

CHAPTER 2

MARINE FISHERIES CATCH RECONSTRUCTION: DEFINITIONS, SOURCES, METHODS, AND CHALLENGES¹

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It is now well established that official fisheries catch data, for perfectly legitimate reasons, have historically ignored or underreported certain sectors (e.g., the subsistence or recreational sectors) as well as fisheries discards, notably because landing data were collected in many cases for purposes of taxation or the management of a small number of target species.

Nowadays, however, when fisheries need to be managed in the context of the ecosys-

tems in which they are embedded (Pikitch et al. 2004), less than full accounting for all withdrawals from marine ecosystems is insufficient. Therefore, this contribution is part of the effort documented in this atlas to provide a time series of all marine fisheries catches from 1950, the first year that the Food and Agriculture Organization of the United Nations (FAO) produced its annual compendium of global fisheries statistics to 2010, that is, 61 years with sharply contrasting economic, political, and environmental conditions.

What is covered here are catches in the waters within the Exclusive Economic Zones

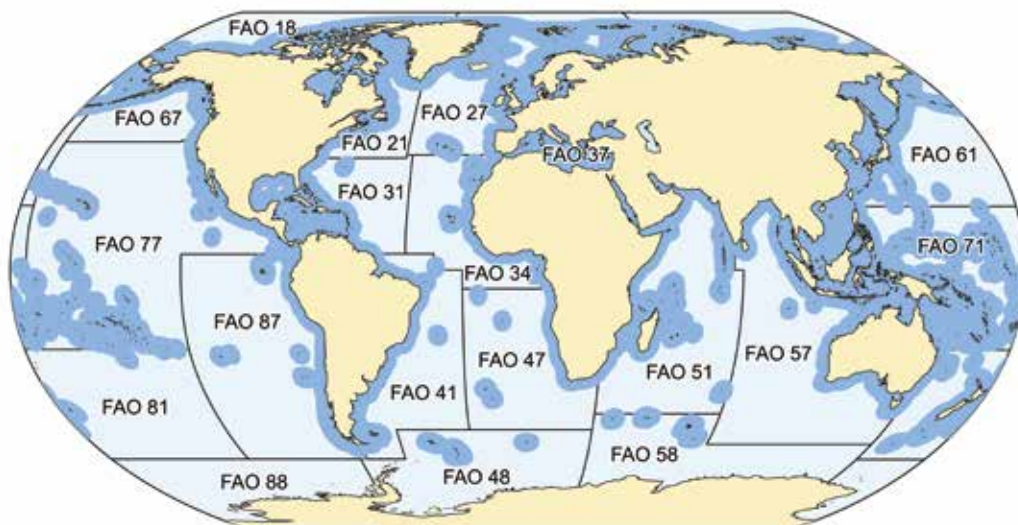


Figure 2.1. The extent and delimitation of countries' EEZs, as declared by individual countries or as defined by the *Sea Around Us* based on the fundamental principles outlined in UNCLOS (i.e., 200 nautical miles or midline rules), and the FAO statistical areas by which global catch statistics are reported. Note that for several FAO areas, some data exist by subareas as provided through regional organizations (e.g., International Council for the Exploration of the Sea [ICES] for FAO area 27). The *Sea Around Us* uses these spatially refined data to improve the spatial allocation of catch data, as described in chapter 5.

(EEZs, figure 2.1) that countries have claimed since they could do so under the United Nations Convention on the Law of the Sea (UNCLOS) or which they could claim under UNCLOS rules but have not (such as many countries around the Mediterranean). The delineations provided by the Flanders Marine Institute (see www.vliz.be and Claus et al. 2014) were used for our definitions of EEZs. Countries that have not formally claimed an EEZ were assigned EEZ-equivalent areas based on the basic principles of EEZs as outlined in UNCLOS (i.e., 200 nmi or midline rules). Note that we:

- Treat disputed zones (i.e., EEZ areas claimed by more than one country) as being owned by each claimant with respect to their fisheries catches, including the extravagant claims by one single country on large swaths of the open South China Sea.
- Treat EEZ areas before each country's year of EEZ declaration as "EEZ-equivalent waters" (with open access to all fishing countries during that time).

Therefore, this contribution deals with catches made in about 40% of the world ocean space, whereas the catches (mainly of tuna and other large pelagic fishes) made in the high seas, which cover the remaining 60%, are dealt with in chapter 3.

METHODS AND DEFINITIONS

The country-by-country fisheries catch reconstructions whose summaries form the core of this atlas are based on the rationale in Pauly (1998, and see chapter 1), as operationalized by Zeller et al. (2007, 2015). The former contribution asserted that there is no fishery with "no data" because fisheries, as social activities, throw a shadow onto the other sectors of the economy in which they are embedded, and it is always worse to put a value of zero (or the ubiquitous "no data" entry) for the catch of a poorly documented fishery than to estimate its catch, even roughly, because subsequent users of one's statistics will interpret the zeroes as "no catches" rather than "catches unknown" (see also Covey 2000).

Zeller et al. (2007) developed a six-step approach for implementing these concepts, as follows:

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

Since these six points were originally proposed, a seventh point has come to the fore that cannot be ignored (Zeller et al. 2015):

- 7 Quantifying the uncertainty associated with each reconstruction.

The first part of this contribution expands on each of these seven reconstruction steps, based on the experience accumulated during the last decade, when completing or guiding

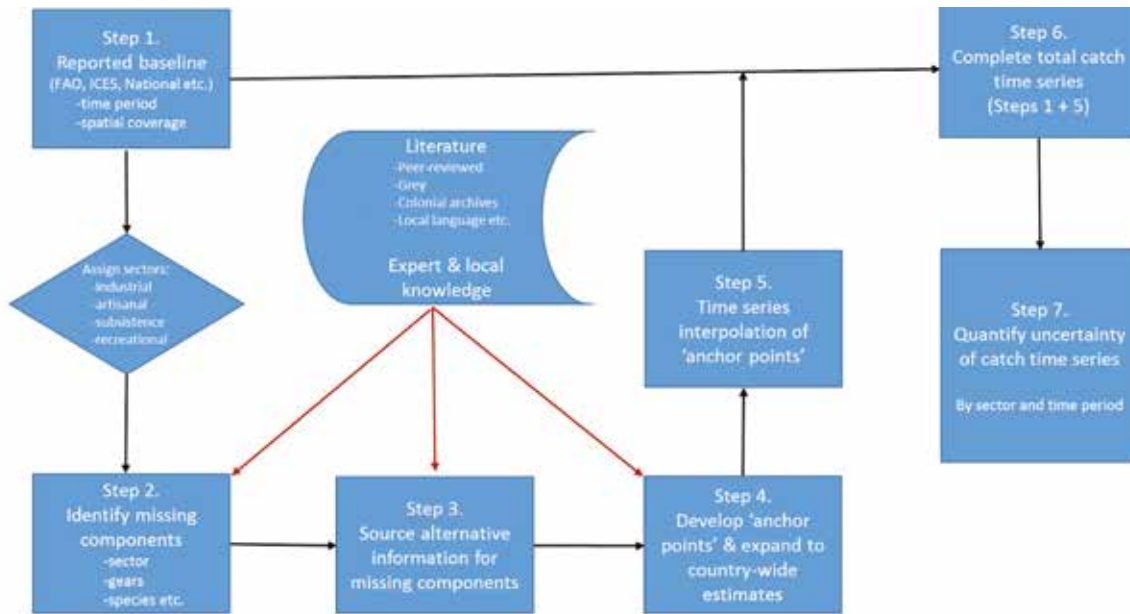


Figure 2.2. Conceptual representation of the 7-step catch reconstruction approach, as initially described in Zeller et al. (2007) and modified here and in Zeller et al. (2015).

the reconstructions that form the core of this atlas (see also figure 2.2 on next page).

