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The State of Biodiversity and Fisheries in Regional Seas

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The State of Biodiversity and Fisheries in Regional Seas

edited by

Villy Christensen, Sherman Lai, Maria Lourdes D. Palomares, Dirk Zeller, and Daniel Pauly

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CONTENTS

A Research Report from the Fisheries Centre at UBC

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DIRECTOR'S FOREWORD

As stated in the Editors' Preface, this report comes as a response to UNEP's call for indicators that will either measure or give inference on the impact of climate change on marine resources of Regional Seas. The contributions included in this report demonstrate that such indicators can be largely extracted from the various components of the *Sea Around Us* projects database, which contains data on fish and fisheries, ranging from the ecological to the economic and social. More data for the computation of these indicators were obtained from global information systems such as FishBase and SeaLifeBase for biological indicators, and atmospheric and oceanographic databases for environmental indicators. The accessibility of the data required for the extraction of these indicators (as most are readily available online) will facilitate global assessments not only for UNEP's Regional Seas, but also for the United Nations Conference of the Parties member countries' EEZs, thereby making it possible to 'repatriate' data and results. Furthermore, the continued emphasis on this body of work by the *Sea Around Us* project and its partners ensures that these indicators can be extracted and updated for future assessments as the existing routines are improved, new routines are developed and more current data are encoded into the various databases used.

I thank the Editors and contributors of this report for documenting and making this body of work available to a wide audience.

U. RASHID SUMAILA
Director and Associate Professor
The Fisheries Centre

Editors' Preface

We present a framework for extracting indicators on the world's 'Regional Seas', ranging from environmental indicators such as nutrients and selected pollutants and biodiversity indicators to fisheries, economics and social indicators. The work builds on a large number of global databases, most of them developed by members of the *Sea Around Us* project at the Fisheries Centre, University of British Columbia.

The draft version of this report, originally titled *'Indicators for Outlook Reports on the State of Marine Biodiversity in Regional Seas* was prepared on the occasion of the International Year of Biodiversity and in support of the Conference of the Parties (COP) at the 2010 meeting of the Convention on Biological Diversity held in Nagoya, Japan in October 2010, one use of these indicators being the need to document progress toward the 2010 Biodiversity Target.

UNEP's Regional Seas Program Coordinators agreed in 2009 to produce an assessment outlook for marine biodiversity in their regions for presentation at the CBD 2010 COP. In support of the work in the Regional Seas Programs, the UNEP Marine and Coastal Ecosystems Branch asked the *Sea Around Us* project at the Fisheries Centre of the University of British Columbia to:

i. Update relevant data using as a baseline the year 1950 where possible (climate change, nitrogen, sea surface temperatures, biodiversity and fish landings, all at global scales);
ii. Collate fisheries (landings, Marine Trophic Index [MTI] and Fishing-in-Balance index [FiB]); climate change, sea surface temperature (SST) and, if available, nitrogen loading trend data for Regional Seas and some shelf areas outside of Regional Seas (Eastern and Western North America; Brazil, Uruguay and Argentina), and for ocean basins;
iii. Model the global impact of climate change on marine ecosystems using Ecopath with Ecosim models (by FAO statistical areas) using two climate change scenarios and collating the results for trends to 2050 of landings, MTI and FiB for the spatial entities mentioned above;
iv. Relate the landed value of fisheries in each spatial unit to indicators of human welfare as derived by the Fisheries Centre's Global Oceans Economic Project;
v. Submit a report outlining the methodology used, and presenting the results and key references for the data analyzed and the indicators derived from them.

Our focus, we may recall, was on developing a framework for extraction of indicators for all existing and some potential UNEP Regional Seas, and for testing this framework by providing examples. The report also included a number of indicators not included in the original agreement. On the other hand, it did not include a human welfare index based on fisheries data (item iv), as it was to be based on work currently being conducted (and hence still in progress) by the UBC Fisheries Centre's Global Oceans Economic Project.

This *Fisheries Centre Research Report* is an updated and slightly expanded version of the draft report described above, through which we hope to make its interesting approaches available to a wider audience.

Methodology

Deriving indicators for Regional Seas[1]

Sherman Lai, Dalai Felinto, Jeroen Steenbeek[2],
Joe Buszowski, Audrey Valls, Reg Watson, Dirk Zeller,
Daniel Pauly and Villy Christensen
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Abstract

The approach is presented, which was used to extract the mean, maximum and minimum values of various features in areas of the global ocean, and aggregate these to yield indicators relevant to the status of Regional Seas, with emphasis on their biodiversity and fisheries. This work, facilitated by the availability of several databases previously spatialized (in a ½° latitude by ½° longitude grid system) by the *Sea Around Us* project, also required a rigorous spatial definition of UNEP's Regional Seas, which had been lacking so far.

Introduction

This contribution describes the method used to allocate various features of the world ocean to the UNEP Regional Seas areas. Various forms for aggregation and summarization were performed, depending on the data type for the various forms of ecological, environmental, economical/social, exploitation and ecosystem modeling indicators. Indicators for which we had complete spatial coverage globally, such as the *Sea Around Us* project's fisheries catch, and catch values (see www.seaaroundus.org) were summarized by Regional Sea through data aggregation. The method for this was to initially distribute values to the ½° by ½° spatial cells used by the *Sea Around Us* project (see Watson *et al.*, 2004a, 2004b) as well as by other international initiatives (e.g., AquaMaps; see www.aquamaps.org). We then mapped the UNEP's Regional Seas, and intersected all the indicator data with these Regional Seas to produce minimum values, maximum values, means and sums (depending on the unit types) for each indicator. The time dynamic data (e.g., catches) were then plotted such as to show the top catch/taxon/fleet/country over time.

Material and Methods

The key aspect of the methodology described here is that we rely on analyses of a large number of spatial databases and files to extract indicators by Regional Seas. For each, a number of output files (typically CSV-files and figures) are extracted to a Regional Sea-specific folder on the server we use to store the databases and data files.

Regional Sea shapefiles

The initial shape files (i.e., GIS polygons) provided by UNEP encompassed 18 Regional Seas identified at the UNEP website, and a few other zones not listed at the UNEP website, but which are included in this study for the sake of completeness (Figure 1). One of the Regional Seas, the Caspian Sea, recognized by UNEP is not included here, as it is not covered by the *Sea Around Us* project, from which most of our data were obtained.

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[1] Cite as: Lai, S., Felinto, D., Steenbeek, J., Buszowski, J., Watson, R., Zeller, D., Pauly, D., Christensen, V., 2011. Deriving indicators for Regional Seas. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 3-9. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

[2] *Sea Around Us* Project and UNIGIS, Vrije Universiteit, Amsterdam, The Netherlands.

The UNEP Regional Sea shape file was cleaned up in ArcGIS by removing sliver polygons, and combining polygons belonging to different jurisdictions to ensure that we had one, and only one, polygon for each Regional Sea. Then, to check the extraction process by comparing to total values for the combined global ocean, we defined a series of 'unofficial Regional Seas', not included in the original dataset. These consisted of: (i) Eastern South America, here called 'South-West Atlantic'; (ii) Eastern United States/Canada, here called 'North-West Atlantic'; (iii) Western United States/Canada, here called 'North Pacific' and (iv) Hawaii, all extending 200 miles offshore, as do Exclusive Economic Zones (EEZs).

This resulted in the map below (Figure 1), whose total ocean area differs from the *Sea Around Us* project's by a negligible 0.02%.

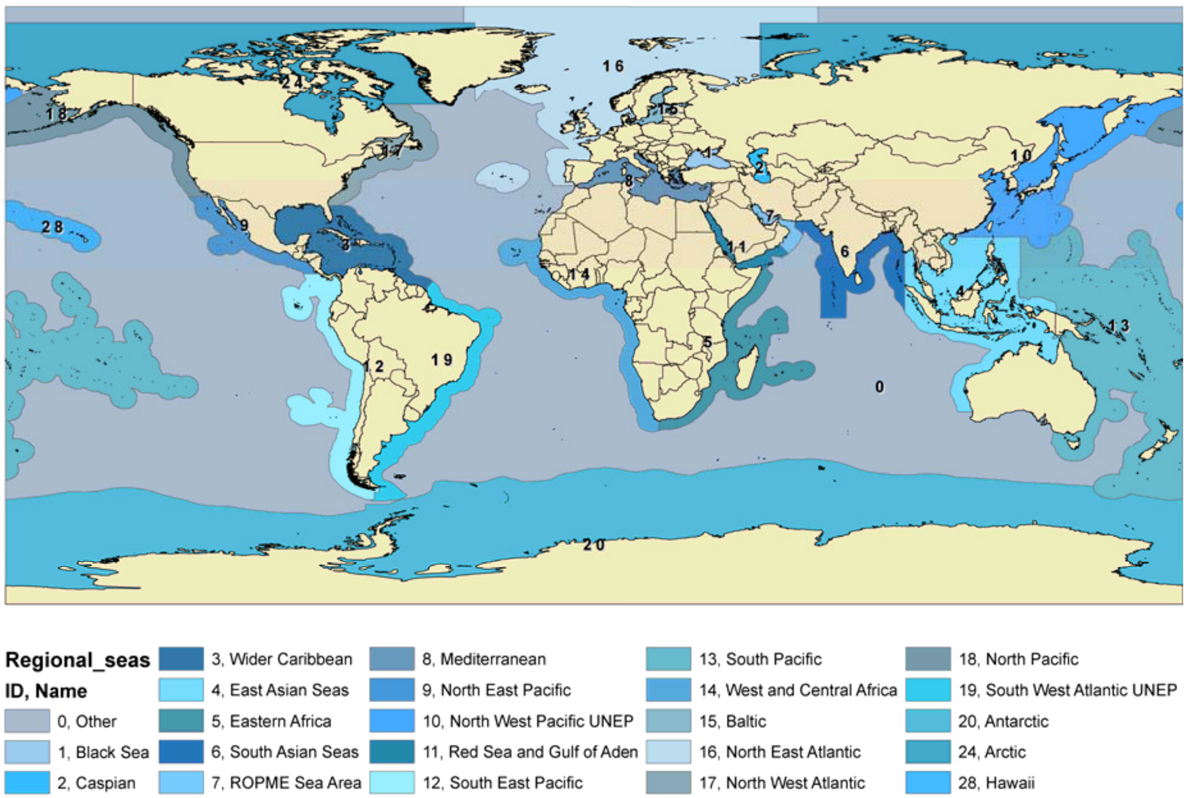

Figure 1. The Regional Seas definitions used in this report (note that we do not cover Regional Sea No 2, i.e., the Caspian).

Converting Regional Sea shape files to cells

Using ArcGIS, the Regional Sea shape files were converted to a grid with ½° latitude by ½° longitude resolution, resulting in 259,200 (360 x 720) cells overall, spanning the world (including land areas), and defining for each cell the water area that belongs to each Regional Sea. This grid, referred to as the RS-raster, is required to obtain statistics for each Regional Sea. In the case of within-cell intersections with Regional Seas, cell proportions were stored and used to compute the cell coverage. This resulted in values ranging from 0-1 in each ½° cell depending on how much of a cell was allocated to each Regional Sea.

Distributing values to ½° cells

Some indicator data were available at the scale of ½° spatial cells, and therefore ready to be intersected with the RS-raster, while indicator data in other formats needed to be converted to this same grid format for analysis. Two types of data were available, requiring different methods of allocation to cells:

- Data produced in mismatching grid formats were re-sampled to the ½° scale using bilinear interpolation in ArcGIS;
- Data reported by country, e.g., jobs or subsidies, were proportionally allocated to individual cells via the country's EEZ. Once allocated to EEZ cells, the data could be re-allocated to Regional Seas via the RS-raster.

Regional Sea statistics

When all data were in ½° cell format, we computed various statistics (e.g., minimum, mean, maximum and sum) for each Regional Sea (simple units for a specific region or cell; unit per area, and statistical probabilities). Also, we defined the following variables: CA_i is the part of a cell that is covered by water (in km^2); PC_i is the proportion of the water area of a cell that belongs to a given Regional Sea (of total area, TA, in km^2), and V_i is the actual value for the cell, expressed in one of the three types above.

For indicators that have simple units, e.g., tonnes, the formula for minimum and maximum will be the smallest or largest value, multiplied by the proportion of the water area of a cell that belongs to a given Regional Sea, divided by the area of the cell, i.e., $V_i \cdot PC_i/CA_i$, with the result reported as value per unit area (km^{-2}). The sum, correspondingly, is given by $\sum(V_i \cdot PC_i)$, while the mean is the sum divided by TA. Minimum, maximum and average for indicators by units are always reported as units per area (km^{-2}, by default), while sums are reported in the original units.

For indicators expressed on a per area basis, such as $t \cdot km^{-2}$, we report the minimum, maximum, mean, and sum. Minimum and maximum are simply the smallest and largest values, respectively, while the 'Sum' is defined as the sum of all values in the cell multiplied by the percentage of Regional Sea coverage multiplied by the total area of the cell, i.e., $V_i \cdot PC_i \cdot CA_i$. The mean is defined as the computed sum over the total area of the Regional Sea. Minimum, maximum and average for indicators expressed on a per area basis are always reported as units per area (km^{-2} by default).

For statistical units, e.g., probability of species occurrence, the computations for the minimum and maximum are reported as the smallest or largest statistical value found in all the cells defined as V_i. The mean is the sum of probabilities of species occurrence multiplied by the area within the regional sea multiplied by the area of the cell, or defined as $VA_i \cdot (CA_i \cdot (PC_i/PC_t))$. Minimum, maximum and mean for indicators are always reported as units per area (km^{-2} by default). The sums were not computed, as data required to perform these computations were unavailable.

Input data that were reported by country produced differences of 0.15-0.20% between the data expressed in EEZs and their re-expression through the RS-raster. This can be attributed to the fact that if any part of an EEZ is touching a cell, the entire cell is counted as belonging to the EEZ, resulting in some double counting[3]. This is in contrast to RS-raster computation, where only the fraction of the Regional Sea overlapping a cell is counted when summing up of the area. However, the absolute differences are minuscule, and can be safely ignored here.

Details on most various indicators that were characterized are given below and in the corresponding appendices (Appendix 1-13 at the end of this report) if applicable, while Appendix 14 describes the CVS files that were generated to describe Regional Seas.

Bathymetric and habitat information

The bathymetric information presented here originates from a global map with 2-minute spatial resolution distributed by the U.S. National Oceanic and Atmospheric Administration (NOAA; www.ngdc.noaa.gov/mgg/fliers/01mgg04.html), from which the *Sea Around Us* derived information at the ½° by ½° spatial scale. The latter served as the basis for the indicator extraction performed here. Thus, we obtained, for each Regional Sea:

[3] Since this was originally written, this feature of the EEZs defined by *Sea Around Us* has been corrected for.

- Surface area (in km^2);
- Shelf area (km^2, down to a depth of 200 m);
- Slope area (km^2, from a depth of 200 m to a depth of 500 m);
- Abyssal area (km^2, from 500 m);
- Volume (km^3).

Figure 2, shows, as an example, shelf areas by Regional Seas. As might be seen, the Regional Seas featuring the largest shelf areas are in East and Southeast Asia (cf. with Figure 1).

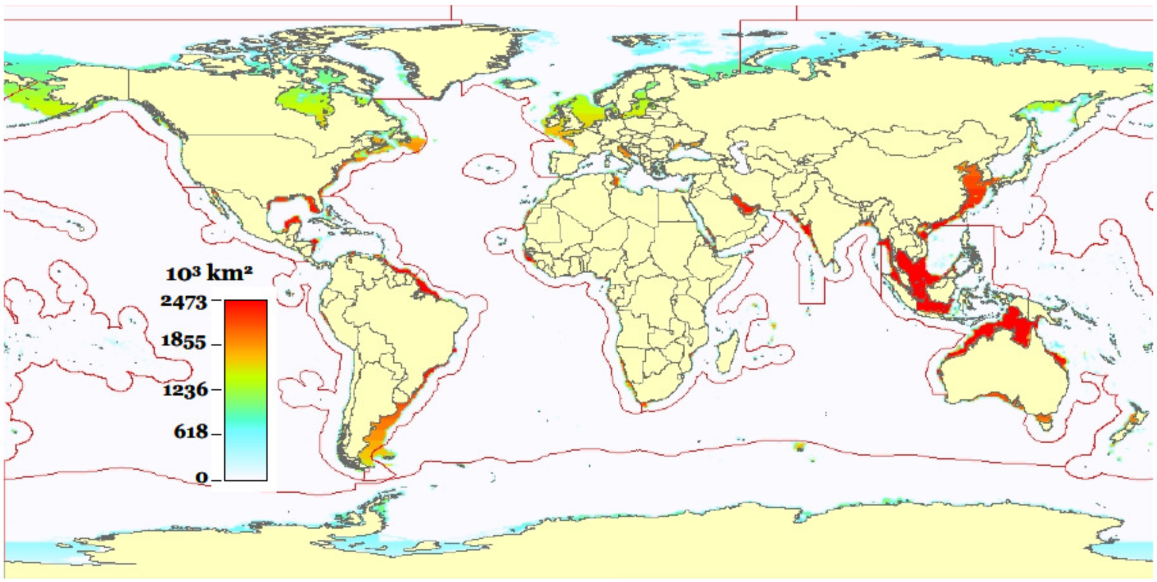

Figure 2. Shelf areas by Regional Seas; note the large shelves in East and Southeast Asia, including Northern Australia.

Seamounts

Seamounts are (extinct) underwater volcanoes that did not grow tall enough to break to the sea surface, and thus turn into islands, or which did, but sank back. Once formed, seamounts tend to gradually sink under their own weight, and the deep regions of the oceans are thus littered with remains of seamounts, which may be called 'sea-mounds'.

Seamounts occur throughout the world ocean, but their number (which may surpass 100,000) is difficult to estimate, even roughly, because it depends on the resolution of the bathymetric map used, as well as the detection threshold employed, i.e., the limit used to distinguish between seamounts and sea-mounds.

The locations of a subset of the seamounts of the world were identified from the bathymetric map mentioned above using two algorithms, both relying on the depth differences between adjacent cells of that electronic map (Kitchingman and Lai, 2004; Kitchingman *et al.*, 2007). About 30,000 likely seamounts were identified by one or the other algorithm, and 14,000 by both (Figure 3), with some seamount locations also verified against locations supplied by NOAA and/or from 'Seamounts Online' (htpp://seamounts.scsc.edu/). However, as their numbers were strongly influenced by the detection thresholds we used, the area-specific estimates of seamount abundance we present here, which underestimate seamount numbers, are expressed in relative terms, as a percent of the unknown 'total' number of seamounts in the world ocean, under the assumption of proportionality.

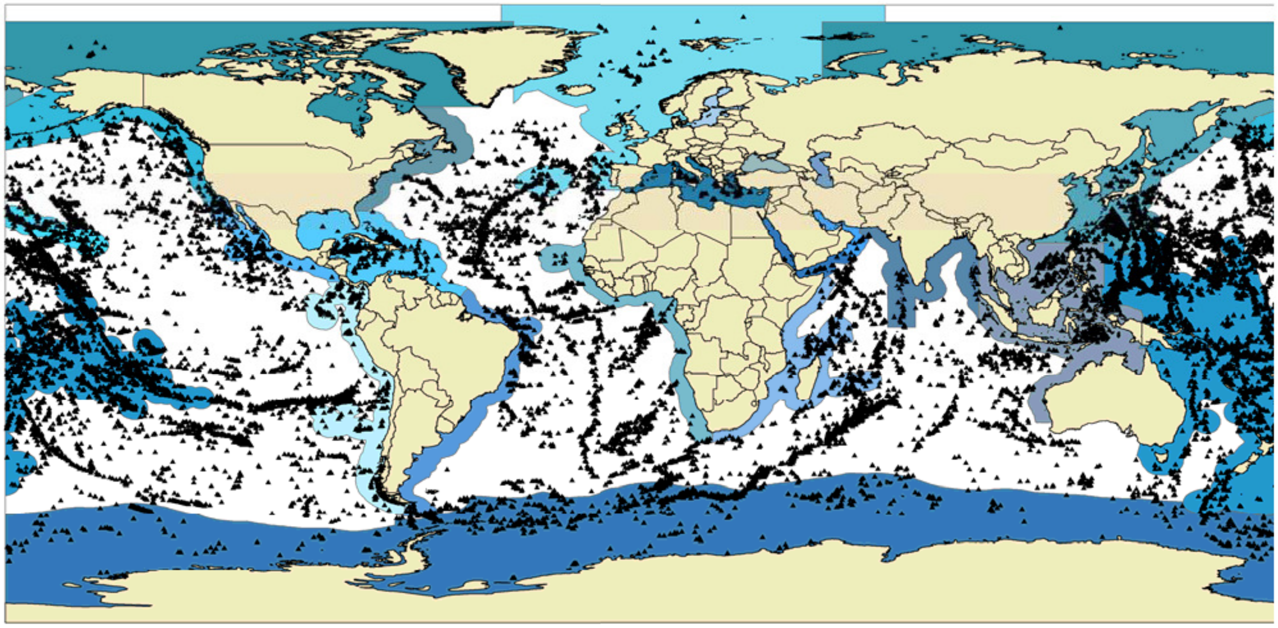

Figure 3. Plot of the 14,000 seamounts identified by Kitchingman and Lai (2004) superimposed on the Regional Seas identified by the UNEP; see also Kitchingman *et al.* (2007)) and text.

Zooplankton

The zooplankton biomass estimates are based on a map of zooplankton abundance in the upper 100 m of the world's ocean, published by FAO (1982), and based on Bogorov *et al.* (1968). The original map was digitized by the *Sea Around Us* project, and pertains to $mg \cdot m^{-3}$ (wet weight down to a depth of 100 m) re-expressed in $t \cdot km^{-2}$ under the assumption that the amount of zooplankton at >100 m is so small that it can be neglected.

Benthos

Global estimates for macrobenthos and meiobenthos were adapted from layers developed by a collaborative project between the Marine Conservation Biology Institute, Bellevue (WA), USA and the *Sea Around Us* (Mason *et al.,* unpublished data; see Christensen *et al.*, 2008, p. 8).

Mesopelagics

A combined spatial biomass of small and large mesopelagic fishes was obtained from the information mapped in Gjøsaeter and Kawaguchi (1980), based on pelagic trawl surveys in the world ocean. The maps were digitized and validated by Lam and Pauly (2005).

Coral reefs

Tropical coral reefs, along with tropical rainforest, are the most diverse ecosystems on Earth. They contain a multitude of species connected through a myriad of complex feeding and behavioral interactions that are still being unraveled. Coral reefs do not occur in deep waters; most coral species live between the water surface and about 30 m as established by Charles Darwin about 180 years ago. Yet, the surface area covered by coral reefs in various parts of the world has long been a matter of controversy. One of the first estimates was by Newell (1971), but it was so uncertain (150,000-1,500,000 km^2) as to be nearly useless. Smith (1978) presented the first credible estimates, which were divided into nine zones ranging from the South Atlantic, with 8,000 km^2, to Southeast Asia with 182,000 km^2. Other estimates followed, again ranging from very low (112,000 km^2; de Vooys, 1979) to very high (1,994,000 km^2; Copper, 1994). Spalding and Grenfell (1997) identified the source of discrepancy between these estimates as issues of definition and issues of scale. They also derived an estimate of 255,000 km^2, which was near the lower range of previous estimates.

We have interfaced the coral reef maps of the UNEP World Conservation Monitoring Centre (Spalding *et al.* 2001; www.unep-wcmc.org), and which estimates a total reef area of 284,000 km^2 with the Regional Seas definitions used for this study to calculate the coral reef area occurring in each Regional Sea.

We warn that this procedure will lead only to approximate values as certain Regional Seas may boast more of certain types of corals than others, which, via one's definition of coral reef, might influence what one perceives as 'coral reef coverage'. The problem here, however, is not determining the absolute amount of coral reef cover, but the fact that in most places, terrigenous pollution, overfishing, coral extraction and global warming have much reduced live coral cover, and will increasingly do so in the next decades.

Estuaries

The *Sea Around Us* project website includes a global database of estuaries, all linked to the more than 16,000 coastal ½° by ½° cells (Alder, 2003). This database contains over 1,200 estuaries (including some lagoon systems and fjords), in over 120 countries and territories. These water bodies (of which over 97% have shape files) were selected such that the estuaries of all the world's major rivers were included, as well as smaller estuaries in countries without major rivers.

Overall, the database accounts for over 80% of the world's freshwater discharge, and contains information about the name, location, area (in km^2) and mean freshwater input (in $m^3 \cdot s^{-1} \cdot day^{-1}$). The shape files were used to identify the 'estuarine cells' among the ½° coastal cells in the *Sea Around Us* map of the global ocean, and thence the area (in km^2) of estuaries in each Regional Sea.

Predicted sea surface temperature

We include here only one set of predictions of future sea surface temperatures, derived from a medium-range greenhouse gas emission scenario (the 550 ppm stabilization experiment, SRES B1), generated by the Geophysical Fluid Dynamics Laboratory of the U.S. National Oceanic and Atmospheric Administration (GFDL's CM 2.1) (Delworth *et al.*, 2006). The sea surface temperatures reported here are those used by Cheung *et al.* (this volume), and predicted to occur within a high- and a low-range greenhouse emission scenario.

Acknowledgements

The *Sea Around Us* project, upon which much of this work relies, is a scientific cooperation between The University of British Columbia and the Pew Environment Group.

References

Alder, J., 2003. Putting the coast in the *Sea Around Us* project. The *Sea Around Us* Newsletter (15), 1-2.

Bogorov, V.G., Vinogradov, M.D., Varonina, N.M., Kanaeva, I.P., Suetova, I.A., 1968. [Distribution of zooplankton biomass within the surficial layer of the world ocean]. *Dokl. Akad. Nauk USSR* 182, 1205-1207 [In Russian].

Christensen, V., Walters, C.J., Ahrens, R., Alder, J., Buszowski, J., Christensen, L.B., Cheung, W.W.L., Dunne, J., Froese, R., Karpouzi, V., Kaschner, K., Kearney, K., Lai, S., Lam, V., Palomares, M.L.D., Peters-Mason, A., Piroddi, C., Sarmiento, J.L., Steenbeek, J., Sumaila, R., Watson, R., Zeller, D., Pauly, D., 2008. Models of the world's large marine ecosystems. GEF/LME global project Promoting Ecosystem-based Approaches to Fisheries Conservation and Large Marine Ecosystems, UNESCO/Intergovernmental Oceanographic Commissions Technical Series No. 80, iv+43 p.

Copper, P., 1994. Ancient reef ecosystem expansion and collapse. *Coral Reefs* 13, 3—11.

de Vooys, G.G.N., 1979. Primary production in aquatic systems. In: Bolin, B., Degens, E.T., Kempe, S., Ketner, P. (eds.), *The Global Carbon Cycle*, pp. 259-292. John Wiley & Sons, New York.

Delworth, T.L., Broccoli, A.J., Rosati, A., Stouffer, R.J., Balaji, V., Beesley, J.A., Cooke, W.F., Dixon, K.W., Dunne, J., Dunne, K.A., Durachta, J.W., Findell, K.L., Ginoux, P., Gnanadesikan, A., Gordon, C.T., Griffies, S.M., Gudgel, R., Harrison, M.J., Held, I.M., Hemler, R.S., Horowitz, L.W., Klein, S.A., Knutson, T.R., Kushner, P.J., Langenhorst, A.R., Lee, H.C., Lin, S.J., Lu, J., Malyshev, S.L., Milly, P.C.D., Ramaswamy, V., Russell, J., Schwarzkopf, M.D., Shevliakova, E., Sirutis, J.J., Spelman, M.J., Stern, W.F., Winton, M., Wittenberg, A.T., Wyman, B., Zeng, F., Zhang, R., 2006. GFDL's CM2 global coupled climate models. Part I: Formulation and simulation characteristics. *Journal of Climate* 19, 643-674.

FAO, 1981. Atlas of the living resources of the seas. 4th Edition. FAO Fisheries Series 15, Rome, Italy, 69 p.

Gjøsaeter, J., Kawaguchi, K., 1980. A review of the world resources of mesopelagic fish. FAO Technical Paper 193, Rome, Italy, 151 p.

Kitchingman, A., Lai, S., 2004. Inferences of potential seamount locations from mid-resolution bathymetric data. In: Morato, T., Pauly, D. (eds.), *Seamount Biodiversity and Fisheries*, pp. 7-12. Fisheries Centre Research Report 12(5), Fisheries Centre, Vancouver

Kitchingman, A., Lai, S., Morato, T., Pauly, D., 2007. How many seamounts are there and where are they located? In: Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N., Santos, R.S. (eds.), *Seamounts: Ecology, Conservation and Management*, pp. 26-40. Blackwell, Oxford, UK.

Lam, V., Pauly, D., 2005. Mapping the global biomass of mesopelagic fishes. *Sea Around Us Project Newsletter* (30), 4.

Newell, N.D., 1971. An outline history of tropical organic reefs. *American Museum Novitates* 2465, 1-37.

Smith, S.V., 1978. Coral reef area and the contributions of reefs to processes and resources of the world's oceans. *Nature* 273, 225-226.

Spalding, M.D., Grenfell, A.M., 1997. New estimates of global and regional coral reef areas. *Coral Reefs* 16, 225-230.

Spalding, M., Ravilious, ., Green, E.P., 2001. *World Atlas of Coral Reefs*. UNEP/WCMC and University of California Press, Berkeley.

Watson, R., Kitchingman, A., Gelchu, A., Pauly, D., 2004a. Mapping global fisheries: sharpening our focus. *Fish and Fisheries* 5, 168-177.

