow}$ can attain. Three points draw the parabolas. In most cases, $P_{shallow}$ is obtained with $D_{60°N}=0$, $D_{60°S}=0$ and $D_{Lhigh}=D_{shallow}$, and P_{deep} with $D_{60°N}=D_{gm}$, $D_{60°S}= D_{gm}$ and $D_{Llow}=D_{max}$. If L_{high} is in the northern hemisphere and L_{low} is in the south, P_{deep} is drawn with D_{meep} at the Equator and conversely for the southern hemisphere. Finally, it is assumed that if a computed $P_{shallow}$ intercepts zero depth at latitudes higher than 60^0 N and/or lower than 60^0 S, then $P_{shallow}$ is recomputed with $D_{60°N}=D_{shallow}$, $D_{60°S}=D_{shallow}$ and $D_{Lhigh}=0$.

Figure S6 illustrates three cases of submergence. These and other constraints are described at www.seaarioubndus.org. When this process is applied to a distribution based on latitudinal range and depth, but which did not account for submergence, it has the effect of 'shaving off' parts of the shallow-end of that distribution at low latitudes, and similarly, shaving off part of the deep-end end of the distribution at high latitudes. Also, besides leading to narrower and more realistic distribution ranges, this leads to narrowing the temperature ranges inhabited by the species in question, which is important for the estimation of their preferred temperature, as used when modelling global warming effects on marine biodiversity and fisheries.

Completed taxon probability distributions

The key outcome of the process described above consists of distribution ranges such as in Figure S8 for over 2,500 taxa, which will be progressively incorporated into the *Sea Around Us* website for viewing. They will also be accessible via FishBase and SeaLifeBase (click '*Sea Around Us* distributions' under the 'Internet sources' section of the species summary pages). These distribution ranges serve as basis for the spatial catch allocation done by the *Sea Around Us*, and we welcome feedback, i.e., suggested comments or corrections.

Predictions of distributions from the *Sea Around Us* algorithm are comparable in performance to other species modeling approaches that are commonly used for marine species [113]. Specifically, AquaMaps [114], Maxent [115] and the *Sea Around Us* algorithm are three approaches that have been applied to predict distributions of marine fishes and invertebrates. Jones, Dye [113] applied these three species distribution modelling methods to commercial fish in the North Sea and North Atlantic using data from FishBase (www.fishbase.org) and the Ocean Biogeographic Information System (OBIS, www.iobis.org). Comparing test statistics of model predictions with occurrence records suggest that each modelling method produced plausible predictions of range maps for each species. However, the pattern of predicted relative habitat suitability can differ substantially between models [116]. Incorporation of expert knowledge, as discussed above with reference to Filter 3, generally improves predictions, and therefore was given here particular attention.