Step 1: Identification, Sourcing, and Comparison of Existing, Reported Catch Time Series

Implicit in this first step is that the spatial entity that is to be reported on (e.g., EEZ of Germany in the Baltic Sea) be identified, delineated, and named, information that is not always obvious and posed serious problems to some of our external collaborators (box 2.1).

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

from truly domestic (national EEZ) fisheries (see chapter 5 for the spatial layering of reconstructed datasets).

For some countries, such as those resulting from the breakup of the USSR (Zeller and Rizzo 2007) and Yugoslavia (Rizzo and Zeller 2007), this involved using the post-breakup catch fractions to roughly split the pre-breakup catches reported for the USSR and Yugoslavia to generate approximations of the catch time series the newly emerged countries would have reported, had these countries already existed in 1950. In other words, we treat all countries recognized in 2010 (or acting like internationally recognized independent countries with regard to fisheries, e.g., the divided island of Cyprus; Ulman et al. 2015a) by the international community as having existed from 1950 to 2010. This was necessary, given our emphasis on “places,” that is, on time series of catches taken from specific ecosystems. This also applies to “overseas territories,” many of which were colonies and which have changed status and borders since 1950. Similar reassignments of former-USSR catches is also undertaken for the global tuna and large pelagic dataset (see chapter 3).

BOX 2.1. CATCH RECONSTRUCTIONS: THE CHALLENGES FOR AND OF LOCAL CO-AUTHORS

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Although we always intend for our catch reconstructions to assist them in their work, catch reconstructions are sometimes perceived as a challenge by the staff of national and international agencies that generates or report the catch data that are being thus corrected or complemented. These challenges often lead to noncooperation (e.g., on the part of ICES staff; see Zeller et al. 2011) and in several cases resulted in pressures on colleagues who started as co-authors but ended as anonymous informants (see Belhabib et al. 2012, Ulman et al. 2013).

In some other cases, it was necessary to make concessions regarding sensitive topics for colleagues to remain on board. Thus, the omission of an EEZ or “EEZ-equivalent waters” in the map on page 12 was not done inadvertently. Similarly, we had to create new geographic terms (e.g., “Central Morocco,” “South Morocco”; see pp. 335 and 337, respectively), and negotiate regarding the island of Cyprus, separated into “north” and “south” sides since 1974 (see pp. 234 and 235). Two prominent scientists from each side helped in identifying acceptable names, and *north* and *south* were finally agreed upon. In the process, it appeared that even placing an article such as *the* before *north* and *south* or adding the suffix *ern* to the end of *north* and *south* would have been unacceptable. Goodwill triumphed here, as it did in the pair of cross-citing papers (Abudaya et al. 2013; Edelist et al. 2013) presenting reconstructions for the Gaza Strip and Israel (see pp. 273 and 300). Similarly, a Syrian co-author of Ulman et al. (2015) shared his data and profound knowledge on the marine fisheries of his country and remained optimistic throughout multiple exchanges of e-mails, all while his country was engulfed in a horrific civil war. Also, having a (South) Korean team member allowed the catch reconstructions for North and South Korea to rely on information available only in Korean (Shon et al. 2014a, 2014b).

Globally, there were few country reconstructions without a local first or co-author or a first or co-author with field experience in the countries in question. These were mostly small island developing states in the Pacific and the Caribbean (e.g., Ramdeen et al. 2013; Zeller et al. 2015), usually with small catches.

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For several countries, the baseline was provided by other international bodies. In the case of EU countries, the baseline data originated from the International Council for the Exploration of the Sea (ICES), which maintains fisheries statistics by smaller statistical areas, as required by the Common Fisheries Policy of the EU, which largely ignores EEZs. A similar area is the Antarctic continent and surrounding islands, whose fisheries are managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), where catches (including discards, a unique feature of CCAMLR) are available by smaller statistical areas (see Ainley and Pauly 2014).

When FAO data are used, care is taken to maintain their assignment to different FAO statistical areas for each country (figure 2.1). The point here is that the FAO statistical areas often distinguish between strongly different ecosystems, such as the Caribbean Sea from the coast of the Eastern Central Pacific in the case of Panama, Costa Rica, Nicaragua, Honduras, and Guatemala.

Step 2: Identification of Missing Sectors, Taxa, and Gear

This step is one where the contribution of local co-authors and experts is crucial (box 2.1). Four fisheries sectors potentially occur in the marine fisheries of a given coastal country, with the distinction between large-scale and small-scale being the most important point (Pauly and Charles 2015):

Industrial sector, consisting of large motorized vessels, requiring large sums for their construction, maintenance, and operation, either domestically, in the waters of other countries or the high seas, and landing a catch that is overwhelmingly sold commercially (as opposed to being consumed or given away by the crew). All gears that are dragged or towed across the seafloor or intensively through the water column (e.g., bottom- and mid-water trawls), no matter the size of the vessel deploying the gear, are here considered *industrial*, following Martín (2012), as are large pirogues (e.g., from Senegal; Belhabib et al. 2014) and

“baby trawlers” (in the Philippines; Palomares and Pauly 2014) capable of long-distance fishing (i.e., in the EEZ of neighboring countries). Thus, the industrial sector can also be considered *large-scale and commercial* in nature.

Artisanal sector, consisting of small-scale (e.g., hand lines, gillnets) and fixed gears (e.g., weirs, traps) whose catch is predominantly sold commercially (notwithstanding a small fraction of this catch being consumed or given away by the crew). Our definition of artisanal fisheries relies also on adjacency: They are assumed to operate only in domestic waters (i.e., in their country’s EEZ). Within their EEZ, they are further limited to a coastal area to a maximum of 50 km from the coast or to 200 m depth, whichever comes first. This is the area we call the Inshore Fishing Area (IFA; see Chuenpagdee et al. 2006). Note that the definition of an IFA assumes the existence of a small-scale fishery, and thus unpopulated islands (e.g., Kerguelen; Palomares and Pauly 2011) have no IFA, although they may have fisheries in their EEZ (which by our definition are *industrial*). The artisanal sector is thus defined as *small-scale and commercial*. The other small-scale sectors we recognize are subsistence and recreational fisheries, which overlap in many countries.

