Marine Policy 70 (2016) 145–152

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

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

D. Zeller *, M.L.D. Palomares, A. Tavakolie, M. Ang, D. Belhabib, W.W.L. Cheung, V.W.Y. Lam, E. Sy, G. Tsui, K. Zylich, D Pauly

Sea Around Us, Global Fisheries Cluster, Institute for the Oceans and Fisheries, University of British Columbia, Vancouver V6T 1Z4, Canada

ARTICLE INFO

Article history:
Received 20 November 2015
Received in revised form
20 April 2016
Accepted 20 April 2016

Keywords:
Catch maps
Discards
Exclusive economic zones
Fishing sectors
Global ocean
Unreported fisheries catch

ABSTRACT

In 2005, *the Sea Around Us* described a website (www.seaaroundus.org) which presented, for all maritime countries and large marine ecosystems in the world, one of the most basic information items required by policy makers and fisheries managers: what catch was taken within their jurisdictional boundaries, and which countries took it. Surprisingly, for many countries this kind of jurisdictionally and/or ecologically assigned data had not been readily available before then. Since the release of these spatialized data, this material has had major influence on how fisheries are perceived by policy makers in various countries and by the global scientific community, as well as by a growing list of other stakeholders such as non-governmental environmental organizations and the general public. Here, the *Sea Around Us* updates the fisheries science, policy, conservation and management audience on the extensively modified spatial allocation method and a substantially improved new website. Also, this contribution points to and describes the much improved catch data underlying this website. These data now account for catches for all countries in the world by fisheries sectors (industrial, artisanal, subsistence, recreational), after augmenting the officially reported landings data through the inclusion of comprehensively reconstructed data of previously unreported catches and major discards, for every maritime country or territory in the world, and their Exclusive Economic Zone (EEZ). Also presented are the extensively improved spatial allocation procedures which assign global catch data to the 180,000 half degree spatial cells used by the *Sea Around Us* to subdivide the global ocean. The reconstructed data for 1950–2010 for all countries in the world and the High Seas, freely accessible and downloadable through the *Sea Around Us* web portal, will be updated regularly. It is hoped that these revised data and the substantially improved web utility will invigorate and assist the debate about the role of fisheries in a global framework as well as in national food security settings.

1. Introduction

As part of the drive for 'internationalization' and global co-operation after WWII, the then developing intergovernmental United Nations system intended to 'quantify the world' [1] as a mean of assisting in the development and optimization of policies and socio-economic development. This included the efforts of the Food and Agriculture Organization (FAO) to assemble and maintain a global dataset on the catches of fisheries reported by every country in the world. While local fisheries management agencies, and their associated stock assessment teams (at least in developed countries) often have access to local and national data that are detailed and spatialized to their assessment needs (e.g., local stock ranges or ecosystems), the same cannot be said for stocks/species that are not primary, assessed stocks, or for most developing countries, or overarching regional and global data.

At the global scale, the only database in existence that covers fisheries is that assembled and harmonized by the FAO. FAO should be recognized and commended for the difficult task of maintaining, on an annual basis since 1950, this database despite many countries not readily providing the requested data [2]. Unfortunately, the basic structure of the global dataset presented by FAO on behalf of its member countries suffers from relatively coarse spatial assignment (e.g., global marine fisheries catches are

* Corresponding author.
E-mail addresses: d.zeller@oceans.ubc.ca (D. Zeller), m.palomares@oceans.ubc.ca (M.L.D. Palomares), a.tavakolie@oceans.ubc.ca (A. Tavakolie), m.ang@oceans.ubc.ca (M. Ang), d.belhabib@oceans.ubc.ca (D. Belhabib), w.cheung@oceans.ubc.ca (W.W.L. Cheung), v.lam@oceans.ubc.ca (V.W.Y. Lam), e.sy@oceans.ubc.ca (E. Sy), g.tsui@oceans.ubc.ca (G. Tsui), k.zylich@oceans.ubc.ca (K. Zylich), d.pauly@oceans.ubc.ca (D. Pauly).

http://dx.doi.org/10.1016/j.marpol.2016.04.046
0308-597X/

reported at the scale of 19 large maritime statistical areas, Fig. 1)[1] which have quite limited alignment with spatial fisheries policy (these days largely conducted at the level of national EEZs, or Regional Fisheries Management Organizations [RFMO]) or ecosystem considerations [e.g., LMEs, [3,4]]. Data reported to FAO by countries also suffer from taxonomic over-aggregation, with resultant loss of valuable ecological information. However, recent efforts by FAO and some countries to improve taxonomic details of catch data are beginning to take hold. Finally, in today's environment of increasingly wide-spread acceptance of the need for ecosystem-based considerations in fisheries policy and management [5], data that exclude discards and are not reported by fisheries sectors have limited utility. Furthermore, the separation of data by large-scale versus small-scale sectors [6] with their strongly differing ecological impacts and socio-economic characteristics [7–9] can bestow substantial policy relevance.