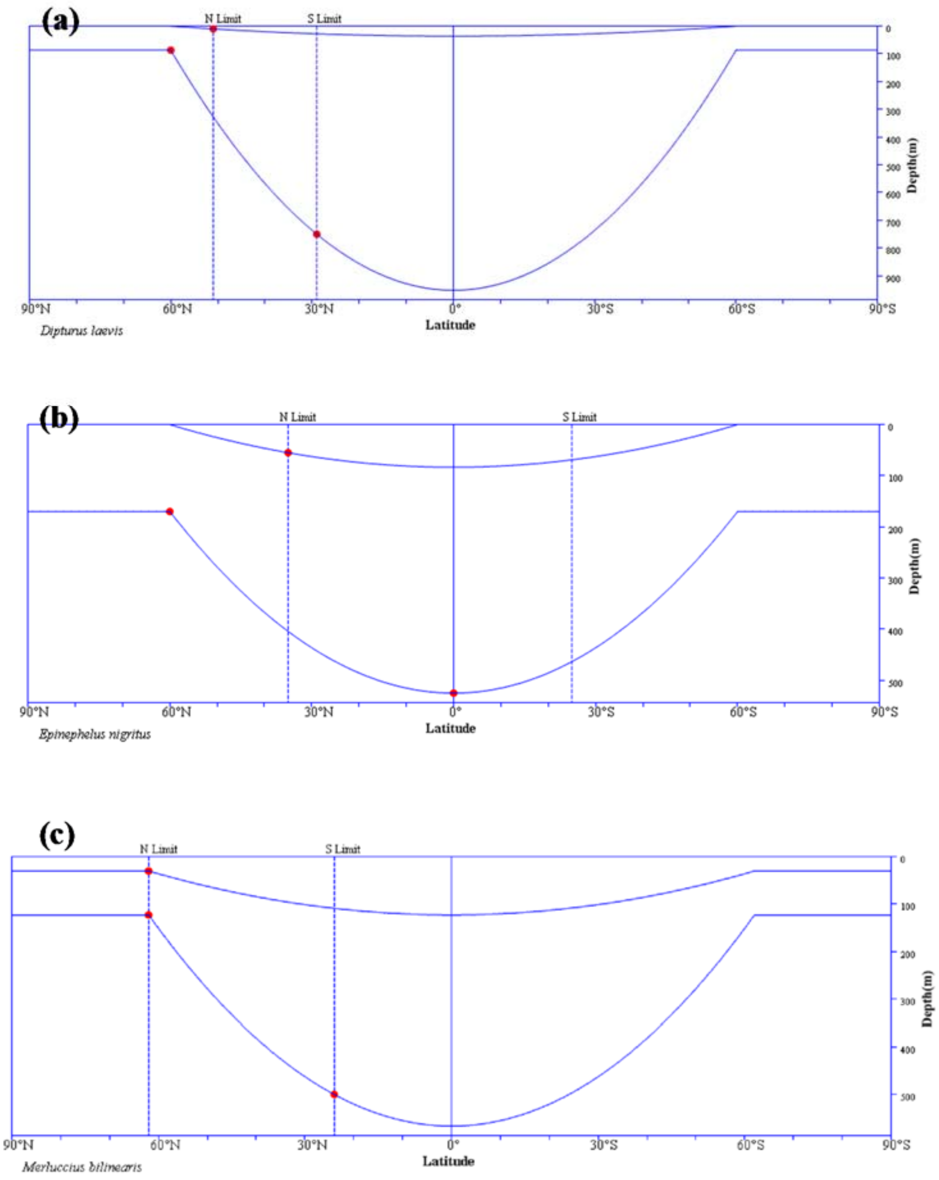

Figure S6 . Shapes used to generate 'equatorial submergence', given different depth/latitude data: (A) Case 1: Barndoor skate (*Dipturus laevis*) – when the distribution range of the species is at lower latitudes than 60º N and/or S, the shallow parabola ($P_{shallow}$) is assumed to intercept zero at 60º N and S; (B) Case 2: When a distribution range is spanning the northern and southern hemispheres, as in the case of the Warsaw grouper (*Epinephelus nigritus*), the deepest depth of the deep parabola (P_{deep}) is at the Equator; (C) Case 3: Silver hake (*Merluccius bilinearis*), where the poleward limit of the latitudinal range (L_{high}) is at higher latitudes than 60º N and S.