Subsistence sector, consisting of fisheries that often are conducted by women for consumption by their own families (box 2.2) or by indigenous groups, though with much overlap with artisanal fisheries (box 2.3). Note that we also count as subsistence catch the fraction of the yield of mainly artisanal boats that is given away to the crews’ families or the local community (as occurs in the Red Sea fisheries; see Tesfamichael et al. 2012).

Recreational sector, consisting of fisheries conducted mainly for pleasure, although a fraction of the catch may end up being sold or consumed by the recreational fishers and their families and friends (Cisneros-Montemayor and Sumaila 2010). Unless data exist on catch-and-release mortalities in a given country, catch from recreational catch-and-release fisheries are not estimated. Often, fisheries

BOX 2.2. WOMEN IN FISHERIES: THE GENDER DIMENSION TO RECONSTRUCTING TOTAL CATCHES

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Both men and women participate in fishing activities, yet the contribution by women to the total catch is usually underestimated or ignored (Harper et al. 2013; Kleiber et al. 2015). Although it is mainly men who go out to sea to fish, women also fish, usually focusing on the gleaning and capture of invertebrates and small fish on reef flats and in shallow waters. The fishing activities of women, usually for subsistence purposes, are of crucial importance for household and communal food security (FAO 2013), yet they are the most neglected part of the sociopolitically marginalized small-scale fisheries sector (Pauly 2006). Moreover, in many countries women dominate postcapture activities, notably processing and marketing of fish and invertebrates, thus adding value to the catch. However, despite their substantial involvement in fisheries activities and contributions to the economy, women are often excluded from management and policy decisions of this resource (Bennett 2005).

This exclusion is intensified by the tendency of many countries to report to FAO and other international agencies only their catches of commercial and high-value species. Catch reconstructions, designed to correct for various kinds of bias in catch reporting, allow incorporation of the previously overlooked contributions by women, as in Senegal (Belhabib et al. 2014) or the Philippines (Palomares et al. 2014).

For most reconstructions, information on the contribution by women to the marine/estuarine catch in the countries in question was specifically sought, and quantitative estimates were included where available, or computed from proxies. This applied particularly to the small-island countries of the South Pacific (Zeller et al. 2015), where women are very involved in capture activities (Chapman 1987). Furthermore, the contribution by women was accounted for indirectly in the many instances where per capita seafood consumption rates were used in combination with coastal population data (including men, women, and children) to derive subsistence catch estimates. Although this inclusive approach probably accounts for some of the previously “invisible” catch components, the lack of reliable quantitative data on women in fisheries was a major limitation to being able to account fully and in all countries for their contribution to catches. Thus, the contribution by women to fisheries is probably substantial and plays a crucial role in food and income security in fishing communities the world over.

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BOX 2.3. INDIGENOUS MARINE FISHERIES: A GLOBAL PERSPECTIVE

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Indigenous groups around the world include some 370 million people, 5% of the global population, but many live in precarious social and ecological conditions (UN-DESA 2009). For marine coastal indigenous groups, ocean resources are vital to their food security and the maintenance of their cultural heritage, and competition with other user groups has historically been a source of conflict. In the modern context, ecological and political pressures affect fisheries dynamics and governance among indigenous groups that are often already marginalized (see Pruner 2005) but exposed to global market and environmental changes. Moreover, the ongoing growth in users and alternative uses of ocean space has increased the literal and figurative confinement of coastal indigenous groups, jeopardizing their ability to continue fishing and, by proxy, maintaining their cultural identity.

Here, we briefly document an ongoing effort to provide a view of the global scale of the marine fisheries conducted by coastal indigenous people, such as the Haida of northern British Columbia and southern Alaska (Breinig 2001) or the Torres Strait Islanders, Australia (Johannes and MacFarlane 1991). We estimated their current number at around 29 million people in 1,800 distinct communities and 600 unique groups in 80 countries and all continents except Antarctica.

Based on fish catch and consumption data available for 12% of all groups, we estimated that the coastal indigenous peoples currently catch a total of around 1.6 million tonnes per year exclusively for subsistence needs, corresponding to 2% of the global officially reported catch (see chapter 14). The use of group-specific consumption data is crucial to an adequate estimation, because coastal indigenous groups on average consume more than three and up to twenty times as much fish as the other groups in their respective countries. Moreover, subsistence catch is only one component of indigenous fisheries; current data suggest that around 70% of total indigenous catch is sold commercially.

Details on fisheries by the coastal indigenous groups are available from www.seararoundus.org. We hope that this information will contribute to a wider appreciation of the crucial role of fisheries in the food security and culture of coastal indigenous people.

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that started out as subsistence (e.g., in the 1950s) changed progressively into recreational fisheries as economic development increased in a given country and its cash economy grew.

Finally, for all countries and territories, we account for *discards*, here treated as “catch type” (and contrasted to “catch type” *retained landings*), which originate mainly from industrial fisheries for the years 1950 to 2010. Discarded fish and invertebrates are generally assumed to be dead, except for the U.S. fisheries, where the fraction of fish and invertebrates report-

edly surviving is generally available on a per species basis (McCrea-Strub 2015). Because of a distinct lack of global coverage of information, we do not account for so-called underwater discards, or net-mortality of fishing gears (e.g., Rahikainen et al. 2004). We also do not address mortality caused by ghost-fishing of abandoned or lost fishing gear (Bullimore et al. 2001; He 2006; Renchen et al. 2010), even though it can be substantial, for example, about 4% of trap-caught crabs worldwide (Poon 2005).

Furthermore, we exclude from consideration all catches of marine mammals, reptiles, corals, sponges, and marine plants (the bulk of the plant material is primarily used not for human consumption but rather for cosmetic or pharmaceutical use). In addition, we do not estimate catches made for the aquarium trade, which can be substantial in some areas in terms of number of individuals but small in overall tonnage, because most aquarium fish are small or juvenile specimens (Rhyne et al. 2012). Note that at least one regional organization (the Secretariat of the Pacific

Community, SPC) is coordinating the tracking of catches and exports of Pacific island countries involved in this trade (see Wabnitz and Nahacky 2014). Finally, we do not explicitly address catches destined for the Live Reef Fish Trade (LRFT; see Warren-Rhodes et al. 2003), although, given that these fisheries are often part of normal commercial operations, the catch tonnages of the LRFT are assumed to be addressed in our estimates of commercial catches. Our subsequent estimates of landed value of catches using the global ex-vessel fish price database (Sumaila et al. 2007; Swartz et

BOX 2.4. WEIRS AND THE GROUND “TRUTH” IN THE PERSIAN GULF

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Catch reconstruction requires accounting for all catches, by all gears. In the countries around the Persian Gulf, weirs (or stake nets; *hadrah* in Arabic) made of wooden poles, which are perpendicular to the coast, are generally not properly accounted for and their catch not included in official statistics. However, *hadrah* are visible from space and thus can be accounted for using Google Earth by combining counts (corrected for low visibility and occasional low map resolution) with scattered reports on their daily catches and fishing season duration to estimate their annual catch from the Gulf (Al-Abdulrazzak and Pauly 2014a). These results, which provided the first example of fisheries catch estimates from space, speak to the potential of satellite technologies for monitoring fisheries remotely, including illegal ones, as some observed *hadrah* were found operating in areas where they are banned, such as Qatar.