Evaluating the impacts of fishing on the marine environment requires, at the minimum, time-series of catch data [10–15] with a spatial resolution suitable for either policy application (e.g., by EEZ) or ecological analyses [16–18]. At the very least, interested parties and stakeholders, including civil society, should be able to readily see what catch has been taken by which country's fleet from a given country's Exclusive Economic Zone. In addition, stakeholders need to know which fishing sector (large- versus small-scale) takes how much, in order to make informed decisions as to the substantially differing impacts these two main sectors have on both the environment and our socio-economic structure [7,8].

Global catch data, catch maps and related products that are spatially meaningful in terms of ecology as well as policy are one of the major outputs of the *Sea Around Us* research initiative. As the improved spatial catch allocation process of the *Sea Around Us* is closely tied to the new catch data reconstructions, the underlying catch database, the associated spatial allocation process and the new website services are summarized here, and described in detail in the Supplementary Materials.

2. The catch challenge

Starting in the mid-2000s, the *Sea Around Us* engaged in a decade long project to re-estimate total fisheries catches (i.e., 'reported' catches + best estimates of 'unreported' catches) in the Exclusive Economic Zones (EEZs, Fig. 1) of all countries in the world, as well as the High Seas [7]. For this, a '*catch reconstruction*' approach was utilized whose rationale was conceptualized by Pauly [19] and whose methodological approach was operationalized by Zeller et al. [20] and refined by Zeller et al. [21]. In essence, this approach determines what the officially reported catch data for each country (e.g., national data and/or data as reported by FAO on behalf of countries)[2] include and what these data did not include, i.e., missing fishing sectors, under-estimated time periods, catches from certain fishing gears etc. (Fig. 2). Reconstructions then derive comprehensive catch time series for all 'missing' (i.e., unreported) fisheries components based on all publicly available information sources and conservatively applied assumptions, by fishing sector, year and taxon, for all countries. Previous work by Pitcher et al. [22], as part of the initial phase of the *Sea Around Us*, also proposed ways to estimate unreported catches, as did others [23]. The catch reconstruction initiative, whose major outcomes are now being widely documented [7,21,24] allows accounting for fisheries catches in a far more comprehensive and detailed manner than ever before.

The country-specific catch data reconstructions summarized in Pauly and Zeller [7] and Pauly and Zeller [25] are all either published in the peer-reviewed literature [e.g., [20, 21, 26, 27–35]] or are available online as technical reports (see publications at www.seaaroundus.org). The taxonomically disaggregated time series of catch data they contain, currently covering 61 years (1950–2010), 4 fishing sectors (industrial, artisanal, subsistence and recreational), 2 catch types (landed versus discarded catch) and 2 types of reporting status (reported versus unreported) for the EEZ areas of all maritime countries and territories of the world ($n > 270$), as well as for the global industrial tuna fisheries heavily conducted in High Seas waters, are too big to be presented as flat tables in papers, however detailed. Thus, the catch data generated by the reconstruction process of the *Sea Around Us* (combining reported and estimated unreported catches including discards) are stored in a dedicated catch reconstruction database, which interacts with the other databases held by the *Sea Around Us* to generate various data products. Foremost among these products are fisheries catches spatially allocated to the 180,000 ½ degree latitude by ½ degree longitude cell grid system used by the *Sea Around Us* to represent the world oceans. These data are also freely accessible and downloadable via the new *Sea Around Us* website (www.seaaroundus.org) for any spatial entity we presently consider.

3. The spatial challenge

The spatial allocation procedure for catch data - although it relies on the same global *Sea Around Us* grid of ½x½ degree cells that was used previously - is different from the approach used in the early phase of the *Sea Around Us* as described in Watson, Kitchingman [36]. In the earlier allocations, catches pertaining to large reporting areas (e.g., FAO Areas, see Fig. 1) were allocated directly to the half-degree cells, subject only to constraints provided by derived distributions for the various taxa [37], and an initial fishing access database granting foreign fleets differential access to the EEZs of various countries [36]. Following this allocation, the catch taken by a given fishing country in a given EEZ was obtained by summing the catch that had been allocated to the cells (or fraction thereof) making up the EEZ of that country [36]. This process made the large-scale spatial assignment of catch data overly sensitive to the precise shape and probabilities of the taxon distribution maps [37], and the precision of sometimes problematic EEZ access rules for different countries. It occasionally resulted in sudden and unrealistic shifts of allocated catches into and out of given EEZs purely due to the lifting or imposing of EEZ access constraints. Attempts to improve the allocation procedure with more programmatically imposed internal allocation rules made the allocation process increasingly unwieldy, fragile and extremely time consuming, and thus the *Sea Around Us* abandoned this approach after 2006.