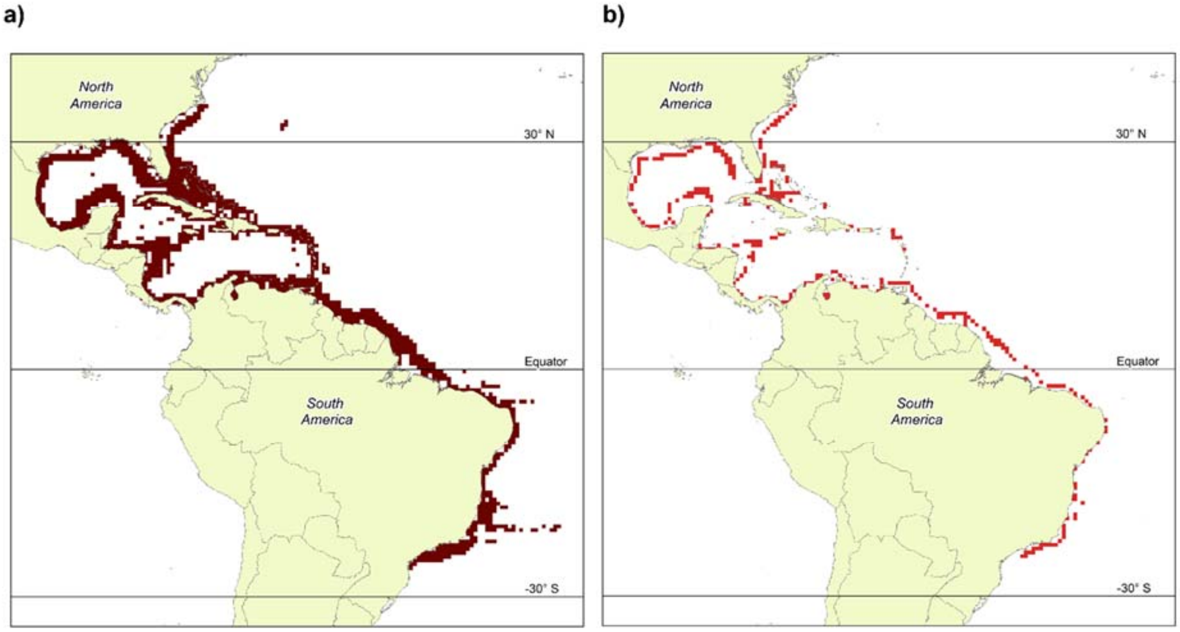

Figure S7. ‘Equatorial submergence’ has the effect of ‘shaving off’ areas from the distribution range of the Warsaw grouper, *Epinephelus nigritus*: (a) original distribution; (b) distribution adjusted for ‘equatorial submergence’.

Spatial allocation

Given the new catch data input structure (Layer 1, 2 and 3) as outlined above, the new and improved spatial allocation process used by the *Sea Around Us* allows focusing on the truly spatial elements of the allocation, which are handled through a series of conceptual algorithmic steps. The general algorithm of spatial allocation of catches is harmonized for Layers 1, 2, and 3 (Table S7), which means better software flow, while maintaining the conceptual differences in data layers. Here, we present an overview of the new allocation process (Figure S8), followed by how each data layer is conceptually unique and how it is handled, and end with an overview of the general algorithm of the spatial allocation.

