

REG WATSON, U. RASHID SUMAILA, AND DIRK ZELLER

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How much fish is being extracted from the oceans and what is it worth?

Any analysis of the impacts of fishing on marine systems, as undertaken by the Sea Around Us project (www.seaaroundus.org), imposes critical demands on fine spatial data documenting the extraction of marine resources. Data sources such as those provided voluntarily from fishing countries through the Food and Agriculture Organization (FAO) of the United Nations are invaluable but have many limitations. Regional datasets are also important in that they provide better detail. Reconstruction of national datasets can also provide great insights into historical catch series (e.g., Zeller *et al.*, 2007), and are important to understand historic baselines (Jackson and Jacquet, this volume). These must be woven into one coherent and harmonized global dataset representing all extractions over time. To provide the necessary spatial detail, the global data are allocated to a fine grid of cells measuring just 30 by 30 minutes of latitude and longitude, resulting in over 180000 such cells covering the world's oceans. The taxonomic identity of the reported catch must be combined with comprehensive databases on where the species occur (and in what abundance) in order to complete this process. This spatial allocation must be further tempered by where countries fish, as not all coastal waters are available to all fleets. After considerable development by the Sea Around Us project, it is now possible to examine global catches and catch values in the necessary spatial context. Like detectives, we have been able to deduce who caught what, where, and when, and how much money they made in the process. Now we can see where fishing has impacted marine resources and examine many other problems such as the potential competition between the diets of marine predators and the insatiable demands of global fishing fleets and consumers.

A PROBLEM OF SCALE

To examine the impacts of fishing on the marine environment requires detailed information on what is caught and on how it is caught. Fisheries data sometimes come from the fishing industry on a voluntary basis but are largely obtained as part of the management controls placed on their operations, usually in response to concerns about the sustainability of catches. These data are collected for a variety of purposes. Sometimes they are quite specific, but often the burden of reporting on fisheries is claimed to interfere with their operations if the reporting process is too arduous and detailed. There are often concerns about confidentiality as fishing is a competitive industry and concerns about further restrictions on fishing have engendered much sensitivity about the end-use of this information. Access to these data, often reported in logbooks, some of which are now sophisticated electronic systems, is restricted and often impossible for outsiders to obtain. Nevertheless, generalized information, in which only average locations or total catches per year are reported, are often made available to the public through management agencies. We will talk about “catches” here when generally we mean “landings” – the fish products actually taken ashore and processed – and hence more completely included in the reporting process.

When dealing with questions about the impacts of fishing on global marine environments, the task of attempting to collect public domain data from individual management agencies can be daunting. Often the level of detail in public domain data is not sufficient, as it may not even include details as to where the catches were taken, much less what gear was used or what was discarded. Sometimes more detailed information is available under strict agreements with the agencies that collect the data, but these may also preclude publishing the details that come from the required analysis. Making and managing these arrangements globally would require many teams of multi-lingual experts and even legal advisors. Fortunately, there are other avenues.

Several major international organizations do publish summaries of fisheries catches. Notably these include regional organizations such as the International Council for the Exploration of the Sea (ICES) and the North East Atlantic Fisheries Commission. There are also summaries reported annually for catches by member countries of the United Nations produced by the Food and Agriculture Organization (FAO). The FAO has also established regional fisheries organizations such as

the Fishery Committee for the Eastern Central Atlantic, the General Fisheries Commission for the Mediterranean, and the Indian Ocean Fishery Commission. All of these, suitably harmonized into one non-overlapping dataset, are excellent sources for a complete summary of global catches, but there are several drawbacks for a project that wishes to look at the impacts of fishing on the marine environment.

The first is that the spatial scale is all wrong. Because the FAO's information is not collected for this purpose, it uses very large statistical reporting areas (see Figure 5.1) that generally exceed ecosystem scales (Watson *et al.*, 2003). Some statistics are available from the FAO's regional bodies at slightly smaller scales and are used when possible.