Watson, R., Alder, J., Booth, S., Christensen, V., Kaschner, K., Kitchingman, A., Lai, S., Palomares, M.L.D., Valdez, F., Pauly, D., 2004b. Welcome to www.seaaroundus.org: launching our 'product' on the web, The *Sea Around Us* Newsletter (22), 1-8

Environmental Indicators

Nitrogen, phosphorus and silica input in Regional Seas[1]

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Abstract

Data are presented on the global river export of total nitrogen, total phosphorus and dissolved silica. These data, indicative of coastal degradation, should be useful as a starting point for ongoing and future enhancements, and for collaborations with other Earth System and policy efforts.

Introduction

The data presented here refer to global river export of total nitrogen, total phosphorus and dissolved silica for different Regional Seas. The river nutrient export data are from the Global NEWS model, of which a synthesis is given in Seitzinger *et al.* (2010).

Material and Methods

The global NEWS system includes river-basin scale models for predicting export of dissolved inorganic nitrogen and phosphorus (DIN, DIP), dissolved organic carbon, nitrogen and phosphorus (DOC, DON, DOP), total suspended solids (TSS), particulate organic carbon (POC), particulate nitrogen and phosphorus (PN and PP), and dissolved silica (DSi).

Data sources

Natural and anthropogenic nutrient sources in watersheds, hydrological and physical factors, and in-river N and P removal are important model components. The Integrated Model for the Assessment of the Global Environment (IMAGE; Bouwman *et al.*, 2006) was used to develop the input datasets for the NEWS model.

Input datasets consist of nonpoint source data (agriculture and natural ecosystems), point source data (urban wastewater), and atmospheric deposition. A full description of the data are given in Bouwman *et al.* (2009). Soil nitrogen and phosphorus balances are calculated for each grid cell as the sum of all inputs minus the sum of the removal of nutrients in the harvested crops and grazing. Inputs are fertilizer use, animal manure, biological nitrogen fixation and atmospheric deposition. Fertilizer use is taken from different sources (IFA/IFDC/FAO, 2003; FAO, 2009). Crop export is based on production data from FAO (2009) and nutrient contents for a variety of crops. Nitrogen fixation is calculated as free-living with fixation rates specific to cropland, grassland and wetland rice. Nitrogen fixation by leguminous crops is based on the production data and nitrogen contents of the harvested product of these crops.

Atmospheric N deposition rates (including dry and wet deposition of NH_3 and NO_y) for the year 2000 were taken from Dentener *et al.* (2006). Deposition rates for historical and future years are obtained by scaling the deposition fields for the year 2000, using emission scenarios for N gases for the corresponding years from the implementation of the MEA scenarios with the IMAGE model.

[1] Cite as: Beusen, A.H.W., Bouwman, L., 2011. Nitrogen, phosphorus and silica input in Regional Seas. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 10-14. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

Point source data are calculated on the basis of the fraction of national populations with a connection to sewage systems, and the fraction of the wastewater that is treated, and a nutrient removal efficiency. Data are from a variety of sources as described in Van Drecht *et al*. (2009).

Indicator characteristics

Global NEWS models have a spatial resolution of individual river basins. Worldwide, more than 6,000 river basins are distinguished, for which 0.5° by 0.5° data on climate, land cover, nutrient balances, wastewater, etc. are lumped. The river basins have one river mouth each, which is specified at the scale of 0.5° by 0.5° grid cells. Global NEWS data have a temporal resolution of one year. Nutrient supply and concentrations can be considered pressure or state indicators depending on the context. In the Global NEWS reports, results for individual river basins covering less than 10 ½° by ½° grid cells are generally not presented; in this case, results are most appropriate when presented for groups of river basins.

Interpretation of indicator

The scope of NEWS2USE is global; the aim is to investigate relationships between nutrient loading and nutrient transformations in coastal marine ecosystems, develop models that quantitatively describe such relationships, and to identify regions where conditions are prone to the development of harmful algal blooms and hypoxia, and where further in-depth research is needed.

Global NEWS is unique in its kind in that it provides an integrated, internally consistent approach to modeling river export of nitrogen, phosphorus, silica and carbon, and the different forms of these elements. As stated above, the Global NEWS framework uses IMAGE (Bouwman *et al*., 2006) to generate spatially explicit land use, greenhouse gas emissions, and climate fields, the Water Balance Model (WBM) for predicting river discharge, and the Global NEWS river-basin scale nutrient export models (Seitzinger *et al*., 2010). The Global NEWS framework can be used to evaluate effects of socio-economic developments, climate change, food consumption, agricultural nutrient management, dam construction and consumptive water use, and sewage treatment trends on river nutrient export. The Global NEWS models use relatively simple approaches for simulating in-stream retention of nutrients, (e.g., denitrification and burial in rivers, lakes, reservoirs, etc.). The global NEWS system uses consistent input databases for predicting export of DIN and DIP; DOC, DON and DOP; TSS; POC, PN and PP; and DSi (see also Appendices 1, 2 and 14 at the end of this report).

Result and Discussion

Global trends in river nutrient export result from changes in human drivers and hydrology. The increased river export of DIN for the period 1970-2000 at the global scale is largely associated with changes in agriculture, particularly increased N inputs due to fertilizer use and animal production (Table 1). Sewage and atmospheric deposition of ammonia and nitrogen oxides from agriculture, energy and industry contribute to a lesser extent to the increased river DIN export. Increases in DIP can be explained by increased inputs of P to rivers primarily from sewage and to a lesser extent from agriculture. Increased export of particulate forms is associated with erosion and land use change. This not only holds for particulate forms of P, but also of N and C. River export of particulate N, P and C is not as large as one would expect from erosion trends alone because increased damming of rivers traps a portion of the mobilized particulates, preventing them from being transported to coastal waters.

There are large differences in recent trends between world regions. It is clear that river nutrient export is larger and increasing much more rapidly in South Asia than in other regions of the world. South Asia also shows the largest change in the relative contribution of watershed N sources to DIN export of all the continents. In 1970, the pattern of source contributions in South Asia was closer to that of less developed continents (South America and Africa). By 2000, however, DIN sources to South Asian rivers were more similar to developed regions than to less developed regions.

River export of all forms of N, P and C increased during the thirty-year period between 1970 and 2000 at the global scale (Table 1). However, the forms responded differently. Relatively large increases (about 30%) were calculated for DIN and DIP, while particulate loads increased by only about 10%. Dissolved organic nutrients increases were very modest (<5%). For the year 2000, we calculate a 16% increase in TN export by rivers over 1970 levels (43 Tg of total N, i.e., DIN+DON+PN) exported by rivers in 2000 versus 37 Tg N in 1970). Our estimate for 1970 is in good agreement with an estimate for global river TN export for 1970 based on a compilation of measured data for world rivers by Meybeck (1982). This increase in TN over time can be largely explained by a 35% increase in DIN export from 14 to 19 Tg N·year^{-1}. About 40% of the N in river export is DIN.

For DIP, the trend is similar to that of DIN: a 29% global increase between 1970 and 2000. The largest absolute increase in P load is calculated for particulate P although it increased by only 13% between 1970 and 2000. This is because particulate P is the dominant form (5.9 Tg P in 2000) of total P export (7.6 Tg P in 2000) by the world rivers. NEWS model estimates for 1970 of DIN and DON (14 and 10 Tg N, respectively) and dissolved P (1.7 Tg P) are in good agreement with estimates for global river export for 1970 by Meybeck (1982; DIN=12 Tg N, DON=10 Tg N and dissolved P=2 Tg P). Our estimates for PN and PP (12 Tg N and 6 Tg P) are considerably lower than Meybeck's (21 Tg N and 20 Tg P), which were based on a POC budget and assumed fixed N:C:P ratios. The NEWS models calculate PN and PP as a function of TSS in rivers, which we consider a more appropriate approach.

Table 1. Global nutrient export by rivers to coastal waters for 1970 and 2000[a].

Year	DIN	DON	PN	TN	DIP	DOP	PP	TP	DOC	POC	TSS[b]	DSi
1970	14.0	10.3	12.4	36.7	1.1	0.6	5.9	7.6	161	127	123	141
2000	18.9	10.8	13.5	43.2	1.4	0.6	6.6	8.6	164	140	145	144

[a] Tg N, P, C, TSS or Si·year^{-1}; [b] TSS·100

Table 2. Description of various scenarios in the output files.

Scenario name	Year	Scenario type
C70	1970	-
C00	2000	-
A30	2030	Adapting Mosaic
T30	2030	Technogarden
G30	2030	Global Orchestration
O30	2030	Order from Strength
A50	2050	Adapting Mosaic
T50	2050	Technogarden
G50	2050	Global Orchestration
O50	2050	Order from Strength

The Millennium Ecosystem Assessment (Alcamo *et al.*, 2006) used four scenarios: Global Orchestration; Order from Strength; Technogarden; and Adapting Mosaic (Table 2). Global Orchestration portrays a globally connected society that focuses on global trade and economic liberalization and takes a reactive approach to ecosystem problems, but also takes strong steps to reduce poverty and inequality and to invest in public goods, such as infrastructure and education. In contrast, Order from Strength is a regionalized and fragmented world, concerned with security and protection, with the emphasis primarily on regional markets, paying little attention to public goods, and taking a reactive approach to ecosystem problems. Technogarden is a globally connected world, relying strongly on environmentally sound technology, using highly managed, often engineered, ecosystems to deliver ecosystem services, and taking a proactive approach to the management of ecosystems in an effort to avoid problems. In the fourth scenario, Adapting Mosaic, regional watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common; societies develop a strongly proactive approach to the management of ecosystems based on simple technologies.

The differences among scenarios in river nutrient export are considerable, suggesting that plausible trajectories could have very different implications for coastal nutrient loading and hence coastal ecosystem health. For DIN an up to 18% increase in river export is projected for the Global Orchestration and Order from Strength scenarios, which assume a reactive approach towards environmental change. In contrast, a decrease in the global river DIN export is projected for both scenarios with a proactive approach towards environmental change (Technogarden and Adapting Mosaic).

While South Asia, Africa and Latin America show rapidly increasing future export of N and P, reflecting the fast population growth and economic development expected to occur in these regions, Europe shows a decreasing trend. This is the result of the small projected population change compared to that in developing countries in conjunction with nutrient management strategies. North America shows an erratic pattern following the scenarios for population growth.

Table 1. Main drivers of ecosystem change for the Millennium Ecosystem Assessment scenarios (adapted from Alcamo *et al.*, 2006; Bouwman *et al.*, 2009; and our assumptions for fertilizer use).

Scenario/Indicators	Global Orchestration	Order from Strength	Technogarden	Adapting Mosaic
Keywords	Globalization, economic development, reactive approach to environmental problems	Regionalization, fragmentation security, reactive approach to environmental problems	Globalization, environmental technology, proactive approach to environmental problems	Regionalization, local ecological management with simple technology, proactive approach to environmental problems
World population (billion)	Low	High	Medium	High
2000	6.1	6.1	6.1	6.1
2030	7.7	8.6	8.2	8.5
2050	8.2	9.7	8.9	9.6
Per capita GDP growth rate ($year^{-1}$)	High	Low	High	Medium
2000-2030	2.6%	1.6%	2.1%	1.8%
2030-2050	3.0%	1.3%	2.6%	2.2%
Global GHG emissions (GtC-eq $year^{-1}$)	High	High	Low	Medium
2000	9.8	9.8	9.8	9.8
2050	25.6	20.3	7.1	18.0
Global mean temp. increase (°C)	High	High	Low	Medium
2000	0.6	0.6	0.6	0.6
2030	1.4	1.3	1.3	1.4
2050	2.0	1.7	1.5	1.9
Per capita food consumption	High, high meat	Low	High, low meat	Low, low meat
Agricultural productivity increase	High	Low	Medium-high	Medium
Energy crops in 2050	4% of cropland area	1% of cropland area	28% of cropland area	2% of cropland area
Fertilizer use and efficiency	No change in countries with a surplus; rapid increase in N and P fertilizer use in countries with soil nutrient depletion (deficit).	No change in countries with a surplus; slow increase in N and P fertilizer use in countries with soil nutrient depletion (deficit).	Rapid increase in countries with a surplus; rapid increase in N and P fertilizer use in countries with soil nutrient depletion (deficit).	Moderate increase in countries with a surplus; slow increase in N and P fertilizer use with soil depletion (deficit); better integration of manure and recycling of N and P from households with improved sanitation but no sewage connection.

Manure is the most important global contributor to the increase in river DIN export between 2000-2030 in the Global Orchestration scenario, which is consistent with the high per capita meat consumption in this scenario. Although the contribution from manure also increases in the Adapting Mosaic scenario, the contribution from fertilizer shows a decrease, resulting in the net decrease in river DIN export in the Adapting Mosaic scenario. This follows from the assumptions in Adapting Mosaic, which focus on cheap and simple solutions such as a better integration of animal manure in agricultural production systems and recycling of human excreta, leading to a reduction of synthetic fertilizer use.

Increases in global river export of DIP are projected in all scenarios. Increases in sewage, fertilizer, P-based detergents, and manure all contribute to the increase in DIP river export in Global Orchestration. All of these sources increase in Adapting Mosaic, but to a lesser extent, resulting in a smaller increase in river DIP export by 2030 than in Global Orchestration. As noted above, reduction in synthetic fertilizer use in Adapting Mosaic is the result of better integration of nutrient sources in agriculture. The smaller contribution to DIP export from sewage in Adapting Mosaic relative to Global Orchestration is a result of the much slower increase of connection of households to sewage systems in the Adapting Mosaic scenario than in the Global Orchestration scenario.

For dissolved organic N and P (DON and DOP), increasing trends are projected in all four scenarios, but the anticipated changes are small, at least at the global scale: the projected 2030 loads differ 1-6% from the 2000 load. Although the absolute increases in DON and DOP loads are small, the relative magnitude of different sources change, which may affect proportion of the DOM export that is bio-available once it enters the coastal ecosystem. For DOC, small decreases are projected for the period 2000-2030. The projected changes in river export of DOC is largely due to anticipated changes in river discharge and extent of wetlands, which control DOC export in the NEWS model and change only slowly in the scenarios.

For particulate forms, we project decreasing river export for all scenarios. By 2030 the loads of PN, PP and POC are calculated to be up to 11% lower than in 2000. This is in contrast with the period 1970-2000, for which we calculate a 10% increase. Both the increasing trends in the past, and the decreasing trends in the future result from increasing inputs of particulates in rivers as a result of land use and erosion, and increased trapping of particulates in river reservoirs. In future years, the scenarios assume increasing numbers of reservoirs in rivers due to construction of dams for irrigation and hydropower. Minor projected changes in global DSi export are comparable to those of TSS and the particulate nutrient forms, and primarily a result of dam construction.

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References

Alcamo, J., Van Vuuren, D., Cramer, W., 2006. Changes in ecosystem services and their drivers across the scenarios. In: Carpenter, S.R., Pingali, P.L., Bennett, E.M., Zurek, M.B. (eds.), *Ecosystems and Human Well-being: Scenarios*, pp. 279-354. Island Press, Washington, D.C.

Bouwman, A.F., Beusen, A.H.W., Billen, G., 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970-2050. *Global Biogeochemical Cycles* 23, doi:10.1029/2009GB003576.

Bouwman, A.F., Kram, T., Klein Goldewijk, K., 2006. *Integrated modelling of global environmental change. An Overview of IMAGE 2.4*. Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Dentener, F., Stevenson, D., Ellingsen, K., van Noije, T., Schultz, M., Amann, M., Atherton, C., Bell, N., Bergmann, D., Bey, I., Bouwman, L., Butler, T., Cofala, J., Collins, B., Drevet, J., Doherty, R., Eickhout, B., Eskes, H., Fiore, A., Gauss, M., Hauglustaine, D., Horowitz, L., Isaksen, I. S. A., Josse, B., Lawrence, M., Krol, M., Lamarque, J. F., Montanaro, V., Müller, J. F., Peuch, V. H., Pitari, G., Pyle, J., Rast, S., Rodriguez, J., Sanderson, M., Savage, N.H., Shindell, D., Strahan, S., Szopa, S., Sudo, K., Van Dingenen, R., Wild, O., Zeng, G., 2006. The global atmospheric environment for the next generation. *Environment Science and Technology* 40, 3586-3594.

FAO, 2009. FAOSTAT database collections (http://faostat.fao.org/), Food and Agriculture Organization of the United Nations, Rome, Italy.

IFA/IFDC/FAO, 2003. Fertilizer use by crop. 5th edition, Food and Agriculture Organization of the United Nations, Rome, Italy.

Meybeck, M., 1982. Carbon, nitrogen and phosphorous transport by world rivers. *American Journal of Science* 282, 401-450.

Seitzinger, S.P. *et al.*, 2010. Global River Nutrient Export Trajectories 1970-2050: A Millenium Ecosystem Scenario Analysis. *Global Biogeochemical Cycles* 23, GB0A08, doi:10.1029/2009GB003587.

Van Drecht, G., Bouwman, A.F., Harrison, J., Knoop, J.M., 2009. Global nitrogen and phosphate in urban waste water for the period 1970-2050. *Global Biogeochemical Cycles* 23, GB0A03, doi:10.1029/2009GB003458.

ATMOSPHERIC NITROGEN DEPOSITION IN REGIONAL SEAS IN 1860, 1993, AND 2050[1]

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ABSTRACT

The dataset described here provides global gridded estimates of atmospheric deposition of total inorganic nitrogen for the years 1860 and 1993 and projections for the year 2050. The dataset was generated using a global three-dimensional chemistry-transport model. Nitrogen emissions estimates were used as input to the model. The dataset contributes to a global nitrogen budget that was developed to answer questions, such as: 1) how has the global nitrogen budget changed from the late 19th century to the late 20th century?; and 2) what is the global nitrogen budget projected to be in the mid-21st century?

INTRODUCTION

The dataset described here is based on the International Nitrogen Initiative project, and is deposited at the Oak Ridge National Laboratory Distributed Active Archive Center, and is available online (Dentener, 2006). Its cover is from -180°W to 180°E and from 90°N to 90°S, and it provides global gridded estimates of atmospheric deposition of total inorganic nitrogen (N), NH_x (NH_3 and NH_{4+}), and NO_y (all oxidized forms of nitrogen other than N_2O), in mg N m^{-2} $year^{-1}$, for the years 1860 and 1993 and projections for the year 2050. The dataset was generated using a global three-dimensional chemistry-transport model (TM3) with a spatial resolution of 5° longitude by 3.75° latitude (Lelieveld and Dentener, 2000; Jeuken *et al.*, 2001). Nitrogen emissions estimates (Van Aardenne *et al.*, 2001) and projection scenario data (IPCC, 1996; 2000) were used as input to the model. The model output grids were subdivided into 50 km x 50 km sub-grids to create spatially defined deposition maps.

MATERIALS AND METHODS

Emission scenarios for NO and NH_3 are based on Van Aardenne *et al.* (2001), and were derived from version 2.0 of the Emission Database for Global Atmospheric Research (EDGAR 2.0; Olivier *et al.*, 1999). The predictions of NO and NH_3 emissions are based on the IS92a scenario (IPCC, 1996). For this scenario, the projected NO_x emissions compares to the higher (more pessimistic) end of the range seen in recent SRES scenarios (IPCC, 2000), but are still well within that range. Neither IS92a or SRES provide scenarios for NH_3 emissions, so the 2050 scenario used in this work for NH_3 is determined in analogy to N_2O emissions (since these grossly represent the development of agricultural activities). In fact, very recent RIVM/IMAGE scenarios for the year 2030 (based on SRES A2/B2) agree well with the increases that the investigator's IS92a based work would predict for 2050. Overall, the IS92a can be considered among the higher end of current scenarios regarding NO_x emissions, and reflects the current information on NH_3 emissions.

RESULTS AND DISCUSSION

The dataset can be used to produce maps that illustrate both the temporal and spatial variability of atmospheric deposition of N, NH_x, and NO_y as well as the degree of alteration and regional heterogeneity in deposition through time. Nine data files are provided to produce the following maps (see Figure 1):

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[1] Cite as: Dentener, F., 2011. Atmospheric nitrogen deposition in Regional Seas in 1860, 1993, and 2050. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 15-16. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

- Global N Deposition (1860, 1993, and 2050);
- Global NHx Deposition (1860, 1993, and 2050);
- Global NOy Deposition (1860, 1993, and 2050).

Also included in the online version of the dataset (Dentener, 2006) as data files are GeoTIFF format files (Tagged Image File Format) created from the nine nitrogen deposition data files. A world file of projection information (*.twf) is included for each GeoTIFF file.

The original data are stored as ASCII text files (*.txt), in space-delimited format. The data values are model outputs provided as annual means (mg N $m^{-2} \cdot year^{-1}$) in arrays of dimension IM x JM, where IM is the number of longitudes (72) and JM is the number of latitudes (48). Each data file contains 10 columns and 346 rows with a spatial resolution of 5 degrees longitude by 3.75 degrees latitude. The data files are organized by nitrogen species by year.

The emissions estimates and projections described above were used as input to the global three-dimensional chemistry-transport model TM_3 (described in Jeuken *et al.*, 2001, and Lelieveld and Dentener, 2000) to produce global maps of atmospheric nitrogen deposition for 1860, 1993, and 2050.

Galloway *et al.* (2004, Appendix I) presents a discussion of uncertainties associated with the deposition estimates. Also note that negative NH_x fluxes may occur over the ocean. These particular model simulations were done using an oceanic NH_3 equilibrium concentration approach. This means that negative deposition fluxes represent net emissions from the ocean.

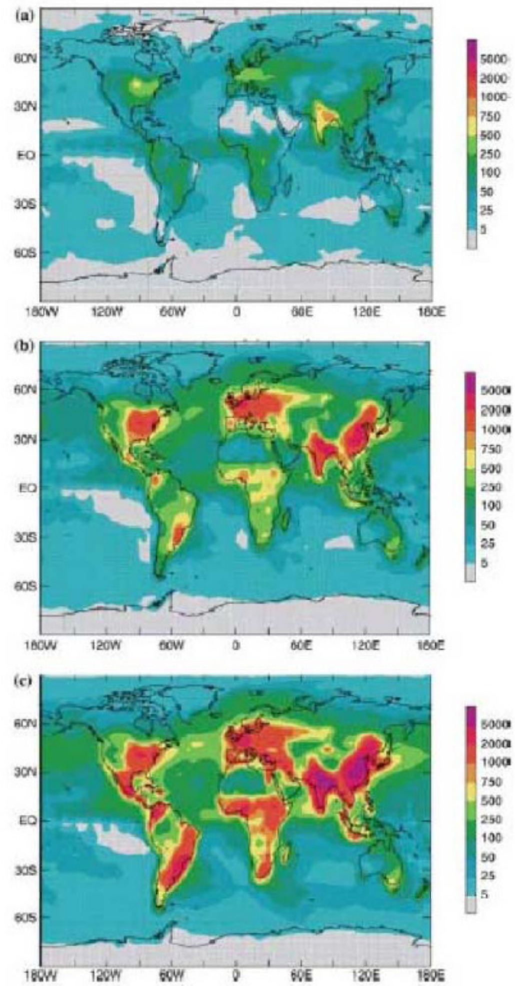

Figure 1. Spatial patterns of total inorganic nitrogen deposition in (a) 1860, (b) early 1990s, and (c) 2050, mg N m^{-2} $year^{-1}$ (from Galloway *et al.*, 2004).

References

Dentener, F.J., 2006. Global Maps of Atmospheric Nitrogen Deposition, 1860, 1993, and 2050. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S. A.ESRI. 1993. Digital Chart of the World. Environmental Systems Research Institute, Inc., Redlands, California.

Galloway, J.N., Dentener, F.J., Capone, D.G., Boyer, E.W., Howarth, R.W., Seitzinger, S.P., Asner, G.P., Cleveland, C., Green, P., Holland, E., Karl, D.M., Michaels, A.F., Porter, J.H., Townsend, A., Vörösmarty, C., 2004. Nitrogen cycles: past, present and future. *Biogeochemistry* 70, 153-226.

Houghton, J.J., Meiro Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A., Maskell, K., Editors, 1996. *Climate Change 1995: The Science of Climate Change*. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, 572 pp.

Jeuken, A., Veefkind, P., Dentener, F., Metzger, S., Robles-Gonzalez, C., 2001. Simulation of the aerosol optical depth over Europe for August 1997 and a comparison with observations. *Journal of Geophysical Research* 106, 28295-28311.

Lelieveld J., Dentener, F., 2000. What controls tropospheric ozone? *Journal of Geophysical Research* 105, 3531-3551.

Nakicenovic, N., Swart, R., Editors, 2000. *Special Report on Emissions Scenarios (SRES)*. A Special Report of Working Group III of the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, 612 pp.

Olivier, J.G.J., Bouwman, A.F., Berdowski, J.J.M., Veldt, C., Bloos, J.P.J., Visschedijk, A.J.H., van de Maas, C.W.M., Zandveld, P.Y.J., 1999. Sectoral emission inventories of greenhouse gases for 1990 on a per country basis as well as on 10 x 10. *Environmental Science and Policy* 2, 241– 264.

Van Aardenne, J.A., Dentener, F.J., Olivier, J.G.J., Klein Goldewijk, C.G.M., Lelieveld, J., 2001. A 1°x1° resolution dataset of historical anthropogenic trace gas emissions for the period 1890-1990. *Global Biogeochemical Cycles* 15(4), 909-928.

BIODIVERSITY INDICATORS

USING 'AQUAMAPS' FOR REPRESENTING SPECIES DISTRIBUTIONS IN REGIONAL SEAS[1]

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ABSTRACT

AquaMaps (www.aquamaps.org) are the products of an on-line approach for generating distribution range maps of marine organisms, which currently covers over 10,000 marine species of fish, marine mammals and invertebrates, the intention being to eventually generate standardized range maps for all species in the oceans. These range maps can be used to generate check-lists or inventories of species occurrence in data-poor areas, e.g., in Regional Seas.

[1] Cite as: Kaschner, K., Ready, J.S., Agbayani, E., Kesner-Reyes, K., Rius-Barile, J., Eastwood, P.D., South, A.B., Kullander, S.O., Rees, T., Watson, R., Pauly, D., Froese, R., 2011. Using 'Aquamaps' for representing species distribution in Regional Seas. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 17-21. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

Introduction

The traditional method of drawing distribution range maps, applicable to species for which many occurrence records (positive and negative) exist, is for an expert on the species in question to plot the occurrence records as dots on a map, and to interpolate (or not) between them, based on knowledge of the species habitat requirements and other (partly intuitive) ecological knowledge.

Unfortunately, there are too few occurrence records, too many species and too few experts for more than a small fraction of marine biodiversity to be mapped this way. Also, intensive biological sampling has taken place in only a few parts of the ocean, e.g., the Northeast Pacific and the North Atlantic, and the small areas covered relative to the distribution range of most marine species makes extrapolation of ocean-scale marine biodiversity difficult.

One alternative to the traditional method of mapping distribution ranges is to use the environmental characteristic — especially temperature and depth — associated with the occurrence records (originating from museum collections and other sources), to define the environmental 'envelope' of a species, then to project a probable distribution through maps of temperature, depth, etc.

AquaMaps is a type of environmental envelope model, i.e., a modified version of the relative environmental suitability model (RES) developed by Kaschner *et al.* (2006b) to predict global distributions of marine mammals, but later modified and expanded to cover all marine species (Kaschner *et al.*, 2008). The model was specifically developed to deal with the sampling biases affecting most large-scale data sets currently available for species distribution modeling in the marine realm by supplementing occurrence records with alternative sources of information about habitat usage.

Material and Methods

Using all available information, the model determines the environmental tolerance of a given species with respect to a pre-defined set of parameters including depth, salinity, temperature, primary production and sea ice concentration. It then predicts the maximum range extents for a given species including the relative probability of species occurrence (PSO) within that range by relating these environmental tolerances (or envelopes) to the physical and oceanographic attributes of each cell in a global grid with 0.5 latitude/longitude cell dimensions (Kaschner *et al.*, 2008, Ready *et al.*, 2010).

Two types of input data are used to generate AquaMaps species predictions. Available point occurrence records for the respective species, used to calculate all environmental envelopes (except for depth preferences) are harvested from online data repositories such as the Ocean Biogeographic Information System (OBIS), and the Global Biodiversity Information Facility (GBIF). Such point data sets are compiled from a variety of different sources and are generally affected by a number of sampling biases including, but not limited to, non-representative coverage of habitats and species misidentifications. To address these issues, AquaMaps supplements point occurrence data with other types of habitat use information obtained directly from online species databases such as FishBase (www.fishbase.org) and SeaLifeBase (www.sealifebase.org). This includes information about the general occurrence of species in the form of bounding boxes, delineating the known maximum range extents for species as described in the scientific literature or FAO area checklists, which is then used as a primary filter to identify possible misidentifications. Heterogeneous sampling, due to the concentration of sampling efforts in continental shelf areas, often results in a mis-representation of the true depth usage of species. To counteract this bias, AquaMaps relies on depth information taken from the literature, as encoded in online species databases. In addition, an expert review function in the AquaMaps algorithm explicitly allows for the incorporation of expert knowledge about species occurrence to further counteract or compensate known sampling biases.

Once the occurrence records have been harvested and verified, they are complemented with the supplementary data, and then processed via a General Linear Model, which access environmental data on a global grid of ½ cells of ½° latitude/longitude cells, until a model is found which generates a statistically robust global distribution map of probabilities of occurrence. The resulting maps then sometimes need to be trimmed (unless a bounding box was used at the onset), as the procedure cannot distinguish by itself, say tropical shallow habitat in the Indo-Pacific from the same habitat type in the Atlantic.

For the purposes of this report, the biodiversity information available in all completed AquaMaps, expressed on ½° latitude by ½° longitude cells was summarized by Regional Seas. Particularly, the minimum, maximum and mean probability of occurrence was summarized for each of the 86 subsets of species in Table 1.

Table 1. Breakdown of the subsets of species used to summarize for each Regional Sea. The # of species used is the number of species that have data available, and # of species is the total number of species in each group.