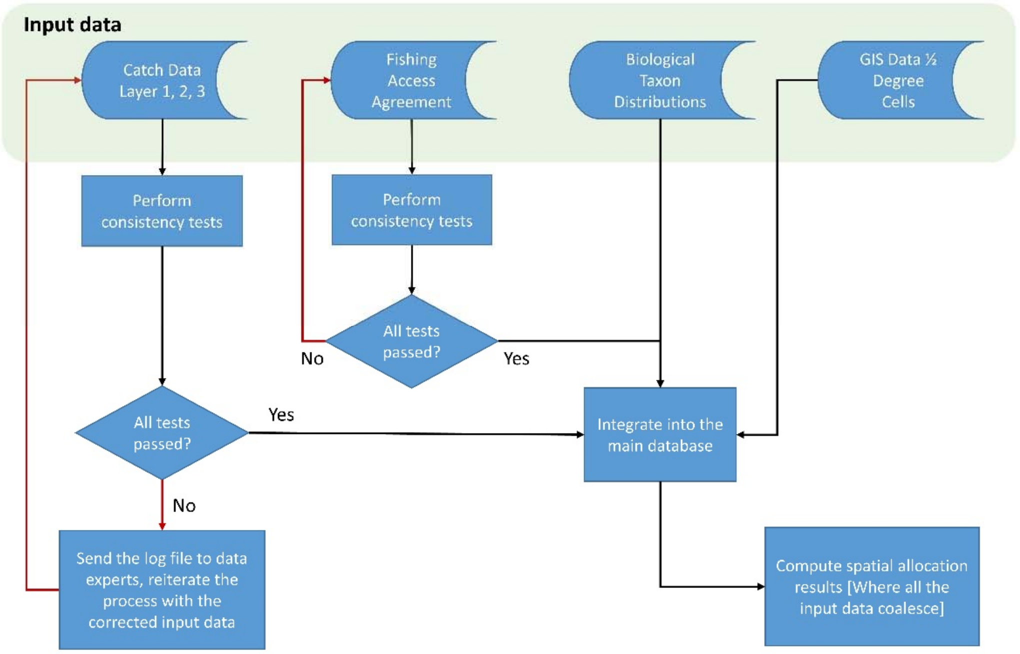

Figure S8. Spatial allocation procedure for catch reconstruction data of the *Sea Around Us*, resulting in the final ½ x ½ degree allocated cell data. For details for the Fishing Access Agreements see '*foreign fishing access database*', for Biological Taxon Distributions, see '*taxon distributions*' above.

The spatial allocation of the catch is the process of computing the catch that can be allocated to each ½ degree cell based on the overlap of three main components: 1) the catch data, 2) the fishing access observations/agreements, and 3) the biological taxon distributions (Figure S8). The overlap amongst these components is calculated using a series of spatial analyses on a collection of Geographic Information System (GIS) datasets.

Table S7: Parameters of the three spatial catch data input layers as used in the spatial allocation to ½ x ½ degree cells of the *Sea Around Us*.

Data layer	**1**	**2**	**3**
Taxa included	All except industrial large pelagics	All except large pelagics	Large pelagics (n =140+)
Spatial scope	Country's own EEZ	Other EEZs and high seas	Global tuna cells
Sectors	Industrial, artisanal, subsistence, recreational	Industrial	Industrial
Distributions	Biological	Biological	Biological
Fishing access	Automatically granted	Used	Used
Granularity of data	EEZ, IFA[1]	EEZ, high seas, ICES, CCAMLAR, NAFO, FAO and other areas	Six types of tuna cells: 1°x1°, 5°x5°, 5°x10°, 10°x10°, 10°x20°, 20°x20°

[1] Inshore Fishing Area (IFA), defined as the area up to 50 km from shore or 200 m depth, whichever comes first [19]. Note that IFAs occur only along inhabited coastlines.

How each data layer is conceptually unique and how it is handled

In Layer 1 (catch of a given fishing country in its own EEZ waters), the data come spatially organized by each fishing entity's EEZ(s). The allocation algorithm assigns the small-scale catches (i.e., artisanal, subsistence, and recreational) only to the cells associated with the Inshore Fishing Area [IFA, 19] of that fishing entity's EEZ(s), while industrial catches can be allocated anywhere within that fishing entity's EEZ(s), as long as they remain compatible with the biological taxon distributions. Foreign fishing access agreements and observations are not applicable to this data layer, as each fishing entity (i.e., country) is always allowed to fish in its own EEZ waters. To represent the historical expansion of domestic industrial fishing since the 1950s, from more easily accessible areas closer to shore to the full extent of each country's EEZ, we use a depth/offshore adjustment function for domestic industrial catches of demersal taxa, as described in Watson and Morato [117]. This mimics the commonly observed feature that, as domestic industrial catches increase over time, an increasing fraction are being taken progressively further offshore and from deeper waters within a country's home waters. This phenomenon was previously already demonstrated by Morato et al. [118] using changes in taxonomic composition in catches over time without any adjustment function.