This mismatch in scale poses a significant problem. Much information is available at fine scales, yet is not readily available from management agencies. Other information is available publicly that covers most of the world's fisheries catches, but ironically exactly where the catches were taken is not known. In the worst case, the catch could have come anywhere from within an FAO statistical area in the southeast Pacific with an area of 48 000 000 km². This is hardly useful, as it spans many environmental areas, habitats, and national exclusive economic zones (EEZ). There are two approaches to deal with this dilemma. One is very time and resource intensive. This is catch reconstruction, and it must be applied country by country. This is described by Zeller *et al.* (2007) and Zeller and Pauly (2007), and is briefly summarized below. The other approach is to somehow provisionally work with the best of existing data. The question then becomes: how to credibly reverse-engineer the large-scale data into smaller reporting areas so that the potential impacts can be examined at ecosystem-relevant scales? Some detective work is required.

CATCH RECONSTRUCTION

As part of our investigations of the impacts of fishing on marine ecosystems, the Sea Around Us project undertakes "catch reconstructions" that aim to improve upon the data reported by countries. The aim is to estimate total catches, in contrast to officially reported landings, which are usually represented by the data reported by countries to the FAO. In many developing countries, catches related to small-scale artisanal and subsistence fisheries are either missing or under-represented in official fisheries statistics, while in developed countries, recreational and commercial under-reporting are often the missing components. Hence, extractions of marine resources are

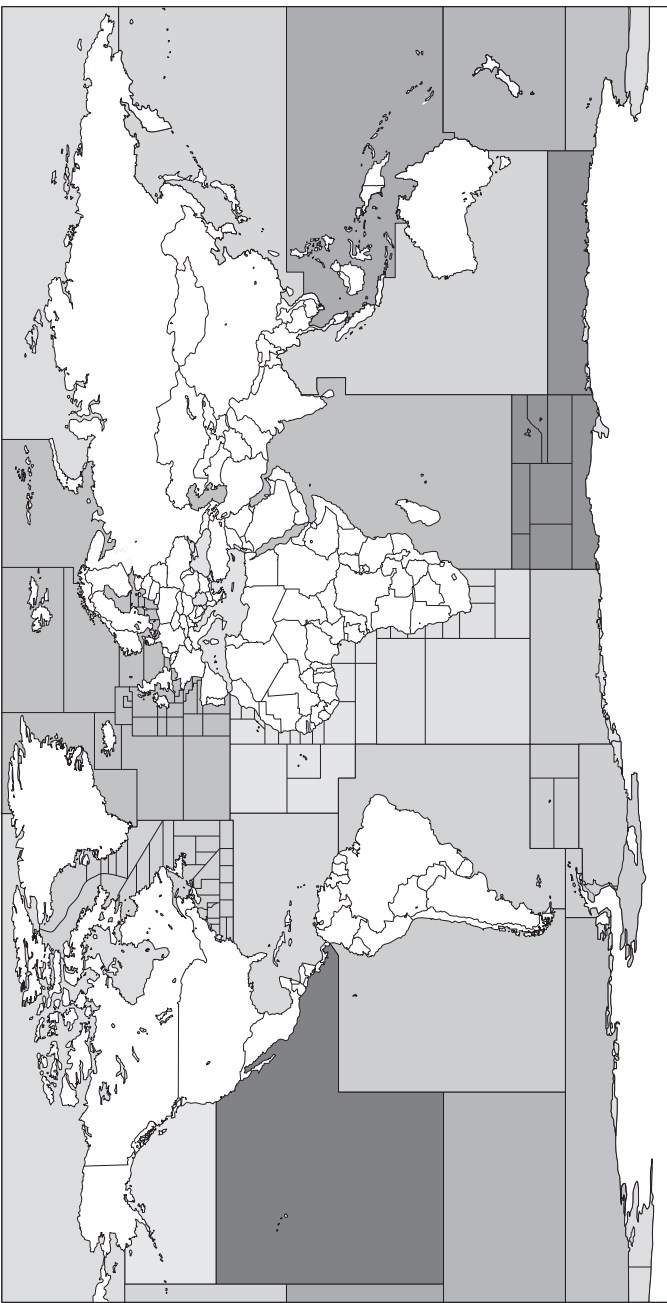


Figure 5.1 Major FAO catch reporting areas shown by shaded areas. Subdivision of these areas represents additional spatial detail available by using records from regional organizations.