Taxon	Category	# of species used	# of species	Taxon	Category	# of species used	# of species
Animalia	kingdom	8393	909760	Cypraeidae	family	15	26
Arthropoda	phylum	263	780288	Dasyatidae	family	28	77
Cnidaria	phylum	198	9937	Engraulidae	family	51	141
Porifera	phylum	7	8368	Euclichthyidae	family	1	25
Actinopterygii	class	6544	29184	Fucaceae	family	1	18
Anthozoa	class	185	5953	Fundulidae	family	6	24
Appendicularia	class	1	65	Gadidae	family	23	32
Cephalaspidomorphi	class	6	42	Gasterosteidae	family	5	137
Cephalopoda	class	77	775	Gempylidae	family	18	84
Elasmobranchii	class	460	996	Gonostomatidae	family	27	11
Holocephali	class	20	40	Haemulidae	family	78	5
Mammalia	class	116	7237	Holocentridae	family	48	25
Maxillopoda	class	6	5234	Istiophoridae	family	7	23
Myxini	class	12	72	Lamnidae	family	5	108
Reptilia	class	16	13106	Lophiidae	family	17	387
Acipenseriformes	order	4	32	Lotidae	family	13	25
Anguilliformes	order	281	878	Lutjanidae	family	78	6
Cetacea	order	83	121	Macrouridae	family	146	249
Characiformes	order	0	1851	Merlucciidae	family	15	57
Clupeiformes	order	132	388	Moronidae	family	4	208
Cyprinodontiformes	order	8	1155	Myctophidae	family	173	17
Gadiformes	order	265	604	Nototheniidae	family	32	42
Scleractinia	order	181	1501	Octopodidae	family	7	11
Stomiiformes	order	209	407	Osmeridae	family	8	102
Acanthuridae	family	56	81	Petromyzontidae	family	6	43
Achiridae	family	12	33	Phycidae	family	9	86
Agonidae	family	29	47	Pleuronectidae	family	62	369
Anguillidae	family	10	24	Polynemidae	family	17	18
Antennariidae	family	24	45	Pomacanthidae	family	45	7
Apogonidae	family	156	337	Pomacentridae	family	197	214
Argentinidae	family	12	25	Priacanthidae	family	13	282
Artedidraconidae	family	12	25	Pristidae	family	4	57
Atherinidae	family	25	66	Salmonidae	family	21	138
Balistidae	family	29	42	Sciaenidae	family	101	503
Blenniidae	family	143	385	Scombridae	family	45	129
Carangidae	family	127	150	Sebastidae	family	77	9
Carcharhinidae	family	40	50	Serranidae	family	234	280
Centrolophidae	family	22	31	Sparidae	family	85	65
Chaetodontidae	family	83	128	Sphyrnidae	family	7	1
Cheilodactylidae	family	14	27	Stomiidae	family	133	4
Clupeidae	family	71	213	Synodontidae	family	39	–
Cottidae	family	81	250	Xiphiidae	family	1	–
Cynoglossidae	family	55	137	Balaenidae	family	4	–

Results and Discussion

Presently, over 10,000 AquaMaps, mainly for marine fishes, have been produced using this approach (and used here). Also, their outputs have been successfully validated using independent, effort-corrected survey data and, in the face of the existing sub-optimal input data sets, AquaMaps model performance compares well with that of other presence-only habitat prediction models, such as GARP, Maxent or GAMs (Ready *et al.*, 2010).

Using the tools available on the AquaMaps web site, subsets of AquaMaps species predictions have been used in various analyses investigating patterns of species richness in different geographic regions (Froese, *in press*). Marine species diversity maps can be generated by overlaying AquaMaps predictions of all or subsets of species and counting all species predicted to be present in a given cell based on a pre-defined probability threshold. As an example we show the distribution of anguilliform fishes (European and American eels, conger eels, etc.) in Figure 1.

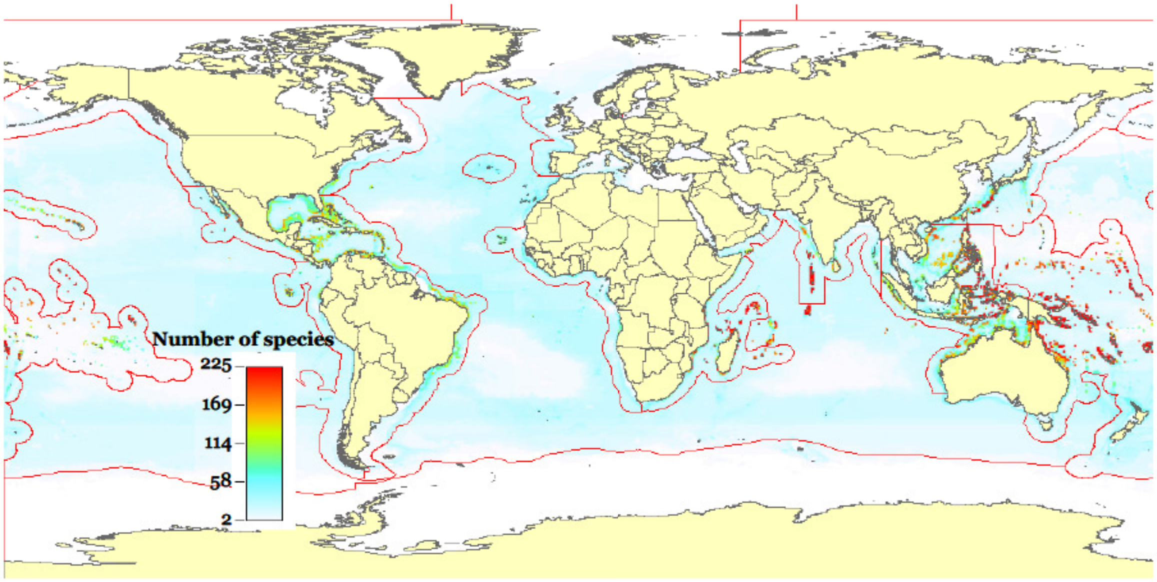

Figure 1. Global distribution of the order Anguilliformes (eel-like fishes; approximately 800 species in 19 families). The legend indicates the predicted number of species occurring in each half-degree cell.

Specific case studies include investigations of the association of marine mammal biodiversity hotspots and global seamount habitat (Kaschner, 2007), the impact of climate change on global marine mammal biodiversity (Kaschner *et al.*, submitted) and European fish fauna (Kaschner *et al.*, *in press*) or to provide an overview of Mediterranean Sea biodiversity patterns (Coll *et al.*, 2010).

Large-scale species distribution models currently probably represent the best, if not only choice to produce species richness maps or comprehensive inventories in many of the often data-poor off-shore regions of the world's oceans. However, the concentration of sampling effort in more accessible habitats, such as the continental shelf regions of the northern hemisphere, also represents a great challenge for the application of any species distribution modeling technique, and the results of all models therefore need to be viewed with caution. In addition, species distribution models predict broad range extents, which often do not consider seasonal movements of animals or subspecies level population structure, and may thus potentially overlook critical habitat needed during certain life stages or for maintaining subspecies level diversity.

For a given species, we are often interested in attributes such as abundance, genetic uniqueness, endemism, and endangered status. However, most models and diversity indices derived from such predictions do not consider relative or absolute abundances of individual species and are indifferent to species substitutions. Hence, mapping of biodiversity hotspots may not reliably pick up on areas important to species of special concern, such as endangered and/or extremely rare species.

Despite these caveats, which affect most currently existing models, AquaMaps-based biodiversity predictions may provide a starting point for species inventories in different Regional Seas (Table 1).

The tools and features available on the AquaMaps website allow for the selection of different subsets of species based on a range of different conservation and management criteria. Currently, taxa such as ray-finned fishes and elasmobranchs as well as marine mammals are either complete or comprehensively covered by AquaMaps, and coverage is currently being expanded to invertebrates, algae and hexacoral taxa. The incorporated expert review process represents a Wiki approach that can greatly facilitate the review of existing data and resulting predictions through expert panels such as IUCN species working groups.

However, to identify most reliably areas of high biological diversity, a range of different modeling techniques should ideally be applied to determine which regions are consistently – across all model outputs – predicted to represent hotspots. Model selection and spatial and temporal scales of the analysis should be based on data availability and the ecology and life history of the taxa in question and outputs should be validated with independent, effort-corrected survey data to the extent possible. Forward projections of changes in species distributions and related areas of high biodiversity under different climate change scenarios can help to identify those significant areas most likely to ensure long-term protection of high biological diversity.

Acknowledgements

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References

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Ben, F., Lasram, R., Aguzzi, J., Ballesteros, E., Bianchi, C.N., Corbera, Dailianis, R. Danovaro, J.T., Estrada, M., Froglia, C., Galil, B.S., Gasol, J.M., Gertwagen, R., Gil, J., Guilhaumon, F., Kesner-Reyes, K., Kitsos, M.-S., Koukouras, A., Lampadariou, N., Laxamana, E., López-Fé de la Cuadra, C.M., Lotze, H.K., Martin, D., Mouillot, D., Oro, D., Raicevich, S., Rius-Barile, J., Saiz-Salinas, J.I., San Vicente, C., Somot, S., Templado, J., Turon, X., Vafidis, D., Villanueva, R., Voultsiadou, E., 2010. The Biodiversity of the Mediterranean Sea: estimates, patterns, and threats. *PLoS ONE* 5(8), e11842. doi:10.1371/journal.pone.0011842.

Froese, R. 2011. The Science in FishBase. P. 47-53 *In:* Christensen, V., Maclean, J. (eds.), *Ecosystem Approaches to Fisheries: A Global Perspective*. Cambridge University Press.

Kaschner, K., Watson, R., Trites, A.W., Pauly, D., 2006. Mapping worldwide distributions of marine mammals using a Relative Environmental Suitability (RES) model. *Marine Ecology Progress Series* 316, 285-310.

Kaschner, K., 2007. Air-breathing visitors to seamounts. Section A: Marine mammals. In: Pitcher, T., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N., Santos, R.S. (eds.), *Seamounts: Ecology, Fisheries & Conservation*, pp. 230-238. Blackwell Fish and Aquatic Resources Series. 12, Oxford, U.K.

Kaschner, K., Ready, J.S., Agbayani, E., Rius, J., Kesner-Reyes, K., Eastwood, P.D., South, A.B., Kullander, S.O., Rees, T., Close, C.H., Watson, R., Pauly, D., Froese, R., 2008. *AquaMaps: Predicted Range Maps for Aquatic Species*. World wide web electronic publication, www.aquamaps.org, Version 10/2008.

Kaschner, K., Kesner-Reyes, K., Barile-Rius, J., Rees, T., Ready, J., Garilao, C., Kullander, S., Froese, R. Impacts of climate change on biodiversity patterns of fish and other marine species in European waters. *BfN-Skripten* (*in press*).

Kaschner, K., Titensor, D, Ready, J, Gerodette, T., Worm, B. Current and future patterns of global marine mammal biodiversity. [Unpublished data].

Ready, J., Kaschner, K., South, A.B., Eastwood, P.D., Rees, T., Rius, J., Agbayani, E., Kullander, S., Froese, R., 2010. Predicting the distributions of marine organisms at the global scale. *Ecological Modelling* 221(3), 467-478.

Distribution and abundance trends for marine mammals[1]

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Abstract

By combining the distribution range maps of marine mammal species originally derived by the first author with trend data on their overall population size estimated by the second, partly spatialized population trends can be obtained. These are briefly discussed here, along with their re-expression by Regional Sea.

Introduction

In this study we combine results from two sets of analyses, one aimed at predicting the relative spatial abundance of marine mammals based on environmental suitability, and the other a non-spatial study of how the abundance of marine mammals in the world's ocean's and Regional Seas may have changed in historic times because of exploitation.

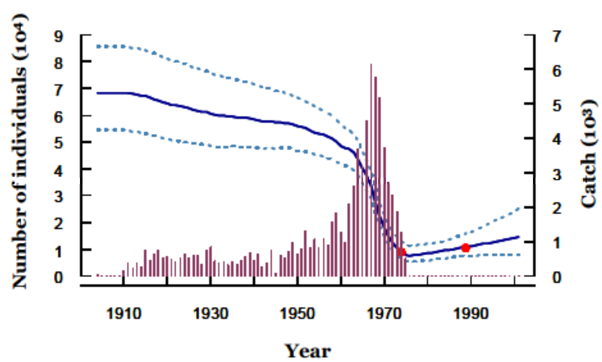

Figure 1. An example of marine mammal population dynamics, here for North Pacific sei whales. The solid line indicates the most likely population trajectory (the median of the posterior), the stippled lines the 95% confidence interval, the vertical lines the catches applied, and the dots the abundance estimates to which the analyses are tuned. (From Christensen, 2006).

Materials and Methods

The global geographic ranges and relative environmental suitability (RES) was estimated for 115 marine mammal species using a rule-based habitat suitability model (Kaschner, 2004; Kaschner *et al.*, 2006a). The model is based on quantitative data, supplemented by non-quantitative and more readily available information about species habitat preferences. Each species was assigned to broad-scale ecological niches with respect to depth, sea surface temperature and ice edge association based on published qualitative and quantitative habitat preference information. Within a global grid with ½° latitude by ½° longitude cell resolution, an index was developed of the relative environmental suitability (RES) of each cell for a given species by relating quantified habitat preferences to locally averaged environmental conditions in a GIS modeling framework.

In the second analysis, marine mammal population estimates and trends for the extant marine mammal species with a commercial exploitation history was reconstructed (Christensen and Martell, 2005; Christensen, 2006). In total, the population trends for nearly half of the 115 extant species were reconstructed. This work, which was part of the *Sea Around Us* project, included creation of a global database of marine mammal whaling, sealing and bycatch/discards estimates. Using a Bayesian approach

[1] Cite as: Kaschner, K., Christensen, L.B., 2011. Distribution and abundance trends for marine mammals. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 22-23. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

to stock reduction analysis (Walters *et al.*, 2006), probability distributions over historical stock sizes were obtained (see Figure 1 for an example).

Results and Discussion

Combining the estimates of abundance by species, by year, and the relative species distributions, we obtain estimates of the spatial abundance of marine mammal species by year (Figure 2). For this, we assume that the relative abundance of each species is independent of the absolute abundance, i.e., that there is no range contraction taking place in connection with species depletion.

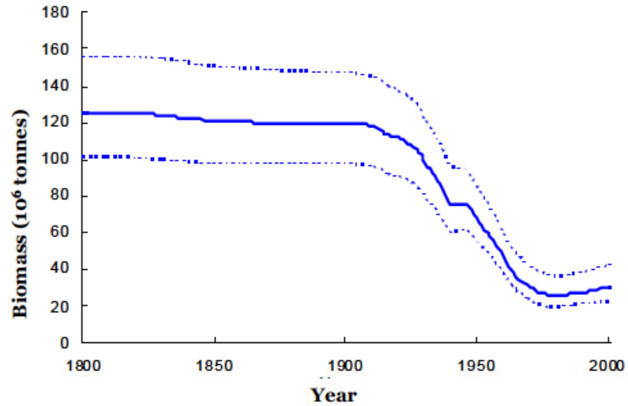

Figure 2. Decline in the global biomass of marine mammals, all species combined. The solid line is the median, and the dotted lines represent the 95% confidence interval (from Christensen, 2006).

For each spatial cell, we sum up the abundance to the Regional Sea level, and thus obtain species-weighted marine mammal abundance by Regional Sea. We have not allocated the catch database of marine mammal kills to spatial cells, because the whaling database, as implemented, does not have enough spatial information, and we are thus unable to reconstruct distinct population trends by Regional Seas. Thus, the abundance trends will be the same for a given species in all Regional Seas in which it occurs.

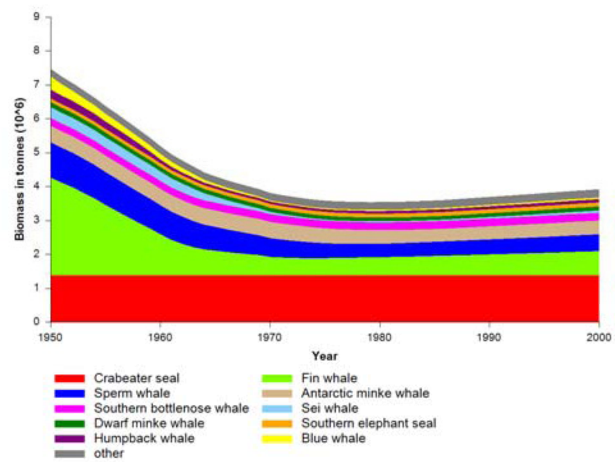

Figure 3. Abundance of marine mammals in the Antarctic Regional Sea (see text).

Marine mammals are important indicator species for the state of ecosystems, and the indicators we present in this study should be regarded as state indicators. We have used ½° by ½° spatial resolution for this study, and report the results by Regional Seas, covering the time period from 1950-2000, as illustrated in Figure 3 for the Antarctic Regional Sea.

We remind the reader, however, that the abundance trends of a given species are similar for all the Regional Seas where it occurs, i.e., we do not yet have area-specific estimates for how abundances have changed. Suggestions on how to interpret the marine mammal distributions and trend indicators are presented in the publications cited below.

References

Christensen, L.B., 2006. *Reconstructing Historical Abundances of Exploited Marine Mammals at the Global Scale*, Fisheries Centre Research Reports 14(9), University of British Columbia, Vancouver.

Christensen, L.B., Martell, S.J.D., 2005. A stochastic framework for reconstructing historical marine mammal abundance from catch records and sparse abundance information: application to the Antarctic blue whale and North Atlantic and Arctic fin whale. ICES, C.M.2005/R:32.

Kaschner, K., 2004. *Modelling and Mapping Resource Overlap between Marine Mammals and Fisheries on a Global Scale*. Ph.D. thesis, University of British Columbia, Vancouver.

Kaschner, K., Watson, R., Trites, A.W., Pauly, D., 2006. Mapping world-wide distributions of marine mammal species using a relative environmental suitability (RES) model. *Marine Ecology Progress Series* 316, 285-310.

Walters, C.J., Martell, S.J.D., Korman, J., 2006. A stochastic approach to stock reduction analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 63, 212-223.

Diversity of commercially exploited fish and invertebrates in Regional Seas[1]

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Abstract

Distribution range maps of commercially exploited species, defined as the marine fishes and invertebrates that are listed in fisheries catch statistics submitted by member countries to the United Nations' Food and Agriculture Organization (FAO), plotted onto a global ½° latitude/longitude cell grid, can be used to characterize the diversity of commercially exploited species in Regional Seas. Some caveats are discussed, notably the fact that low-latitude countries tend to taxonomically over-aggregate their fisheries statistics.

Introduction

Biodiversity – the variability among living organisms from all sources, including diversity within species, between species and of ecosystems (Convention on Biological Diversity 1992) – performs a multitude of services to humans. In the oceanic spheres, these include providing the basis for fisheries (for food or recreation), drug development or non-extractive use, such as providing scenery for scuba divers (Pauly *et al.*, 2005) and whale watchers (Sorongon *et al.*, 2010). Yet, this same biodiversity is coming under threat in the open ocean (Dulvy *et al.*, 2003). The main cause for this is fisheries (Pauly *et al.*, 2005), and the task is to design management regimes that minimize diversity loss (Alder and Wood, 2004). To this end, detailed knowledge must be available for the ecosystems and individual species occurrences at various places along with broad-based knowledge about global patterns of diversity. It is the latter that this index offers. The index is based on diversity of commercially exploited species, defined as the marine fishes and invertebrates that are listed (by at least one country, in at least one year since 1950) in fisheries catch statistics submitted by member countries to the United Nations' Food and Agriculture Organization (FAO).

Materials and Methods

Distributions of a total of 1,066 exploited marine fish (836 spp.) and invertebrate species (230 spp.) were predicted using the method described in Close *et al.* (2006), using an algorithm which uses probability of occurrence of a species on a ½° latitude by ½° longitude grid based on its depth range, latitudinal range and broadly known occurrence regions. The resulting distributions indicate average patterns of species' relative abundance in recent decades (i.e., 1980–2000). The species included in the analysis were all relatively abundant, by definition, since they must be included in the fisheries statistics of at least one FAO member country (see definition above). This also weighted the sample of marine biodiversity towards the species, which: i) contribute most to marine metazoan biomass; and ii) are more accessible to fishing gears.

The distributions were further refined by assigning habitat preferences to each species, such as affinity to shelf (inner, outer), estuaries and coral reefs. Such information was mainly obtained from FishBase

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(www.fishbase.org) for fish and SeaLifeBase for other taxa (www.sealifebase.org); both databases contain key information on the latitudinal and depth distribution of the animals in question, and on their occurrence in various parts of the world ocean. The distribution maps are available at www.seaaroundus.org, along with the habitat preferences and other parameters used in their construction.

Results and Discussion

The diversity of commercially exploited species is highest along the continental shelf and oceanic ridges, with species richness ranging from 0 to 346 species per cell (Figure 1). Latitudinal patterns of species richness of marine fish and invertebrates show a plateau of around 40ºN–30ºS and declines towards the poles. Species richness per cell also appears to decrease with increasing depth and distance from the coastline.

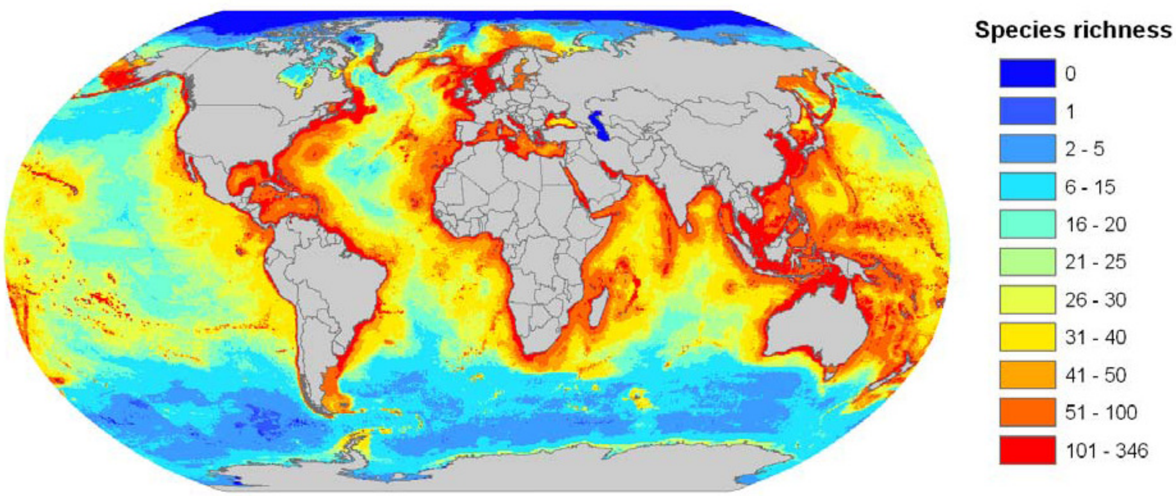

Figure 1. Species richness of exploited marine fishes and invertebrates by ½° cell.

The indicator shows that richness of exploited species is highest in tropical regions, which mimics empirically observed patterns of marine species richness reported by Hoeksema (2007), and specific groups, e.g., fishes (Carpenter and Springer, 2005; Cheung *et al.*, 2005; Bellwood and Meyer, 2009), bivalves (Roy *et al.*, 2000), gastropods (Rex *et al.*, 2005; Bellwood and Meyer, 2009), bryozoans (Clarke and Lidgard, 2000) and various invertebrates (Macpherson, 2002), as well as benthic marine algae (Kerswell, 2006). However, this is different for the high values in the Northeast Atlantic, which are probably an artifact of the very detailed fisheries statistics of the countries operating in this area, e.g., Norway. Indeed, the pattern does not fully reflect diversity patterns of marine fishes and invertebrates as a whole, because the species included in the calculation of this indicator are biased by different levels of taxonomic resolution in landing records of different regions. In particular, low-latitude (mostly developing) countries aggregate their reported catch statistics into higher taxonomic groupings, e.g., genera, family (Pauly and Palomares, 2005). This can be taken into account (by comparing each country's scores with the score of countries with which it shares species) when evaluating the relative thoroughness of countries' fisheries statistics (Pauly and Watson, 2008), but such procedure would not have any meaning when applied to oceanic regions. Thus, while it is straightforward to use the data in Figure 1 to compute scores for Regional Seas, further studies are required on what they mean in biological terms.

Acknowledgements

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References

Alder, J. and L. Wood. 2004. Managing and Protecting Seamounts. In: Seamounts: Biodiversity and Fisheries. In: T. Morato and D. Pauly (eds). *Seamounts: Biodiversity and fisheries*. Fisheries Centre Research Reports 12(5).

Bellwood, D.R., Meyer, C.P., 2009. Searching for heat in a marine biodiversity hotspot. *Journal of Biogeography* 36, 569-576.

Carpenter, K.E., Springer, V.G., 2005. The center of the center of marine shore fish biodiversity: the Philippine Islands. *Environmental Biology of Fishes* 72, 467-480.

Cheung, W.L., J. Alder, V. Karpouzi, R. Watson, V. Lam, C. Day, K. Kaschner, and D. Pauly. 2005. *Patterns of species richness in the high seas*. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series no. 20, 31 p.

Cheung, W.W.L., Lam, V.W.Y. and Pauly, D. (2008a) Modelling Present and Climate-Shifted Distribution of Marine Fishes and Invertebrates. In: W.W.L. Cheung, V.W.Y., Lam and D. Pauly (eds.). Modelling Present and Climate-shifted Distribution of Marine Fishes and Invertebrates. Fisheries Centre Research Report 16(3).

Clarke, A., Lidgard, S., 2000. Spatial patterns of diversity in the sea: bryozoan species richness in the North Atlantic. *Journal of Animal Ecology* 69, 799-814.

Close, C., Cheung, W.W.L., Hodgson, S., Lam, V., Watson, R. and Pauly, D. (2006) Distribution ranges of commercial fishes and invertebrates. In: D. Palomares, K.I. Stergiou and D. Pauly (eds) Fishes in Databases and Ecosystems Fisheries Centre Research Report 14(4), University of British Columbia, Vancouver, pp. 27–37.

Dulvy, N.K.,Y. Sadovy, and J.D. Reynolds. 2003. Extinction vulnerability in marine populations. Fish and Fisheries, 4(1): 25-64.

Hoeksema, B.W., 2007. Chapter 5. Delineation of the Indo-Malayan centre of maximum marine biodiversity: the Coral Triangle. In: Renema, W. (ed.), *Biogeography, Time and Place: Distributions, Barriers, and Islands*, pp. 117-178. Springer, Dordrecht, The Netherlands, 414 pp.

Kerswell, A.P., 2006. Global biodiversity patterns of benthic marine algae. *Ecology* 87(10), 2479-2488.

Macpherson, E. (2002) Large-scale species-richness gradients in the Atlantic Ocean. Proceedings of the Royal Society of London Series B 269, 1715–1720.

Pauly D, J. Alder, A. Bakun, S. Heileman, K.H. S, Kock, P. Mace, W. Perrin, K.I. Stergiou, U.R. Sumaila, M. Vierros, K.M.F. Freire, Y. Sadovy, V. Christensen, K. Kaschner, M.L.D. Palomares, P. Tyedmers, C. Wabnitz, R. Watson, and B. Worm. 2005. Marine Systems. Chapter 18, p. 477-511 *In:* R. Hassan, R. Scholes and N. Ash (eds.) *Ecosystems and Human Well-being: Current States and Trends, Vol. 1*. Millennium Ecosystem Assessment and Island Press, Washington, D.C.

Pauly, D. and M.L. Palomares. 2005. Fishing down marine food webs: it is far more pervasive than we thought. *Bulletin of Marine Science* 76(2): 197-211.

Pauly, D. and R. Watson. 2008. Adjusting for context in evaluating national fisheries statistics reporting systems. p. 57-61 *In*: J. Alder, J. and D. Pauly (eds.). A comparative assessment of biodiversity, fisheries and aquaculture in 53 countries' exclusive economic zones. Fisheries Centre Research Reports 16(7).

Rex, M.A., Crame, A.J., Stuart, C.T., Clarke, A., 2005. Large-scale biogeographic patterns in marine molluscs: a confluence of history and productivity? *Ecology* 86(9), 2288-2297.

Roy, K., Jablonski, D., Valentine, J.W., 2000. Dissecting latitudinal diversity gradients: functional groups and clades of marine bivalves. *Proceedings of the Royal Society of London Biological Sciences* 267, 293-299.

Climate-change induced species invasions and extirpations in Regional Seas[1]

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Abstract

Climate change will impact the pattern of marine biodiversity through, among other things, changes in species distributions. So far, however, global studies on climate change impacts on ocean biodiversity have been scarce to non-existent. Here, we show that climate change impact can be analyzed by projecting the distributional ranges of a large sample of exploited marine fish and invertebrates to the year 2050, by using a recently developed dynamic bioclimate envelope model. Our projections show that climate change may lead to numerous extirpations (i.e., local extinctions) in the sub-polar regions, the tropics and semi-enclosed seas. Simultaneously, species invasions are projected to be most common in the Arctic and the Southern Ocean. Jointly, extirpations and invasions result in a dramatic species turnover of over 60% of the present biodiversity, implying ecological disturbances that will likely reduce the ecosystem services that are presently provided by the various Regional Seas.

Introduction

Climate change is an important factor in determining the past and future distributions of biodiversity. In the ocean, observations and theory suggest that marine species respond to ocean warming by shifting their latitudinal range, (e.g., Perry *et al.*, 2005; Parmesan, 2006; Hiddink and Hofstede, 2008; Mueter and Litzow, 2008) and depth range (Dulvy *et al.*, 2008). Such species responses may lead to local extinction and invasions, resulting in changes in the pattern of marine species richness. For example, in the North Sea, species richness of fish fauna increased from 1985 to 2006, which was related to large-scale biogeographical patterns and climate change (Hiddink and Hofstede, 2008). Here, local extinction refers to a species ceasing to exist in an area although it still exists elsewhere, while invasion refers to the expansion of a species into an area not previously occupied by it. The indices presented here represent potential effects of climate change on species invasion and local extinction under the SRES A1B climate change scenario.