The more structured allocation procedure that was devised as a replacement (for details see the Supplementary Materials) relies on catch data that are spatially pre-assigned through comprehensive, country-by-country catch reconstructions. Catch reconstructions pre-assign catches to the EEZ or EEZ-equivalent waters (for years pre-dating the declaration of individual EEZs) of a given maritime country or territory, and, in the case of small-scale fisheries (i.e., the artisanal, subsistence and recreational sectors), to the *Inshore Fishing Areas* [IFA, [38]] within each

[1] Although for some of the 19 FAO maritime statistical areas, data or subsets of data are available by finer resolution statistical sub-areas.

[2] We would like to point out that we believe that FAO does an admirable job of annually assembling the reported catch data for every country in the world, given the mandate restrictions and financial constraints under which FAO operates, and also given the often poor support and response it gets from countries [2] Garibaldi L. The FAO global capture production database: A six-decade effort to catch the trend. *Mar Policy*. 2012; 36:760–8.

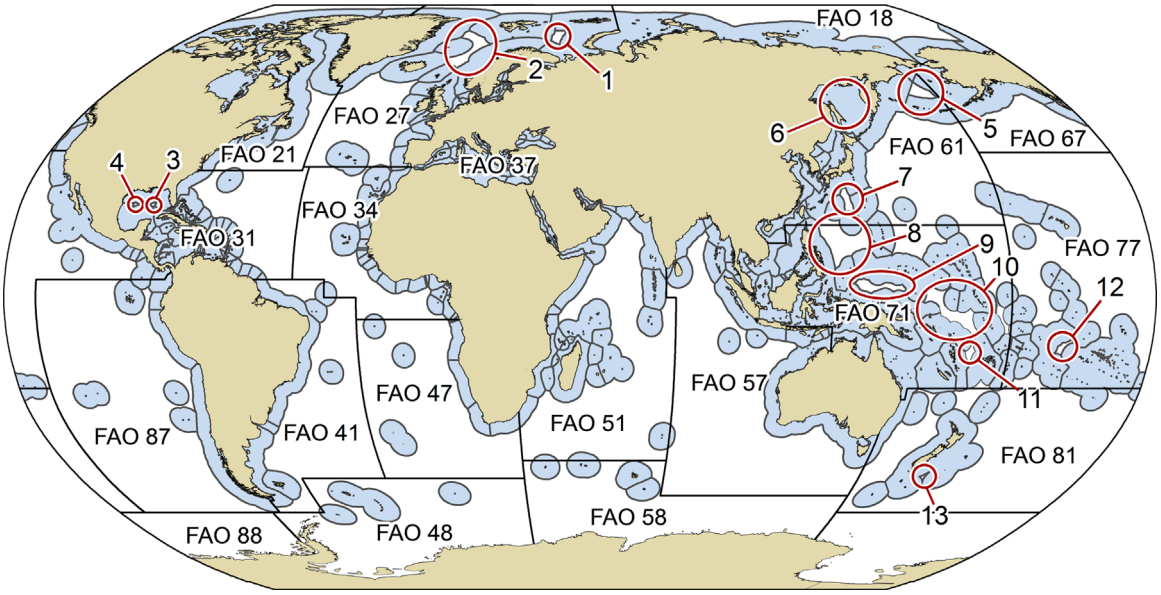

Fig. 1. Extent of countries' Exclusive Economic Zones (EEZs), as declared by individual countries, or as defined by the *Sea Around Us* based on the fundamental principles outlined in UNCLOS (i.e., 200 nautical miles or mid-line rules), and the 19 maritime FAO statistical areas by which global marine fisheries catch statistics are reported. Note that for several FAO areas some data exist by sub-areas as provided through regional organizations (e.g., ICES for FAO Area 27). Also indicated are the 13 High Seas enclaves (or 'donuts') that are fully surrounded by EEZ waters. Numbers refer to entries in Supplementary Table S8, which should also be consulted for details on how these areas were treated by the *Sea Around Us* for the spatial allocation of catches. Map modified from Pauly and Zeller [7].