usually underestimated in official statistics, as are their economic and social importance (Zeller *et al.*, 2006b). Various approaches can be conceived to retroactively estimate catches in cases where reliable time series data are lacking (Pauly, 1998). The approach used here applies a “re-estimation” methodology to approximate historic catch time series (Zeller *et al.*, 2006a, 2007). Such an approach typically requires assumption-based inferences and interpolations, but is justified, despite data uncertainties, given the less acceptable alternative outcome, namely that subsequent users of the available data will interpret non-reported or missing data as zero catches. Thus, our catch reconstruction approach consists of six general steps:

- (1) Identification of existing nationally reported catch time series, e.g., country-specific catch datasets, and comparison with the equivalent data as reported by the FAO on behalf of the country in question. This allows identification of data transfer efficiencies between national statistics departments and the FAO, and may help identify data uncertainties in the reported data;
- (2) Identification of fisheries sectors, time periods, species, gears, etc. not covered by (1), i.e., missing catch data, via literature searches and consultations;
- (3) Searches for available alternative information sources that contain additional data or qualitative information related to items identified in (2). This may involve extensive literature searches and consultations with local experts;
- (4) Development of data anchor points in time for missing data items, and their expansion to countrywide catch estimates;
- (5) Interpolation for time periods between data anchor points for missing data items; and
- (6) Estimation of final total catch time series for total catch, combining reported catches (1) and interpolated, countrywide expanded missing data series (5).

As countries differ in terms of fisheries sectors, their coverage of reported data, and available alternative information, this general approach has to be adjusted to each country situation, making this approach more resource and labor intensive. However, the final result is a “value-added” accounting that builds on the officially reported data as presented by the FAO on behalf of each country. The differences between estimates of total catch and reported landings vary considerably between cases, and currently range from essentially no missing data in the case of Cuba (Baisre *et al.*, 2003), a 30% underreporting by

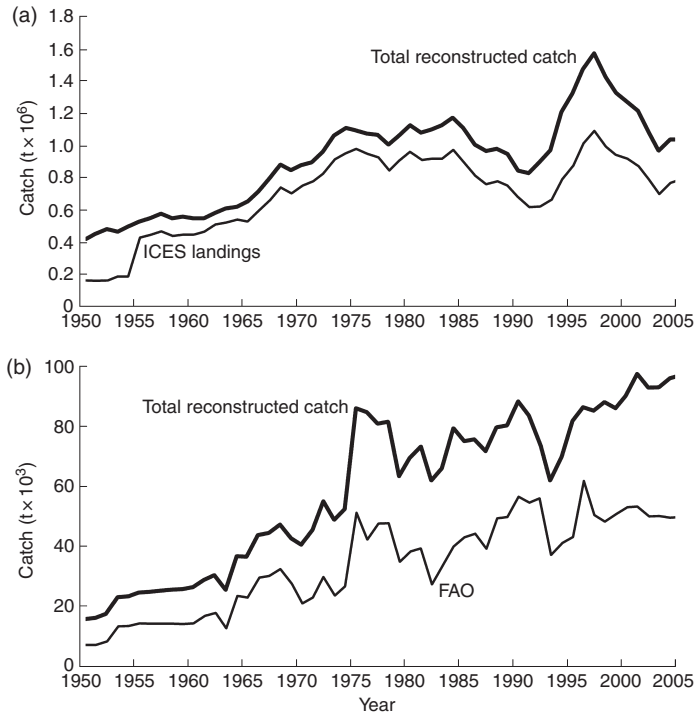


Figure 5.2 Total reconstructed catch (t) for (a) the nine Baltic Sea countries (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, and Sweden), being 30% higher than reported landings from the ICES catch statistics database, 1950–2007 (Source: Rossing *et al.* 2010); and (b) the United Republic of Tanzania compared to FAO reported catch, 1950–2005, indicating the missing data from Zanzibar. Source: Jacquet *et al.* (2010).

Baltic Sea countries (Figure 5.2a; Rossing, Booth, and Zeller, 2010), missing whole parts of (nationally recorded and reported) country data as in the case of Tanzania (Figure 5.2b, Jacquet *et al.*, 2010), or underreporting of total catches of 2–7-fold shown for US Pacific Island areas (Figure 5.3; Zeller *et al.*, 2007) or 60 times for Russian arctic fisheries (Pauly and Swartz, 2007).

As part of the continued development of the spatial catch database of the Sea Around Us project, we progressively substitute FAO country data with reconstructed datasets, which amend FAO data by the value-added components as derived through catch reconstruction.