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Material and Methods

Species invasion and extirpation (i.e., local extinction) indices were derived from predicted global patterns of local extinction and invasion for the year 2050 relative to the early 2000s by projecting future ranges of a sample of 1,066 exploited marine fish and invertebrate species under climate change scenarios (see Cheung *et al.*, 2009 for details). Species extirpation, invasion and turnover are considered good measures of biodiversity and ecosystem perturbation (Peterson *et al.*, 2002; Thuiller, 2004). We employ a generic dynamic bioclimate envelope model for marine fish and invertebrates that incorporates population and dispersal dynamics to project future species distributions under climate change (for details, see Cheung *et al.*, 2008a). We projected the global rate of shift of marine species distributions and illustrate the potential future hotspots of climate change impacts on marine biodiversity, including sea surface and bottom temperature, coastal upwelling, salinity, distance from sea-ice and habitat types (coral reefs, estuaries and seamounts). Since invasion to and extinction from an area can affect biodiversity, community structure and ecosystem functions, we calculated the mean frequency of invasion and extirpation events in each ½° by ½° cell from 2040 to 2060 relative to the mean of 2001 to 2005 to identify hotspots of climate change induced impacts for 2050. First, we calculated the current species richness in each ½° by ½° cell by overlaying distribution maps of all the 1,066 marine species, which resulted in a latitudinal pattern of species richness similar to the empirically observed patterns for fishes, invertebrates and algae (see Cheung *et al.*, this volume). Then, using the dynamic bioclimate envelope model, we projected the change in distributions of the 1,066 marine species under the high-, medium- and low- climate change scenarios. We calculated the number of newly occurring species (invasion) and the number of locally extinct species in each cell. As the species distribution maps available for analysis were not evenly distributed, but concentrated on continental shelves and around islands in non-polar regions, we standardized the number of invading or locally extinct species in each cell by the initial species richness (number of species) to calculate invasion intensity (I) and local extinction intensity (E):

$$I_{i,y} = \frac{n^{I}_{i,y}}{n_i} \quad \text{... 1)}$$

$$E_{i,y} = \frac{n^{E}_{i,y}}{n_i} \quad \text{... 2)}$$

where $n^{I}_{i,y}$ and $n^{E}_{i,y}$ represent the number of invading and locally extinct species, respectively, in cell i and year y; n is the initial species richness (mean of year 2001 to 2005) measured by the number of species with positive relative abundance in each cell. Thus, turnover, invasion and extirpation intensities were expressed as a proportion to the initial species richness in each spatial cell. To minimize the effect of inter-annual variability of the climate projection, projections for 2050 were represented by the average from 2040 to 2060. In addition, we calculated the zonal (latitudinal) average of species invasion and local extinction across all climate scenarios to reveal the latitudinal patterns of climate change impact on marine biodiversity.

Data sources

Key information for predicting distribution maps were obtained mainly from FishBase (www.fishbase.org) for fish and SeaLifeBase for other taxa (www.sealifebase.org); both databases contain key information on the latitudinal and depth distribution of the animals in question, and on their occurrence in various parts of the world ocean. The distribution maps of the 1,066 species used in this analysis are available at www.seaaroundus.org, along with their habitat preferences and other parameters used in their construction.

Indicator characteristics

This is an indicator that shows the area where marine biodiversity is most likely to be impacted by climate change in the future under the SRES A1B scenario. As such, it is an impact indicator. The spatial scale of the underlying analysis is ½° by ½° spatial cells, here summarized at the Regional Sea level. The indicators are rate of species invasion and local extinction by 2050 (10-year average).

The rate of species invasion and local extinction indicate the relative effect of climate change on species composition in an area (½° spatial cell) through climate-induced shift in species distributions. The higher the index, the higher the potential impacts of climate change on species composition due to invasion and local extinction of species.

Results and Discussion

Generally, high intensity of species invasion was predicted to be concentrated in high latitude regions, specifically the Arctic and the Southern Ocean. These areas correspond to the marginal sea ice and sub-polar biomes as defined by the oceanographic features categorized by Sarmiento *et al.* (2004). This also parallels the bioregional classification of Longhurst (2006), as both schemes identify marine provinces from oceanographic features.

Extirpations, or local extinctions, were predicted to be most common in the tropics, the Southern Ocean, the north Atlantic, the northeast Pacific coast and in semi-enclosed seas such as the Mediterranean, the Red Sea and the Persian Gulf. Species turnover, which accounts for invading and extirpated species, was predicted to be highest in the Arctic and the sub-polar regions of the Southern Ocean. Globally, the average projected mean invasion intensity for 2040–2060 relative to 2001 - 2005 and under the three climate scenarios was 55% of the initial species richness. Mean invasion intensity in high latitudes such as the Arctic (> 60° N) and around the Southern Ocean (40° – 60° S) were nearly 5.5 and 2 times the global average, respectively, while at the equator, mean invasion was less than half of the global average. Global average local extinction rate was 3% of the initial species richness. However, local extinction intensity was higher in the tropics (between 30° N and 30° S) and in the sub-polar biomes (Sarmiento *et al.*, 2004) where the mean local extinction intensity was 4% and 7%, respectively.

Separating the species into pelagic and demersal groups showed that the pelagic system displayed considerably higher invasion intensity than the demersal system. However, the spatial patterns of species invasion and local extinction generally are similar between the pelagic and benthic realms, with the low initial species richness in polar regions strongly contributing to the high biodiversity impact. Zonal average patterns of invasion and extirpation intensity between ocean basins (Pacific, Atlantic and Indian Oceans) are generally consistent with the global pattern. However, in the Atlantic and Indian Oceans, extirpation intensity is high in the sub-tropical region in the Northern Hemisphere (around 30° N) – an effect of the high extirpation intensity in semi-enclosed seas, including the Mediterranean Sea and the Red Sea. On the contrary, extirpation intensity in similar regions in the Pacific Ocean corresponds approximately to the global average intensity.

The high sensitivity of polar species to temperature change renders the polar regions particularly susceptible to climate change. Polar species generally have temperature limits that are 2-4 times narrower than lower latitude species (Peck *et al.*, 2004). Therefore, increasing temperatures lead to the retreat of the low-latitude range boundaries of polar species, which results in bands of high local extinction intensity in the sub-polar regions of the north Atlantic and the Southern Ocean (Figure 1, bottom). Simultaneously, the poleward extension of other species' high-latitude range, compounded with the higher species richness of lower latitudes, results in high invasion intensity in the polar region.

These predictions, which agree with the eco-physiology of poikilotherms (Pörtner *et al.*, 2007; Tewksbury *et al.*, 2008), suggest that marine communities at the extreme ends of the environmental temperature spectrum are especially at risk from climate change. Particularly, the expansion of the high latitude range of Arctic and Antarctic species is limited by the availability of suitable habitats. Thus, retractions of the low latitude range leads overall, to range contraction, which further increases the impact on individual population and biodiversity.

Biodiversity in tropical regions is likely to be impacted by higher rates of local extinction. Tropical marine poikilotherms tend to have a thermal tolerance (defined by the upper and lower lethal temperature limits of a species) close to the maximum temperature of their habitat (Pörtner and Knust, 2007; Tewksbury *et al.*, 2008), rendering them highly sensitive to increase in seawater temperature. Thus, generally, these animals were projected to move to colder habitats in higher latitude when tropical water temperature increases, leading to extirpations in the tropical regions.

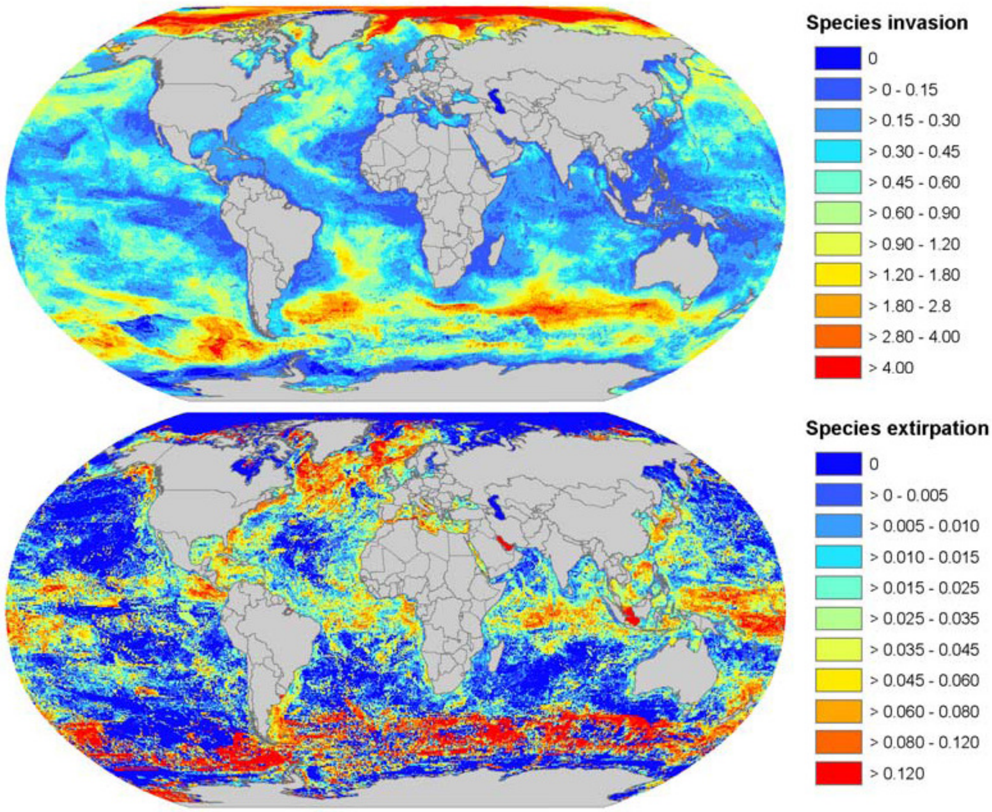

Figure 1. Projected rate of species invasion (top) and extirpation (or local extinction; bottom) projected under the SRES A1B scenario. (From Cheung *et al.*, 2009)

The index did not consider the potential implications of climate change impact on habitat-forming organisms such as corals. For example, warming is predicted to increase the frequency and scale of coral bleaching and mortality (e.g., Donner *et al.*, 2005), which may affect coral reef species (Munday *et al.*, 2008). Thus, our projected rate of extirpation in the tropics can be viewed as conservative.

There are a number of key assumptions and approximations in the calculation of the indices. Firstly, the current distribution maps are imperfect, which affects both the inferred species' habitat preferences and their simulated distribution shifts. Secondly, accurate estimates of population and dispersal parameters were not available; thus we estimated their values using indirect methods. Thirdly, distribution shifts may be influenced by synergistic effects between species or anthropogenic factors that were not captured in our model (e.g., fishing).

Moreover, the effects of changes in ocean chemistry, (e.g., ocean acidification) were not considered, although they are known to have negative impacts on the respiration of fishes and invertebrates (Pauly, 2010), and, obviously, on animal with calcareous shells and coral reefs. On the positive side, possible genotypic or phenotypic adaptations to the changing temperature were not considered (Pearson and Dawson, 2003). In addition, because we only considered climate scenarios generated from one coupled atmosphere and ocean model (NOAA's GFDL), variability between projections from different models may affect the magnitude of the effects we predicted.

Acknowledgements

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References

Cheung, W.W.L., Lam, V.W.Y., Pauly, D., Editors, 2008a. *Modelling Present and Climate-shifted Distribution of Marine Fishes and Invertebrates*. Fisheries Centre Research Report 16(3), Fisheries Centre, UBC, Vancouver, Canada, 726 pp.

Cheung, W.W.L., Close, C., Lam, V.W.Y., Watson, R., Pauly, D., 2008b. Application of macroecological theory to predict effects of climate change on global fisheries potential. *Marine Ecology Progress Series* 365, 187-197

Cheung, W.W.L., Close, C., Kearney, K., Lam, V., Sarmiento, J., Watson, R., Pauly, D., 2009. Projections of global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries* 10, 235-251.

Donner, S.D., Skirving, W.J., Little, C.M., Oppenheimer, M., Hoegh-Gulderg, O., 2005. Global assessment of coral bleaching and required rates of adaptation under climate change. *Global Change Biology* 11, 2251-2265.

Dulvy, N.K., Rogers, S.I., Jennings, S., Vanessa, S., Dye, S.R., Skjoldal, H.R., 2008. Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. *Journal of Applied Ecology* 45, 1029-1039.

Hiddink, J.G., Hofstede, R.T., 2007. Climate induced increases in species richness of marine fishes. *Global Change Biology* 14, 453-460.

Longhurst, A. 2006. *Ecological Geography of the Sea*, Academic Press, London, 542 pp.

Mueter F.J., Litzow, M.A., 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. *Ecological Applications* 18, 309–320.

Munday, P.L., Jones, G.P., Pratchett, M.S., Williams, A.J., 2008. Climate change and the future for coral reef fishes. *Fish and Fisheries* 9, 261-285.

Parmesan, C., 2006. Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution, and Systematics* 37, 637-669.

Pauly, D., 2010. Gasping *Fish and Panting Squids: Oxygen, Temperature and the Growth of Water-Breathing Animals*. Excellence in Ecology (22), International Ecology Institute, Oldendorf/Luhe, Germany, xxviii + 216 p.

Pearson, R.G., Dawson, T.P., 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global Ecology and Biogeography* 12, 361-371.

Peck, L.S., Webb, K.E., Bailey, D.M., 2004. Extreme sensitivity of biological function to temperature in Antarctic marine species. *Functional Ecology* 18, 625-630.

Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D., 2005. Climate change and distribution shifts in marine fishes. *Science* 308, 1912-1915.

Peterson, A.T., Ortega-Huerta, M.A., Bartley, J., Sa´nchez- Cordero, V., Sobero´n, J., Buddemeier, R.H., Stock- well, D.R.B., 2002. Future projections for Mexican faunas under global climate change scenarios. *Nature* 416, 626–629.

Pörtner, H.O., Knust, R.C., 2007. Climate change affects marine fishes through the oxygen limitation of thermal tolerance. *Science* 5, 95-97.

Tewksbury, J.J., Huey, R.B., Deutsch, C.A., 2008. Putting the heat on tropical animals. *Science* 320, 1296-1297.

Thuiller, W., 2004. Patterns and uncertainties of species' range shifts under climate change. *Global Change Biology* 10, 2220–2227.

Fisheries, Economic and Social Indicators

Fisheries landings from Regional Seas[1]

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Abstract

The methods, through which global landings are reported to the Food and Agriculture Organization of the United Nations (FAO) by member countries, and by other international and national agencies, are presented, with emphasis on sources of uncertainties and attempts to overcome these. The results of this spatial allocation process are landing data on a ½° latitude by ½° longitude grid, covering the about 180,000 cells of the world's ocean for 1950 to 2006, from which various, first- and second-order indicators can be derived for any area of the ocean, including Regional Seas.

Introduction

In order to examine spatial patterns in global fisheries landings for each year and fishing country, it is necessary to first map global landings from a harmonized dataset to smaller spatial units which can be aggregated to represent areas of interest, such as UNEP's Regional Sea.

Data sources such as those provided voluntarily from fishing countries through the Food and Agriculture Organization of the United Nations (FAO) are invaluable, but have many limitations. Regional datasets are also important, notably in providing better detail. Reconstruction of national datasets can also provide great insights into historical catch series (e.g., Zeller *et al.*, in press). These different datasets are then woven into one coherent and harmonized global dataset representing all commercial extractions since 1950. To provide the necessary spatial detail, this global dataset is then allocated to a fine grid of cells (here, ½° latitude by ½° longitude). The taxonomic identity of the reported catch is combined with comprehensive databases on where these species occur (and in what abundance) in order to complete this process. This spatial allocation must be further tempered by where fishing countries actually fish, as not all coastal waters are available to all fleets. After considerable development, it is now possible to examine global catches and catch values in the necessary spatial context.

Material and Methods

The global catch database is used to allocate the tonnages reported to a system of ½° lat./long. cells (Watson *et al.*, 2004). These spatial cells are small enough to be used to look at the impacts of fishing in ecosystem models and in other analyses.

In a process called 'taxonomic disaggregation', the identity of the various low-level taxa (genera and species) included in over-aggregated groups is deduced (where possible), based on what was reported elsewhere, what taxa occur there and even what taxa are likely not to be specifically named. The most recent attempts at 'taxonomic disaggregation' are very conservative and require that candidate taxa for disaggregation process must have been previously reported by the reporting country, and/or by one of its nearest neighbours.

[1] Cite as: Watson, R., 2011. Fisheries landings from Regional Seas. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 32-34. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

It has become a common practice for some fishing companies to save money, avoid quota limitations, or acquire access to a country's Exclusive Economic Zone (EEZ) by 'reflagging' their vessels, e.g., by obtaining a so-called 'flag of convenience'. Many countries allow this practice which causes confusion for fisheries managers and researchers alike. Determining the real identity of the fishing country is important to work out which country is actually getting the benefits from fishing. However, in the context of spatial catch allocation, this is required in order to apply our knowledge about which countries are allowed to fish where. Reversing the reflagging process is necessary to determine who is really fishing.

The allocation process used the taxonomic identity of the catch (after the disaggregation process described above) to allocate catch to the system of spatial cells based on our taxonomic distributions (Close *et al.*, 2004). Also used is information about the fishing access and fishing patterns of reporting countries, sometimes after the effects of reflagging were removed (Watson *et al.*, 2004). This process is tested in terms of self-consistency: catches could have come only from the reporting areas where the reported taxa occur, and only in locations (EEZs) where and when the country reporting it is allowed to operate. All reported catch was accounted for, i.e., passed this test of self-consistency.

Each organism or group of organisms in the global catch database developed by the *Sea Around Us* project based on FAO and other data sources (Watson *et al.*, 2004; Watson *et al.*, 2006a, 2006b) is associated with one or more gear types as defined by von Brandt (1984). Von Brandt (1984) found it possible to associate the majority of global catch records with up to five important gear types, and to extrapolate these associations to all global catch records. In this way, it was possible to use the mapped results of the *Sea Around Us* (Watson *et al.*, 2005) to produce maps of catches by all gear types annually since 1950. Association of reported catch with gear types allows catch associated with destructive gear types, such as trawling and dredging, to be examined in detail (Watson *et al.*, 2006b).

Data sources

A harmonized global catch database of over one million records was prepared from a wide range of data sources including the FAO, regional organizations such as the International Council for the Exploration of the Sea (ICES), the North East Atlantic Fisheries Commission, and FAO regional bodies such as the Fishery Committee for the Eastern Central Atlantic, the General Fisheries Commission for the Mediterranean, and the Indian Ocean Fishery Commission, as well as several reconstructions of national databases (Zeller and Pauly, 2007; Zeller *et al.*, 2007).

Indicator characteristics

Fishing impacts on the marine environment are best represented by spatial indicators of fauna mortality and habitat destruction. Of these the most readily available is reported landings. In order to study where the impact is occurring, it is necessary to map the catch to finer spatial units so that individual areas such as Regional Seas can be examined.

The initial spatial resolution varies and is determined by statistical reporting areas. Data from ICES and some regional FAO bodies, covering small enough areas, can be used in their own right. However, much of global landings are still reported by FAO statistical areas, which are large portions of the world's ocean basins (such as the Northwest Atlantic). These are here resolved to landings for ½° lat./long. spatial cells, and regrouped by Regional Sea (Appendix 3, 14).

Results and Discussion

Each of the filters and gradients used to resolve the landings (or catches) to ½° spatial cells has some uncertainty. First, there is the uncertainty in the identification of the landed species (or group). This has to be resolved through 'taxonomic disaggregation', as described above. Second, the country reporting the catch can be in doubt, as vessels may be reflagged. Finally, the statistical area where the catch was reported from may be in doubt, as sometimes, for convenience, some countries simply report all their catch from one area though they fish in several.

Once uncertainty in the initial dataset is resolved as much as possible, the process relies on the accuracy of other databases. These include databases of taxonomic ranges and gradients based on associations with oceanographic features and critical habitats. Additionally, part of the mapping process includes using known fishing patterns and fishing arrangements of the reporting countries. This is very important in deciding, for example, which inshore areas may be closed to fishing for the country reporting the catch. As these arrangements are often confidential, they generate another source of uncertainty.

In spite of all these caveats, the spatially allocated landings described here can be used to provide inputs to a number of secondary indicators, notably:

- Stock-status plots, an often used plots summarizing the state of the exploited fish populations in a given ecosystem (see Kleisner and Pauly, 2010a, this volume, and Appendix 5);
- Catch from bottom-disturbing gears, a major stress factor impacting benthic habitats (Appendix 6);
- Top predators in the catches, a state variable reflecting how ecosystem composition may be changing (Appendix 7);
- Marine trophic index (or mean trophic level of the catch), the key state indicator for fishing down food webs (see Kleisner and Pauly, 2010b, this volume, and Appendix 9).

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References

Close, C., Cheung, W.L., Hodgson, S., Lam, V., Watson, R., Pauly, D., 2006. Distribution ranges of commercial fishes and invertebrates. In: Palomares, M.L.D., Stergiou, K.I., Pauly, D. (eds.), *Fishes in Databases and Ecosystems*, pp. 27-37. Fisheries Centre Research Reports 14(4). Fisheries Centre, Univ. British Columbia, Vancouver.

Sea Around Us, 2008. A global database on marine fisheries and ecosystems. World Wide Web site www.seaaroundus.org. Fisheries Centre, University British Columbia, Vancouver (British Columbia, Canada).

Watson, R., Alder, J., Kitchingman, A., Pauly, D., 2005. Catching some needed attention. *Marine Policy* 29, 281-284.

Watson, R, Kitchingman, A., Gelchu, A., Pauly, D., 2004. Mapping global fisheries: sharpening our focus. *Fish and Fisheries* 5, 168-177.

Watson, R., Revenga, C., Kura, Y., 2006. Fishing gear associated with global marine catches: I Database development. *Fisheries Research* 79, 97-102

Watson, R., Revenga, C., Kura, Y., 2006. Fishing gear associated with global marine catches: II Trends in trawling and dredging. *Fisheries Research* 79, 103-111

Zeller, D., Pauly, D., Editors, 2007. Reconstruction of marine fisheries catches for key countries and regions (1950-2005). Fisheries Centre Report 15(2), University of British Columbia, Vancouver, Canada, 163 pp.

Zeller, D., Booth, S., Davis, G., Pauly, D., 2007. Re-estimation of small-scale fisheries catches for U.S. flag island areas in the Western Pacific: the last 50 years. *Fisheries Bulletin* 105, 266-277.

Zeller, D., Rossing, P. Harper, S., Persson, L., Booth, S., Pauly, D., (in press). The Baltic Sea: estimates of total fisheries removals 1950-2007. *Fisheries Research*.

MARICULTURE PRODUCTION IN REGIONAL SEAS[1]

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ABSTRACT

The scope of mariculture production in Regional Seas can be roughly estimated, based on statistics of the United Nations' Food and Agriculture Organization (FAO), assembled from reports of member countries. Approaches to improve on these preliminary estimates are briefly discussed.

INTRODUCTION

The United Nations' Food and Agriculture Organization (FAO) defines aquaculture as follows: "*Aquaculture is the farming of aquatic organisms: fish, molluscs, crustaceans, aquatic plants, crocodiles, alligators, turtles, and amphibians. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.*"

Mariculture is a subset of aquaculture, and is defined as follows: *"By mariculture is understood that the cultivation of the end product takes place in seawater, such as fjords, inshore and open waters and inland seas in which the salinity generally exceeds 20‰. Earlier stages in the life cycle of these aquatic organisms may be spent in brackishwater or freshwater."* (www.fao.org/fishery/cwp/handbook/J/en).

The FAO also assemble annual reports about annual production from its member countries, and present the resulting global mariculture statistics by country, species and year on its website (www.fao.org).

MATERIAL AND METHODS

FAO aquaculture statistics by country, covering the years 1950 to 2008 were redistributed evenly over the coastal cells of the producing countries, and then summarized by Regional Seas as described in Lai *et al.* (this volume). Maps and CSV file were produced for all Regional Seas and global values (see Appendices 4 and 14).

RESULTS AND DISCUSSION

Figure 1 provides an example of mariculture production in a Regional Sea, the Northwest Pacific (see Figure 1 in Lai *et al.*, this volume). Mariculture can be considered a state indicator, even though for many species (e.g., salmonids), there is a close connection with fisheries, which may result in mariculture production having a stress impact on ecosystems.

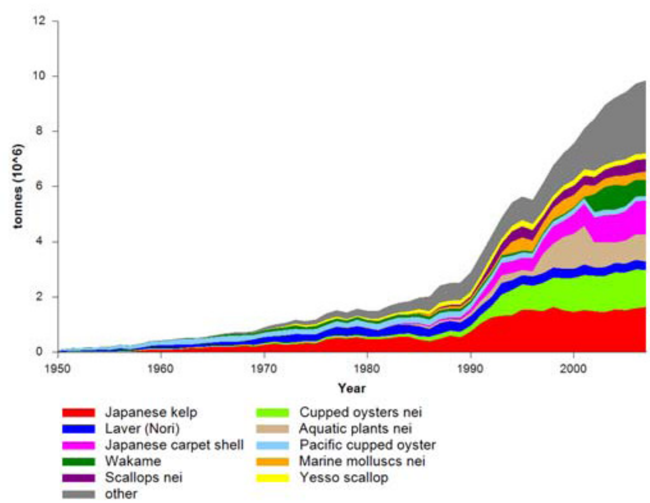

Figure 1. Mariculture production in the Northwest Pacific Regional Sea (1950 – 2008).

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Also, some mariculture operations negatively impact the marine environment through habitat degradation, encroaching, parasites, antibiotics and other stress factors (Pullin *et al*., 2005; Trujillo, 2008). This aspect is not considered here, i.e., we do not distinguish between low and high impact mariculture.

The *Sea Around Us* project is currently mapping mariculture operations in all countries where they occur, such that the assumption that these operation are spread uniformly along their coast does not have to be made. However, this is not likely to have much of the effect on Regional Sea estimates of mariculture production.

Acknowledgements

The *Sea Around Us* project, on which this study relies, is a scientific cooperation between The University of British Columbia and the Pew Environment Group.

References

FAO, 2010. www.fao.org/fishery/statistics/software/fishstat/en, accessed June 30, 2010.

Pullin, R.S.V., Froese, R., Pauly, D., 2007. Indicators for the sustainability of aquaculture. In: Bert, T.M. (ed.), *Ecological and Genetic Implications of Aquaculture Activities*, pp. 53-72. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Trujillo, P. 2008. Using a mariculture sustainability index to rank countries' performance. In: Alder, J., Pauly, D. (eds.), *A Comparative Assessment of Biodiversity, Fisheries and Aquaculture in 53 Countries' Exclusive Economic Zones*, pp. 28-56. Fisheries Centre Research Reports 16(7).

STOCK-STATUS PLOTS OF FISHERIES FOR REGIONAL SEAS[1]

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ABSTRACT

Stock-status plots are bivariate graphs summarizing the status ('underdeveloped', 'developing', 'fully exploited', 'overexploited', etc.), through time, of the multispecies fisheries of an area or ecosystem. Given that the limitations of these plots are understood, they are very useful for communicating, at a glance, the evolving status of multispecies fisheries in Regional Seas. Here, we present a new version of this approach that addresses some previous concerns.

INTRODUCTION

Stock-status plots were initially conceived by Grainger and Garcia (1996), who defined development phases of marine fisheries as part of a trend analysis of global marine fisheries landings. Their analysis was conducted for the top 200 species-area combinations, or 'stocks', which then accounted for 77% of the world marine fish catch. Their data were standardized by rescaling the time series of catch to a mean of zero and a standard deviation of one. Then every two-year increment of the time series was classified as 'increasing' (slope>0.5), 'little change' (slope between +0.05 and -0.05), or 'decreasing' (<-0.05). This illustrated the property of global fisheries catch in expansion or decline.

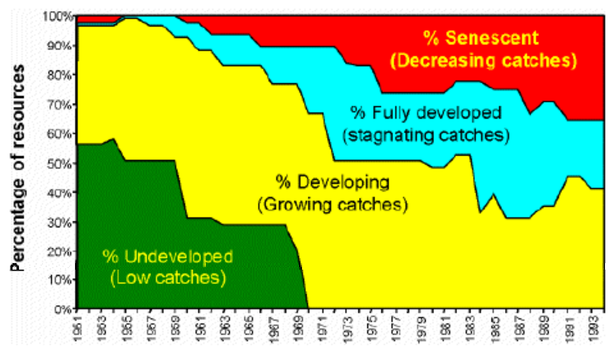

Figure 1. Evolution of the state of world resources from 1950-1994, based exclusively on statistical trends for 200 major stocks from Grainger and Garcia (1996).

The next step in their analysis was to classify the resources by development stage. They grouped time series by the shape of polynomial curves fitted to the average standardized landings, which roughly relates to the stage of fishery development or fishery status change (e.g., 'developing'). The slopes of these polynomial fits were classified as defined above. Increasing slopes corresponded to 'developing', decreasing to 'senescent', little change or a slope of zero corresponds to high exploitation 'mature' (a maximum) or low exploitation 'undeveloped' (a minimum). Plots of development phases were constructed for the total number and percentage of resources in each year for the whole dataset (Figure 1).

Grainger and Garcia's (1996) main finding was that catch increases were not possible in many cases and that increased exploitation would result in lower catch rates. The picture was of stocks that tended to show greater declines in productivity, highlighting the fact that there may be a false sense of security obtained from total aggregate landings when development phase is not taken into account.