This was achieved by associating our ½ x ½ degree spatial cells with 'bins' (#1, 2, 3, etc.) of increasing distance from the coast. The most inshore 'bin' #1 in each EEZ is represented by the IFA in that EEZ. Then, if and when the catch of a given demersal taxon at the start of its catch time series was lower than later in the series, this low catch was allocated entirely to 'bin' #1 (i.e., to coastal IFA cells). Then, as catches increase over the years, they are allocated to 'bins' #1 and #2, then to 'bins' #1, #2 and #3, and so on, until the catch reaches a maximum, at which point the catch is assigned to all 'bins', i.e., to the entire fraction of the taxon's distribution that overlaps with the EEZ in question (Figure S9). All 'bins' are also used for all catches after the year with the maximum catch, on the assumption that in a period of declining catches of a given taxon, its entire distribution area (within an EEZ) is available to the industrial fleet of the country in question.

In Layer 2, the spatial granularity of the catch data can be by EEZ, high seas, or any other form of regional reporting areas, i.e., ICES, CCAMLAR, NAFO, or FAO statistical areas. However, in all cases it excludes the fishing entity (fishing country's) own EEZ waters (which are treated in Layer 1). In Layer 2, the foreign fishing access observations/agreements are used to compute the areas which allow fishing for a particular fishing entity, year, and taxon. Once this area is computed, it is superimposed on the biological taxon distributions to derive the final spatial catch allocation of Layer 2 data.

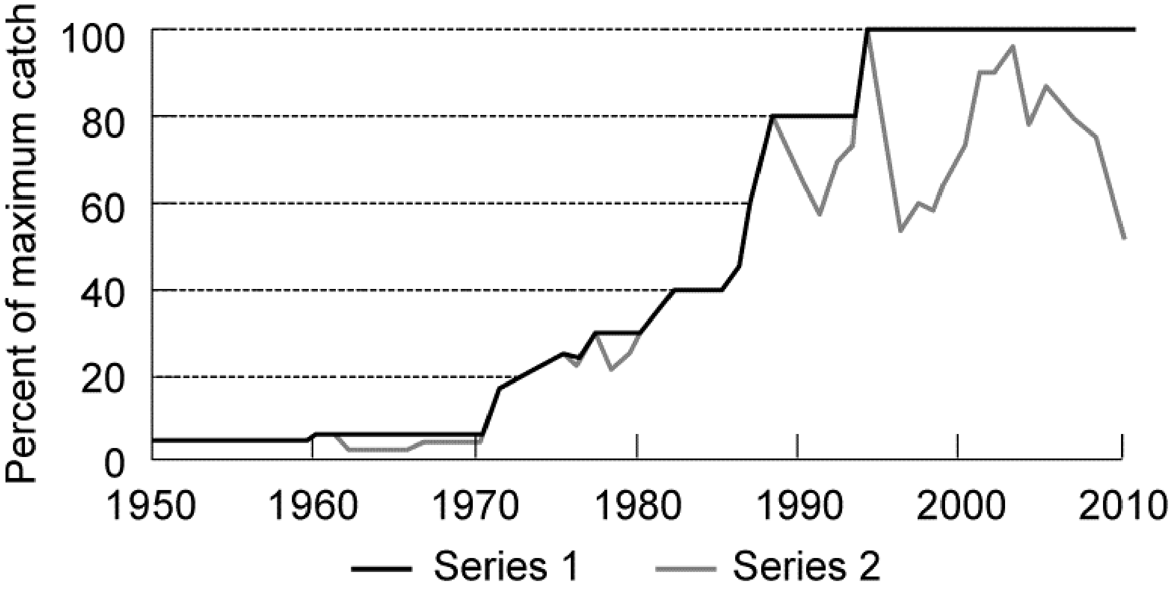

Figure S9. Schematic representation of the method suggested by Watson and Morato [117] to simulate the offshore expansion of demersal industrial fishing: typically, when a demersal industrial fisheries is initiated, only the nearshore/shallow parts of the distribution of each resource species is exploited. To increase its catch (grey line, Series 2), the fishery gradually moves offshore and into deeper water, until it covers the entire distribution areas of the species in question and extracts its maximum catch. Thereafter, excessive fishing may cause the catch to decline, although the entire area continues to be available and accessible to the fleet for exploitation. This is the reason why the fishing fleet is assumed to move offshore in a ratchet-like fashion, i.e., not moving back when the catch declines (black solid line, Series 1).