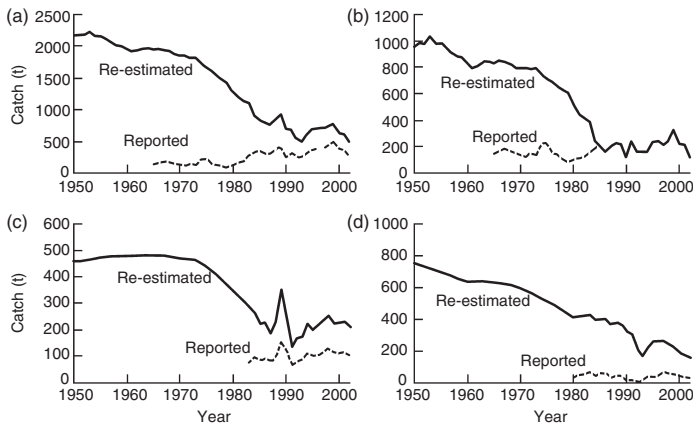


Figure 5.3 Reconstructed catches of small-scale fisheries for the major US flag island areas in the Western Pacific versus the officially reported statistics. Total re-estimated catches (a) summed over all the major US flag island areas of the Western Pacific considered here; (b) for Guam; (c) for the Commonwealth of the Northern Mariana Islands; and (d) for American Samoa. Source: Zeller *et al.* (2007).

WHERE WAS THE CATCH TAKEN?

If we accept that reported catches by the FAO and other bodies, and increasingly reconstructed catches, represent the bulk of catches by fishing countries, and if we further accept that it is reported accurately by statistical reporting areas, however large they may be, then what is required is a way of assigning the catch more accurately within those reporting areas. The first step that came to mind was that many of the records represent the catch of a taxon (usually a species), and that many of these have known limits to their ecological distributions. For example, Atlantic cod (*Gadus morhua*) has a well known global distribution (Figure 5.4), outside of which catches of this species are nonexistent. This would limit where cod could be taken realistically in the FAO's north-eastern and north-western Atlantic statistical reporting area. Though these limits were not documented well for many commercial species when the Sea Around Us project started, there were maps of distributions for several major commercial species of fishes produced by the FAO, and descriptions of ranges of many others available from FishBase (www.fishbase.org). It was necessary to refine these significantly, adding many more commercial species, especially invertebrate species. This became a major work in itself and has led to a range of