Froese and Kesner-Reyes (2002), in their analysis of time series of catch data from ICES and FAO with respect to the resilience of species towards fishing, simplified the approach of Grainger and Garcia (1996) by setting arbitrary designations for stock status. They defined the fishing status of over 900 stocks as

[1] Cite as: Kleisner, K., Pauly, D., 2011. Stock-status plots of fisheries for Regional Seas. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 37-40. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

undeveloped, developing, fully exploited, overfished, or collapsed. The last three designations refer to a decline in species abundance. The algorithm they used to assign status is presented in Table 1.

They excluded years 1950 (first) and 1999 (last year) because 'after max. year' and 'before max. year' could not be applied. The typical transition of a fishery from undeveloped through fully exploited, to collapsed or closed is shown in Figure 2. The benefit of this method for interpreting trends in world fisheries was that it did not require fitting polynomial curves to the time series of catches of each stock; hence many more species could be included in analyses (see, e.g., Froese and Pauly, 2003). Froese and Kesner-Reyes (2002) also noted that there is a distinct acceleration towards overfished and collapsed status. In addition to increasing losses to the global economy and the livelihoods of millions of people globally, this trend has significant ecological implications: the increasing number of stock collapses and stocks that are overfished point to a decrease in biodiversity. Worm *et al.* (2006) extrapolated the trend in collapsed fisheries resources to 2048 to show that, assuming continuation of current trends, globally most stocks would experience collapse — a topic that has been hotly debated in the scientific literature.

Table 1. Algorithm designed by Froese and Kesner-Reyes (2002) to interpret the status of a fishery resource.

Status of fishery	Criterion applied
Undeveloped	Year < max. catch AND catch < 10% of max value
Developing	Year < max. catch AND catch 10-50% of max. value
Fully exploited	Catch > 50% of max. value
Overfished	Year > max. catch AND catch 10-50% of max. value
Collapsed	Year > max. catch AND catch < 10% of max. value

Recently, Pauly *et al.* (2008) created 'stock-status plots' for a UNEP compendium on Large Marine Ecosystems (LMEs, Sherman and Hampel, 2008), applying slightly modified definitions of Froese and Kesner-Reyes (2002) to produce graphs of percentage of stocks by status and percentage catch by stock-status over time (Table 2). One of the main modifications was the combination of the previous categories 'undeveloped' and 'developing' into a single category. Pauly *et al.* (2008) presented stocks as time series of species, genus, or family for which: 1) the first and last reported landings are at least ten years apart; 2) there are at least five years of consecutive catches; and 3) the catch in a particular area (LME) is at least 1,000 tonnes. Higher taxonomic groupings and pooled groups were excluded. Two plots were created for each LME. The first was a plot of number of stocks by status (Figure 3). To contrast the decline of (stock) biodiversity and bulk catch status, Pauly *et al.* (2008) also developed the second plot, being graphs of percentage catch by stock-status over time (Figure 4). These plots, which may be called 'stock-catch status' plots, jointly with the 'stock-status' plots referring to stock numbers, tend to confirm that biodiversity is affected by fishing more strongly than bulk catch.

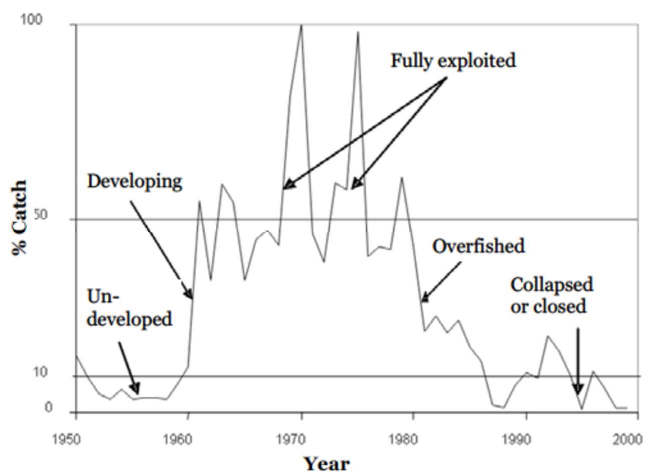

Figure 2. Typical transition of a time series of catches (here: from a fishery for basking shark *Cetorhinus maximus*), from 'undeveloped' through 'fully exploited', to 'collapsed' (or closed). See Table 1 for definition of these stages from Froese and Kesner-Reyes (2002).

Table 2. Algorithm designed by Pauly *et al.* (2008) to interpret the status of a fishery resource.

Status of fishery	Criterion applied
Undeveloped	Year < max landing AND landing < 10% of max value
Developing	Year < max landing AND landing 10-50% of max value
Fully exploited	Landing > 50% max value
Overexploited	Year > max landing AND landing 10-50% of max value
Collapsed	Year > max landing AND landing < 10% of max value

Here we present the subsequent development of the original model of Grainger and Garcia (1996) including modifications to make it usable both for the purpose of the *Sea Around Us* project and eventually for Regional Seas.

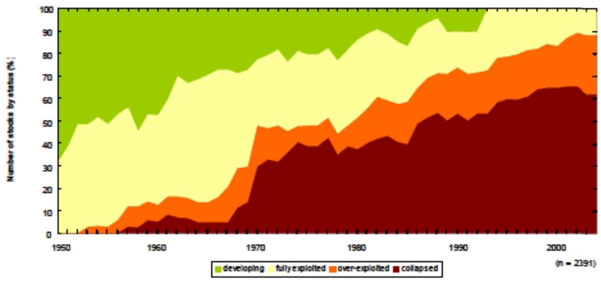

Figure 3. Percentage of stocks of a given status, by year, showing a rapid increase of the number of overexploited and collapsed stocks, here for the Norwegian LME (Aquarone, 2008, based on Pauly *et al.*, 2008).

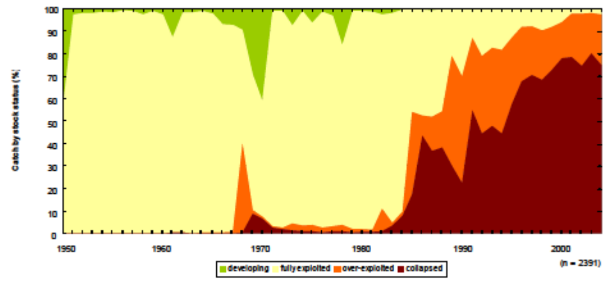

Figure 4. Percentage of catches extracted from stocks of a given status, by year, showing a slower increase of the percentage of catches that originate from overexploited and collapsed stocks, here for the Norwegian LME (Aquarone, 2008, based on Pauly *et al.*, 2008).

METHODS

One of the criticisms of the previous versions of the stock-status plots is that by definition the percentage of undeveloped or developed stocks is zero in the final year of the time series. To address this, we count stocks that have a peak in catch in the final year of the time series as 'developing.'

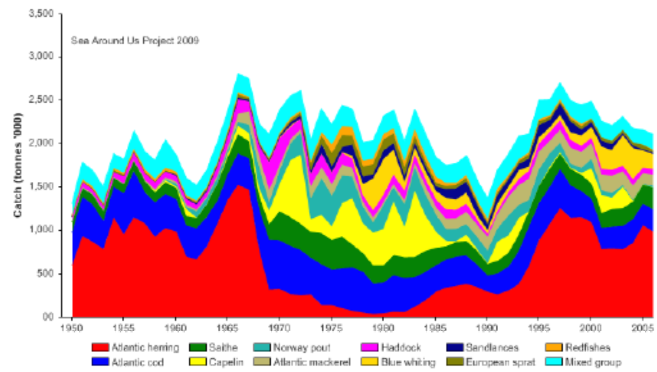

Figure 5. Norwegian catch by species. Note the strong recovery of Atlantic herring.

Additionally, we deal with the serious criticism that, in cases where stocks have recovered (e.g., through management actions), the 'stock- status plots' do not take stock recovery into account (Branch, 2008). Norway provides an excellent example of this, especially with regards to the Atlantic herring (Figure 5), where the catch increases to a maximum in 1966 and then plummets to a minimum in 1979. Thereafter, the catch gradually increases through the 1980s and early 1990s as a result of management rebuilding actions and remains above 50% of the maximum catch through 2006. This recovery should not be reclassified as a 'developing' stock as would have been using Pauly *et al.* (2008). Therefore, an additional category, 'recovery', is defined when the stock drops to 'collapsed' status and then recovers. To facilitate this, a 'post-maximum minimum' was defined as the minimum landing occurring after the maximum landing. This modification also addresses the former concern where, by definition the percentage of developing stocks is zero in the final year of the time series. Because 'recovery' is a form of stock (re-) development, it is displayed with the 'developing' category in the plots, and thus better demonstrates the amount of improvement in the status of stocks within a particular area.

Table 3. Algorithm used to interpret the status of fishery resources based on time series of catch. This requires the definition of a 'post-maximum minimum' (post-max. min.): the minimum landing after the maximum landing.

Status of fishery	Criterion applied
Recovering	Year of landing > year of post-max. min. landing AND post-max. min. landing < 10% of max. landing AND landing is 10-50% of max. landing
Developing	Year of landing < year of max. landing AND landing is < or = 50% of max. landing OR year of max. landing = final year of landing
Exploited	Landing > 50% of max. landing
Over exploited	Year of landing > year of max. landing AND landing is between 10-50% of max. landing
Collapsed	Year of landing > year of max. landing AND landing is < 10% of max. landing

The final algorithm for determining the stocks' status by area is presented in Table 3. To better view the overall trend and remove anomalous peaks in the stock-catch status plots, we use a three-year running average to smooth the curves.

Results and Discussion

The stock-status plots as defined here are useful for demonstrating how global fisheries resources have transitioned through the development stages, and the general inability of management to maintain them at an acceptable level of exploitation (see also Appendix 5). We show here the plots for numbers of stocks (Figure 6) and catch by stock-status (Figure 7) for the Norwegian EEZ as an example. This illustrates the increasing importance of 'recovery' previously diminished ('collapsed') stocks, now accounting for close to 10% of all stocks, while around 50% of stocks, as defined here, are still considered 'collapsed' (Figure 6). It also illustrated that, in terms of catch amounts, over 90% of tonnage caught is derived from 'exploited' or 'over-exploited' stocks (Figure 7). The application of this approach to LMEs and Regional Seas is a straightforward extension. However, the interpretation of the stock-catch status plots can be somewhat problematic due to the fact that they are based on catches and not on population size estimates. Despite this, stock-status plots remain a useful tool for visualizing fisheries resource trends at the global level.

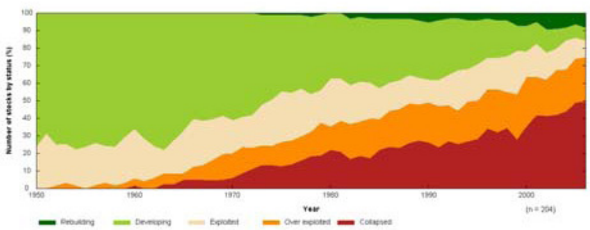

Figure 6. Percentage of stocks of a given status, by year, showing a rapid increase of the number of overexploited and collapsed stocks, here for the Norwegian EEZ.

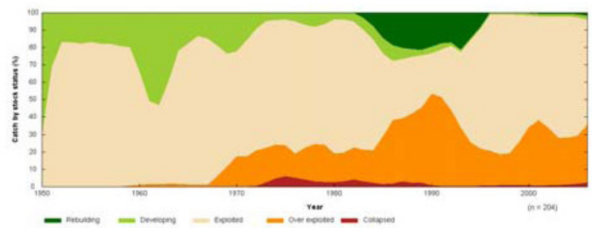

Figure 7. Percentage of catches extracted from stocks of a given status, by year, showing a slower increase of the percentage of catches that originate from overexploited and collapsed stocks, here for the Norwegian EEZ.

Acknowledgements

The *Sea Around Us* project, on which this study relies, is a scientific cooperation between The University of British Columbia and the Pew Environment Group.

References

Aquarone, M.C., Adams, S. 2008. Norwegian Sea LME, pp. 581-598 *in* Sherman, K. and Hempel, G., (eds.), The UNEP Large Marine Ecosystem Report: a Perspective on Changing Conditions in LMEs of the World's Regional Seas. UNEP Regional Seas Reports and Studies No. 182, Nairobi.

Branch, T.A., 2008. Not all fisheries will be collapsed in 2048. *Marine Policy* 32, 38-39.

Froese, R., Kesner-Reyes, K., 2002. Impact of fishing on the abundance of marine species. Rainer. ICES CM 2002/L: 12, 15 p.

Froese, R., Pauly, D., 2003. Dynamik der Überfischung. *In:* Lozán, J.L., Rachor, E., Reise, K., Sündermann, J., von Westernhagen, H. (eds.), *Warnsignale aus Nordsee und Wattenmeer – eine aktuelle Umweltbilanz*, pp. 288-295. GEO, Hamburg.

Grainger, R.J.R., Garcia, S., 1996. Chronicles of marine fisheries landings (1950-1994): trend analysis and fisheries potential. FAO Fish. Tech. Pap. 359, 51 p.

Pauly, D., Alder, J., Booth, S., Cheung, W.W.L., Christensen, V., Close, C., Sumaila, U.R., Swartz, W., Tavakolie, A., Watson, R., Wood, L., Zeller, D. 2008. Fisheries in large marine ecosystems: descriptions and diagnoses. In: Sherman, K., Hempel, G. (eds.), *The UNEP Large Marine Ecosystem Report: a Perspective on Changing Conditions in LMEs of the World's Regional Seas*, pp. 23-40.. UNEP Regional Seas Reports and Studies No. 182.

Worm, B. Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J., Watson, R., 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science* 314, 787-790.

The Marine Trophic Index (MTI), the Fishing in Balance (FiB) Index and the spatial expansion of fisheries[1]

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Abstract

The Marine Trophic Index (MTI), used by the Convention of Biological Diversity (CBD) as an index of marine biodiversity has been recently shown to display increases in the absence of recovery of traditionally exploited high-trophic level groups. This is interpreted here as the result of the spatial expansion of fisheries, as can be demonstrated by widespread increases of the Fishing-in-Balance (FiB) Index, which can be re-interpreted as an indicator of spatial expansion. We show that it is possible to modify the MTI such that it explicitly accounts for the spatial expansion. This leads to a new index, the Fisheries Sustainability Index (FSI), the potential utility of which is briefly discussed with reference to Regional Seas.

Introduction

Globally, fisheries are in decline, mainly due to overfishing, with pollution and habitat degradation, and possibly global warming, adding to the stresses. However, defining indicators that reflect the state of fisheries is often challenging, especially in data-sparse contexts. The Convention of Biological Diversity's (CBD) Marine Trophic Index (MTI) was developed, based on the contribution of Pauly *et al.* (1998), on the assumption that a decline of the mean trophic level of fisheries catch (mTL=MTI) is generally due to a fisheries-induced reduction of the biomass and hence biodiversity of vulnerable top predators. The MTI tracks changes in mean trophic level (mTL), defined for year *k* as:

$$mTL_k = \sum(Y_{ik} \cdot TL_i) \ / \ \sum(Y_{ik}) \qquad \ldots 1)$$

where Y_{ik} is the catch of species *i* in year *k*, and TL_i the trophic level of species (or group) *i*, the latter usually obtained from the diet composition studies in FishBase (www.fishbase.org).

Usually, mTL (and hence, the MTI) declines as the result of fishing pressure being focused on the higher trophic levels at the start of the fishery, which is then replaced by pressure on the lower trophic levels as the abundance of high trophic level species declines. Therefore, the MTI can be seen as an index of the biodiversity of the top predators (Appendix 9). The occurrence of 'fishing down marine food webs' (FDMW) was initially documented globally using FAO landings data from 1950 to 1994, combined with estimates of trophic levels extracted from 60 published mass-balance trophic models from every major aquatic ecosystem type (Christensen and Pauly, 1993; Pauly and Christensen, 1993; Christensen, 1995; Pauly and Christensen, 1995). Since it was first proposed in 1998, the notion that we are 'fishing down' has been largely validated through numerous studies on a large number of marine and freshwater ecosystems (see, e.g., Jackson *et al.*, 2001; Worm and Myers, 2003; Bellwood *et al.*, 2004; Hutchings and Reynolds, 2004; Frank *et al.*, 2005; Scheffer *et al.*, 2005; Morato *et al.*, 2006), and it has been straightforward to fend off its earlier critics (Pauly, 2010). However, several recent studies demonstrate that a downward MTI trend can be masked when a geographic expansion of the fisheries of a given region or country has occurred, which enables them to maintain or even augment their catch of high-trophic level species.

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[1] Cite as: Kleisner, K., Pauly, D., 2011. The Marine Trophic Index (MTI), the Fishing in Balance (FiB) Index and the spatial expansion of fisheries. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 41-44. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

The effect of geographic expansion on the trophic level of catch was first analyzed with an index called Fishing-in-Balance (FiB; Appendix 10). This index was developed to address what may occur when the decline in mTL is attributable to the deliberate choice of targeting low trophic level species. In this case, one might assume that fishers may choose to fish lower in the food web because biological production is higher at lower trophic levels (Pauly *et al.*, 2000). If the choice to fish lower in the food web is deliberate, one would expect there to be an increase in the catch that is commensurate with the decline in mTL. This leads to the development of the FiB (Pauly *et al.*, 2000b), defined for any year *k*:

$$FiB = \log(Y_k \cdot (1/TE)^{mTL_k}) - \log(Y_o \cdot (1/TE)^{mTL_o}) \qquad \ldots 2)$$

where *Y* is the catch, *TL* is the mTL in the catch, *TE* is the transfer efficiency between trophic levels, and 0 refers to the year used as a baseline. The FiB is calculated with the geometric mean of each of the terms thereby preserving the relationship between equivalent amounts of fish at different trophic levels. Therefore, this index should:

- remain constant (=0) if the fishery is 'balanced', i.e., all trophic level changes are matched by 'ecologically equivalent' changes in catch;
- increase (>0) if there are (a) bottom-up effects (e.g., an increase in PP, as described above and in Caddy *et al.*, 1998), or (b) geographic expansion of the fishery to new waters which in effect expands the ecosystem exploited by the fishery; or
- decrease (<0) if discarding occurs that is not represented in the catch, or if the ecosystem functioning is impaired by the removal of excessive levels of biomass.

The FiB is an index, which, as proposed, was meant to be viewed jointly with the MTI, whose interpretation it was supposed to facilitate. However, few if any authors account for changes in the FiB index when they examine trends in mTL. If they did, they would notice that generally, mTLs fail to decline in regions where the FiB index increases (see MTI and FiB trends for all maritime countries and Large Marine Ecosystems of the world at www.seaaroundus.org).

Butchart *et al.* (2010) and Sethi *et al.* (2010) reported that for many regions, and for the world ocean as a whole, mTLs, while declining from the 1950s to the early 1980s, have tended to increase in the 1990s and 2000s. As there is no independent evidence that high trophic level fish populations have been rebuilt throughout the world, we must conclude that either:

1. the mTL of fisheries catches cannot be used as indicators of fisheries impacts on biodiversity because trophic levels may change in unpredictable fashion, or similar *ad hoc* explanation; or
2. the mTL can detect fishing down reliably, but only after accounting for one or several 'hidden variables'.

We present the case for (2) and suggest that the 'hidden variable' is the spatial expansion of fisheries from the late 1980s to the 2000s.

Methods for Correcting for Geographic Expansion

Spatial considerations are relatively easy to incorporate into the trophodynamic considerations underlying FDMW and the FiB index. Ecosystems may be conceived as biomass flow pyramids whose base is proportional to the amount of primary productivity in the system, and the top angle is related to the transfer efficiency between trophic levels. Such pyramids, when exploited (say from the top down), imply that a relatively small catch is available at higher trophic levels and larger catches at lower trophic levels, with the mTL of the catch providing an indication of a fishery's position.

Thus, as presented before for the FiB index, when a fisheries exploits a given area (and pyramid), the catch should increase when mean trophic level of the catch decreases and *vice versa*, the relationship between these two quantities being mediated by the transfer efficiency (TE) between trophic levels (i.e., the slope of the pyramid). However, when the catch increases more than is compatible with the observed change in trophic level, this suggests that, in effect, another adjacent pyramid is being exploited, i.e., that the fisheries has expanded (and conversely for a decline in catch not matched by a simultaneous increase in mTL, suggesting that a contraction of fisheries has occurred). The key assumption here is that 'adjacent pyramids' have the same productivity. This assumption obviously does not hold in reality. However, it can be assumed that fisheries are generally initiated in areas of relatively high productivity (e.g., inshore), and then move into areas of lower productivity (e.g., offshore). Therefore, the assumption of equal productivity would generally lead to an underestimation of spatial expansion (see Bhatal and Pauly, 2008). Thus, we can derive the mTLs, which would be realized if geographic expansion had not occurred. The main assumptions for this are:

- Spatial expansion and contraction of fisheries do in fact occur, i.e., the increase in the FiB is not due to other factors (such as bottom-up effects); and
- FiB remains at 0 when there is no expansion or contraction of the fisheries.

The computations involved here consist of solving the FiB for the trophic level that would have been realized if geographic expansion had not occurred, then using that difference to correct the MTI. Therefore, equation (2) can be used to define, for any year k, a stationary mean trophic level where we have corrected for expansion (mTL_{stat}) where:

$$mTL_{stat} = mTL_o - \log(Y_k/Y_o) \qquad \ldots 3)$$

This correction factor is then subtracted from the mTL in a given year and the absolute value of this difference used to express a 'Corrected Trophic Index' (CTI):

$$CTI_k = mTL_k - |mTL_k - mTL_{stat}| \qquad \ldots 4)$$

The absolute value of the difference is necessary because FiB can fluctuate in both the negative and the positive direction from the first year (chosen arbitrarily as 1950, the first year of the time series in this case), and it is the *magnitude* of this difference that we are correcting for. Finally, we define a new 'Fishing Sustainability Index' (FSI), which is simply the CTI re-expressed in standard deviation units, so that the ordinate scale indicates change without reference to absolute trophic levels. This latter point is necessary given that CTI values can be very low, even negative, which would not be accepted by most users, even by those who understand that CTI values reflect a hypothetical situation (i.e., the mTL a fishery would have if it had not expanded). Thus, we have, finally:

$$FSI = (CTI_k - A_{CTI})/SD_{CTI} \qquad \ldots 5)$$

where CTI_k is the CTI in a given year k, A_{CTI} is the average of the CTI, and SD_{CTI} is the standard deviation of the CTI.

Results and Discussion

We demonstrate the ability of the FSI to account for the historical expansion and contraction of fisheries with an example from the waters of Australia. Fishing in Australia has provided an important source of protein for aboriginal people in the country for many centuries and for European settlers since the late 18th century. Modernization of fishing fleets in the 1960s allowed for the expansion of Australian fishing vessels into deeper waters further from shore; the FiB index has thus increased (Figure 1, upper right). From 1950 to about 1970, catches were relatively flat, and the MTI declined, indicating 'fishing down' in inshore waters. For this period, the FiB index indicates that the fisheries were, in a sense, 'balanced'. It is not until the period of rapid geographic expansion in the 1970s that the MTI begins to increase. This increasing trend, which is due to geographic expansion, is precisely what the FSI corrects for. In this case, the FSI

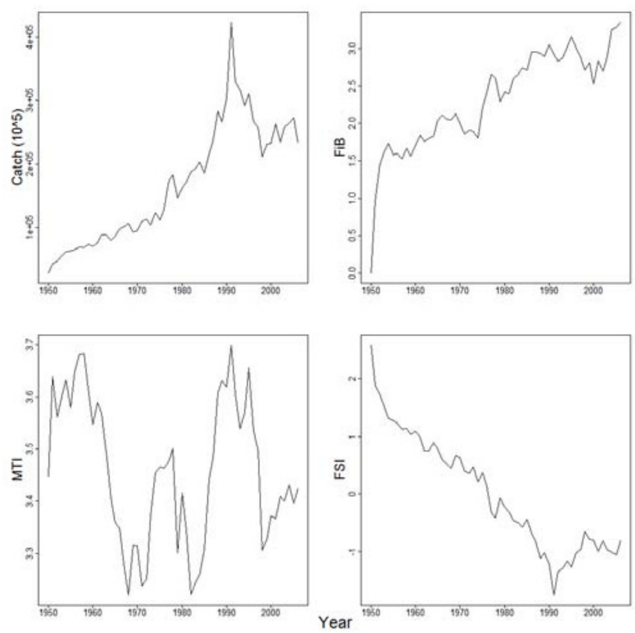

Figure 1. Trends in catch (upper left panel); Fishery in Balance Index (FiB; upper right): Marine Trophic Index (MTI; lower left); and Fisheries Sustainability Index (FSI; lower right) for the Australian EEZ (see text for interpretation).

indicates that had geographic expansion not allowed for tapping into a previously unexploited, high-trophic level fish community, the MTI would have continued the decline it featured in the 1950s and 1960s.

Based on the newly defined FSI, it is suggested that the increasing trends in MTI occurring in some regions since the 1980s are mainly due to geographic expansion of the fisheries. As this expansion reaches its limits, we expect that landings will decrease more rapidly, and that 'fishing down' effects will become more obvious in Regional Seas and the world ocean.

Acknowledgements

The *Sea Around Us* project, on which this study relies, is a scientific cooperation between The University of British Columbia and the Pew Environment Group.

References

Bellwood, D.R., Hughes, T.P., Folke, C., Nystrom, M., 2004. Confronting the coral reef crisis. *Nature* 429, 827-833.

Bhatal, B. Pauly, D., 2008. "Fishing down marine food webs" and spatial expansion of coastal fisheries in India, 1950-2000. *Fisheries Research* 91, 26-34.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Hernandez Morcillo, M., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrell, T.D., Vie, J-C., Watson, R., 2010. Global biodiversity: indicators of recent declines. *Science* 328 (5982), 1164-1168.

Christensen, V., 1995. A model of trophic interaction in the North Sea in 1981, the year of the stomach. *Dana 11* (1), 1-28.

Christensen, V., Pauly, D., 1993. *Trophic Models of Aquatic Ecosystems*. ICLARM Conference Proceedings 26, Manila, 390 p.

Frank, K.T., Petrie, B., Choi, J.S., Leggett, W.C., 2005. Trophic cascades in a formerly cod-dominated ecosystem. *Science* 308(5728), 1621-1623.

Hutchings, J.A., Reynolds, J.D., 2004. Marine fish population collapses: consequences for recovery and extinction risk. *Bioscience* 54(4), 297-309.

Jackson, B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Ecology* 84, 162-173.

Morato, T., Watson, R., Pitcher, T.J., Pauly, D., 2006. Fishing down the deep. *Fish and Fisheries* 7 (1), 23-33.

Pauly, D., 2010. *Five Easy Pieces: The Impact of Fisheries on Marine Ecosystems*. Island Press, Washington, DC, 193 p.

Pauly, D., Christensen, V., 1993. Stratified models of large marine ecosystems: a general approach and an application to the South China Sea. In: Sherman, K., Alexander, L.M., Gold, B.D. (eds.), *Large Marine Ecosystems: Stress, Mitigation and Sustainability*, pp. 148-174. AAAS Press, Washington, DC.

Pauly, D., Christensen, V., 1995. Primary production required to sustain global fisheries. *Nature* 374, 255-257.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres Jr, F.C., 1998. Fishing down marine food webs. *Science* 279, 860-863.

Pauly, D., Christensen, V., Walters, C., 2000. Ecopath, ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science* 57, 697-706.

Scheffer, M., Carpenter, S., de Young, B., 2005. Cascading effects of overfishing marine systems. *Trends in Ecology and Evolution* 20(11), 579-581.

Sethi, S.A., Branch, T.A., Watson, R., 2010. Global fishery development patterns are driven by profit but not trophic level. *Proceedings of the National Academy of Science* 107 (2), 12163-12167.

Worm, B., Myers, R.A., 2003. Rapid worldwide depletion of predatory fish communities. *Nature* 423, 280-283.

Ecosystem size spectra as indicator for Regional Seas[1]

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Abstract

The size-spectra of organisms are informative about the status of exploitation or 'stress' of marine ecosystems such as Regional Seas, but are very difficult to construct from observed data because of the extremely wide range of organisms to be considered (phytoplankton to whales). Here, a method is proposed which allows the construction of ecosystems' size-spectra from balanced trophic (Ecopath) models and growth parameters for each of the functional groups therein. An example pertaining to the South China Sea ecosystem is provided.

Introduction

Different ecosystems have characteristic size distributions of the organisms they contain. These distributions are usually represented as 'size-spectra', i.e., double logarithmic plots of the biomass of organisms of different sizes *vs.* their body weights (Kerr and Dickie, 2001). In practice, however, size-spectra covering the whole range of the different size domains (i.e., from phytoplankton to whales) in an ecosystem are difficult to produce. Thus, most empirically obtained size-spectra cover a narrow range of sizes, as obtained by, e.g., plankton nets or water samplers for phyto- and zooplankton or trawls for fish (Sheldon *et al.*, 1972; Bianchi *et al.*, 2000).

However, trophic spectra can be constructed from the relative biomasses of the various functional groups of Ecopath models of ecosystems. Thus, once a food web has been constructed and balanced with Ecopath, including biomasses that are mutually compatible over a certain period, at least (Christensen and Pauly, 1992), the biomasses of each functional group can be re-expressed as biomass by log size and then summed over all functional groups. Details are given below as well as an example with a brief discussion of potential applications to Regional Seas.

Material and Methods

The method to construct size-spectra from balanced Ecopath models, assuming steady-state, does the following (adapted from Pauly and Christensen, 2002, p. 221):

- uses the von Bertalanffy growth curves and the values of P/B (i.e., total mortality, Z; Allen, 1971) entered for each group in the model to re-express its biomass in terms of a size-age distribution;
- divides the biomass in each (log) weight class by the time, Δt, required for the organisms to grow out of that class (to obtain the average biomass present in each size class);
- adds the $B/\Delta t$ values by (log) class, irrespective of the groups to which they belong.