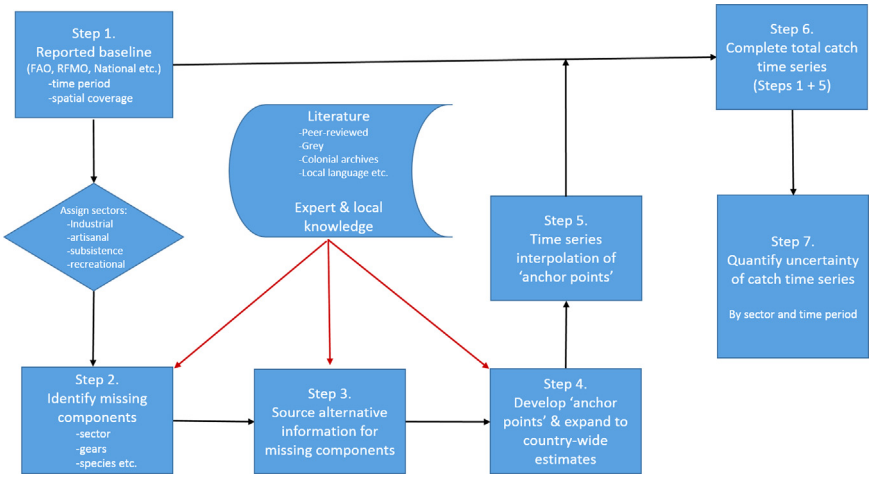

Fig. 2. Flowchart illustrating the 7-step fisheries catch data reconstruction approach as first described in Zeller et al. [20] and refined in Zeller et al. [21]. For details see the Supplementary Materials.

country's EEZ. IFAs are defined as the waters within 50 km from shore or waters up to 200 m depth, whichever comes first. The *Sea Around Us* adds to this definition that only territory that has a permanent human population, and thus the potential for local small-scale fleets, should have an IFA. Thus, uninhabited islands do not have this feature (Fig. 3). This radically reduces the number of access rules and constraints that the allocation procedure must consider, avoids domestic catches showing up in the EEZs of the wrong country, and dramatically reduces the processing times of the allocation procedure from several months to a few days or even hours.

At the same time as the catch database was revised and improved through spatially detailed reconstructed catch data, the *Sea Around Us* also revised the database of fishing access agreements and observed foreign fishing from 1950 to the present. This database, which had its origin in a smaller database kindly made available by FAO [39], documents fishing access agreements that control the formal access of fishing fleets to the waters of other countries. The observations of such activities were enriched even when no agreement is known (i.e., "observed access" as confirmed by experts, or other carefully vetted documents, with source material listed on our website), or when foreign fishing occurred in the EEZ-equivalent waters of a country before the EEZ had been established (see Supplementary Materials).

High Seas areas (also called Areas Beyond National Jurisdiction), as well as EEZ-equivalent waters prior to the year of EEZ declaration by a country have historically been open access with regards to fisheries, and are generally treated as such by the *Sea Around Us*. We recognise that several RFMOs are engaged in trying to control and manage fisheries in High Seas areas under their mandate, albeit country compliance is usually on a voluntary basis. There are several relatively small High Seas areas that are enclosed by EEZs, and which are generally termed High Seas enclaves (also called 'High Seas donuts', Fig. 1). We try and tread these areas as