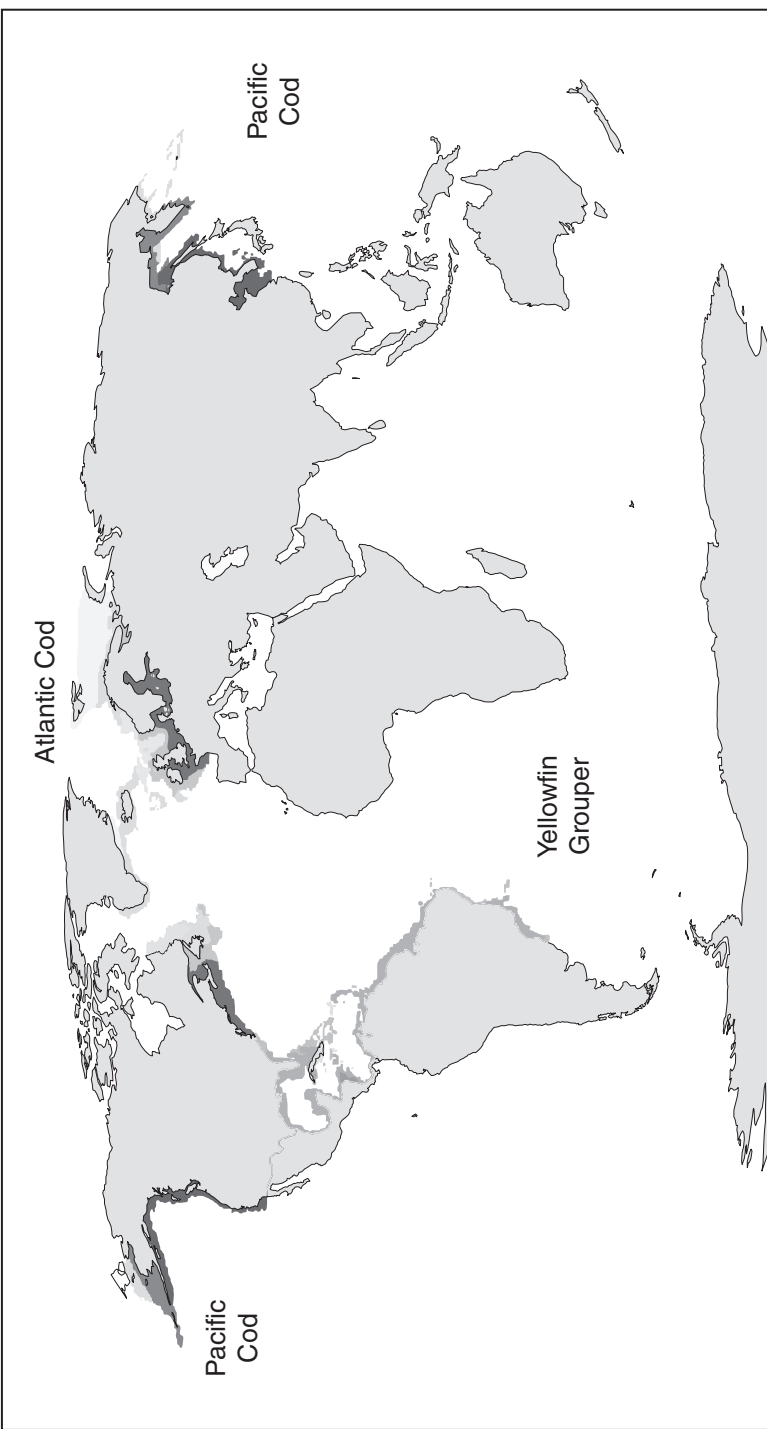


Figure 5.4 The global distributions of a few major commercial species such as are used in the allocation of catches to spatial cells.

publications (e.g., Close *et al.*, 2006), online pages (www.seaaroundus.org/topic/species/), and a body of knowledge that allows us to look at a variety of other research areas, including climate change (Cheung *et al.*, 2008, 2009)

The next important point about determining where a species could be caught is to recognize that fish are caught by fishing fleets, that most fishing is done in inshore and shelf waters currently claimed as national EEZs, and as such, usually requires some agreement to access the resource by other countries. The FAO had the makings of a database of fishing agreements, which we subsequently expanded. We also had to consider that many agreements were confidential or otherwise not documented, and that some fishing is done without agreement, i.e., illegally. Often agreements were for only certain types of fish, and sometimes there were quotas imposed. We had to include all information about fishing patterns. For example, if we did not find an agreement for country *x* to fish in the inshore waters of country *y*, then we may still find evidence of such occurrences through descriptions in trade magazines, etc. By studying where fishing fleets fish, whose waters they access, and when, it is possible to also greatly limit the possible areas where reported catch is taken.

There remains one persistent problem. Too often catches are reported only by vague groupings such as the highly aggregated group “Miscellaneous Marine Fishes” in the global statistics. Without knowing the taxonomic identity of species included, it is very hard to use information about specific distributions or even to use fishing agreements. Obviously more detective work is required.

WHAT KIND OF FISH IS THAT ANYWAY?

Since the beginning of the Sea Around Us project in 1999, we have made several attempts to “disaggregate” the highly aggregated reporting groups used by the FAO and others. Mostly, we deduce the identity of the mysterious individual taxa included in the aggregated group 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 are very conservative and require that candidates for the disaggregation process must be taxa that have been previously reported by the reporting country and/or by one of its nearest geographic neighbors. Though this approach does not introduce new taxa to regional catches, it does not necessarily always provide suitable candidates either. Sometimes we are still left wondering. Nevertheless,

with the identity of most catches deduced, it is then possible to use taxonomic distribution limits to effectively limit the possible catch areas for most species. Even more useful was the development of measures of habitat suitability within the taxonomic limits (Cheung *et al.*, 2007). For example, it was logical to conclude that many “reef” fishes normally require the presence of reef habitat, and that some areas are richer, and will hence support more abundance than other areas. Many species have a complex range of needs and these can be combined to sculpt gradients of likely abundance for most of them. Our project did much work collaborating with other groups to get detailed global maps of critical habitats such as coral reefs, seagrasses, and mangroves. This allows us to determine that more catch is likely to have come from some areas than others.