It is surprising that these obvious results should have inspired a critical response. However, Garibaldi et al. (2014) criticized the methods on which they were based and, in particular, attempted to show that the *hadrah* that were only partly visible (e.g., because of sea surface glare) were derelict and should not have been counted. Unfortunately for them, the two examples of “derelict *hadrah*” they provided were a *maskar* in one case [i.e., a different type of trap built of stones parallel to the coast and explicitly excluded from consideration by Al-Abdulrazzak and Pauly (2014a)] and an anchorage in the other case, built by the senior author’s father in shallow waters in front of her family’s house on the coast of Kuwait (Al-Abdulrazzak and Pauly 2014b).

Several lessons can be learned from this comedy of errors: Ground truthing requires nuanced expertise about a given area, which is not acquired simply by working for an organization with a mandate that happens to include the area in question; critiques alleging that things are “more complicated” (without quantifying the omitted factors and demonstrating that their omission distorts the results in question) do not advance science (see also Cheung et al. 2013); and using Google Earth can advance our knowledge of fisheries.

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al. 2013) will therefore undervalue the catch of any taxa destined directly to the LRFT. All the data omissions indicated above are additional factors why our reconstructed total catches are a conservative metric of the impacts of fishing on the world's marine ecosystems.

For any country or territory we check whether catches originating from the above four fishing sectors are included in the reported baseline of catch data, notably by examining their taxonomic composition and any metadata.

The absence of a taxon known to be caught in a country or territory from the baseline data (e.g., cockles gleaned by women on the shore of an estuary; see box 2.2) can also be used to identify a fishery that has been overlooked in the official data collection scheme, as can the absence of reef fishes in the coastal data of a Pacific island state (Zeller et al. 2015). However, to avoid double counting, tuna and other large pelagic fishes, unless known to be caught by a local small-scale fishery (and thus not likely to be reported to a regional fisheries management organization [RFMO]), are not included in this reconstruction step (industrial large pelagic catches are reconstructed using a global approach; see chapter 3).

Finally, if gears are identified in national data or information sources, but a gear known to exist in a given country is not included, then it can be assumed that its catch has been missed, as documented by Al-Abdulrazzak and Pauly (2013) for weirs in the Persian Gulf (see also box 2.4).

Step 3: Sourcing of Available Alternative Information Sources for Missing Data

The major initial source of information for catch reconstructions is governments' (and specifically their Department of Fisheries or equivalent agency) websites and publications, both online and in hard copies. Contrary to what could be expected, it is sometimes not the agency or staff responsible for collecting fisheries data that supplies the catch statistics to FAO but other agencies or staff, such as a statistical office or staff, with the result that

much of the granularity of the original data (i.e., catch by sector, by species or by gear) is lost before it reaches Rome. Furthermore, the data request form sent by FAO each year to each country does not actively encourage improvements or changes in taxonomic composition, because the form (an Excel spreadsheet) contains the country's previous years' data in the same composition as submitted in earlier years and requests the most recent year's data. This encourages the pooling of detailed data at the national level into the taxonomic categories inherited through earlier (often decades old) FAO reporting schemes (e.g., Bermuda; Luckhurst et al. 2003). Thus, if we get back to the original data, much of the original granularity can be regained during reconstructions (e.g., Bermuda reconstruction; Teh et al. 2014). A second major source of information on national catches is international research organizations such as FAO, ICES, or SPC, an RFMO such as the Northwest Atlantic Fisheries Organization or CCAMLR (Cullis-Suzuki and Pauly 2010), or current or past regional fisheries development or management projects (many of them launched and supported by FAO), such as the Bay of Bengal Large Marine Ecosystem (BOBLME) Project. All these organizations and projects issue reports and publications describing, sometimes in great detail, the fisheries of their member countries. Another source of information is obviously the academic literature, now widely accessible through Google Scholar.

A good source of information for the earlier decades (especially the 1950s and 1960s) for countries that formerly were part of colonial empires (especially British or French) are the colonial archives in London (British Colonial Office), as well as the Archives Nationales d'Outre-Mer in Aix-en-Provence, and the publications of the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), for the former French colonies. A further good source of information and data is also nonfishery sources, including household or nutritional surveys, which can be of great use for estimating unreported subsistence catches

BOX 2.5. RECONSTRUCTING SUBSISTENCE FISH CATCH, WITH EMPHASIS ON SOUTHEAST ASIA

Lydia Teh, *Sea Around Us*, University of British Columbia, Vancouver, Canada

Subsistence fishing is fishing with the primary intent of meeting household nutritional needs, as opposed to artisanal (small-scale commercial) fishing, where the primary driver of fishing is the sale of catch for profit (Schumann and Macinko 2007). As it does in most of the world, subsistence fishing occurs throughout Southeast Asia, where it is a traditional source of animal protein for coastal communities (see Firth 1966). However, it tends to be unmonitored and unmanaged throughout most of the region. Consequently, subsistence catches are underrepresented in fisheries statistics kept by national agencies (de Graaf et al. 2011).

The estimation of subsistence catches, which is often gleaned by women and children (see box 2.2), commonly uses one of two methods. One is to estimate total fish consumption in coastal areas, on the assumption that subsistence fishers catch a given fraction of the seafood consumed by the coastal population. Temporal trends in coastal populations can be derived from international databases, whereas fish consumption rates rely on the availability of household socioeconomic surveys or nutritional studies, which are typically harder to find.

The other approach estimates subsistence catch on the basis of the fishing population and catch rates (see Palomares et al. 2014). Anthropological studies on fishing livelihoods can also provide valuable insight on who was fishing, the type of fish that fishers were catching, and the disposition of the catch (Firth 1966; Elliston 1967). They can also be used to infer the composition of reconstructed subsistence catches, which, besides small fishes, often consists of snails, octopus, crabs, and sea urchins and are hardly ever included in official fisheries statistics.