Results and Discussion

Figure 1 presents two size-spectra, for different periods, constructed as described above. As might be seen, their slopes reflect the intensity of stress (due to fishing) exerted on the ecosystem, which here contains fewer large organisms than the earlier period. A number of other inferences can be drawn from such spectra as may be verified in the literature cited above. Important here is that given Ecopath models for all Regional Seas (and they exist, see Ahrens and Christensen, this volume), size spectra could be straightforwardly constructed for Regional Seas given the present availability of growth parameters for

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functional groups in all Regional Seas (Palomares and Pauly, 2008; Palomares and Pauly, 2009; see also www.fishbase.org and www.sealifebase.org).

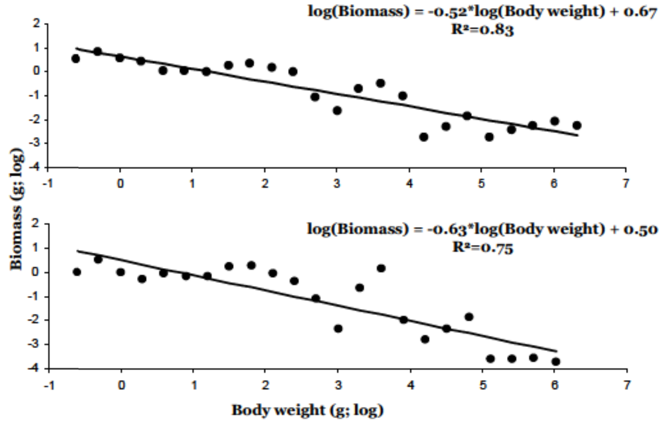

Figure 1. Size-spectra of functional groups of the northern South China Sea ecosystem based on published Ecopath models (see Cheung and Sumaila, 2008) for the period 1970s (upper graph) and 2000s (lower graph) showing a change in the size composition of functional groups (smaller sizes) in the latter period, thus inferring stress (due to fishing).

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The *Sea Around Us* project, on which this study relies, is a scientific cooperation between The University of British Columbia and the Pew Environment Group.

References

Allen, R.R., 1971. Relation between production and biomass. *Journal of the Fisheries Research Board of Canada* 28, 1573-1581.

Bianchi, G., Gislason, H., Graham, K., Hill, L., Jin, X., Koranteng, K., Manickchand-Heileman, S., Payá, I., Sainsbury, K., Arreguin-Sánchez, F., Zwanenburg, K., 2000. Impact of fishing on size composition and diversity of demersal fish communities. *ICES Journal of Marine Science* 57, 558-571.

Cheung, W.W.L., Sumaila, U.R., 2008. Trade-offs between conservation and socio-economic objectives in managing a tropical marine ecosystem. *Ecological Economics* 66, 193-210.

Christensen, V., Pauly, D., 1992. The ECOPATH II - a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling* 61, 169-185.

Kerr, S.R., Dickie, L.M., 2001. *The Biomass Spectrum. A Predator-Prey Theory of Aquatic Production.* Columbia University Press, New York, 320 p.

Palomares, M.L.D., Pauly, D., Editors, 2008. Von Bertalanffy Growth Parameters of Non-fish Marine Organisms. Fisheries Centre Research Reports 16(10). Fisheries Centre, UBC, Vancouver, Canada.

Palomares, M.L.D., Pauly, D. 2009. The growth of jellyfishes. *Hydrobiologia* 616(1): 11-21.

Pauly, D., Christensen, V., 2002. Ecosystem Models. Chapter 10. *In:* Hart, P., Reynolds, J., (eds.), *Handbook of Fish and Fisheries*, pp. 211-227. Blackwell Publishing, Oxford, Volume 2.

Sheldon, R.W., Prackash, A., Sutcliffe, W.H., 1972. The size distribution of particles in the ocean. *Limnology and Oceanography* 17, 327-340.

MODELING FUTURE FISHERIES CATCH SCENARIOS[1]

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ABSTRACT

The Ecopath with Ecosim software was used, along with preliminary estimates of efforts for 5 major fleet categories (demersal, distant-water, tuna purse seines, tuna longline and small pelagic) to predict future catches, under three scenarios of climate change, using models with 43 functional groups, for 15 of the 18 FAO statistical areas (i.e., excluding the 1 Arctic and 4 Antarctic areas).

Overall, the results, which are expressed by FAO area, and not yet by Regional Sea, indicate that increased effort will result, for all climate change scenarios, in decreasing catches, especially for high-trophic level species, leading to decreasing mean trophic levels. On the other hand, for all climate scenarios, lowering fishing effort would lead to rebuilding of the ecosystem, higher catches, and increasing mean trophic levels. For regions where the results indicate large increases in catches, this is largely due to increased abundance of low-trophic level species, such as small pelagic and small demersal fishes, for which the uncertainty is considerable, due to poor knowledge of the potential productivity for these species complexes.

INTRODUCTION

Catch projections under various effort and primary production forecast scenarios were made using a modified version of the global EcoOcean model detailed in Alder *et al.* (2007). The model was constructed using 43 functional groups that are common to the world's oceans. The groups were selected with special consideration for exploited fish species, but are intended to jointly include all major groups in the oceans. The fish groups are based on size categories, and feeding and habitat characteristics. Fishing effort is the most important driver for the ecosystem model simulations; 15 of 18 FAO marine statistical areas (Figure 1) were included in the analysis and due to data scarcity, polar regions (FAO areas 18, 48, 58 and 88) were excluded. Five major fleet categories (demersal, distant-water, baitfish tuna [purse seine], tuna longline and small pelagic) were used to distinguish different fishing efforts based on historical information. A description of catch and effort reconstructions can be found in Alder *et al.* (2007). The models we used for this report are based on the FAO statistical areas, which cover the world oceans. We were not able, due to time constraints, to develop models for the Regional Seas for this report.

METHODS

Although the base models and fitting criteria were similar to those described in Alder *et al.* (2007) some modifications were made to improve model fits and more realistically capture changes in fishing effort. The most notable difference in the new models was the application of a technology creep factor to the previously used effort time series. The use of gross tonnage as a metric of fishing effort is unlikely to capture the modernization of fishing technology since 1950. To capture this effect a 'technology creep' of 3% a year was applied, based on the review of Pauly and Palomares (2010). The net result was notably different effort time series that necessitated model refitting. The model tuning procedures used were similar to those outlined in Alder *et al.* (2007) with some additional alterations to the diet composition matrix. Changes to the diet composition matrix were necessary as fisheries, in reality, target only a sub component of each functional group and may represent some fraction of a predator's diet. The net result of these model refinements were better fits to the observed catches.

[1] Cite as: Ahrens, R., Christensen,V., 2011. Modeling future fisheries catch scenarios. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 47-49. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

Total catch of finfish, the mean trophic level of the catch (mTL; Pauly *et al*., 1998; Pauly and Watson, 2005; Kleisner and Pauly, 2010a, this volume), and a fishing-in-balance index (FiB; Pauly and Watson, 2005; Kleisner and Pauly, 2010a, this volume) were calculated for each FAO area under a combination of future fishing effort and primary production scenarios. For future effort scenarios, effort was either 1) increased or 2) decreased by 3% per year from 2004-2050 or 3) retained at 2004 levels. Future primary production scenarios were modeled using an empirical model which estimated chlorophyll based on physical properties. This technique, described in detail in Sarmiento *et al*. (2004), fits observed SeaWiFS chlorophyll data to a function of sea surface temperature, sea surface salinity, maximum winter mixed layer depth, and growing season length for different biogeochemical provinces, and then uses the empirical fits to predict chlorophyll under varying physical conditions. The resulting chlorophyll values were converted to primary production values based on three different algorithms: Carr (2002), Marra *et al*. (2003), and Behrenfeld and Falkowski (1997). All three algorithms estimate primary production as a function of surface chlorophyll, light, and temperature.

Indicator files

The output of the FAO models can be found in the Global\EcosystemIndicators folders (see Appendix 14), i.e., a CSV file per model, each pertaining to an FAO area. Within each CSV file, there are the three scenarios 1, 2 and 3, corresponding to three algorithms for estimating primary production mentioned above. For each scenario, there are three effort levels, representing no change in effort, -3% and +3% annual changes in effort, in that order (from top to bottom). All the CSV output data files (incl. catch, FIB and total landed catch) were then plotted on a single graph panel per FAO area showing the different effort levels and scenarios.

Results and Discussion

The world's catches have been declining for the last decade (Watson and Pauly, 2001) and it is clear that drastic measures may be needed to curb global fishing capacity to restore catches to a sustainable level. We evaluate the consequences of constant, moderate increase, and moderate decrease of effort in 14 of the 18 FAO areas that span the marine world (Figure 1, excluding area 18 in the Arctic and areas 48, 58 and 88 in Antarctica).

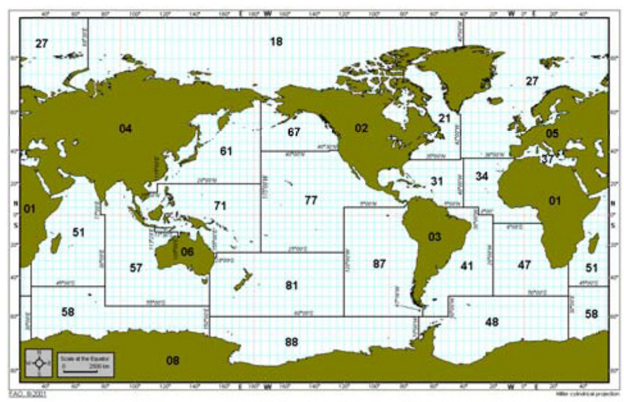

Figure 1. Map of the 18 large 'Statistical Areas' which the Food and Agriculture Organization of the United Nations (FAO) uses to report the world marine fisheries catches.

Overall, the results indicate that increased effort will result in decreasing catches especially of high-trophic level species, and this will be associated with declining mean trophic levels and associated indices (Kleisner and Pauly 2010b, this volume). As an example, in the Northeast Pacific (FAO Area 67), all the three climate scenarios with increased effort show a system collapse associated with a bottoming-out of mean trophic levels (not shown). Alternatively, the climate scenarios with lowering of effort indicate the reverse situation, i.e., rebuilding of the ecosystem, higher catches, and steady mean trophic levels. We caution that where the results indicated large increases in catches, this was largely due to increased catches of low-trophic level species, such as small pelagic and small demersal fishes, for which the uncertainty is considerable, due to poor knowledge of potential productivity for these species complexes. As an example, for the Northeastern Atlantic (FAO area 27), all three scenarios with increasing effort show increased catches, a result which we doubt is realistic, given the overall declines in catches observed in this area since the late 1970s. As well, the three climate scenarios with decreasing effort all show that the catches will remain close to constant, but the trophic levels of the catch will increase to the 1970s level. This suggests that the stocks will be rebuilding, and that the catches will consist of larger, higher-value species.

We could not, for this report, produce new models for each of the Regional Seas although this could be undertaken using a modified version of the database-driven ecosystem model generation methodology (Christensen *et al*., 2009) developed to analyze the world's Large Marine Ecosystems.

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REFERENCES

Alder, J., Guénette, S., Beblow, J., Cheung, W., Christensen, V., 2007. Ecosystem-based global fishing policy scenarios, Fisheries Centre Research Report 15(7), University of British Columbia, Vancouver.

Behrenfeld, M.J., Falkowski, P.G., 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnology and Oceanography* 42, 1-20.

Carr, M.-E., 2002. Estimation of potential productivity in eastern boundary currents using emote sensing. *Deep Sea Research Part II* 49, 59-80.

Christensen, V., Walters, C., Ahrens, R., Alder, l, Buszowski, l, Christensen, L.B., Cheung, W.W.L., Dunne, J., Froese, R., Karpouzi, V., Kaschner, K., Kearney, K., Lai, S., Lam, V., Palomares, M.L.D., Peters-Mason, A., Piroddi, C, Sarmiento, J.L., Steenbeek, J., Sumaila, R., Watson, R., Zeller, D. and Pauly, D., 2009. Database-driven models of the world's Large Marine Ecosystems. *Ecological Modelling* 220, 1984-1996.

Marra, J., Ho, C., Trees, C., 2003. An alternative algorithm for the calculation of primary productivity from remote sensing data. Lamont Doherty Earth Observatory Technical Report (LDEO-2003-1).

Pauly, D., Christensen, V., Dalsgaard, L.B., Froese, R., Torres Jr., F.C., 1998. Fishing down marine food webs. *Science* 279, 860-863.

Pauly, D., Palomares, M.L.D., 2010. An empirical equation to predict annual increases in fishing efficiency *Fisheries Centre Working Paper* #2010-07, UBC, Vancouver. ftp://ftp.fisheries.ubc.ca/FCWP/2010/FCWP_2010-07_PaulyPalomares.pdf

Pauly, D., Watson, R., 2005. Background and interpretation of the 'Marine Trophic Index' as a measure of biodiversity. *Philosophical Transactions of the Royal Society: Biological Sciences* 360, 415-423

Sarmiento, H., Slater, R., Barber, R., Bopp, L., Doney, S.c., Hirst, A.C., Kleypas, l, Matear, R., Mikolajewicz, U., Monfray, P., Soldatov, V., Spall, S.A., Stouffer, R., 2004. Response of ocean ecosystems to climate warming. *Global Biogeochemical Cycles* 18:doi:1029/2003GB002134.

Watson, R., Pauly, D., 2001. Systematic distortions in world fisheries catch trends. *Nature* 414, 534-536.

Global-warming induced changes in the catch potential of Regional Seas[1]

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Abstract

We projected changes in global catch potential for over one thousand species of exploited marine fish and invertebrates from the early to the mid 21st century, under conservative climate change scenarios. We show that climate change will lead to large-scale redistributions of global catch potential, with an average that may reach increases of 30–70% in high-latitude regions and a drop of up to 40% in the tropics. Moreover, maximum catch potential declines considerably in the southward margins of semi-enclosed seas, while it increases in poleward tips of continental shelf margins. Such changes are most apparent in the Pacific Ocean. Among the 20 most important fishing Exclusive Economic Zone (EEZ) regions in terms of their total landings, EEZ regions with the highest increase in catch potential by mid-century include Norway, Greenland, the United States (Alaska) and Russia (Asia). On the contrary, EEZ regions with the biggest loss in maximum catch potential include Indonesia, the United States (excluding Alaska and Hawaii), Chile and China. Many highly impacted Regional Seas, particularly those in the tropics, lie adjacent to countries which are socioeconomically vulnerable to these changes.

Introduction

Marine fisheries productivity is likely to be affected by the alteration of ocean conditions, including water temperature, ocean currents and coastal upwelling, as a result of climate change (e.g., Bakun, 1990; IPCC, 2007; Diaz and Rosenberg, 2008). Such changes in ocean conditions affect primary productivity, species distribution, community and food web structure that have direct and indirect impacts on distribution and productivity of marine organisms.

Empirical and theoretical studies show that marine fish and invertebrates tend to shift their distributions according to the changing climate in a direction that is generally towards higher latitude and deeper water, with observed and projected rates of range shift of around 30-130 $km \cdot decade^{-1}$ towards the pole and

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3.5 m·decade^{-1} to deeper waters (e.g., Perry *et al.*, 2005; Cheung *et al.*, 2008b, 2009; Dulvy *et al.*, 2008; Mueter and Litzow, 2008).

Relative abundance of species within assemblages may also change because of the alteration of habitat quality by climate (e.g., Przeslawski *et al.*, 2008; Wilson *et al.*, 2008). Global primary production is projected to increase by 0.7-8.1% by 2050, with very large regional differences such as decreases in productivity in the North Pacific, the Southern Ocean and around the Antarctic continent and increases in the North Atlantic regions (Sarmiento *et al.*, 2004).

Analysis of empirical data shows that maximum fisheries catch potential of exploited fishes and invertebrates is dependent on primary production and range size of the species (Cheung *et al.*, 2008a). Based on projected changes in primary production (Sarmiento *et al.*, 2004) and distribution range (Cheung *et al.*, 2009), Cheung *et al.* (2010) projected changes in maximum catch potential by 2055, relative to 2005. This index, formed by such projections, should contribute to assessments of potential climate change impacts on marine fisheries.

Methods

Maximum catch potential is defined as the maximum exploitable catch of species combined, assuming that the geographic range and selectivity of fisheries remain unchanged from the current (year 2005) level. We include 1,066 species of marine fish and invertebrates, representing the major commercially exploited species, as reported in the FAO fisheries statistics (see http://www.fao.org), belonging to a wide range of taxonomic groups from around the world. Future distributions of these species are projected using a dynamic bioclimate envelope model under the SRES A1B scenario (see Cheung *et al.*, 2008b, 2009 for details) while primary production is projected by empirical models (Behrenfeld and Falkowski, 1997; Carr, 2002; Marra *et al.*, 2003; Sarmiento *et al.*, 2004).

Using a published empirical model described in Cheung *et al.* (2008a), we calculated the annual maximum catch potential for each of the ½° spatial cells. The empirical model estimates a species' maximum catch potential (MSY) based on the total primary production within its exploitable range (P), the area of its geographic range (A), its trophic level (λ) and includes terms correcting the biases from the observed catch potential (CT is the number of years of exploitation and HTC is the catch reported as higher taxonomic level aggregations):

$$\log_{10}MSY_t = -2.881 + 0.826\cdot\log_{10}P_t - 0.505\cdot\log_{10}A_t - 0.152\cdot\lambda + 1.887\cdot\log_{10}CT + 0.112\cdot\log_{10}HTC_t + \varepsilon \qquad \ldots 1)$$

where t is year and ε is the error term. We assume that the proportion of exploitable range relative to the geographic range of a species remains constant in the future. Thus, P was calculated from the sum of primary production (estimated from each of the three primary production algorithms) from the exploitable range weighted by the relative abundance in each spatial cell. Range area (A) was the sum of the area of all spatial cells that contribute to 95% of the total abundance at year t from which distributions of relative abundance were simulated from the dynamic bioclimate envelope model described above. The trophic level (λ) of each species was obtained from FishBase (www.fishbase.org), SeaLifeBase (www.sealifebase.org) and the *Sea Around Us* Project databases (www.seaaroundus.org) and was assumed to be constant over time. However, change in species distributions and community structure resulting from climate change may affect the trophic level of the species. This would affect the estimated change in maximum catch potential and remains a major uncertainty of our projections. The spatial distribution of the calculated maximum catch potential was assumed to be proportional to the relative abundance of each species in each cell.

Data sources

Key information for predicting distribution maps was mainly obtained from FishBase for fish and SeaLifeBase for other taxa. Both databases contain key information on the latitudinal and depth distribution of the animals in question, and on their occurrence in various parts of the world ocean. The distribution maps are available at www.seaaroundus.org, along with their habitat preferences and other parameters used in their construction.

Indicator category (pressure/state/impact/response)

Catch potential can be seen as an impact indicator. It is developed with a ½° by ½° spatial resolution, summarized here to the level of the UNEP Regional Seas. The indicator is the projected proportional changes in maximum catch potential in each ½° cell by 2055 (10-year average) relative to 2005. The reduction in maximum catch potential indicates negative impacts of climate change on fisheries and vice versa (see Appendix 8).

Results and Discussion

Overall, the index, representing the projected proportional changes in maximum catch potential by 2055 relative to 2005 (10-years average) under the SRES A1B scenario, shows that climate change may considerably alter the distribution of catch potential, particularly between tropical and high-latitude regions (Figure 1). Specifically, impacts in the Indo-Pacific region appear to be most intense, with up to 50% decrease in 10-year average maximum catch potential by 2055 under a higher greenhouse gas emission scenario (SRES A1B).

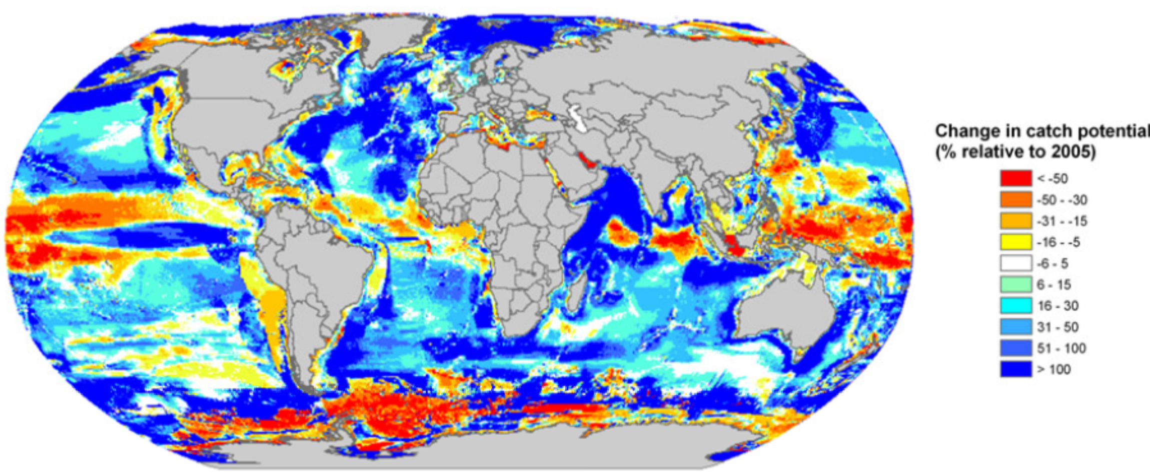

Figure 1. Projected percent change in maximum catch potential by 2055 relative to 2005 (10-year average) under the SRES A1B scenario (redrawn from Cheung *et al*., 2010)

Simultaneously, catch potential in semi-enclosed seas such as the Red Sea and the southern coast of the Mediterranean Sea suffer from a reduction in catch potential. In fact, catch potential from many coastal regions appear to decline. In addition, maximum catch potential in the Antarctic region declines considerably. By contrast, catch potential in the higher latitudinal regions, particularly the offshore regions of the North Atlantic, the North Pacific, the Arctic and the northern edge of the Southern Ocean increase greatly by more than 50% from the 2005 level.

Specifically, we project a large reduction in catch potential in the tropics, semi enclosed seas and inshore waters, while catch potential increases largely in the North Atlantic, North Pacific (particularly the Bering Sea) and the poleward tips of continental margins such as around South Africa, southern coast of Argentina and Australia.

These results suggest that climate change will have a large impact on the distribution of maximum catch potential – a proxy for potential fisheries productivity – by 2055. The redistribution of catch potential is driven by projected shifts in species' distribution ranges and by the change in total primary production within the exploited ranges of different species. In the tropics and the southern margin of semi-enclosed seas such as the Mediterranean Sea, species are projected to move away from these regions as the ocean warms up. Thus, the catch potential in these regions decreases considerably. Simultaneously, ocean warming and the retreat of sea ice in high-latitude regions open up new habitat for lower latitude species and thus may result in a net increase in catch potential.

Moreover, catch potential increases in the poleward continental margins (e.g., southern parts of Australia and Africa), because most commercially exploited species are associated with continental shelves. Thus these continental margins represent a limit to the distribution shifts of numerous species. In subtropical and temperate regions, cold-water species are replaced by warm-water species, making the trend in catch potential changes in these regions generally weaker than in tropical, high-latitude and polar regions.

The large reduction in catch potential in the southern ocean is the result of a shift in the lower-latitude range boundary of many Antarctic species, resulting in a loss of catch potential. In addition, as species move offshore to colder refuges as the ocean warms up, catch potential also shifts to offshore regions from coastal areas. Such inshore-to-offshore shifts as estimated here corroborate observations from field studies (Dulvy *et al*., 2008).

Various uncertainties are associated with our projections. First, they do not consider the effect of changes in eco-physiology, such as the increased physiological stress resulting from ocean acidification and the predicted reduction of the dissolved oxygen content of subsurface waters, i.e., factors which are likely to have negative impacts on catch potential (Pauly 2010). Secondly, projections from dynamic bioclimate envelope models are uncertain (Cheung *et al*., 2009). However, sensitivity analysis of the dynamic bioclimate envelope model shows that its projections are generally robust to key input parameters. Also, our projected rates of range-shift for exploited fishes are of similar magnitude to the observed rates in the North Sea (Perry *et al*., 2005) and the Bering Sea (Mueter and Litzow, 2008) in recent decades; this provides support to the validity of our projections.

Distribution shifts may be influenced by evolutionary or physiological adaptation of marine species and interactions between species or anthropogenic factors that were not captured in our model. Consideration of these factors is expected to increase the rate of range shifting of the species; thus our projected distribution shifts are considered conservative (Cheung *et al*., 2009). Moreover, there are uncertainties associated with projections of ocean conditions that were applied to predict primary production and changes in species distributions. Particularly, because of the coarse resolution of the underlying oceanographic models, representation of dynamics in finer spatial resolution (e.g., coastal processes) is particularly uncertain. This is likely to affect estimated changes in the catch potential of Regional Seas, but less, we think, than caused by the non-consideration of eco-physiological processes (which we soon will remedy).

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References

Bakun, A., 1990. Global climate change and intensification of coastal ocean upwelling. *Science* 247, 198-201.

Behrenfeld, M.J., Falkowski, P.G., 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnology and Oceanography* 42(1), 1-20.

Carr, M.E., 2002. Estimation of potential productivity in Eastern Boundary Currents using remote sensing. *Deep Sea Research Part II* 49, 59-80.

Cheung, W.W.L., Close, C., Lam, V.W.Y., Watson, R., Pauly, D., 2008. Application of macroecological theory to predict effects of climate change on global fisheries potential. *Marine Ecology Progress Series* 365, 187-197

Cheung, W.W.L., Close, C., Kearney, K., Lam, V., Sarmiento, J., Watson, R., Pauly, D., 2009. Projections of global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries* 10, 235-251

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., Zeller, D., Pauly, D., 2010. Large-scale redistribution of maximum catch potential in the global ocean under climate change. *Global Change Biology* 16, 24-35.

Dulvy, N.K., Rogers, S.I., Jennings, S., Vanessa, S., Dye, S.R., Skjoldal, H.R., 2008. Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. *Journal of Applied Ecology* 45, 1029-1039.

Diaz, R.J., Rosenberg, R., 2008. Spreading dead zones and consequences for marine ecosystems. *Science* 321, 926-929.

IPCC, 2007. Summary for Policymakers. In: Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M.M.B., Miller, H.L. Jr., Chen, Z. (eds.), *Climate Change 2007: The Physical Science Basis*, pp. 1-18. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Marra, J., Ho, C., Trees, C.C., 2003. *An Algorithm for the Calculation of Primary Productivity from Remote Sensing Data*. Lamont-Doherty Earth Obs., Palisades, New York. 27 p.

Mueter F.J., Litzow, M.A., 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. *Ecological Applications* 18, 309–320.

Pauly, D., 2010. *Gasping Fish and Panting Squids: Oxygen, Temperature and the Growth of Water-Breathing Animals*. Excellence in Ecology (22), International Ecology Institute, Oldendorf/Luhe, Germany, xxviii + 216 p.

Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D., 2005. Climate change and distribution shifts in marine fishes. *Science* 308, 1912-1915.

Przeslawski, R., Ahyong, S., Byrne, M., Wörheide, G., Hutchings, P., 2008. Beyond corals and fish: the effects of climate change on noncoral benthic invertebrates of tropical reefs. *Global Change Biology* 14, 2773-2795.

Sarmiento, J.L., Slater, R., Barber, R., Bopp, L., Doney, S.C., Hirst, A.C., Kleypas, J., Matear, R., Mikolajewicz, U., Monfray, P., Soldatov, V., Spall, S.A., Stouffer, R., 2004. Response of ocean ecosystems to climate warming. *Global Biogeochemical Cycles* 18(3), GB3003.1-GB3004.23.

Wilson, S.K., Fisher, R., Pratchett, M.S., Graham, N.A.J., Dulvy, N.K., Turner, R.A., Cakacaka, A., Polunin, N.V.C., Rushton, S.P., 2008. Exploitation and habitat degradation as agents of change within coral reef fish communities. *Global Change Biology*, 14, 2796-2809.

VALUE OF FISHERIES LANDINGS IN REGIONAL SEAS[1]

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ABSTRACT

We describe a global ex-vessel fish price database, as required for understanding the economic behavior of participants in the world's fisheries. We demonstrate its usefulness, in the Regional Sea context, using the marine fisheries of the Eastern African Regional Sea as an example, by linking it to a spatially defined catch database, which makes it possible to attach landed values to species in both time and space.

INTRODUCTION

The Ex-Vessel Price Database (Sumaila *et al.*, 2007) of the Fisheries Economics Research Unit and the *Sea Around Us* project at the University of British Columbia, contains reported and estimated annual average ex-vessel prices (i.e., prices that fishers receive for their catches, or the price at which fish are sold when they first enter the seafood supply chain) for all commercially exploited marine species (groups) and for all fishing countries from 1950 to the present (2005).

MATERIALS AND METHODS

The Global Ex-Vessel Fish Price Database, described by Sumaila *et al.* (2007), represents the first fish price database that offers a complete list of commodity (i.e., type of fish) and market (based on the nationality of the fishing fleet, and thus the presumed location of the landing port) specific annual average ex-vessel prices for all marine taxa reported to have been caught from 1950 to the present. Through their extensive search of publicly available, but widely scattered and incompatible, national and regional statistical reports and grey literature, Sumaila *et al.* (2007) accumulated over 31,000 records of observed ex-vessel prices in 35 countries, representing about 20% of the global landings over the 55-year period. In order to fill the gaps in the database, a series of rules were developed whereby all catches with no reported prices were inferred to have an estimated price computed from the reported prices from related taxa, similar markets or years.

The ex-vessel price for each taxon was then multiplied by the corresponding catch (or landing) for each to produce the landed value by country, year and gear by Regional Sea. Since catch was temporal, the results were output to CSV format and plotted in a cumulative graph similar to catches (see Appendix 11 and 14).

Indicator characteristics

Landed values are based on multiplying ex-vessel prices with spatial catches with a ½° by ½° resolution, here aggregated to the Regional Seas level.