WHO IS REALLY FISHING?

It has become a common practice for some fishing companies to save money or increase fishing access by “reflagging” their vessels. This means that, although the vessels or company would normally be considered as nationality x, they flag their vessel as if it were from another country, a so-called “flag of convenience.” Many countries allow this practice but it causes confusion for fisheries managers and researchers alike. For example, it seems strange that the small nation of Belize would be fishing in European waters, until you determine that these are actually European vessels reflagged with the Belize flag. Determining the real identity of the fishing nation is important to work out which nation is actually getting the benefits from fishing, but more immediately, it is required to know how to apply our knowledge about which countries are allowed to fish where. Reversing the reflagging process is necessary to determine who is really fishing.

HOW WERE THEY FISHING?

Different types of fishing gear have widely varying characteristics. Some gear such as trawl gear has been implicated in much damage to bottom structures and habitats. Some use much more fuel than others. Knowing how the fish were caught can be important in trying to assess the likely impacts. Working with The Nature Conservancy, we were able to determine the common associations between the use of different types of fishing gears and their target species (Watson *et al.*, 2006a). These associations change from country to country, by region, and over

time. For example, trawling is more common now than it was in the 1950s. Using this information, we were able to associate catches with the likely gear used to catch it.

HOW MUCH IS IT WORTH?

It is important to determine what the value of the catch is because it motivates the fishing process and determines how decisions are made, and what benefits flow. The price of fish products varies greatly from country to country, by species of fish, and from year to year. Fish products are a true global commodity and are widely traded. Often the catch consumed in one country could have come from huge distances. A global ex-vessel price database was assembled from a wide range of international sources (Sumaila *et al.*, 2007; Sumaila *et al.*, this volume). Subsequently, a process was developed by our project to use this database to provide prices and landed values for all reported global catches.

GLOBAL CATCH DATABASE

A harmonized global catch database of over one million records is prepared from a wide range of data sources. Strictly speaking, the data presented are largely landings, as this database currently includes predominantly retained and landed catches. Increasingly, however, we are replacing reported landings with reconstructed total catch data to more comprehensively account for total extractions of marine resources. Global totals by major grouping per year (including tentative estimates of discards and illegal, unreported, and unregulated [IUU] catches) are shown in Figure 5.5a, while the landed values (in real US\$, adjusted for inflation to the year 2000) for the reported catches are shown in Figure 5.5b (excluding discards and IUU).

PUTTING IT ALL TOGETHER

The global catch database is used to allocate the tonnages (as well as landed values) reported to a system of 30-minute latitude by 30-minute longitude cells. These spatial cells were small enough to be used to look at the impacts of fishing in ecosystem models and in other analyses. The allocation process used the taxonomic identity of the catch (after the disaggregation process described earlier) to allocate catch to the system of spatial cells based on our taxonomic distributions. Information about fishing access and fishing patterns of reporting

