

In the format provided by the authors and unedited.

Ending fishery overexploitation by expanding from local successes to globalized solutions

Yimin Ye*, Nicolas L. Gutierrez*

Fisheries and Aquaculture Department
The United Nations of Food and Agriculture Organization
00153 Rome, Italy

*Correspondence to: Yimin.Ye@fao.org or Nicolas.Gutierrez@fao.org

SI Guide

1. Landing vs. catches
2. Fishing capacity and effort
3. Stock status
4. Developed country fishing mortality and overfished stocks
5. Supplementary References

Supplementary Tables 1 to 3
Supplementary Figures 1-4

1. Landings vs. catches

Landings data were drawn from the latest 2015 release of the FAO fishery capture production database. Updates to these data are normally loaded in March each year and can be accessed using the FishStat Plus program publically available from the FAO¹.

FAO's catch data record nominal landings, i.e. weight of the whole and live animal. Processed catches are converted to live weight by the reporting countries or by FAO if reporting countries failed to do so. Following a recommendation of the CWP 16th Session, recreational catches are also included when available. Unfortunately, only a limited number of countries collect this information and submit it to FAO. In addition, data on discarded catches are not included in the FAO database as it covers only retained and landed catches. As estimated by Pauly and Zeller¹, reporting total catches, including discards, subsistence and recreational components may alter these figures. To understand the potential implications of analysing total removals instead of reported landings in our conclusions, we have compared FAO trends with Pauly and Zeller² reconstructed trends. Moreover, to compare patterns in catch and landings between developed and developing countries from both data series (instead of focusing on their magnitude), we have standardized catches and landings as $C_t/C_{\max}$ (where C_t is catch at year t and $C_{\max}$ is the maximum catch in the time series). Although Pauly and Zeller² total catch data shows a slight smaller gap between developed and developing countries, the trends still confirm our conclusions (Supplementary Figure 1). In addition, reconstructed catches from Pauly and Zeller² go up to 2010, while more up to date landings from FAO (up to 2013) show a greater gap between both country groups.

2. Fishing capacity and effort

The major datasets used in the estimation of global fishing effort are listed below:

- 1) FAO global handbook 1950 to 1967, which provides the annual gross registered tonnage at the country level, albeit for a limited number of countries and a restricted number of years;
- 2) FAO global fleet registrar 1970 to 1995, which provides a breakdown of the number of vessels, by country, year, gross registered tonnage and fishing gear;
- 3) FAO fleet registrar 1970 to 2012, which provides a breakdown of the number of vessels by country, year and length class;
- 4) EUROPA (<http://ec.europa.eu/fisheries/fleet/>): European Union vessel registrar. Accessed March 2015. Provides individual vessel statistics (tonnage, length, horsepower, activity periods, fishing gears and more) for all European Union member countries that have a marine fishing fleet;

- 5) EU effort database (<http://datacollection.jrc.ec.europa.eu/>). Accessed in September 2014. This database includes fleet demographics of European Union member countries including sea days and fishing days by length category and gear category from 2008 to 2011;
- 6) Tuna commissions: These include the International Commission for the Conservation of Atlantic Tunas (<http://www.iccat.es/en/>), the Indian Ocean Tuna Commission (www.iotc.org/), the Inter-American-Tropical-Tuna-Commission (www.iattc.org/Homeeng.htm), and the Western and Central Pacific Fisheries Commission (<https://www.wcpfc.int/>). These provide varying quantities of information on fleet statistics, effort, catch and the country in which the vessel is flagged, although the primary focus is on catch and effort.
- 7) CCAMLR (<https://www.ccamlr.org/>): Provides very detailed information on the 36 member and acceding countries that fish in Antarctic marine waters including fishing gear, vessel specifications and varying effort measures.