The value of the fisheries is an important pressure indicator. Fluctuations in value will impact the fishing effort, for instance, as observed in the Gulf of Mexico when high oil prices combined with low shrimp prices caused by increasing supply from Southeast Asian aquaculture resulted in a marked decrease in shrimp trawling effort.

[1] Cite as: Swartz, W., Watson, R., Sumaila, U.R., 2011. Value of fisheries landings in Regional Seas. *In*: Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 55-56. Fisheries Centre Research Reports 19(3). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

Results and Discussion

Figure 1 documents, as an application example, the ex-vessel values of the marine fisheries in the Eastern African Regional Sea, expressed in constant (2005) USD, from 1950 to 2006.

A database such as the one described here, on ex-vessel fish prices, requires updating and improvement over time, both in terms of recorded price data and in terms of its price estimation methodology. Over the past several years, the database has been utilized in various economic analyses of world fisheries (Khan *et al.*, 2006; Sumaila *et al.*, 2007; Sumaila *et al.*, 2008), many areas of improvements and amendments have been identified and efforts continue to be made in order to address them. Because of this, we believe the database and its landed value estimates will continue to serve as a valuable research tool for evaluating fisheries policies at national, regional and global levels.

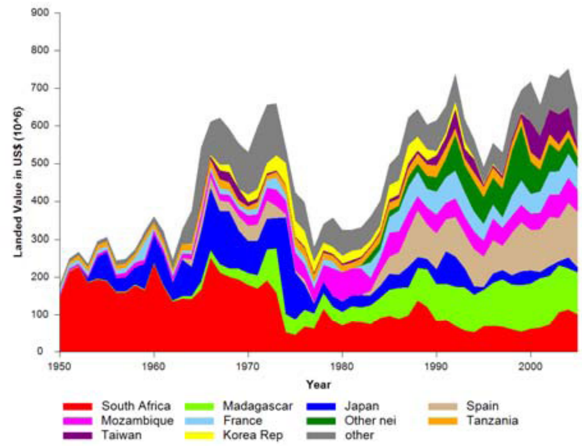

Figure 1. Landed value by country fishing in the Eastern Africa Regional Sea.

Acknowledgements

The *Sea Around Us* project, on which this work relies, is a scientific cooperation between The University of British Columbia and the Pew Environment Group.

References

Khan, A., Sumaila, U.R., Watson, R., Munro, G., Pauly, D., 2006. The nature and magnitude of global non-fuel fisheries subsidies. In Sumaila, U.R., Pauly, D. (eds.), *Catching More Bait: a Bottom-up Re-estimation of Global Fisheries Subsidies*, pp. 5-37. Fisheries Centre Research Reports 14(6). Fisheries Centre, UBC, Vancouver.

Sumaila, U.R., Marsden, A.D., Watson, R., Pauly, D., 2007, A global ex-vessel fish price database: construction and applications, *Journal of Bioeconomics* 9(1), 39-51.

Sumaila, U.R., Teh, L., Watson, R., Tyedmers, P., Pauly, D., 2008. Fuel price increase, subsidies, overcapacity, and resource sustainability. *ICES Journal of Marine Science* 65(6), 832-840.

EMPLOYMENT IN MARINE FISHERIES: NATIONAL, REGIONAL AND GLOBAL ESTIMATES[1]

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ABSTRACT

A summary is given of the approach that was used to compile a global database of employment in fisheries, including small-scale fishers. The values that were obtained, including a global estimate of of 260 million marine fisheries jobs, which includes 22 million small-scale fishers, are reasonable, but mapping them by Regional Sea is not, due to their large size, which results in data from highly disparate countries being pooled.

INTRODUCTION

Marine capture fisheries contribute to the global economy, from the catching of fish through to the provision of support services for the fishing industry. A general lack of data and uncertainty about the level of employment in capture fisheries can lead to underestimation of fishing effort and hence overexploited fisheries, or result in inaccurate projections of economic and societal costs and benefits. To address this gap, a database of marine capture fisheries employment for 144 coastal countries was compiled, and its major features are discussed.

MATERIAL AND METHODS

For each country, we first searched the literature for estimates of the number of fishers. If no estimate was available, or if an available estimate was assessed as not reliable, then government websites and other sources were investigated for a better estimate. If an estimate could not be found from FAO or other sources (i.e., the International Labor Organization, peer reviewed publications, as well as fisheries and agriculture departments of individual countries), we used a benefit transfer approach (direct value transfer) to fill in the gap.

We paid particular attention to quantifying the number of small-scale and/or unlicensed fishers globally. We first searched FAO 'Country Profiles' for indications of small-scale fishing, followed by peer reviewed literature and grey literature as necessary. Where small-scale fishing existed, but no data were available, we used a Monte Carlo algorithm to estimate the number of small-scale fishers based on coastal population and proportion of the coastal population that fishes.

The resulting employment estimates, which pertain to the year 2000, initially referred to a set of 144 maritime countries. Here, they were also assigned proportionately to the ½° cells making countries' EEZ, around the world, and then aggregated by Regional Seas, as defined in Lai *et al.* (this volume; see Appendix 13 and 14).

RESULTS AND DISCUSSION

The FAO currently estimates that there are 140 million participants in the primary, secondary, and ancillary sectors of both marine and inland fisheries worldwide. Given that inland fisheries constitute a relatively large portion of the capture fisheries of some countries, our current global estimate of 260

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million participants in marine fisheries is about 1.75 times higher than the FAO's. The addition of small-scale fishers increased participants in the primary sector by about 40%.

There are no comparable global estimates for small-scale fishers. However, Chuenpagdee *et al*. (2006) reported 12 million small-scale fishers worldwide in 2006, while FAO estimated 26 million small-scale fishers in developing countries. These estimates neatly bracket our estimate of 19 million small-scale fishers worldwide, and hence we are relatively confidant that our global estimate is reasonable, as well as the national estimate upon which it is based.

Examination of a map (not shown) of employment intensity by Regional Seas suggested, however, they may not represent an appropriate scale for socio-economic data such as employment in fisheries (and neither for subsidies; see Sumaila *et al*. this volume). This is because Regional Seas, which are rather large compared, say, with Large Marine Ecosystems (Sherman and Hempel, 2008) include the coastal waters of socio-economically very heterogeneous countries. Thus, the East Asian Regional Sea includes both Southeast Asia (which has an enormous number of fishers) and Northern Australia (which has few).

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The *Sea Around Us* project, on which this study relies, is a scientific cooperation between The University of British Columbia and the Pew Environment Group.

References

Chuenpagdee R., Liguori L., Palomares M.L.D., Pauly D., 2006. *Bottom-Up, Global Estimates of Small-Scale Marine Fisheries Catches*. Fisheries Centre Research Report 14(8), 112pp.

Sherman, K., Hempel, G., Editors, 2008. *The UNEP Large Marine Ecosystem Report: a Perspective on Changing Conditions in LMEs of the World's Regional Seas*. UNEP Regional Seas Reports and Studies No. 182, 852 p.

Subsidies to fisheries in Regional Seas[1]

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Abstract

A summary is given of the approach that was used to compile a global database of government subsidies to fisheries. The estimates obtained were reasonable, as evidenced by their acceptance by the World Trade Organization and the World Bank. However, mapping these subsidies by Regional Sea is questionable, due to their large size, which results in subsidy intensities from socioeconomically disparate countries being pooled.

Introduction

Fisheries subsidies are defined as government financial transfers to the fishing industry, which serve to reduce the cost of fishing (e.g., fuel subsidies), or programs that artificially increase revenue to fishing enterprises (e.g., price support schemes). Subsidies to the fishing industry for all maritime countries/political entities of the world are reported by Sumaila and Pauly (2006), and updated by Sumaila *et al.* (2010). The capacity-enhancing subsidies (bad) generate additional pressure on the Regional Seas, which may also be the case for the ambiguous (ugly) subsidies. In contrast, the beneficial subsidies may relieve pressure, or are neutral. Overall, subsidies impact fishing effort, and may be characterized as pressure indicators.

Material and Methods

Government financial transfer (subsidy) data were obtained from a number of sources including international organizations such as the Organization for Economic Cooperation and Development (OECD) and national statistical agencies, and were augmented by information estimated by Sumaila *et al.* (2008)

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concerning fuel subsidies and Cullis-Suzuki and Pauly (2010), who estimated the costs of managing marine protected areas. Overall, the database of fisheries subsidies spans the years 1990-2009, with the year 2003 being covered best.

Both quantitative and qualitative data regarding government financial transfers was collected and categorized according to the information presented in Table 1. Where the information was qualitative (i.e., without supporting quantitative data), we treated subsides values as missing rather than as zero, thus allowing estimation of missing data using a simple benefit-transfer approach (Sumaila *et al.*, 2010).

The subsidy estimates in Sumaila *et al.* (2010) for all maritime countries/political entities were then distributed over the ½° latitude/longitude cell sizes of the corresponding EEZ, then aggregated to Regional Seas (Appendix 12 and 14).

Table 1. Subsidy Types and categories identified in Sumaila *et al.* (2010).

Type	Category	Sub-category (if applicable)
Beneficial (good)	Fishery management	Monitoring and control
		Stock assessment
		Stock enhancement
		Other beneficial programs
	Research and Development	
	Marine protected areas (MPA)	
Capacity-enhancing (bad)	Vessel construction and modernization	State fishery investments
		Subsidized loans
		Vessel modernization
		Other capacity-enhancing programs
	Fishery Development Projects	Development grants
		Institutional support
	Port and harbor expenditure	
	Marketing and processing support	
	Tax exemptions	
	Access agreements	
	Fuel price support	
Ambiguous (ugly)	Fisher assistance programs	Income support
		Retraining initiatives
		Unemployment assistance
		Other worker assistance programs
	Decommissioning schemes	Permit and license buybacks
		Vessel buyback programs
		Other decommissioning programs
	Rural community development programs	

Results and Discussion

Fisheries subsidies are an indicator of government involvement in the fisheries sector, and their effects can be assessed when, as is the case here, the subsidies are grouped into categories based on their assumed effect on the health of ocean fish populations. Presently, this database represents the most concise and complete collection of fisheries subsidies data available. There is, however, an opportunity for further work to flesh out the time element of the database, especially for years prior to 2000.

The fisheries subsidy database briefly described here continues to evolve, and forms the basis for several past (Sumaila *et al.*, 2008) and current contributions, including Sumaila *et al.* (2010), who estimated that fisheries subsidies total 25-30 billion USD per year or about a third of the global value of fisheries landings. Also, the content of the database is available at the website of the *Sea Around Us* (www.seaaroundus.org), by country. It is also used to inform negotiations at the World Trade Organization, and for assessments by the World Bank.

Examination of a map (not shown) of subsidy intensity by Regional Seas suggested, however, that they might not represent an appropriate scale for economic data such as subsidies (and neither for employment data; see Teh and Sumaila, this volume). This is because Regional Seas, which are rather large, compared, say, with Large Marine Ecosystems (Sherman and Hempel, 2008) include the coastal waters of economically very heterogeneous countries.

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References

Cullis-Suzuki, S., Pauly, D., 2010. Marine Protected Area Costs as 'Beneficial' Fisheries Subsidies: A Global Evaluation. Coastal Management 38(2), 113. doi:10.1080/08920751003633086.

Sumaila, U. R., Pauly, D., 2006. *Catching more bait: a bottom-up re-estimation of global fisheries subsidies*. Fisheries Centre Research Reports 14(6). Fisheries Centre, UBC, Vancouver.

Sumaila, U.R., Khan, A.J., Dyck, A., Watson, R., Munro, G., Peter Tyedmers, Pauly, D., 2010. A bottom-up re-estimation of global fisheries subsidies. *Journal of Bioeconomics* 12, 201–225.

Sumaila, U. R., Teh, L., Watson, R., Tyedmers, P., Pauly, D., 2008. Fuel price increase, subsidies, overcapacity, and resource sustainability. *ICES Journal of Marine Science 65*(6), 832-840.

Appendices

The following are summary descriptions of the potential and/or computed Regional Sea indicators described in this report.

Appendix 1. Nitrogen, phosphorus and silica

1. Indicator	
Indicator name	Nitrogen, phosphorus, and silica
Category	Pressure and state
Definition of indicator / Descriptor	The data presented refer to global river export of total nitrogen, total phosphorus and dissolved silica for different Regional Seas, as output by the Global NEWS model, described in Seitzinger *et al.* (2010)
Units of measurements	tonnes·year^{-1}
2. Relevance (n.a.)	
3. Methodology	
Description of measurement methods and calculation of the indicator	The global NEWS system includes river-basin scale models for predicting export of dissolved inorganic nitrogen and phosphorus (DIN, DIP), dissolved organic carbon, nitrogen and phosphorus (DOC, DON, DOP), total suspended solids (TSS), particulate organic carbon (POC), particulate nitrogen and phosphorus (PN and PP), and dissolved silica (DSi). Natural and anthropogenic nutrient sources in watersheds, hydrological and physical factors, and in-river N and P removal are important model components. The Integrated Model for the Assessment of the Global Environment (IMAGE) (Bouwman *et al.*, 2006) was used to develop the inputs for the NEWS model.
Scale	Over 5000 watersheds are included. Based on 1970-2000 period, with future scenarios developed
4. Assessment of data	
Data sources, availability and quality (Existing datasets)	Input datasets consist of nonpoint source data (agriculture and natural ecosystems), point source data (urban wastewater), and atmospheric deposition. A full description of the data is given in Bouwman *et al.* (2009). Soil nitrogen and phosphorus balances are calculated for each grid cell as the sum of all inputs minus the sum of the removal of nutrients in the harvested crops and grazing. Inputs are fertilizer use, animal manure, biological nitrogen fixation and atmospheric deposition. Fertilizer use is taken from different sources (IFA/IFDC/FAO, 2003; FAO, 2009). Crop export is based on production data from FAO (2009) and nutrient contents for a variety of crops. Nitrogen fixation is calculated as free-living with fixation rates specific to cropland, grassland and wetland rice. Nitrogen fixation by leguminous crops is based on the production data and nitrogen contents of the harvested product of these crops. Atmospheric N deposition rates (including dry and wet deposition of NH_3 and NO_y) for the year 2000 were taken from Dentener *et al.* (2006). Deposition rates for historical and future years are obtained by scaling the deposition fields for the year 2000, using emission scenarios for N gases for the corresponding years from the implementation of the MEA scenarios with the IMAGE model. Point source data are calculated on the basis of the fraction of national populations with a connection to sewage systems, the fraction of the wastewater that is treated, and a nutrient removal efficiency estimate. Data are from a variety of sources, as described in Van Drecht *et al.* (2009).
5. Partners	
Partners/agencies involved in the development of the indicator	Netherlands Environmental Assessment Agency (PBL), Rutgers University, UNESCO-IOC, IGBP

6. References

Bouwman, A.F., Beusen, A.H.W., Billen, G., 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970-2050. Global Biogeochemical Cycles, 23, doi:10.1029/2009GB003576.

Bouwman, A.F., Kram, T., Goldewijk, K., 2006. Integrated modelling of global environmental change. An Overview of IMAGE 2.4, Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Dentener, F., Stevenson, D., Ellingsen, K., Noije, T.v., Schultz, M., Amann, M., Atherton, C., Bell, N., Bergmann, D., Bey, I., Bouwman, L., Butler, T., Cofala, J., Collins, B., Drevet, J., Doherty, R., Eickhout, B., Eskes, H., Fiore, A., Gauss, M., Hauglustaine, D., Horowitz, L., Isaksen, I.S.A., Josse, B., Lawrence, M., Krol, M., Lamarque, J.F., Montanaro, V., Müller, J.F., Peuch, V.H., Pitari, G., Pyle, J., Rast, S., Rodriguez, J., Sanderson, M., Savage, N.H., Shindell, D., Strahan, S., Szopa, S., Sudo, K., Dingenen, R.V., Wild, O., Zeng, G., 2006. The global atmospheric environment for the next generation. Environment Science and Technology, 40:3586-3594.

FAO, 2009. FAOSTAT database collections (http://faostat.fao.org/), Food and Agriculture Organization of the United Nations, Rome.

IFA/IFDC/FAO, 2003. Fertilizer use by crop. 5th edition, Food and Agriculture Organization of the United Nations, Rome.

Seitzinger, S.P., Mayorga, E., Kroeze, C., Bouwman, A.F., Beusen, A.H.W., Billen, G., Drecht, G.V., Dumont, E., Fekete, B.M., Garnier, J., Harrison, J.A., 2010. Global River Nutrient Export Trajectories 1970-2050: A Millenium Ecosystem Scenario Analysis. Global Biogeochemical Cycles 23, GB0A08, doi:10.1029/2009GB003587.

Van Drecht, G., Bouwman, A.F., Harrison, J., Knoop, J.M., 2009. Global nitrogen and phosphate in urban waste water for the period 1970-2050. Global Biogeochemical Cycles 23, GB0A03, doi:10.1029/2009GB003458.

APPENDIX 2. NITROGEN DEPOSITION

1. INDICATOR	
Indicator name	Atmospheric nitrogen deposition
Category	Pressure
Definition of indicator / Descriptor	Atmospheric deposition of total inorganic nitrogen (N), NH_x (NH_3 and NH_{4+}), and NO_y (all oxidized forms of nitrogen other than N_2O).
Units of measurements	mg $N \cdot m^{-2} \cdot year^{-1}$
2. RELEVANCE	
Significance for inter-linkages with other water systems	Model is global, covering terrestrial and ocean environments.
3. METHODOLOGY	
Description of measurement methods and calculation of the indicator	Emission scenarios for NO and NH_3 are based on Van Aardenne *et al.* (2001). These estimates were derived from version 2.0 of the Emission Database for Global Atmospheric Research (EDGAR 2.0) (Olivier *et al.*, 1999). The emissions estimates and projections described above were used as input to the global three-dimensional chemistry-transport model TM3 (described in Jeuken *et al.*, 2001 and Lelieveld and Dentener, 2000) to produce global maps of atmospheric nitrogen deposition for 1860, 1993, and 2050.
Scale	5° longitude by 3.5° latitude. Output gridded to 50 km by 50 km. Years 1860, 1993 and with projections for 2050.
4. ASSESSMENT OF DATA	
Data sources, availability and quality *(Existing datasets)*	Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.
Variations among data sources and alternative methods	The predictions of NO and NH_3 emissions are based on the IS92a scenario (Houghton *et al.*, 1996). For this scenario, the projected NO_x emissions compares to the higher (more pessimistic) end of the range seen in recent SRES scenarios (Nakicenovic and Swart, 2000), but are still well within that range. Neither IS92a or SRES provide scenarios for NH_3 emissions, so the 2050 scenario used in this work for NH_3 is determined in analogy to N_2O emissions (since these grossly represent the development of agricultural activities). In fact, very recent RIVM/IMAGE scenarios for the year 2030 (based on SRES A2/B2) agree well with the increases that the investigator's IS92a based work would predict for 2050. Overall, the IS92a can be considered among the higher end of current scenarios regarding NO_x emissions, and reflects the current information on NH_3 emissions.
5. PARTNERS	
Partners/agencies involved in the development of the indicator	Joint Research Center, Ispra (Italy).

6. REFERENCES

Houghton, J.J., Meiro Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A., Maskell, K., Editors, 1996. Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, 572 pp.

Nakicenovic, N., Swart, R., Editors, 2000. Special Report on Emissions Scenarios (SRES). A Special Report of Working Group III of the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, 612 pp.

Jeuken, A., Veefkind, P., Dentener, F., Metzger, S., Robles-Gonzalez, C., 2001. Simulation of the aerosol optical depth over Europe for August 1997 and a comparison with observations. Journal of Geophysical Research 106, 28295-28311.

Lelieveld J., Dentener, F., 2000. What controls tropospheric ozone? Journal of Geophysical Research 105, 3531-3551.

Olivier, J.G.J., Bouwman, A.F., Berdowski, J.J.M., Veldt, C., Bloos, J.P.J., Visschedijk, A.J.H., van de Maas, C.W.M., Zandveld, P.Y.J., 1999. Sectoral emission inventories of greenhouse gases for 1990 on a per country basis as well as on 10 x 10. Environmental Science Policy 2, 241-264.

Van Aardenne, J.A., Dentener, F.J., Olivier, J.G.J., Klein Goldewijk, C.G.M., Lelieveld, J., 2001. A 1°x1° resolution dataset of historical anthropogenic trace gas emissions for the period 1890-1990. Global Biogeochemical Cycles 15(4), 909-928.

APPENDIX 3. FISHERIES LANDINGS

1. INDICATOR	
Indicator name	Fisheries catches by species, functional groups, gear, country Catches from bottom-impacting fisheries.
Category	State/pressure
Definition of indicator / Descriptor	Catches and landings are often used synonymously, though the difference, discards, is important to evaluate stress on the ecosystems. Fishing fleets catch fish, but do not retain all they catch, as some are discarded before the vessels return to port. 'Landings' do not include the fish and invertebrates discarded at sea. Moreover, some of the landed catch may remain unrecorded (especially when caught illegally). Thus the precise term for this component is 'reported landings'.
Units of measurements	weight in t·year^{-1}
2. RELEVANCE	
Rationale for inclusion	Fisheries have very strong impact on life in the oceans.
Significance for inter-linkages with other water systems	There are strong linkages between especially coastal, shelf, and open ocean systems, notably associated with migration and ontogenetic shift in distribution.
Linkage with other indicators	Important for deriving socio-economic indicators for the fisheries sector
3. METHODOLOGY	
Description of measurement methods and calculation of the indicator	Catches in the *Sea Around Us* database are based on catches reported to FAO, combined with national or regional databases to provide a more complete picture. In addition, catches from parts of the fishing sector that is not or only poorly covered in the official statistics is added through 'catch reconstructions' (Zeller and Pauly, 2007). The *Sea Around Us* allocation process use the taxonomic identity of the catch (after the disaggregation process) to allocate catch to the system of spatial cells based on the distribution ranges of the species caught (Close *et al.*, 2004). Also used is information about fishing access and fishing patterns of reporting countries, where possible after the effects of reflagging are removed (Watson *et al.*, 2004). Maps of catches by all gear types annually since 1950 are also available. The catch data are associated with likely associated fishing gear types based on reported associations by fishing year, fishing country and landed taxa (Watson *et al.*, 2006a, 2006b). For details of the methodology, see also Pauly *et al.* (2008)
Scale	Catches reported by FAO are by reporting country and statistical areas. Catches from *Sea Around Us* project are allocated to spatial cells and with finer spatial (½° by ½°) and taxonomic resolution and breakdown to gears.
Limitations	Fisheries indicators require accurate and complete catch data, which are lacking for most countries. The methods used for re-expressing FAO's global reported landings dataset on a spatial basis cannot compensate for these limitations. Rather, it makes them visible, and emphasizes the need for catch reconstruction at the national level (*sensu* Zeller *et al.* 2006, 2007), from which spatial catch time series can then be derived: • To evaluate stress factors, estimated catches are needed rather than estimated landings. The difference (Illegal, Unreported and Unregulated, IUU catches) may account for up to 30% of the catches globally, and better estimation of this is warranted; • Species breakdown in reported catches are often poor; • Using flag of convenience may obscure where benefits from fishing are accrued.

4. Assessment of Data	
Data sources, availability and quality *(Existing datasets)*	*Sea Around Us* catches are available at www.seaaroundus.org
Variations among data sources and alternative methods	Described above
5. Partners	
Partners/agencies involved in the development of the indicator	*Sea Around Us* project
6. References	

Close, C., Cheung, W.L., Hodgson, S., Lam, V., Watson, R., Pauly, D., 2006. Distribution ranges of commercial fishes and invertebrates. In: Palomares, M.L.D., Stergiou, K.I., Pauly, D., (eds.), *Fishes in Databases and Ecosystems*, pp. 27-37. Fisheries Centre Research Reports 14(4). Fisheries Centre, Univ. British Columbia, Vancouver.

Pauly, D., Alder, J., Booth, S., Cheung, W.W.L., Christensen, V., Close, C., Sumaila, U.R., Swartz, W., Tavakolie, A., Watson, R., Wood, L., Zeller D., 2008. Fisheries in large marine ecosystems: descriptions and diagnoses. In: Sherman, K., Hempel, G. (eds.), *The UNEP Large Marine Ecosystem Report: a Perspective on Changing Conditions in LMEs of the World's Regional Seas*, pp. 23-40. UNEP Regional Seas Reports and Studies No. 182.

Watson, R, Kitchingman, A., Gelchu, A., Pauly, D., 2004. Mapping global fisheries: sharpening our focus. *Fish and Fisheries* 5, 168-177.

Watson, R., Revenga, C., Kura, Y. 2006. Fishing gear associated with global marine catches: I Database development. *Fisheries Research* 79, 97-102.

Watson, R., Revenga, C., Kura, Y. 2006. Fishing gear associated with global marine catches: II Trends in trawling and dredging. *Fisheries Research* 79, 103-111.

Zeller, D., Booth, S., Craig, P., Pauly, D., 2006. Reconstruction of coral reef fisheries catches in American Samoa, 1950-2002. *Coral Reefs* 25, 144-152.

Zeller, D., Pauly, D., 2007. Reconstruction of marine fisheries catches for key countries and regions (1950-2005). Fisheries Centre Report 15(2), University of British Columbia, Vancouver, Canada, 163 pp.

APPENDIX 4. MARICULTURE PRODUCTION

1. INDICATOR	
Indicator name	Mariculture (FAO)
Category	State/Pressure
Definition of indicator / Descriptor	*"By mariculture is understood that the cultivation of the end product takes place in seawater, such as fjords, inshore and open waters and inland seas in which the salinity generally exceeds 20‰. Earlier stages in the life cycle of these aquatic organisms may be spent in brackishwater or freshwater."*(FAO: see www.fao.org/fishery/cwp/handbook/J/en).
Units of measurements	tonnes·year^{-1}
2. RELEVANCE (N.A)	
3. METHODOLOGY	
Description of measurement methods and calculation of the indicator	The FAO database presented data by country, species, environment, fishing area and year (Fishstat, 2010). The data were filtered by brackishwater and marine environments, and then summed by country and year. Then, we redistributed the data over EEZ cells evenly per country and then summarized them by Regional Seas. Maps and CSV file were produced for all regional seas and global values.
Scale	Global, and temporal from 1950 to 2010.
Limitations	The statistics are as reported to FAO by member countries.
4. ASSESSMENT OF DATA	
Data sources, availability and quality *(Existing datasets)*	The data source was the FAO Fishstat website cited below.
5. PARTNERS	
Partners/agencies involved in the development of the indicator	Food and Agriculture Organization
6. REFERENCES	
Fishstat, FAO Fishstat Plus, March 2010, http://www.fao.org/fishery/statistics/software/fishstat/en, June 30, 2010.	

APPENDIX 5. STOCK-STATUS PLOTS

1. INDICATOR	
Indicator name	Stock status plots
Category	State
Definition of indicator / Descriptor	Stock-status plots are useful for demonstrating how global fisheries resources have transitioned through the development stages and the inability of management to maintain them at an acceptable level of exploitation. Interpretation of the stock-status plots can be somewhat problematic due to the fact that they are based on catches and not on actual population estimates. However, they remain a useful tool for visualizing fisheries resource trends at the global level.
Units of measurements	Status by stock (catch category) or as proportion of catch
2. RELEVANCE	
Rationale for inclusion	Stock-status plots have been used to great effect in papers by Granger and Garcia (1996), FAO, Froese and Pauly (2003) and Worm *et al.* (2006).
3. METHODOLOGY	
Description of measurement methods and calculation of the indicator	Here, we also use a variant of what may be called 'stock number by status plots': a 'catch by status plot', defined such that it documents, for a series of years, the fraction of the reported landings biomass that is derived from stocks in various phases of development (Pauly *et al.*, 2008). We have modified the interpretation of status above to: • Combine the undeveloped and developing categories above to a single "exploited" category; • To discard stocks where the maximum landing occurs within the last 3 years of the time-series; • Added a "recovering" category and defined a "post-maximum minimum" landing value that must be less than 10% of the overall maximum landing value. The new phases are defined as: • Exploited: Landing > 50% of max. landing; • Over exploited: Year of landing > year of max. landing AND landing is between 10-50% of max. landing; • Recovering: Year of landing > year of post-max. min. landing AND post-max. min. landing < 10% of max. landing AND landing is 10-50% of max. landing; • Collapsed: Year of landing > year of max. landing AND landing is < 10% of max. landing.
Scale	Analysis can be done at the national, LME and Regional Seas level, i.e., at any level where it is deemed appropriate to relate stock status to the signals from landings. Time coverage is from 1950 to the present, in annual steps.
Limitations	The approach has important limitations: • The undeveloped and the developing categories will by definition have disappeared by the end of the time series since the scale is based on the year with maximum catch (which has to occur somewhere on the time line); • Catches may not say much about the stock status if, e.g., catch reductions are due to management interventions. Unfortunately, this may, however, be the exception rather than the rule.

4. Assessment of Data	
Data sources, availability and quality *(Existing datasets)*	The plots rely on analysis of catches only. It is assumed that the catches are reflective of the underlying population (stock) status
Variations among data sources and alternative methods	Stock status plots can be expressed relative to number of stocks or weighted by the catches by stocks.
5. Partners (n.a.)	
6. References	

Froese, R., Kesner-Reyes, K., 2002. Impact of Fishing on the Abundance of Marine Species. Rainer. ICES CM 2002/L:12, 15 p.

Froese, R., Pauly, D., 2003. Dynamik der Überfischung. In: Lozán, J.L., Rachor, E., Reise, K., Sündermann, J., von Westernhagen, H. (eds.), Warnsignale aus Nordsee und Wattenmeer – eine aktuelle Umweltbilanz, pp. 288-295. GEO, Hamburg.

Grainger, R.J.R., Garcia, S., 1996. Chronicles of marine fisheries landings (1950-1994): trend analysis and fisheries potential. FAO Fish. Tech. Pap. 359, 51 p.