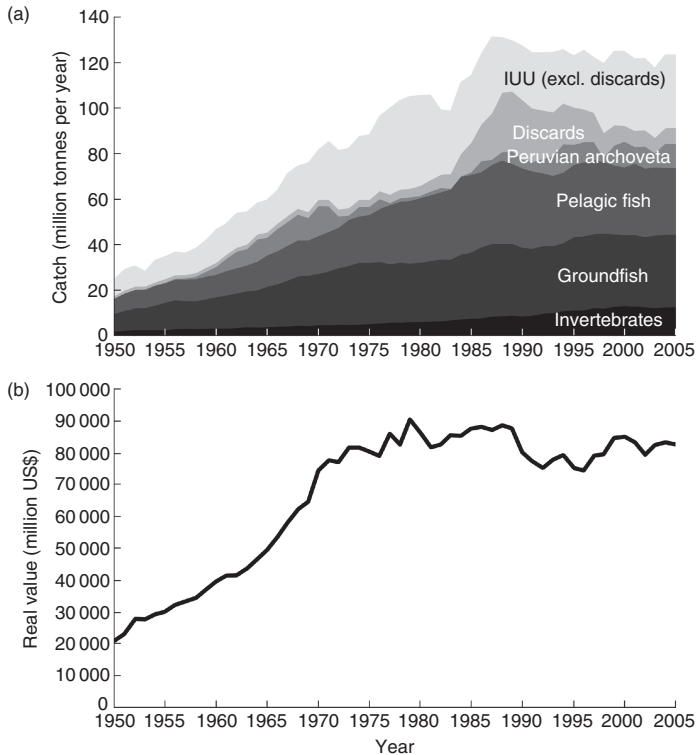


Figure 5.5 Time series of (a) global fisheries catches, adjusted for over-reporting by China (Watson and Pauly, 2001), and including estimates of discards (Zeller and Pauly, 2005) and IUU. Graph modified from Pauly *et al.* (2002). Note that the data for discards and IUU catches are tentative, but their values are likely to be considerable; and (b) real landed value in million US\$ (inflation adjusted to the year 2000) for reported global fisheries catches as determined by the Sea Around Us project (note that this excludes discards and IUU). These data are based on the global ex-vessel fish price database described in Sumaila *et al.* (2007).

countries was also used (sometimes after the effects of reflagging were removed) (Watson *et al.*, 2004). This process was successful, as it passed a test of self-consistency. Catches could have come only from the reporting areas, only from areas within this reporting area where the reported taxa are found, and only in locations where the country reporting it can fish. All reported catch was accounted for. Broadly speaking, the dominant pattern that emerges is one where inshore and rich upwelling areas supply most of the global catch (Figure 5.6). Our results also reflected other known patterns in fish catches such as



Figure 5.6 Global catches expressed as catch rates for each of more than 180 000 global spatial cells for 2001.

latitudinal gradients. With further work and collaboration, we estimated not only what catch was caught by which country in which spatial cells, but also how much fuel was used in the process (Tyedmers *et al.*, 2005), what gear was likely used (Watson *et al.*, 2006a), what the value of the catch taken was (Sumaila *et al.*, 2007), and how much discards (Zeller and Pauly, 2005) and IUU may likely add to total global catches. We make catch and landed value data taken in the waters of a country and large marine ecosystems widely available on our website (www.seaaroundus.org).

USES OF MAPPED CATCH

How are these mapped catch data used? They have led to maps showing where the use of destructive fishing gear types such as bottom trawl nets is expanding (Watson *et al.*, 2006b; Halpern *et al.*, 2008). They have been used to try to validate national statistics. For example, these data were instrumental in showing that there were problems with reporting of Chinese catches to the FAO, leading to distortions of world trends in catch data (Watson and Pauly, 2001). They have also been used to look at resource competition between fishing and marine mammals (Kaschner, 2004) and nesting seabirds (Kaschner *et al.*, 2007). They have allowed us to examine the ecological footprints of fishing activities (Sea Around Us, 2008), and to present and discuss the impacts of fisheries at the scale of large marine ecosystems (Pauly *et al.*, 2008). These data have facilitated the valuation of global marine resources (Sumaila *et al.*, 2007) and marine biodiversity (Worm *et al.*, 2006), and the impacts of overfishing (Srinivasan *et al.*, 2008). They serve as critical input data in ecological models examining fisheries-induced changes (Christensen *et al.*, 2003, 2009) and even play a role in predicting the likely impacts of global warming (Cheung *et al.*, 2009).

FUTURE IMPROVEMENTS

What is the future of catch mapping and how can its accuracy and usefulness be improved? The key to better mapping is undoubtedly better catch data. To accomplish this requires detailed catch reconstructions for reporting countries. This will not only allow more accurate representations of catch but it will greatly improve our knowledge of historical trends (Zeller *et al.*, 2006a, 2007). Often, catch reports for early periods were only grossly estimated. We also hope to have more comprehensive distribution maps for commercial species based on

improved mapping of critical habitats, such as seagrasses and mangroves. We are only beginning to have datasets that include catch that was obtained illegally or was discarded. In the future, we hope that the catch data will prove even more useful in addressing some of the major questions about marine resources such as the impacts of global warming. With more exposure of the products will hopefully come more opportunities to validate and improve the underlying databases and procedures. Work is underway to map global fishing effort, initially as independently as possible from that used to map catch – this will allow cross validation. Fishing catches cannot occur where fishing effort does not happen – moreover the catch rates will hopefully indicate broad trends in the biomass and health of commercial stocks. Assessing and evaluating human impact on global marine environments will always need accurate maps of where fishing occurs.

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