In Layer 3, which only covers industrial large pelagics and their associated bycatch and discards, the input catch data are spatially organized by larger tuna cells which range from 1 x 1 to 20 x 20 degrees (Table S7, see also '*reconstructed global tuna data*' above). Similar to the region specific areas in Layer 2, these larger tuna cells are intersected with all the EEZ boundaries to create a GIS layer with fractional tuna cells which is suitable for further use in the allocation algorithm. Thereafter, the foreign fishing access observations/agreements and taxon distributions are applied to the tuna cell data and fractional tuna cells GIS layer as done for layer 2 to calculate the final layer 3 catch allocation.

High seas areas (also called Areas Beyond National Jurisdiction) have historically been open access with regards to fisheries, and are generally treated as such by the *Sea Around Us*. The 13 relatively small h seas areas that are enclosed by EEZs, and which are generally termed high seas enclaves or 'donuts' (Figure 1), are treaded as realistically as possible in terms of fisheries utilization (see Table S8 for decision rules for each enclave).

Table S8: High seas enclaves (also called 'high seas donuts') that are enclosed by EEZs, and their treatment by the *Sea Around Us* catch data allocation. The map number for each area refers to Figure 1.

Map #	Ocean	Enclave name	EEZs surrounding the enclave	Treatment by *Sea Around Us* spatial allocation	Sources
1	Atlantic	Barents Sea enclave	Russia, Norway	As per ICES statistical area data	ICES
2	Atlantic	Norwegian Sea enclave	Norway, Iceland, Faroe Islands	As per ICES statistical area data	ICES
3	Atlantic	Gulf of Mexico enclave east	USA, Mexico, Cuba	USA, Mexico, Cuba	Assumption
4	Atlantic	Gulf of Mexico enclave west	USA, Mexico	USA, Mexico	Assumption
5	Pacific	Bering Sea enclave	USA, Russia	Fishing countries as per Convention agreements, i.e., mainly Japan, Poland, USA, South Korea, Russia, Ukraine, and Taiwan: up to the early-mid 1990s moratorium on pollock.	The Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea
6	Pacific	Sea of Okhotsk enclave	Russia	Assigned as Russian internal waters	Assumption
7	Pacific	Japan enclave	Japan	Open access	Assumption
8	Pacific	Philippine-Mariana enclave	Japan, Philippines, Palau, Micronesia, Guam, Northern Marianas,	Open access	Assumption
9	Pacific	West Oceania enclave[1]	Micronesia, Palau, Indonesia, Papua New Guinea	Gear and fishing country specific as per sources	Nauru agreement and WCPFC[2]
10	Pacific	Greater Oceania enclave[1]	Micronesia, Papua New Guinea, Solomon Islands, Fiji, Tuvalu, Kiribati, Nauru, Marshall Islands	Gear and fishing country specific as per sources	Nauru agreement and WCPFC[2]
11	Pacific	Smaller Oceania enclave[1]	Solomon Islands, Vanuatu, Fiji	Gear and fishing country specific as per sources	Nauru agreement and WCPFC[2]
12	Pacific	Moana enclave[1]	Cook Islands, French Polynesia, Kiribati	Gear and fishing country specific as per sources	Nauru agreement and WCPFC[2]
13	Antarctic	New Zealand enclave	New Zealand	Assigned as NZ internal waters	Assumption

[1] Naming derived from [119]; [2] Western and Central Pacific Fisheries Commission

An overview of the algorithm

The spatial allocation algorithm has 4 main processes:

1. Validating and importing the foreign fishing access observations/agreements database;
2. Validating and importing the catch reconstruction database;
3. Importing the biological taxon distributions; and
4. Computing the catch that can be allocated to each ½ degree cell for each catch data layer in an iterative process (allowing for verifications and corrections to any of the input parameters).