3. Stock status

3.1. RAM Legacy stock assessment database. The RAM Legacy Stock Assessment Database¹ is a global compilation of stock assessment results for commercially exploited marine populations. For each stock, the database contains data from the most recent available stock assessment from many jurisdictions, including NMFS, DFO, NAFO, ICES, Australia, New Zealand, Argentina, South Africa, and RFMOs. Specifically, it provides time series of biomass estimates relative to biomass reference points (B/B_{target} , as defined by B/B_{MSY} , SSB/SSB_{MSY} , or $SSB/SSB_{40\%}$) and landings for stock assessed fisheries spanning from 1950 to 2010. Most recent stock assessments were used from 2007 to 2015. From those 199 stocks, 74% were from developed countries, 11% from developing countries, and 15% managed under tuna RFMOs (Supplementary Table 1 and Table 2). By calculating the median B/B_{target} for developed and developing countries, we found stock status was 41% higher and the proportion of overexploited stocks (defined as biomass below target) 21% lower for developed countries when comparing to their developing counterpart. Although we acknowledge this is not a random sample of fish stocks from developed and developing countries, it constitutes the most quantitative and comprehensive stock status database accessible and widely used in fishery analyses globally.

3.2. Costello's approach to stock status. Building on published literature and technical reports, Costello *et al.*⁴ developed a multivariate regression approach to identify predictors of stock status (B/B_{MSY}) from assessed fisheries and use these models to estimate the status of unassessed fisheries. The authors couple the compilation of existing stock assessments to an extensive database of

characteristics of each unassessed fishery, such as time series of catch and fishery development and species' life history traits. This approach does not produce precise estimates for individual stocks or fisheries and therefore is not a substitute for formal assessment. However, it does provide a method for estimating the likely (or most likely) status of collections (including the global status) of previously unassessed stocks. To predict the status of unassessed fisheries, the authors compiled a companion database of 7721 marine fisheries from the FAO landings database. By analysing the resulting B/B_{MSY} estimates, Costello *et al.*⁴ found that those stocks lacking quantitative stock assessments and with small catches were in worse shape and declining faster than those stocks with stock assessment and large catches (Supplementary figure 3). These small stocks lacking quantitative stock assessments (and therefore not included in the RAM database) are typically used by small-scale or artisanal fisheries from developing countries. Costello *et al.*⁴ describe this methodology in details including caveats and limitations of the data and approach.

3.3. FAO's approach to stock status. Despite several ways of defining overfishing, the FAO stock status review focuses on biological overexploitation as it is the key reference point of most fishery-related international treaties⁵. FAO classifies stocks/species into three categories: non-fully exploited, fully exploited and overexploited. The criteria corresponding to each category are listed in FAO⁶. Relative Stock abundance is the fundamental attribute on which the three categories of stock status have been defined in the FAO's review⁴. Spawning potential, catch trend and size composition have been used together with other supplementary information when abundance (biomass) data are absent or believed unreliable. Classification of stock status has been undertaken by integrating all the sources of information available. Therefore, FAO⁴ provides a list of stocks together with their classification and main targeting countries. For the purpose of this analysis, stocks were divided in (i) stocks targeted by one or more developed countries ("developed") and (ii) stocks targeted only by developing countries ("developing"). Stocks targeted by a mix of developing and developed countries were aggregated in a third category ("mixed"). Supplementary figure 4 shows percentages of overexploited stocks per category, where the number of overfished stocks targeted by developing countries were 4% higher than those targeted by developed countries. See FAO⁴ for detail of the methodology used by FAO stock status classification.

4. Developed country fishing mortality and overfished stocks

For Figure 2, information on fishing mortality for European fisheries was obtained from the International Council for the Exploration of the Seas (ICES)⁷ and data on stock status

for US fisheries from the National Oceanographic and Atmospheric Administration (NOAA)⁸.

5. Supplementary references

1. Food and Agricultural Organization. Fishstat J – Software for fishery statistical time series (2015). www.fao.org/fishery/statistics/software/fishstatj/en.
2. Pauly, D & Zeller, D. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Comms*. **7**:10244 (2016).
3. Ricard, D., Minto, C., Jensen, O. P. & Baum, J. K. Examining the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. *Fish Fish*. **13**, 380-398 (2012).
4. Costello, C. *et al.* Status and solutions for the world's unassessed fisheries. *Science* **338**, 517-520 (2012).
5. Food and Agricultural Organization, “Code of Conduct for Responsible Fisheries” (FAO, Rome, 1995).
6. Food and Agricultural Organization of the United Nations. *Review of the state of world marine fishery resources* (FAO, Rome, 2011).
7. International Council for the Exploration of the Sea (ICES). (2015). <http://ices.dk/marine-data/tools/Pages/stock-assessment-graphs.aspx>
8. National Oceanographic and Atmospheric Administration (NOAA). (2015) http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/