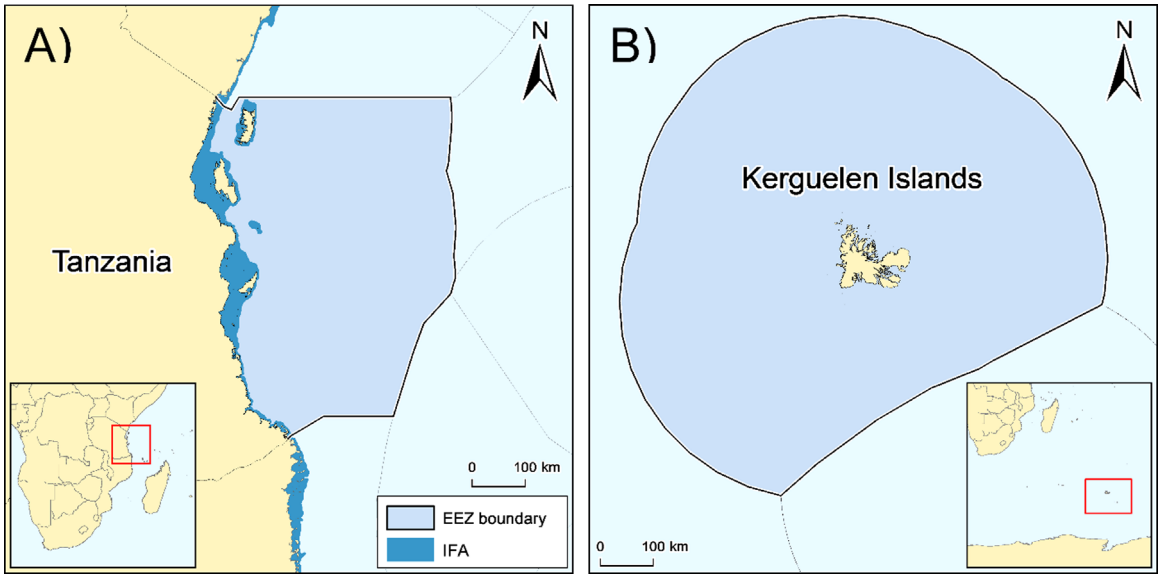

Fig. 3. Map illustrating the *Inshore Fishing Area* concept [38] used by the *Sea Around Us* to spatially define small-scale fisheries to waters within 50 km from shore or waters up to 200 m depth, whichever comes first. To this concept the provision was added that only (A) areas with permanent human populations (e.g., Tanzania), and thus possibly small-scale fleets, should have an IFA; while (B) islands without permanent human populations (e.g., Kerguelen Islands) should not.

realistically as possible in our spatial catch allocation with regards to fishing access (see Supplementary Table S8 for decision rules for each enclave). The naming of most enclave areas was derived based on geographic location, while the major high seas enclaves in the tropical Pacific were named based on [40]. At present, these considerations are in the process of being implemented in our data.

Finally, the *Sea Around Us* re-invigorated and streamlined the procedure used to derive taxon distributions, thereby updating and modifying the approach originally described by Close, Cheung [37], with the new version now described in Palomares, Cheung [41]. Besides embedding a regular and detailed biodiversity and distribution data feedback procedure with the globally leading online databases on fishes (FishBase, www.fishbase.org) and non-fish marine life (SeaLifeBase, www.sealifebase.org), the new procedure also incorporates several improvements, including longitudinal limits on distributions based on biodiversity data and range maps from expert reviewed sources, e.g., the IUCN Red List and FAO species catalogs. Furthermore, the previous heavy reliance on manual input and data processing has been revised into a streamlined procedural algorithm. Since the refined and expanded catch reconstruction database emphasizes improved taxonomic accounting of catches as part of the reconstruction process, the number of taxa for which distributions are required was also expanded to currently over 2500 taxa. The revision of the taxon distribution database is an ongoing process, with improvements and new distributions feeding automatically into each new round of catch data allocation (see Supplementary Materials).

These three databases, namely one comprehensively quantifying the catches taken by all fisheries of a country in its own waters, other countries' waters or the High Seas (i.e., the catch reconstruction database, itself consisting of three data layers, see Supplementary Materials), the second database describing where taxa caught by fisheries can be found with what probabilities (i.e., revised taxon distributions), and the third database documenting where fishing countries actually fished (i.e., updated access database), allow catch data to be spatially 'reverse engineered'. Taken together, these three databases project a comprehensive picture of global as well as national fisheries over a 60+ year period.

4. Output

The final results of this decade-long process are global time series of catches (currently from 1950 to 2010, to be updated regularly) by ½ degree cells that are ecologically relevant (i.e., taxa are caught where they occur, and in relation to their relative abundance) and politically viable (i.e., by fishing country and within EEZ waters where they have explicit or observed access). This allows the presentation of more accurate and comprehensive time series of catches within the waters of specific countries [e.g., Senegal, [24]] as well as regional assessments [e.g., Pacific small island states and territories, [21]]. Of particular importance also are the new parameters the revised *Sea Around Us* data now contain, i.e., (besides taxonomic resolution, Fig. 4(a)) catches by four fishing sectors (industrial, artisanal, subsistence or recreational, Fig. 4(b)), two catch types (landings or discards, Fig. 4(c)), as well as whether or not a given catch is deemed reported or unreported (Fig. 4(d)). In addition, the spatial allocation procedure, by utilizing the updated fishing access database, enables presentation of catches within EEZs by fishing country (Fig. 4(e)). Thus, these new features add substantial utility to the spatialized data of the *Sea Around Us*, as they allow for the first time to compare, among others, the contribution of large- and small-scale sectors to the catch in each country. This should be of great interest to the global community as it moves forward with the implementation of the recently adopted '*Voluntary Guidelines for Securing Sustainable Small-scale Fisheries in the Context of Food Security and Poverty Eradication*' [6,42].

Furthermore, the revised and improved data and allocation process allows more accurate spatio-temporal maps of catches and associated data to be generated. Here, this is illustrated as annual average catches (t km^{-2}) for the 2000–2010 time period for global large pelagic catches, dominated by tuna (Fig. 5(a)), or the catches by all fishing countries as allocated to the waters off north-west Africa [Fig. 5(b), [24,35]]. The revised website of the *Sea Around Us* also features web-based global data mapping that displays the data for selected sets of parameters.