Understanding the social context of fishing is essential for reconstructing subsistence catches, because political, social, and economic conditions affect what and how subsistence fishers operate. Thus, in Vietnam and Cambodia, fishing activities, including for subsistence, were reduced in the 1970s due to war, whereas in Sabah, Malaysia, fishing intensity rose in the 1980s when refugees from the Philippines settled in Sabah's many remote islands and started to earn their livelihood from fishing (Teh et al. 2009). Although subsistence catch is sometimes small, it is important for food security at local scales and thus ought to be accounted for in national fisheries statistics.

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(box 2.5). We find the Aquatic Sciences and Fisheries Abstracts and the University of British Columbia library services (and especially its experienced librarians) and its Interlibrary Exchange invaluable for tracking and acquiring such older documents.

Our global network of local collaborators is also crucial in this respect, because they have access to key datasets, publications, and local knowledge not available elsewhere (box 2.1), often in languages other than English (see below).

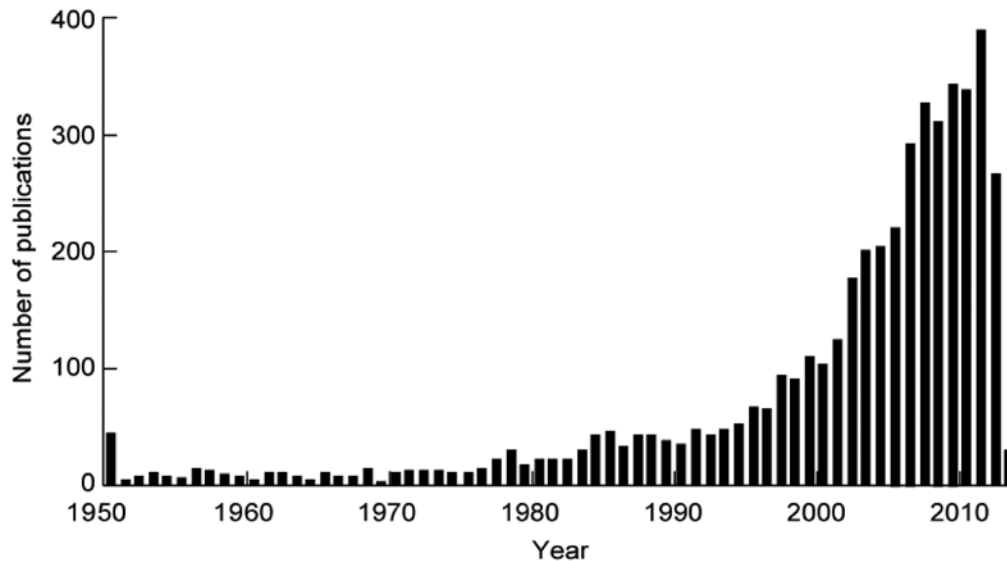


Figure 2.3. Number of publications (scientific and gray literature) and their publication dates used for 110 of the 270 country/territory catch reconstructions presented here. A total of 4,000 publications (excluding personal communications and online sources) were consulted for the 110 reconstructions, resulting in an average of 36 publications being used per reconstruction. The elevated number for 1950 is due to pooling of material dated before 1950 (as far back as the early twentieth or even late nineteenth century) that was used to inform 1950 anchor point information.

Figure 2.3 shows a plot of the publications used for and cited in 110 of the 273 country/territory catch reconstructions presented on pp. 185 to 457 of the atlas against their date of publication. Although recent publications predominate overall, older publications firmly anchor the 1950s catch estimates of many reconstructions. Note also that the data in figure 2.3 imply the use of, on average, about thirty-six publications per reconstruction (not counting online sources and personal communications, including orally provided information, e.g., via interviews or meetings, cited in the text of catch reconstruction reports). Although further details on sources are given in boxes 2.1–2.5, the reconstructions themselves should be consulted for fine-grained information on specific countries or territories. Every reconstruction we undertook is thoroughly documented and published, either in the peer-reviewed scientific literature (e.g., Zeller et al. 2011a, 2011b, 2015; Le Manach et al. 2012), as detailed technical reports in the publicly accessible and search engine-indexed Fisheries Centre Research Reports series (e.g., Zeller and Harper 2009; Harper and Zeller 2011; Harper et al. 2012) or the Fisheries Centre

Working Paper series (e.g., Miller and Zeller 2013; Nunoo et al. 2014; Persson et al. 2014; Divovich et al. 2015a), or as reports issued by regional organizations (e.g., BOBLME 2011).

We use this opportunity to mention the issue of language. Some fisheries research groups behave as if something that is not published in English does not exist, and thus they add to the widespread misperception that “there are no data.” We take this language bias very seriously in the *Sea Around Us*, which, besides team members who read Chinese, also has or had others who speak Arabic, Danish, Filipino/Tagalog, French, German, Hindi, Japanese, Portuguese, Russian, Spanish, Swedish, and Turkish. To deal with languages none of us master, we hired research assistants who spoke those languages, and we relied on our multilingual network of colleagues and friends throughout the world. Although it is true that English has become the undisputed language of science (Gordin 2015), other languages are used by billions of people, and one cannot assemble knowledge about the fisheries of the world without the willingness and capacity to explore the literature in languages other than English.

Step 4: Development and Expansion of Anchor Points

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

Step 5: Interpolation for Time Periods between Anchor Points

As a social activity involving multiple actors, fishing is very difficult to govern; in particular, fishing effort is difficult to reduce, at least in the short term. Thus, if anchor points are available for years separated by multiyear intervals, it will usually be more reasonable to assume that the underlying fishing activity went on in the intervening years with no data. Strangely enough, our continuity assumption is something that some colleagues are reluctant to make, which is why the catches of, say, small-scale fisheries monitored intermittently, often have jagged time series of reported catches. Exceptions to such continuity assumptions are obvious major environmental impacts such as hurricanes or tsunamis (e.g., cyclones Ofa and Val in 1990–1991 in Samoa; Lingard et al. 2012; hurricane Hugo in 1989 in Montserrat; Ramdeen et al. 2012) or major sociopolitical disturbances, such as military conflicts (e.g., 1989–2003 Liberian civil war; Belhabib et al. 2013), which we explicitly consider with regard to raising factors and the structure of time series. In such cases, our reconstruc-

tions mark the event through a temporary change (e.g., decline) in the catch time series (documented in the text of each catch reconstruction), if only to give pointers for future research on the relationship between fishery catches and natural catastrophes or conflicts. As an aside, we note here that the absence of such a signal in the officially reported catch statistics (e.g., a reduction in catch for a year or two) in countries having experienced a major event of this sort (e.g., cyclone Nargis in 2008 in Myanmar) is a sure sign that their official catch data are manufactured, without reference to what occurs on the ground (see also Jerven 2013). Overall, our reconstructions assume—when no information to the contrary is available—that commercial catches (i.e., industrial and artisanal) between anchor points can be linearly interpolated, whereas for noncommercial catches (i.e., subsistence and recreational), we generally use the fisher population trends over time to interpolate between anchor points (via per capita rates).