Pauly, D., Alder, J., Booth, S., Cheung, W.W.L., Christensen, V., Close, C., Sumaila, U.R., Swartz, W., Tavakolie, A., Watson, R., Wood, L., Zeller, D., 2008. Fisheries in large marine ecosystems: descriptions and diagnoses. In: Sherman, K., Hempel, G. (eds.), *The UNEP Large Marine Ecosystem Report: a Perspective on Changing Conditions in LMEs of the World's Regional Seas*, pp. 23-40. UNEP Regional Seas Reports and Studies No. 182

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J., Watson, R. 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science* 314, 787-790.

Appendix 6. Catch from bottom-disturbing gears

1. Indicator	
Indicator name	Catch by bottom disturbing gear
Category	Pressure
Definition of indicator / Descriptor	The combined effort of bottom-dragging and dredging fishing gears
Units of measurements	catches by weight (tonnes·year^{-1}) or as relative catches
2. Relevance	
Rationale for inclusion	Habitats are impacted by bottom-disturbing gears in many parts of the world, and this may significantly change the environments and lead to species substitutions.
3. Methodology	
Description of measurement methods and calculation of the indicator	For each organism or group of organisms in the global catch database developed by the *Sea Around Us* project based on FAO and other data sources (Watson *et al*., 2004), Watson *et al*. (2006 a, 2006b) associated gear types. They found it possible to associate the majority of global catch records with up to five gear types in order of importance and to extrapolate these associations to all global catch records. In this way it was possible to use the mapped results of the *Sea Around Us* (Watson *et al*., 2005) to produce maps of catches by all gear types annually since 1950. The catch data were associated with likely associated fishing gear types, based on reported associations by fishing year, fishing country and landed taxa.
Scale	Original data available at ½° by ½° spatial cells, but here aggregated to Regional Seas. Available from 1950 to 2006.
Limitations	The key stress factor is effort, and not catches. Catches are, however, used as a proxy, as effort estimates not are yet available.
4. Assessment of Data	
Data sources, availability and quality *(Existing datasets)*	Based on the *Sea Around Us* databases.
5. Partners	
Partners/agencies involved in the development of the indicator	*Sea Around Us* project, Fisheries Centre, UBC.
6. References	

Watson, R., Alder, J., Kitchingman, A., Pauly, D., 2005. Catching some needed attention. *Marine Policy* 29, 281-284.

Watson, R, Kitchingman, A., Gelchu, A., Pauly, D., 2004. Mapping global fisheries: sharpening our focus. *Fish and Fisheries* 5, 168-177.

Watson, R., Revenga, C., Kura, Y., 2006. Fishing gear associated with global marine catches: I Database development. *Fisheries Research* 79, 97-102

Watson, R., Revenga, C., Kura, Y., 2006. Fishing gear associated with global marine catches: II Trends in trawling and dredging. *Fisheries Research* 79, 103-111

APPENDIX 7. CATCH OF TOP PREDATORY FISH

1. INDICATOR	
Indicator name	Catch of top predatory fish
Category	Pressure and state indicator, depending on context
Definition of indicator / Descriptor	Describes the catch trend for high trophic level (TL) fish, i.e., for those species with a TL higher than 3.75. This excludes low TL fish, such as small pelagics from the catches.
Units of measurements	catches by weight (tonnes·year^{-1}) or as relative catches
2. RELEVANCE	
Rationale for inclusion	High TL fish are overall larger and slower growing, and therefore more vulnerable to fishing. This index evaluates how the catches have changed, and will typically show an increasing trend as fisheries are developing and expanding, followed by stagnation and likely decline.
Significance for inter-linkages with other water systems	
Linkage with other indicators	Should be compared to the MTI and FiB indicators.
3. METHODOLOGY	
Description of measurement methods and calculation of the indicator	Based here on the catches from the *Sea Around Us* database with TLs from FishBase and SeaLifeBase.
Scale	Calculated by ½° spatial cells, but here aggregated to Regional Seas. Available from 1950 to 2006.
Limitations	The key stress factor is not catch levels per se, but the fishing intensity, i.e., the catch relative to the biomass. The catch is used as a proxy as effort or population analysis at the global level not yet are available.
4. ASSESSMENT OF DATA	
Data sources, availability and quality *(Existing datasets)*	Based on *Sea Around Us* databases.
Variations among data sources and alternative methods	Can be calculated from any catch database, but global spatial coverage only possible through the *Sea Around Us* database.
5. PARTNERS	
Partners/agencies involved in the development of the indicator	*Sea Around Us* project of the Fisheries Centre, University of British Columbia
6. REFERENCES (N.A.)	

APPENDIX 8. CATCH POTENTIAL

1. INDICATOR	
Indicator name	Predicted catch potential (2055/2005)
Category	Impact
Definition of indicator / Descriptor	The maximum exploitable catch over all species combined, assuming that the pressure from fishing fleet remain unchanged from the current (year 2005) level.
Units of measurements	
2. RELEVANCE	
Rationale for inclusion	Marine fisheries productivity is likely to be affected by the alteration of ocean conditions, especially water temperature, ocean currents and coastal upwelling, as a result of climate change, (see, e.g., Bakun, 1990; IPCC, 2007; Diaz and Rosenberg, 2008)
Significance for inter-linkages with other water systems	Here considered for marine and estuarine systems jointly.
Linkage with other indicators	
3. METHODOLOGY	
Description of measurement methods and calculation of the indicator	The indicator is based on analysis of 1,066 species of marine fish and invertebrates, representing the major commercially exploited species, as reported in the FAO fisheries statistics, belonging to a wide range of taxonomic groups from around the world. Future distributions of these species are projected using a dynamic bioclimate envelope model under the SRES A1B scenario (see Cheung *et al.*, 2008b, 2009 for details), while primary production is projected by empirical models (Behrenfeld and Falkowski, 1997; Carr, 2002; Marra *et al.*, 2003; Sarmiento *et al.*, 2004). The annual maximum catch potential for ½° by ½° spatial cells is calculated based on the model of Cheung *et al.* (2008). The empirical model estimates a species' maximum catch potential is based on the total primary production within its exploitable range, the surface area of its geographic range and its trophic level.
Scale	½° by ½° spatial cells, global coverage. Compares catch potential for 2055 relative to for 2005.
Limitations	Some of the recognized limitations are: • The approach does not consider effect of changes in eco-physiology, e.g., increased physiological stress resulting from ocean acidification; • Projections from dynamic bioclimate envelope model are uncertain (Cheung *et al.*, 2009). The current distribution maps may not adequately reflect species' habitat preferences; • There are uncertainties associated with projections of the ocean conditions that were applied to predict primary production and changes in species distributions; • Does not explicitly consider the responses of fisheries to potential changes in species distribution and catch potential. It is implicitly assumed that the exploitable area of a species follows the species distribution; • Ecological impacts, e.g., food web modifications, are not yet considered.
4. ASSESSMENT OF DATA	
Data sources, availability and quality *(Existing datasets)*	Output from global dataset available from the *Sea Around Us* project.
Variations among data sources and alternative methods	N.A.; development of alternative methods should be encouraged.

5. PARTNERS	
Partners/agencies involved in the development of the indicator	*Sea Around Us* project (UBC), University of East Anglia. Princeton University.

6. REFERENCES

Bakun, A., 1990. Global climate change and intensification of coastal ocean upwelling. *Science* 247, 198-201.

Behrenfeld, M.J., Falkowski, P.G., 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnology and Oceanography* 42(1), 1-20.

Carr, M.E., 2002. Estimation of potential productivity in Eastern Boundary Currents using remote sensing. *Deep Sea Research Part II* 49, 59-80.

Cheung, W.W.L., Close, C., Lam, V.W.Y., Watson, R., Pauly, D., 2008. Application of macroecological theory to predict effects of climate change on global fisheries potential. *Marine Ecology Progress Series* 365, 187-197.

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., Zeller, D., Pauly, D., 2010. Large-scale redistribution of maximum catch potential in the global ocean under climate change. *Global Change Biology* 16, 24-35.

Diaz, R.J., Rosenberg, R., 2008. Spreading dead zones and consequences for marine ecosystems. *Science* 321, 926-929

Marra, J., Ho, C., Trees, C.C., 2003. *An Algorithm for the Calculation of Primary Productivity from Remote Sensing Data.* Lamont-Doherty Earth Obs., Palisades, New York. 27 p.

IPCC, 2007. Summary for Policymakers. In: Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M.M.B., Miller, H.L. Jr., Chen, Z. (eds.), *Climate Change 2007: The Physical Science Basis*, pp. 1-18. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Sarmiento, J.L., Slater, R., Barber, R., Bopp, L., Doney, S.C., Hirst, A.C., Kleypas, J., Matear, R., Mikolajewicz, U., Monfray, P., Soldatov, V., Spall, S.A., Stouffer, R., 2004. Response of ocean ecosystems to climate warming. *Global Biogeochemical Cycles* 18(3), GB3003.1-GB3004.23.

APPENDIX 9. MARINE TROPHIC INDEX

1. INDICATOR	
Indicator name	Marine Trophic Index
Category	State
Definition of indicator / Descriptor	Mean trophic level in the fisheries catches
Units of measurements	None
2. RELEVANCE	
Rationale for inclusion	When a fishery begins in a given area, it usually targets the largest among the accessible fish, which are also intrinsically most vulnerable to fishing (Pauly *et al*., 1998; Cheung *et al*., 2007). Once these are depleted, the fisheries then turn to less desirable, smaller fish. This pattern has been repeated innumerable times in the history of humankind (Jackson *et al*., 2001) and also since the 1950s, when landing statistics began to be collected systematically and globally by FAO. With a trophic level assigned to each of the species in the FAO landings data set, Pauly *et al*. (1998) were able to identify a worldwide decline in the trophic level of fish landings. This phenomenon, now widely known as 'fishing down marine food webs', has been since shown to be ubiquitous when investigated on a smaller scale. The Convention on Biological Diversity (CBD) adopted the mean trophic level of fisheries catch, which it renamed Marine Trophic Index (MTI) as one of eight biodiversity indicator for 'immediate testing' (CBD 2004, Pauly and Watson, 2005).
Significance for inter-linkages with other water systems	
Linkage with other indicators	Closely related to the Fishing-in-Balance (FiB) index, and should preferably be interpreted in connection with this index.
3. METHODOLOGY	
Description of measurement methods and calculation of the indicator	Trophic levels are assigned to all catches from a given area, typically based on information in FishBase or SeaLifeBase. The weighted TL of the catch is then calculated by weighting the species/group TL with the corresponding catch level.
Scale	Can be estimated for any given spatial scale. Analysis typically covers from 1950 to the present.
Limitations	• Diagnosing fishing down from the mean trophic level of landings is problematic as landings reflect abundances only crudely; • The trophic level (TL) is typically assumed constant for a given species/group, but may change over time, notably if the size of individuals in the catches change; • Changes in MTI may reflect spatial expansion of fisheries, which can cause temporary increases in the index.
4. ASSESSMENT OF DATA	
Data sources, availability and quality *(Existing datasets)*	Primarily based on catch data and trophic level estimates, typically from FishBase and SeaLifeBase.
Variations among data sources and alternative methods	As for FiB, see 11.

5. PARTNERS	
Partners/agencies involved in the development of the indicator	*Sea Around Us* project (Fisheries Centre, UBC), FishBase, SeaLifeBase and the Convention on Biological Diversity.

6. REFERENCES

CBD, 2004. Annex I, decision VII/30. The 2020 biodiversity target: a framework for implementation. Decisions from the Seventh Meeting of the Conference of the Parties of the Convention on Biological Diversity, Kuala Lumpur, 9–10 and 27 February 2004, pp. 351. Montreal: Secretariat of the CBD.

Cheung, W., Watson, R., Morato, T., Pitcher, T., Pauly, D., 2007. Change of intrinsic vulnerability in the global fish catch. *Marine Ecology Progress Series* 333, 1-12.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Cooke, R., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293, 629-638.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres Jr., F.C., 1998. Fishing down marine food webs. *Science* 279, 860-863.

Pauly, D., Watson, R., 2005. Background and interpretation of the 'Marine Trophic Index' as a measure of biodiversity. *Philosophical Transactions of the Royal Society: Biological Sciences* 360, 415-423.

Appendix 10. Fishing-in-Balance (FiB)

1. Indicator	
Indicator name	Fishing-in-Balance
Category	State
Definition of indicator / Descriptor	The FiB index is defined such that its value remains the same when a downward trend in mean trophic level is compensated for by an increase in the volume of 'catch', as should happen given the pyramidal nature of energy flows in ecosystems and the transfer efficiency of about 10% between trophic levels alluded to above (Pauly *et al.*, 2000). The index is scaled to the first year of the time series, and usually expressed on a log-scale so that the starting value is zero.
Units of measurements	None
2. Relevance	
Rationale for inclusion	Evaluates if a change in the Marine Trophic Index is balanced by a corresponding change in catch levels.
Significance for inter-linkages with other water systems	
Linkage with other indicators	Supplements the CBD Marine Trophic Index and should preferably be interpreted in connection with this index.
3. Methodology	
Description of measurement methods and calculation of the indicator	Calculation details are given above.
Scale	Can be estimated for any given spatial scale. Analysis typically covers from 1950 to the present.
Limitations	Similar to the Marine Trophic Index, with the added uncertainty caused by the assumption that the energy transfer efficiency of 10% between trophic levels. This assumption is based on the estimate of Pauly and Christensen (1995).
4. Assessment of Data	
Data sources, availability and quality *(Existing datasets)*	The index relies primarily on catch data, trophic levels typically from FishBase and SeaLifeBase, and an assumed trophic transfer efficiency of 10%.
Variations among data sources and alternative methods	
5. Partners	
Partners/agencies involved in the development of the indicator	*Sea Around Us* project, Fisheries Centre, University of British Columbia. FishBase, SeaLifeBase.
6. References	
Pauly, D., Christensen, V., 1995. Primary production required to sustain global fisheries. *Nature* 374: 255-257. Pauly, D., Christensen, V., Walters, C., 2000. Ecopath, Ecosim and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science* 57, 697-706.	

APPENDIX 11. LANDED VALUE OF FISHERIES

1. INDICATOR	
Indicator name	Value of fisheries landings.
Category	Pressure
Definition of indicator / Descriptor	Value of fisheries landings in year 2000 inflation-adjusted prices
Units of measurements	US$
2. RELEVANCE	
Rationale for inclusion	Fishing effort is one of the major stress factors for marine ecosystems, and effort is in turn directly influenced by the value of the landings.
Significance for inter-linkages with other water systems	N.A.
Linkage with other indicators	A (non-linear) function of fisheries landings.
3. METHODOLOGY	
Description of measurement methods and calculation of the indicator	Relies on a database of ex-vessel fish price, which is based on 1) observed prices in different countries at different times for different species; and 2) inferred prices, based on observed prices and an averaging algorithm which took taxonomic affinity, adjacency of countries and time into account (Sumaila *et al.*, 2007). The year-, species- and time-specific prices in the database where then adjusted for inflation to year 2000 real prices in US$, using consumer price index (CPI) data from the World Bank, and multiplied by the spatially allocated landings for the corresponding years and species (groups). This yielded time series of the value of fisheries landings in year 2000 inflation adjusted prices, which can be compared in time and space (Sumaila *et al.*, 2007), and which, in the aggregate, match, for example, estimates of the ex-vessel values of fisheries catches produced by the OECD.
Scale	Value for landings by groups/species by year.
Limitations	As observed prices were available for the most important commercial species, the inferred prices have little influence on the total value of landings.
4. ASSESSMENT OF DATA	
Data sources, availability and quality *(Existing datasets)*	Based on the global price database of Sumaila *et al.* (2007), made available through the *Sea Around Us* website (www.seaaroundus.org).
Variations among data sources and alternative methods	N.A.
5. PARTNERS	
Partners/agencies involved in the development of the indicator	*Sea Around Us* and Fisheries Economics Research Unit, Fisheries Centre, University of British Columbia.
6. REFERENCES	
Sumaila, U.R., Marsden, A.D., Watson, R., Pauly, D., 2007. A global ex-vessel price database: construction and applications. *Journal of Bioeconomics* 9, 39-51.	

Appendix 12. Fisheries subsidies

1. Indicator	
Indicator name	Subsidies
Category	Pressure
Definition of indicator / Descriptor	Fisheries subsidies are defined as government financial transfers to the fishing industry that serve to reduce the cost of fishing, e.g. fuel subsidies, or programs that artificially increase revenue to fishing enterprises, e.g. price support schemes.
Units of measurements	$ per year
2. Relevance	
Rationale for inclusion	Sumaila *et al.* (2010) estimates that fisheries subsidies total $25-30 billion USD per year or about a third of the global value of fisheries landings. Subsidies can drive fisheries to being unsustainable.
Significance for inter-linkages with other water systems	Of relevance anywhere where fishing occurs.
Linkage with other indicators	Impacts fisheries effort landings, value, cost, and employment.
3. Methodology	
Description of measurement methods and calculation of the indicator	Both quantitative and qualitative data regarding government financial transfers are collected and categorized as beneficial (management, R&D, MPAs), capacity-enhancing (vessel construction and modernization, fishery development projects, port expenditure, marketing and processing support, tax exemptions, access agreement, fuel), or ambiguous (fisheries assistance, decommissioning, community development) scale.
Scale	Subsidies to the fishing industry for all maritime countries/political entities of the world were reported by Sumaila and Pauly (2006) and Sumaila *et al.* (2010). Information collected in the database of fisheries subsidies spans the years 1990-2009. Output currently does not have a time component, but are standardized to one year.
Limitations	Where collected information is qualitative without supporting quantitative data, the subsidies values are treated as missing rather than as zero. This allows estimation of values for this missing data using a simple benefit-transfer approach (Sumaila *et al.*, 2010).
4. Assessment of Data	
Data sources, availability and quality *(Existing datasets)*	Government financial transfer (subsidy) data are obtained from an exhaustive list of sources including international organizations such as the Organization for Economic Cooperation and Development (OECD) and national statistical agencies. These data were augmented by information estimated by Sumaila *et al.* (2008) on fuel subsidies, and by Cullis-Suzuki and Pauly (2010), who estimated the costs of managing marine protected areas. The fisheries subsidy database is under continuous development.
Variations among data sources and alternative methods	N.A.

5. PARTNERS	
Partners/agencies involved in the development of the indicator	*Sea Around Us* project, Fisheries Centre, University of British Columbia

6. REFERENCES

Cullis-Suzuki, S., Pauly, D., 2010. Marine protected area costs as 'beneficial' fisheries subsidies: A global evaluation. *Coastal Management* 38(2), 113. doi:10.1080/08920751003633086.

Sumaila, U.R., Dyck, A.J., Huang, L., Watson, R. (in preparation a). Worldwide returns to fisheries management expenditure.

Sumaila, U.R., Khan, A.J., Dyck, A., Watson, R., Munro, G., Peter Tyedmers, Pauly, D., 2010. A bottom-up re-estimation of global fisheries subsidies. *Journal of Bioeconomics* 12, 201–225.

Sumaila, U.R., Pauly, D., Editors, 2006. Catching more bait: a bottom-up re-estimation of global fisheries subsidies. Fisheries Centre Research Reports 14(6), 114 p.

Sumaila, U. R., Teh, L., Watson, R., Tyedmers, P., Pauly, D., 2008. Fuel price increase, subsidies, overcapacity, and resource sustainability. *ICES Journal of Marine Science* 65(6), 832-840.

Appendix 13. Fisheries employment

1. Indicator	
Indicator name	Employment in fisheries
Category	Pressure/state
Definition of indicator / Descriptor	
Units of measurements	
2. Relevance	
Rationale for inclusion	The FAO estimates that there are 104 million participants in the primary, secondary, and ancillary sectors of both marine and inland fisheries in developing countries. Taking into account that developing countries make up about 75% of global fisheries employment, and that capture fisheries account for approximately three quarters of total fisheries employment, it is estimated that roughly 139 million people are involved in capture fisheries worldwide. Given that inland fisheries constitute a relatively large sector in the capture fisheries of some countries, this estimate is about 1.5 times higher than the FAO's. The addition of small-scale fishers increased participants in the primary sector by about 21%.
Significance for inter-linkages with other water systems	Fisheries are connected in notably lakes, rivers, estuaries, and coastal zones, especially through small-scale fisheries.
Linkage with other indicators	
3. Methodology	
Description of measurement methods and calculation of the indicator	Data on global fisheries employment were sourced from technical reports published by institutions such as FAO and the ILO, peer reviewed publications, as well as fisheries and agriculture departments of individual countries. Particular attention was paid to quantifying the number of small-scale and/or unlicensed fishers globally. To determine if small-scale fishing occurred, this involved assessing the fisheries characteristics of 144 maritime countries. First FAO Country Profiles were searched for indications of small-scale fishing, followed by peer reviewed literature and grey literature as necessary. Where small-scale fishing existed but no data were available, a Monte Carlo algorithm was used to estimate the number of small-scale fishers based on coastal population and proportion of population that fishes.
Scale	These data were initially reported by a pre-defined set of countries. These countries were then distributed to ½° cells around the world, and then aggregated to reporting areas.
Limitations	Describes situation for year 2000.
4. Assessment of Data	
Data sources, availability and quality *(Existing datasets)*	Available from Fisheries Economic Research Unit, Fisheries Centre, University of British Columbia, by country or aggregated to spatial zones.
Variations among data sources and alternative methods	
5. Partners	
Partners/agencies involved in the development of the indicator	*Sea Around Us* project and Fisheries Economics Research Unit of the University of British Columbia.
6. References	
Teh, L., Sumaila, U.R., 2011. Employment in marine fisheries: national, regional and global estimates. Christensen, V., Lai, S., Palomares, M.L.D., Zeller, D., Pauly, D. (eds.), *The State of Biodiversity and Fisheries in Regional Seas*, pp. 55-56, this volume.	

APPENDIX 14. FILE MAPPING

Most of the indicators described in this report were extracted globally and for each Regional Sea. The files for each Regional Sea are in numbered folders, each with the Regional Sea number in Figure 1 of Lai et al. (this volume). Within each regional sea folder, there are sub-folders with content as displayed in the table below.

Indicator Name	File folder	File Name
Bathymetry and habitat	BathymetricAndHabitat	Global-RS-BathymetricAndHabitat-Abyssal.csv + map.png Global-RS-BathymetricAndHabitat-Coral.csv + map.png Global-RS-BathymetricAndHabitat-Estuary.csv + map.png Global-RS-BathymetricAndHabitat-Shelf.csv + map.png Global-RS-BathymetricAndHabitat-Slope.csv + map.png Global-RS-BathymetricAndHabitat-Water_Area.csv + map.png Global-RS-BathymetricAndHabitat-Water_Volume.csv + map.png RS_XX-BathymetricAndHabitat-Abyssal-Map.png RS_XX-BathymetricAndHabitat-Coral-Map.png RS_XX-BathymetricAndHabitat-Estuary-Map.png RS_XX-BathymetricAndHabitat-Shelf-Map.png RS_XX-BathymetricAndHabitat-Slope-Map.png RS_XX-BathymetricAndHabitat-Water_Area-Map.png RS_XX-BathymetricAndHabitat-Water_Volume-Map.png
Average abundance	AverageAbundance	Global-RS-AverageAbundance-Macrobentho.csv + map.png Global-RS-AverageAbundance-Meiobenthos.csv + map.png Global-RS-AverageAbundance-Mesopelagics.csv + map.png Global-RS-AverageAbundance-Zooplankton.csv + map.png RS_XX-AverageAbundance-Macrobentho-Map.png RS_XX-AverageAbundance-Meiobenthos-Map.png RS_XX-AverageAbundance-Mesopelagics-Map.png RS_XX-AverageAbundance-Zooplankton-Map.png
Catch	Catch	Global-RS-Catch-BottomDisturbingCatchInPropOfTotalCatch.csv Global-RS-Catch-CatchTL.csv Global-RS-Catch-CatchTopPredatorsTotal.csv Global-RS-Catch-CatchTotal.csv Global-RS-Catch-FiB.csv Global-RS-Catch-PPR_total.csv RS_XX-Catch-Country.csv + (top 10 plot).png RS_XX-Catch-Gear.csv + (top 10 plot).png
Catch potential	CatchPotential	Global-RS-CatchPotential-AvgCatchCommitted2000.csv + map.png Global-RS-CatchPotential-AvgCatchCommitted2055.csv + map.png Global-RS-CatchPotential-AvgCatchSRESA1B2000.csv + map.png Global-RS-CatchPotential-AvgCatchSRESA1B2055.csv + map.png RS_XX-CatchPotential-AvgCatchCommitted2000-Map.png RS_XX-CatchPotential-AvgCatchCommitted2055-Map.png RS_XX-CatchPotential-AvgCatchSRESA1B2000-Map.png RS_XX-CatchPotential-AvgCatchSRESA1B2055-Map.png
Species diversity	SpeciesDiversity	Global-RS-SpeciesDiversity-Exploited_Species.csv + map.png RS_XX-SpeciesDiversity-Exploited Species-Map.png
Invasion, extirpation	InvasionExtinction	Global-RS-InvasionExtinction-Species_Invasion.csv + map.png Global-RS-InvasionExtinction-Species_Local_Extinction.csv + map.png RS_XX-InvasionExtinction-Species Invasion-Map.png RS_XX-InvasionExtinction-Species Local Extinction-Map.png
Jobs	Global/Jobs	Global-RS-Jobs-Total_Employment_2000.csv + map.png RS_XX-Jobs-Total_Employment_2000-Map.png
Landed value	LandedValue	Global-RS-LandedValue-CatchTotal.csv RS_XX-LandedValue-Country.csv + (top 10 plot).png RS_XX-LandedValue-Gear.csv + (top 10 plot).png
Marine mammals	MarineMammals	Global-RS-MarineMammals-Biomass_Mammals.csv RS_XX-MarineMammals-Biomass_Mammals.csv + (top 10 plot).png
Mercury	Mercury	Global-RS-Mercury-down_hg.csv + map.png Global-RS-Mercury-ionic_hg.csv + map.png Global-RS-Mercury-particulatehg.csv + map.png Global-RS-Mercury-up_hg.csv + map.png RS_XX-Mercury-down_hg-Map.png RS_XX-Mercury-ionic_hg-Map.png RS_XX-Mercury-particulatehg-Map.png RS_XX-Mercury-up_hg-Map.png

Indicator Name	File folder	File Name
Nutrient loading	NutrientLoading	(Global folder)NEWS_a30.csv (Global folder)NEWS_a50.csv (Global folder)NEWS_c00.csv (Global folder)NEWS_c70.csv (Global folder)NEWS_g30.csv (Global folder)NEWS_g50.csv (Global folder)NEWS_o30.csv (Global folder)NEWS_o50.csv (Global folder)NEWS_t30.csv (Global folder)NEWS_t50.csv RS_XX-NutrientLoading-DIN_plot.png RS_XX-NutrientLoading-DIP_plot.png RS_XX-NutrientLoading-DON_plot.png RS_XX-NutrientLoading-DOP_plot.png RS_XX-NutrientLoading-DSi_plot.png RS_XX-NutrientLoading-PN_plot.png RS_XX-NutrientLoading-PP_plot.png RS_XX-NutrientLoading-TN_plot.png RS_XX-NutrientLoading-TP_plot.png RS_XX-NutrientLoading-DIN_plot.png
Nitrogen Deposition	NitrogenDeposition	Global-RS-Nitrogen-NitrogenDeposition_1860.csv Global-RS-Nitrogen-NitrogenDeposition_1993.csv Global-RS-Nitrogen-NitrogenDeposition_2050.csv RS_XX-NitrogenDeposition-_Average_plot.png RS_XX-NitrogenDeposition-Nitrogen Deposition 1860-Map.png RS_XX-NitrogenDeposition-Nitrogen Deposition 1993-Map.png RS_XX-NitrogenDeposition-Nitrogen Deposition 2050-Map.png
Species Distribution	SpeciesDistribution	Global-RS-SpeciesDistribution-XXXXX.csv + map.png RS_XX-SpeciesDistribution-XXXXX-Map.png
Stock Status	StockStatus	RS_XX-StockStatus-Number of stocks by status (%).png RS_XX-StockStatus-Catch by stock status (%).png
Mari-culture	Mariculture	RS_XX-Mariculture-Mariculture.png RS_XX-Mariculture-Mariculture.csv
Sea-mounts	Sea Mounts	RS_seamount_count.txt RS_Seamounts.png RS_XX.png
Subsidies	Global/Subsidies	Global-RS-Subsidies-2003 US Dollars-Map.png Global-RS-Subsidies-Bad.csv Global-RS-Subsidies-Good.csv Global-RS-Subsidies-Total.csv Global-RS-Subsidies-Ugly.csv
Sea surface temperature	SeaSurfaceTemperature	Global-RS-SeaSurfaceTemperature-Annual_Average.csv Global-RS-SeaSurfaceTemperature-Annual_Maximum.csv Global-RS-SeaSurfaceTemperature-Annual_Minimum.csv Global-RS-SeaSurfaceTemperature-Summer_Average.csv Global-RS-SeaSurfaceTemperature-Summer_Maximum.csv Global-RS-SeaSurfaceTemperature-Summer_Minimum.csv Global-RS-SeaSurfaceTemperature-Winter_Average.csv Global-RS-SeaSurfaceTemperature-Winter_Maximum.csv Global-RS-SeaSurfaceTemperature-Winter_Minimum.csv RS_XX-SeaSurfaceTemperature-Summer_Average_plot.png RS_XX-SeaSurfaceTemperature-Winter_Average_plot.png RS_XX-SeaSurfaceTemperature-Annual_Average_plot.png
Eco- system Models	Global/EcoSystemIndicators	(GLOBAL FOLDER)FAOXXFIB.csv (GLOBAL FOLDER)FAOXXTLC.csv (GLOBAL FOLDER)FAOXXCatch.csv Global-FAO-EcoSystemIndicators-XX.png