In addition, based on the long-standing partnership with the *Fisheries Economics Research Unit* at the University of British Columbia, the *Sea Around Us* continues to update and improve ancillary databases, such as the global ex-vessel price database

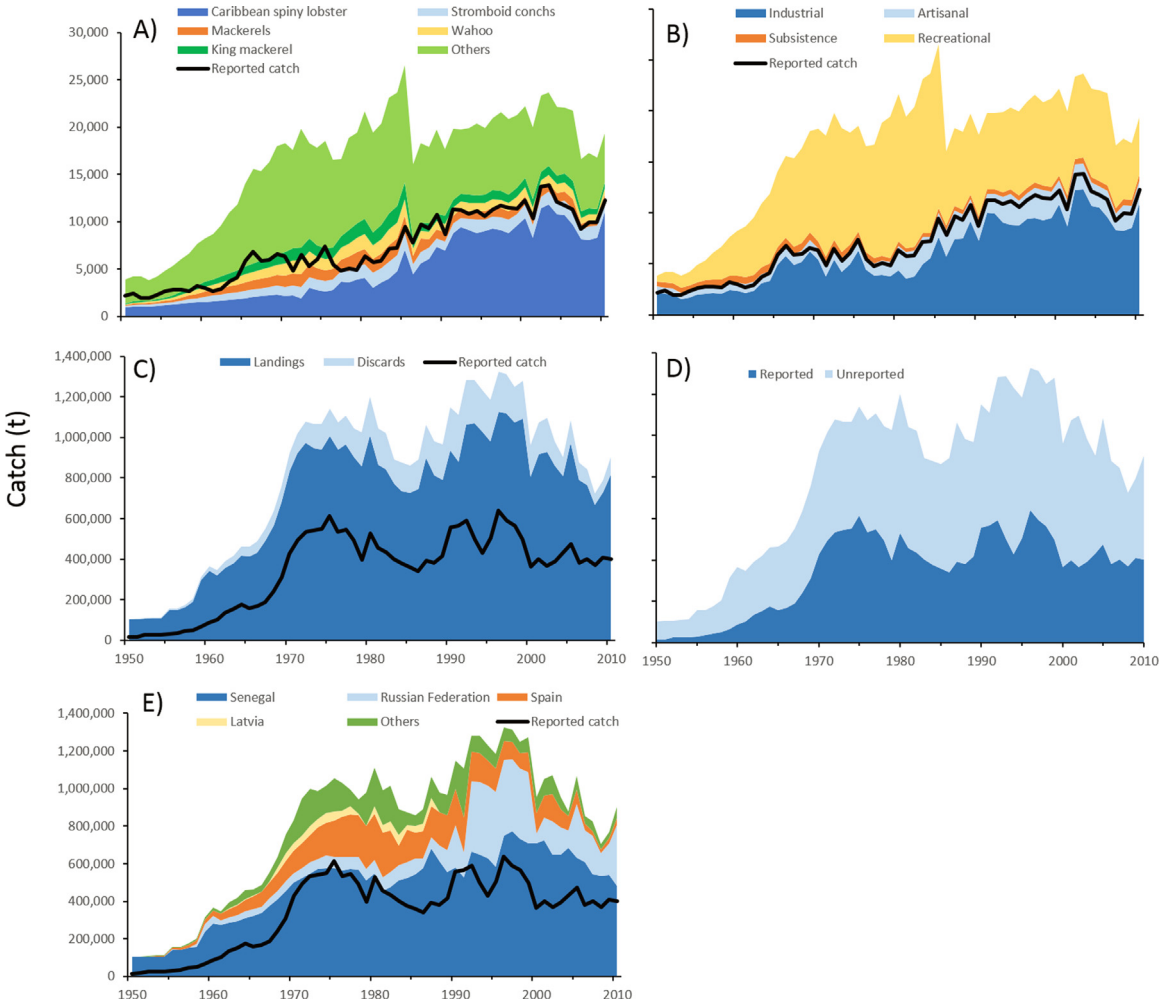

Fig. 4. Catch time series of reconstructed total catches, as derived and spatially allocated by the *Sea Around Us* for every country in the world, by (A) taxonomic composition [e.g., top 5 taxa in the Bahamas, with the rest pooled into 'Others'; [45]]; (B) four fishing sectors [e.g., illustrating the importance of recreational fisheries in the Bahamas, [45]]; (C) two catch types [e.g., documenting the scale of discarded catches in Senegal, [24]]; (D) reporting status [e.g., illustrating the extent of unreported catches in Senegal's waters, [24]]; and (E) fishing country [e.g., documenting the extensive distant-water fleet access to Senegalese waters, [24]].