Radical and rapid effort reductions (or even their attempts) as a result of an intentional policy decision (and actual implementation) do not occur widely. One of the few exceptions that comes to mind is the trawl ban of 1980 in Western Indonesia, whose very partial implementation is discussed in Pauly and Budimartono (2015). The ban had little or no impact on official Indonesian fisheries statistics for Central and Western Indonesia, another indication that they, also, may have little to do with the realities on the ground. FAO (2014; pp. 10–11) hints at this being widespread in the Western Central Pacific and the Eastern Indian Ocean (incidentally the only FAO areas where reported catches appear to keep on increasing) when they note that “while some countries (i.e., the Russian Federation, India and Malaysia) have reported decreases in some years, marine catches submitted to FAO by Myanmar, Vietnam, Indonesia, and China show continuous growth, that is, in some cases resulting in an *astounding* decadal increase (e.g., Myanmar up 121 percent, and Vietnam up 47 percent)” (emphasis added),

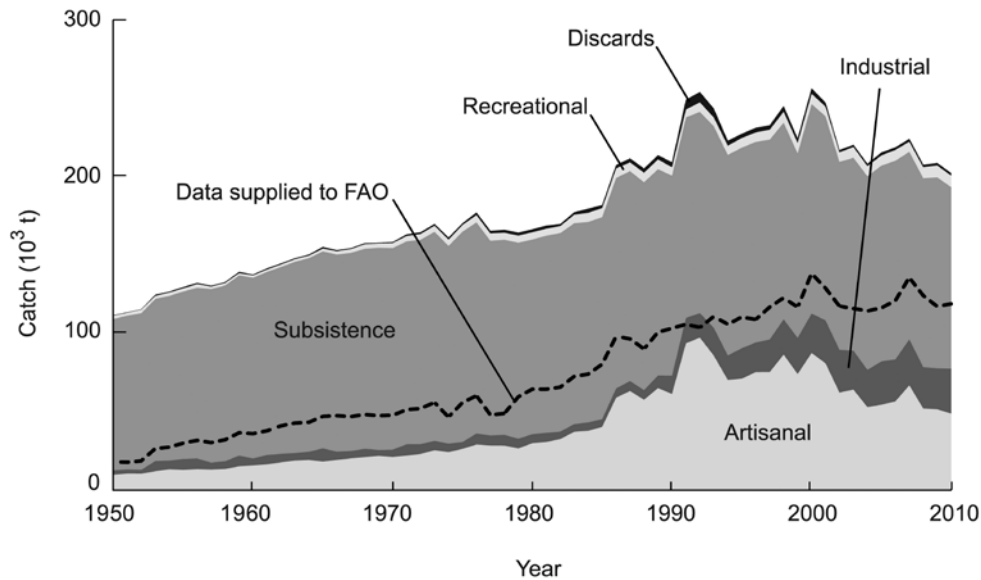


Figure 2.4. Catch reconstruction for the 25 Pacific island countries, states, and territories (Zeller et al. 2015) by the fishing sectors defined here: industrial (large-scale commercial), artisanal (small-scale commercial), subsistence (small-scale noncommercial), and recreational (small-scale noncommercial), with discards shown separately, and the official reported data as presented by FAO on behalf of these entities overlaid as a line graph. This clearly demonstrates the preponderance of commercial catch data in officially reported data as presented by FAO to the global community on behalf of countries. Note that industrial fisheries for large-pelagic species (i.e., tuna and billfishes) are excluded from consideration by Zeller et al. (2015) unless they are conducted by truly domestic fleets. These industrial large-pelagic fisheries and their catches are addressed separately using a global approach (see chapter 3). (Modified from Zeller et al. 2015.)

which probably is FAO-diplomatic-speak for saying the officially reported data are made up.

Step 6: Estimation of Total Catch Time Series by Combining Steps 1 and 5

A reconstruction is completed when the estimated catch time series derived through steps 2–5 are combined and harmonized with the reported catch of step 1 (see figure 2.4 for a regional synthesis example). Generally, this will result in an increase of the overall catch, but the accounts on pp. 185–457 include several cases when the reconstructed total catch was lower than the reported catch. The best documented case of this situation is that of mainland China (Watson and Pauly 2001), whose overreported catches for local waters in the Northwest Pacific are inflated by underreported catches taken by Chinese distant water fleets, which in the 2000s operated in the EEZs of more than ninety countries, that is, most parts of the world’s oceans (Pauly et al. 2014). The step of harmonizing reconstructed catches with the reported baselines obviously goes hand in hand with

documenting the entire procedure, which is done via a text that is formally published in the scientific literature or, pending publication, is made available online as either a contribution in the Fisheries Centre Research Reports series (e.g., Harper et al. 2012) or as a Fisheries Centre Working Paper (e.g., Divovich et al. 2015a, 2015b). These documents (rather than only the summaries on pp. 185–457) should be consulted by anyone intending to work with our data. Both the data and the documentation associated with each reconstruction are available at www.seaaroundus.org.

Several reconstructions were performed in the mid- to late 2000s, when official data (i.e., FAO statistics or national data) were not available to 2010 (e.g., Zeller et al. 2006, 2007, 2008; Zeller and Harper 2009). All these cases were subsequently updated to 2010 through dedicated contributions (e.g., Divovich et al. 2015b) or forward-carry procedures (e.g., Zeller et al. 2015) adapted from the approach used for the estimation of missing catches for each country or territory.

Step 7: Quantifying the Uncertainty in Step 6

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

However, this is an ultimately frustrating argument, as is the argument that officially reported catch data, despite being themselves sampled and estimated data (e.g., from commercial market sampling [Ulman et al. 2015b] or landing site sampling [Jacquet and Zeller 2007; Jacquet et al. 2010; McBride et al. 2013]) with unknown but potentially substantial margins of uncertainty, are never expected or thought to require measures of uncertainty. Therefore, we applied to all reconstructions summarized in this atlas the procedure in Zeller et al. (2015) for quantifying their uncertainly, which is inspired by the pedigrees' of Funtowicz and Ravetz (1990) and the approach used by the Intergovernmental Panel on Climate Change to quantify the uncertainty in its assessments (Mastrandrea et al. 2010).

This procedure consists of the authors of the reconstructions summarized in this atlas attributing to each catch estimate by fisheries sector (e.g., industrial, artisanal) in each of three periods (1950–1969, 1970–1989, and 1990–2010) a score expressing their evaluation of the quality of the time series: 1, *very low*; 2, *low*; 3, *high*; and 4, *very high*. Note the absence of a “medium” score, to avoid the non-choice that this easy option would represent. Each of these scores corresponds to a percent range of uncertainty (table 2.1), adapted from

Monte Carlo simulations in Ainsworth and Pitcher (2005) and Tesfamichael and Pitcher (2007).