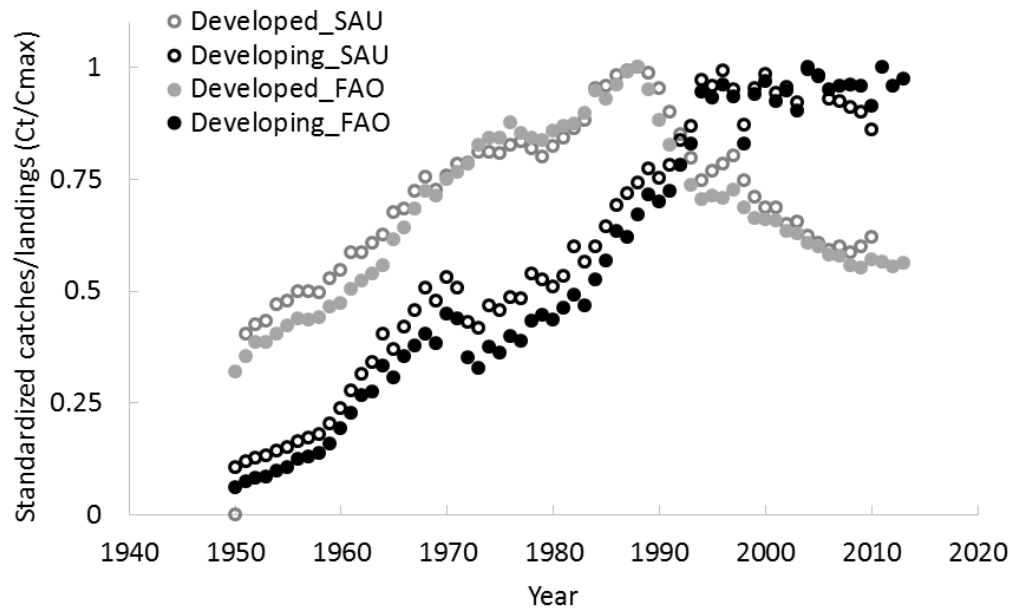
Supplementary Table 1. Fish stocks from the RAM database with information on stock status available (from 2007 to 2014)³. Accessed: <http://ramlegacy.marinebiodiversity.ca/ram-legacy-stock-assessment-database/downloads/ram-legacy-version-1.0-ms-excel> and <http://ramlegacy.org/database/>. See Excel file.

Supplementary Table 2. Median B/B_{target} (i.e., B/B_{MSY} , SSB/SSB_{target} or $B/B_{40\%}$), percentage of overexploited ($B/B_{\text{target}} < 1$), and total number stocks for developed and developing countries and those managed under tuna Regional Fisheries Management Organizations (t-RFMOs). Data from Supplementary Table 1.

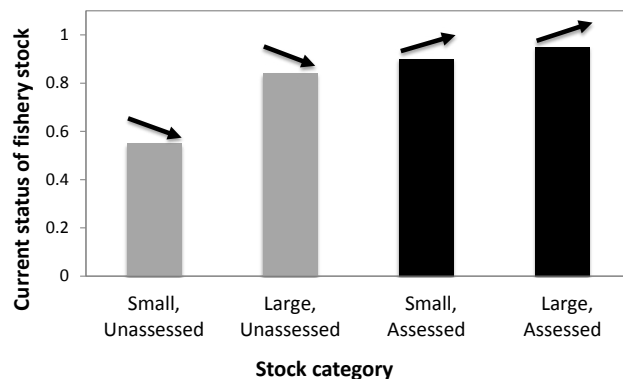
	Median B/B_{target}	Percentage of overexploited	Number of stocks
Developed	1.34	36%	148
Developing	0.79	57%	21
t-RFMOs	0.99	52%	31

Supplementary Table 3. Analysis of Variance for differences in stock status classification by Governance Index scores bins.