1. Validating and importing the foreign fishing access observations/agreements database

The foreign fishing access observations/agreements are first verified using several consistency and 'matching' tests (Figure S8) and upon passing the tests they are imported into the main allocation database. This fishing access information is subsequently used in two different processes: (a) the verification process of the catch data (Layers 1, 2, and 3); and (b) the computing of the areas where a given fishing entity (i.e., fishing country) is allow to fish for a specific year and taxon.

2. Validating and importing the catch reconstruction database

The validating and importing of the catch data is a more complex process than the validating and importing process for the foreign fishing access database. This process involves about 22 different pre-allocation data tests (Figure S8). These tests are designed to make sure that the data are coherent from the stand point of database logic, and do not contain any accidental errors. These tests range from simple tests like "*is the TaxonKey valid?*" to more complex tests like "*validate if the given fishing entity has the required fishing access observations/agreements to fish in the given marine area*". Every single row of catch data is examined via these tests, and if it passes all the tests, then the data row in question is added to the main allocation database. If it fails *any* of the tests it is returned to the relevant *Sea Around Us* data experts for review (Figure S8). This process is repeated until all the data rows pass all the pre-allocation tests.

The process of importing the catch reconstruction database includes an important sub-module which is tasked with harmonizing the marine areas. This module is crucial, as the catch data come in a variety of different spatial reporting areas that are not globally homogenous in GIS definitions (e.g., the EEZ of Albania is one entity, while the EEZ of the USA is subdivided into several regions; the north-east Atlantic uses ICES statistical areas, etc.). To harmonize these marine areas and make them accessible to the core allocation process, any given ½ degree marine cell is split into its constituent countries EEZs and high sea components, then the foreign fishing access observations/agreements are applied to this layer to determine which of these 'shards' of ½ degree cells are allowing access to a given fishing entity. Once this is determined, these collections of ‘shards’ are assigned to the given row of catch data, the result is a harmonized view of all the different marine areas. Presently, we have assigned over 12,000 marine areas into their constituent ‘shards’ of ½ degree cells, these marine areas range from EEZs and LMEs, to ICES, CCAMLAR, NAFO, and FAO statistical areas. The procedure allows future marine areas to be readily assigned.

3. Importing biological taxon distributions

Importing the biological taxon distributions is a fairly straightforward process. The over 2,500 individual biological taxon distributions (see ‘*taxon distributions*’ above) are generated as individual text files (csv) containing for each ½ x ½ degree cell the specific taxon’s probability of occurrence. These individual taxon distribution files are compiled into a database table for a more centralized and database centric use.

4. Computing/allocating the catch to ½ degree cells

Once the Steps 1, 2, and 3 are completed, we perform the computations which yields the final spatial ½ x ½ degree allocation results. The catch of a given data row, *TotalCatch*, of taxon *T* is distributed amongst eligible ½ degree cells, *Cells 1…n*, using the following weighted average formula:

$$Cell_{i_{AllocatedCatch}} = TotalCatch \times \frac{Cell_{i_{SurfaceArea}} \times Cell_{i_{RelativeAbundance\,of\,Taxon\,T}}}{\sum_1^n Cell_{i_{SurfaceArea}} \times Cell_{i_{RelativeAbundance\,of\,Taxon\,T}}}$$

Throughout the allocation process, catch reconstruction parameters in addition to *year* and *taxon*, such as *fishing sector*, *catch type*, *reporting status* etc. are preserved and carried over into the final ½ x ½ degree allocated database.

Conclusion

The final output of the various *Sea Around Us* databases and spatial allocation processes described here is a spatialized catch database that presents the reconstructed fisheries catches of every country in the world in ecologically meaningful and politically feasible space, over time back to 1950, and by currently best taxonomic, sectoral, catch type and reporting status composition. All data are viewable, accessible and downloadable via the *Sea Around Us* website at www.seaaroundus.org. We encourage and welcome all contributions to improve upon these data to increase their accuracy and comprehensiveness, and invite colleagues to collaborate with us to achieve this goal.

Acknowledgments

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