The overall score for the reconstructed total catch of a sector or period can then be computed from the mean of the scores for each sectors, weighted by their catch, and similarly for the relative uncertainty. Alternatively, the percentage uncertainty for each sector and period can be used for a full Monte Carlo analysis (figure 2.5).

Note that this procedure was applied to countries' domestic catches (i.e., data “Layer 1”; see below and chapter 5) but not to foreign catches, whose uncertainty is generally very high and probably exceeds the ranges suggested in table 2.1.

FOREIGN AND ILLEGAL CATCHES

Foreign catches are catches taken by *industrial* vessels (by definition, all foreign fishing in the waters of another country is deemed to be industrial) of a coastal state in the EEZ or EEZ-equivalent waters of another coastal state. Because the high seas legally belong to no one (or to everybody, which is here equivalent), there can be no “foreign” catches in the high seas. Before UNCLOS and the declaration of EEZs by maritime countries, foreign catches were illegal only if conducted within the *territorial* waters of such countries (generally but not always 12 nmi). Since the declarations of EEZs by the overwhelming majority of maritime countries, foreign catches are considered illegal if conducted within the (usually 200 nmi) EEZ and without access agreement with the coastal state (except in the EU, whose waters are managed by a Common Fisheries Policy, which implies a multilateral access agreement).

Such agreements can be tacit and based on historic rights, or more commonly explicit and involving compensatory payment for the coastal state. The *Sea Around Us* has created a database of such access and agreements, which is used to allocate the catches of distant-water fleets to the waters where they were taken (see chapter 5).

Table 2.1. Scores for evaluating the quality of time series of reconstructed catches, with their approximate confidence intervals (IPCC criteria from figure 1 of Mastrandrea et al. 2010); the percentage intervals, here updated from Zeller et al. (2015), are adapted from Ainsworth and Pitcher (2005) and Tesfamichael and Pitcher (2007).

Score		± (%)	Corresponding IPCC criteria ^a
4	Very high	10	High agreement and robust evidence
3	High	20	High agreement and medium evidence or medium agreement and robust evidence
2	Low	30	High agreement and limited evidence or medium agreement and medium evidence or low agreement and robust evidence
1	Very low	50	Low agreement and low evidence

^aMastrandrea et al. (2010) note that “confidence increases” (and hence confidence intervals are reduced) “when there are multiple, consistent independent lines of high-quality evidence.”

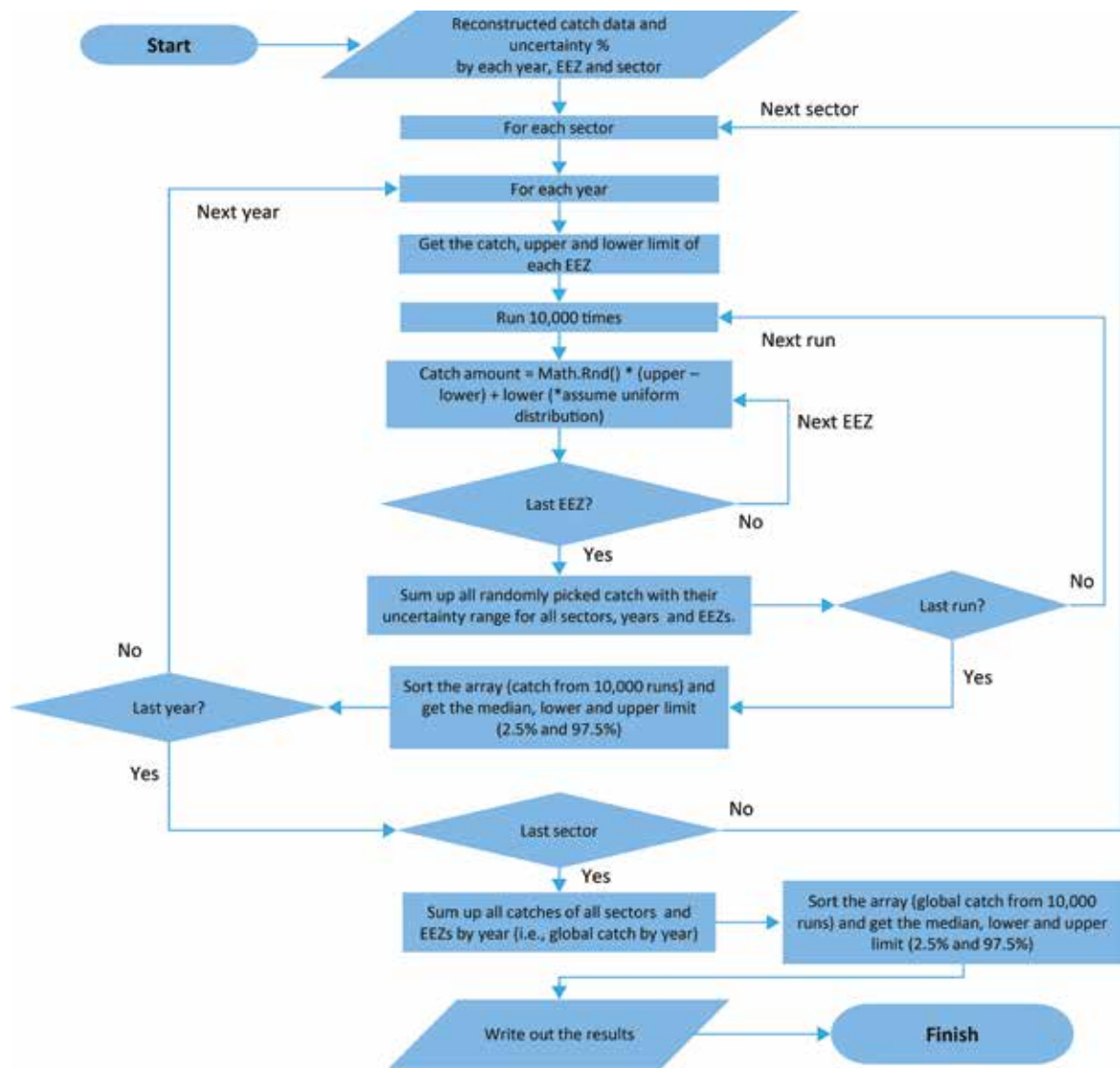


Figure 2.5. Flowchart detailing the manner in which the uncertainty scores (and the corresponding percentage intervals) in table 2.1 can be used to assess the uncertainty associated with the summed catches from a group of EEZs (e.g., those bordering the Mediterranean) or the entire world. MSY, maximum sustainable yield. (Computation and original graph courtesy of V. W. Y. Lam.)

Suffice it here to say, therefore, that most catch reconstructions, in addition to identifying the catch of domestic fleets, often at least mention the foreign countries fishing in the waters of the country they cover (information we use in our access database), whereas other reconstructions explicitly quantify these catches (particularly in West Africa; see Belhabib et al. 2012).