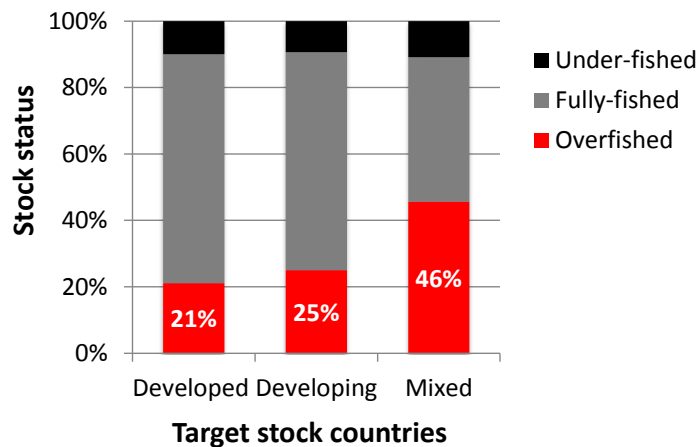
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Group	6	2.983	0.49719	2.4417	0.0257*
Residuals	275	55.996	0.20362		



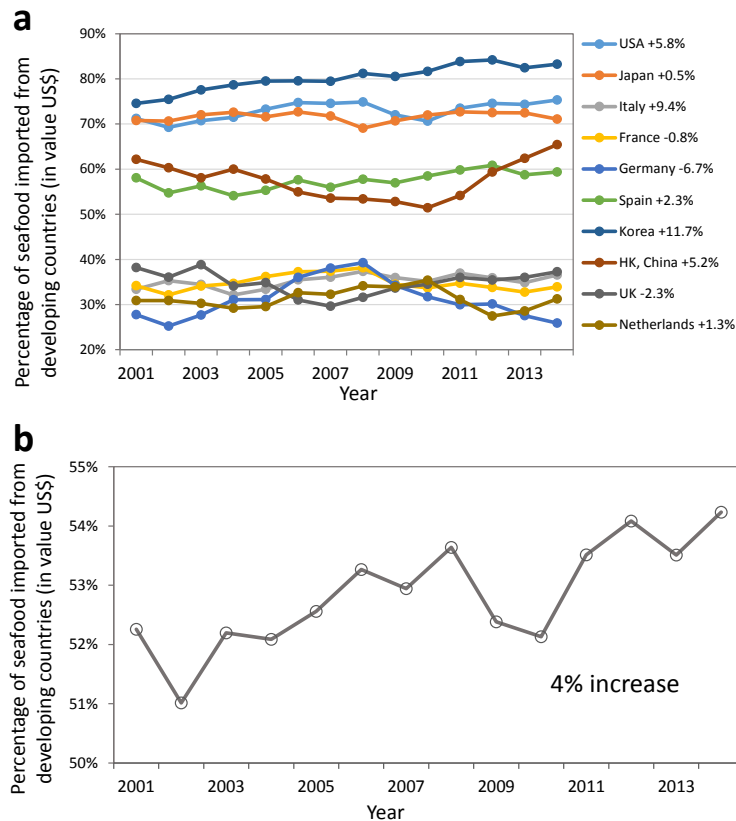
Supplementary Figure 1. Fishery patterns in landings₁ (filled circles) and total catches₁, including subsistence and small-scale (empty circles) discriminated by developed (black circles) and developing countries (grey circles).



Supplementary Figure 2. Stock status (B/B_{MSY}) and trends of small and large, assessed and unassessed fisheries worldwide. Both large and small unassessed fisheries are in worse shape than their assessed counterpart (bar heights) and show a decreasing trend in stock status (i.e., worsening; downwards arrows) whereas small and large assessed stocks are improving (upwards arrows). Modified from Costello et al.⁴.



Supplementary Figure 3. Proportion of overfished stocks targeted by only developing countries (21%; N=96) versus those targeted only by developed countries (25%; N=90) and by countries from both developed and developing world (Mixed; 46%, N= 92). Data from FAO6



Supplementary Figure 4. Proportion of imported seafood (in US dollars) coming from developing countries; (a) for the 10 top seafood importers (in value) accounting for 67% in value of global seafood imports; Numbers next to country name show % of seafood import increase from developing countries; (b) mean proportions of imports from developing countries for the top 10 countries showing an average increase of 4% since 2001. Notes: Sweden was excluded since it only imports 1% from developing countries. Germany has shown almost 7% decrease of imports from developing countries. China's exports due to outsourcing and processing were not discriminated in this analysis. Data: International Trade Centre.

<http://www.intracen.org/itc/market-info-tools/trade-statistics/>