[43,44], which allows the above mentioned reconstructed catch data sets (i.e., Fig. 4) to be presented as landed values (in 2005 US dollars). Country-specific data, such as fisheries subsidies, are also updated [45] and incorporated, now making subsidies data available for two time periods, i.e., the early 2000s (labelled '2003') and late 2000s (labelled '2009').

Besides EEZs, all reconstructed data and the associated parameters can also be displayed and downloaded by other spatial entities, such as Large Marine Ecosystems (LMEs), High Seas areas, Regional Fisheries Management Organizations (RFMOs), FAO statistical areas (allowing a direct comparison between the data reported by FAO on behalf of countries, which however do not include discards, and our reconstructed data), and the global ocean. Non-spatial features for presenting our data include presenting reconstructed data by fishing countries globally. In all cases, reconstructed total catches (including discards) can be differentiated from reported landings data as allocated to the entities being examined, through the simple overlay of a reported catch line on all our data web pages.

A further feature that is new to the *Sea Around Us* web portal is the inclusion of increasingly more customizable data queries. Options include the grouping of numerous EEZ or LME datasets for viewing and data access, and additional custom options are being developed. Given the *Sea Around Us*' extensive connection to developing countries with often limited bandwidth of internet services and the wide-spread use of older browser versions in these regions, the new web portal also includes a 'basic' search site which strips bandwidth-heavy graphics and other features from the site to allow easier direct access to the data. Switching to the basic site is achieved automatically when the user's browser has 'disabled' JavaScript and/or early browser versions are being used. Options to enable smartphone optimized access to key web products are also being developed. It is hoped that these enhanced service utilities will increase the usability of these data to other researchers, NGOs and the policy community.

The improved spatialized form of *Sea Around Us* catch data provides a more powerful tool than previously available [e.g., for Large Marine Ecosystems, [3,4]] for illustrating trends that cannot be seen in the context of standard catch statistics reported by large, ecologically and politically less meaningful statistical areas (Fig. 1), or which extend beyond the geographic scales that restrict the interest or mandate of most fisheries agencies (e.g., Fig. 5). The *Sea Around Us* has been able to show, for example, that total global fisheries catches were 50% higher than officially reported data suggest over the six decades from 1950 to 2010, and, importantly, that total global catches have been declining strongly since catches peaked in the mid-1990s [7]. This suggests that society has far more to lose than currently thought by not addressing overfishing, but also, that the global community has more to gain by turning fisheries into sustainable activities. Interestingly, the decline in