This information is then combined and harmonized with the catches deemed to have been taken outside a country's EEZ, as derived in step 1 above and in chapter 5, and the landings of countries reported by FAO as fishing outside the FAO areas in which they are located (e.g., Spain in FAO area 27 reporting catches from area 51; figure 2.1), which always identifies these catches as distant-water landings and thus allows estimation of the catch by foreign fisheries in a given area and even EEZ. Conservative estimates of discards are then added to these foreign landings, estimated from the discarding rates of the fisheries operating in the countries or FAO areas in question. Ultimately, the total catch thus extracted from a given area (i.e., a chunk of EEZ or EEZ-equivalent waters, or high seas waters within a given FAO area) is then computed as the sum of three data layers: the reconstructed domestic catches (what the *Sea Around Us* calls "Layer 1" data, chapter 5), the inferred catches by foreign fleets ("Layer 2" data, chapter 5), and the tuna and other large pelagic fishes caught in the high seas and in EEZs, here treated separately from all other catches as "Layer 3" data (see chapter 3). Details of the harmonization and spatial allocation of these three data layers are presented in chapters 3 and 5.

Besides addressing foreign legal catches (including estimates of discards), we also examine illegal fishing. In line with INTERPOL, we believe that illegal fishing is a crime; here we define it as foreign fishing within the EEZ waters of another country without a formal or traditional permission to access. We do not treat domestic fisheries' violations of fishing regulations as illegal. In general, our reconstruction method cannot readily distinguish

between legal and illegal foreign fishing (because we do not necessarily know about all access agreements). By default, our data pertain only to "reported" versus "unreported," irrespective of legal status of foreign fleets in a host country (Pauly et al. 2014; Belhabib et al. 2015). However, for about two dozen countries where the number of illegally operating vessels could be inferred (e.g., West Africa), the fleet size could be multiplied by appropriate catch per unit of effort rates, leading to an estimate of illegal catch, which was then harmonized with other layer 2 data.

In most cases, the magnitude of foreign catches will be highly uncertain (more so than domestic catches); however, the uncertainty associated with foreign catches was not assessed, contrary to domestic catches (see above, step 7).

CATCH COMPOSITION

The taxonomy of catches is what allows catches to be mapped in an ecosystem setting, because different taxa have different distribution ranges and habitat preferences (Close et al. 2006; chapter 4). Also, temporal changes in the relative contributions of different taxa in the catch data may also indicate changes in fishing operations or in dominance patterns in exploited ecosystems. Thus, various ecosystem state indicators can be derived from catch composition data, such as the "mean temperature of the catch," which tracks global warming (Cheung et al. 2013); "stock-status plots," which can provide a first-order assessment of the status of stocks (Kleisner et al. 2013; chapter 1); and the marine trophic index, which reveals instances of "fishing down marine food webs" (Pauly et al. 1998; Pauly and Watson 2005; Kleisner et al. 2014; see also www.fishingdown.org).

Most statistical systems in the world manage to present at least some of their catch in taxonomically disaggregated form (i.e., by species), but many report a large fraction of their catch as overaggregated, uninformative categories such as "other fish" or "miscellaneous marine fishes" (or "marine fishes nei"

BOX 2.6. SPECIES COMPOSITION AND TAXONOMIC DISAGGREGATION AS CHALLENGES IN CARIBBEAN FISHERIES CATCH RECONSTRUCTIONS

Robin Ramdeen, *Sea Around Us*, University of British Columbia, Vancouver, Canada

For a catch reconstruction to be complete, estimates of catches have to be provided for each sector that exists in a given country (e.g., industrial, artisanal, subsistence, recreational), after which these catches must be split into distinct species or species groups (Pauly 1998; chapter 1). The latter task, which should also include discarded fish and is referred to as taxonomic disaggregation, presented a considerable challenge during the reconstructions of biodiverse tropical fisheries catches, such as those in the wider Caribbean region (e.g., Ramdeen et al. 2012, 2014).

Caribbean fisheries are usually small-scale coastal operations for which data are typically sparse, especially with regard to quantitative information (Salas et al. 2011). This is particularly true for information on the taxonomic composition of catches, which ideally is collected at landing sites through a labor-intensive process requiring fisheries officers well trained in fish identification, because the fisheries are usually multispecific, and land catches consisting of dozens of similar-looking species. Thus, given the scattered and often remote landing sites of Caribbean and other small island developing states, and fisheries departments with limited human resources, these catches are often reported as broad taxa, with the exception of unique and often exported taxa such as conch or spiny lobster (e.g., Ulman et al. 2015).

To taxonomically disaggregate the reconstructed catch estimates, we relied on more detailed catch studies from numerous short-term projects (1–3 years) conducted in the region. This allowed us to split larger groups into species. Also, qualitative information on seafood preferences (by locals and tourists) and export data, notably to the United States, proved useful for catch disaggregation. Finally, when such detailed catch studies related only to recent time periods, we included in a few cases an adjustment to reflect generally known changes in species availability. This applied especially to groupers (family Serranidae), which are highly targeted and highly vulnerable to the fishing techniques used on coral reefs and thus were far more common in catches in earlier time periods than currently.

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[not elsewhere included] in FAO parlance). Interestingly, many official national datasets have better taxonomic resolution than the data reported to FAO by national authorities (see Luckhurst et al. 2003). It is highly likely that this is largely the result of the design of the data request form that FAO distributes to countries each year, which does not actively and easily encourage (even if accompanying

instructional material suggests this option) that more detailed national taxonomic resolution data should be provided whenever possible. We aim to reduce the contribution of such overaggregated groups to a reconstruction by using the approach outlined in chapter 1, adapted to fit local conditions (see also box 2.6).

The species and higher taxa in the catch of a given country or territory can thus belong to one of three groups:

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

We are labeling every taxon in the catch time series of every country with (1), (2), or (3) such that (3) and perhaps also (2) are not used to compute indicators such as outlined above (they would falsely suggest an absence of change), although we fear that this will still occur.

In summary, the approach we developed and used for undertaking the catch reconstructions for every maritime country/territory in the world (as summarized on pp. 185–457,

and presented as a regional example in figure 2.4) consists of a well-structured system for using all available data sources and applying a conservative but comprehensive integration approach. With the addition of the recently developed estimation approach for uncertainty (step 7; Zeller et al. 2015), the approach presented here can provide a more nuanced view of fisheries catches (e.g., by fisheries sector; figure 2.4). Verifying and integrating these data into the global *Sea Around Us* database of fisheries catches, followed by spatial allocation of these catches in an ecosystem setting within given political constraints (i.e., EEZ access permissions), is the next step in using global reconstructed catch data. This process is described in chapter 5.

ACKNOWLEDGMENTS

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NOTE

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