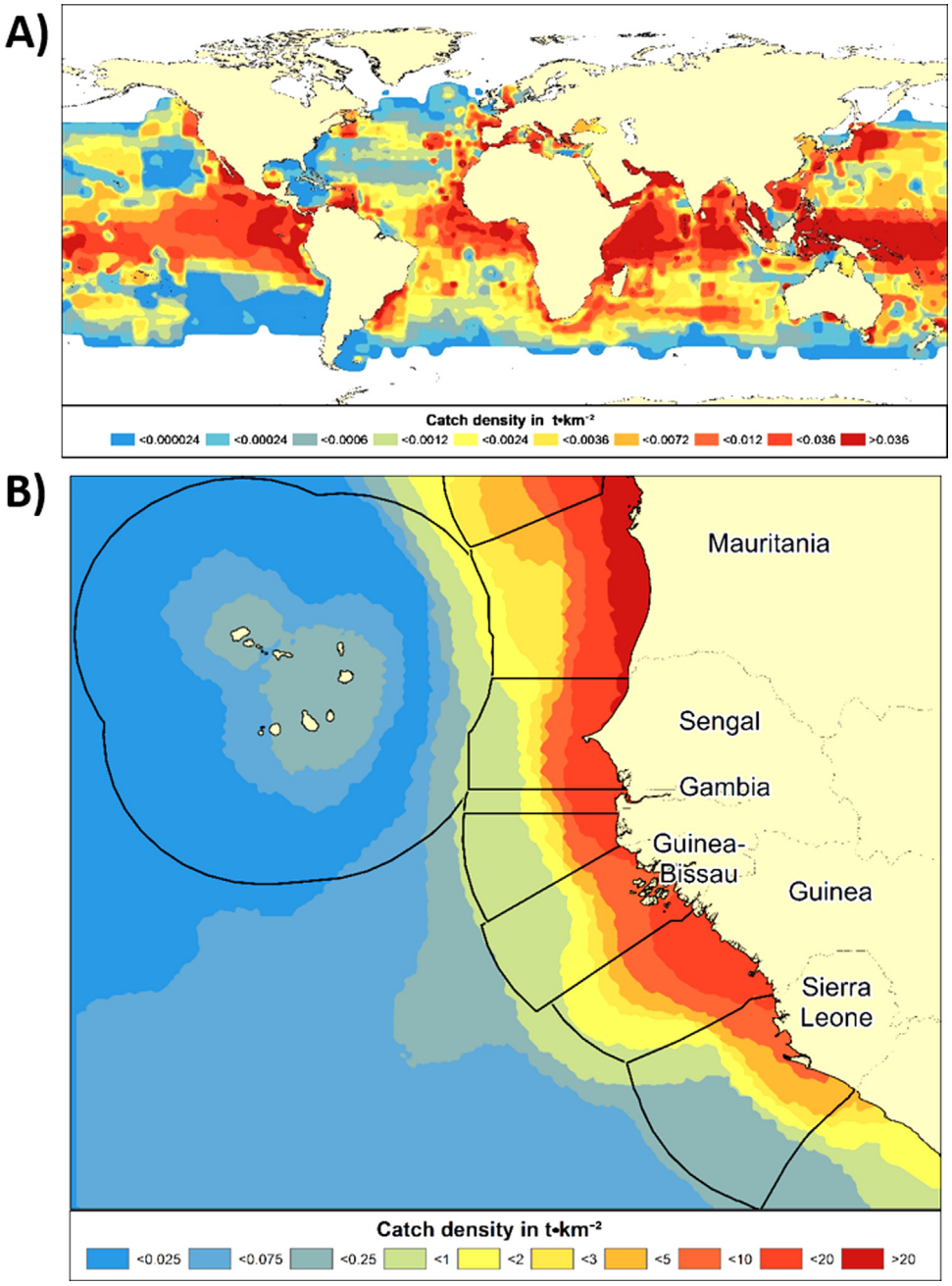

Fig. 5. The global databases and spatial allocation procedure of the *Sea Around Us* allows the mapping of catches in space and time, e.g., of (A) the global average annual catches (t km^{-2}) of large pelagic species (mainly tuna and billfishes) for 2000–2010 as derived from various sources; and (B) the average catches by all fishing countries in and around the EEZs of Senegal and The Gambia and neighboring areas for 2000–2010 [24,35].

global catches are driven mainly by declining industrial catches [7], which currently are largely taken by distant-water fleets from developed countries fishing in developing countries [e.g., [35]]. In contrast, small-scale fisheries, including non-commercial subsistence fisheries [21] have stable or gradually increasing catches [7]. Such small-scale fisheries benefit more people directly, support more livelihoods and generally have fewer negative environmental or socio-economic side-effects.

The *Sea Around Us* is making their data available for viewing and downloading via the revised and improved website (www.seaaroundus.org). The research team of the *Sea Around Us* encourages and welcomes collaborations and constructive feedback on all the country catch reconstructions, and invites all interested parties to utilize the data and indicators assembled and presented. It is hoped that the added value generated by the decade long catch reconstruction project will assist countries in their ongoing process of improving their national data collection and reporting systems, which is of benefit to everyone.

Finally, experts in all countries are hereby being asked for their help in reviewing, improving and updating the existing reconstruction coverage of their countries' marine fisheries and ecosystems. Usually, such exchanges and feedback lead to improvements of data and visualization products, and improvement of their delivery, which is gratifying because local experts often admit that they themselves would otherwise not have access to much of the information now freely available via the *Sea Around Us* pages. Thus, the efforts of the *Sea Around Us* have been well received over the last 15+ years by a global research, conservation and policy constituency that needs information to assess what has been going on in their ocean. We appreciate that aspects of our

work is being critically examined [46], but also see [47] and challenged [48], but also see [49]. While bringing the issue of global fisheries to the attention of a global audience has been a success [e.g., [50–52], work continues as an ongoing contribution to supporting change, hopefully leading humanity to a sustainable fisheries future in a period of global change [53–57].

Acknowledgements

This is a contribution of the *Sea Around Us*, funded by The Paul G. Allen Family Foundation, whose executive arm, Vulcan Inc., undertook the redesign and reprogramming of the *Sea Around Us* website. We thank The Pew Charitable Trusts for 15 years of support, trust and collaboration, and the MAVA Foundation for additional funding. We also thank the hundreds of individuals all around the world who have collaborated with us on catch reconstructions, and the many hundreds more that were patiently willing to answer our often annoyingly detailed questions about their country's fisheries. Finally, we thank the FAO and their fisheries statistical team for their dedication to maintaining the only global database of capture fisheries.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2016.04.046.

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