

Synthesis of underreported small-scale fisheries catch in Pacific island waters

D. Zeller · S. Harper · K. Zylich · D. Pauly

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Abstract We synthesize fisheries catch reconstruction studies for 25 Pacific island countries, states and territories, which compare estimates of total domestic catches with officially reported catch data. We exclude data for the large-scale tuna fleets, which have largely foreign beneficial ownership, even when flying Pacific flags. However, we recognize the considerable financial contributions derived from foreign access or charter fees for Pacific host countries. The reconstructions for the 25 entities from 1950 to 2010 suggested that total domestic catches were 2.5 times the data reported to FAO. This discrepancy was largest in early periods (1950: 6.4 times), while for 2010, total catches were 1.7 times the reported data. There was a significant difference in trend between reported and reconstructed catches since 2000, with reconstructed catches declining strongly since their peak in 2000. Total catches increased from 110,000 t yr⁻¹ in 1950 (of which 17,400 t were reported) to a peak of over 250,000 t yr⁻¹ in 2000, before declining to around 200,000 t yr⁻¹ by 2010. This decrease is driven by a declining artisanal (small-scale commercial) catch, which was not compensated for by increasing domestic industrial (large-scale commercial) catches. The artisanal fisheries appear to be declining from a peak of 97,000 t yr⁻¹ in 1992 to less than 50,000 t yr⁻¹ by 2010. However, total catches were dominated by

subsistence (small-scale, non-commercial) fisheries, which accounted for 69 % of total catches, with the majority missing from the reported data. Artisanal catches accounted for 22 %, while truly domestic industrial fisheries accounted for only 6 % of total catches. The smallest component is the recreational (small-scale, non-commercial and largely for leisure) sector (2 %), which, although small in catch, is likely of economic importance in some areas due to its direct link to tourism income.

Keywords Catch reconstruction · Artisanal fisheries · Subsistence fisheries · Recreational fisheries · Unreported catches

Introduction

Island ecosystems are often more tenuous with regard to their vulnerability to fishing, more so than continents (Fischer 2012), and coastal fisheries in Pacific small island countries and territories are of crucial social, cultural and food security significance (Dalzell et al. 1996; Zeller et al. 2006, 2007b; Bell et al. 2009). Yet, the economic importance of these coastal fisheries is generally undervalued (Zeller et al. 2007a). However, in contrast to many of the predominantly industrial (i.e., large-scale commercial) fisheries for tuna and other large pelagic species, which are dominated by foreign fleets or foreign beneficial ownership and are much better documented (but see Gillett 2011 for accounting and traceability issues), many of the coastal fisheries are small scale in nature and poorly documented and un- or underreported (Gillett and Lightfoot 2002; Zeller et al. 2006, 2007b; Pauly and Zeller 2014). Underlying reasons for this discrepancy, which is not limited to Pacific island countries (see, e.g., Jacquet et al. 2010;

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D. Zeller (✉) · S. Harper · K. Zylich · D. Pauly
Sea Around Us, Fisheries Centre, University of British
Columbia, Vancouver V6T 1Z4, Canada
e-mail: d.zeller@fisheries.ubc.ca

Zeller et al. 2011a; Le Manach et al. 2012), include financial, technical and human resource limitations accounting for these spatially dispersed fisheries, as well as the historical marginalization of small-scale fisheries and the associated misperception that small-scale fisheries are ‘small’ in catch and importance, and hence impact (Pauly 1997, 2006).

While governments and regional or global organizations (e.g., Secretariat of the Pacific Community www.spc.int; United Nations Food and Agriculture Organization, FAO www.fao.org) understandably are forward looking when trying to assist in accounting and traceability improvements of fisheries data, knowledge of past catches is important, given our growing knowledge of historical impacts of fishing and other human activities on marine ecosystems (Roberts 2007). Better knowledge of the likely real extent of past catches provides important historic baselines for understanding the present-day status and trends of coastal marine resources, which are often overfished, especially near major human population centers, such as main islands and towns (Zeller et al. 2006; Houk et al. 2012).

Previous studies illustrate often substantial discrepancies between landings data reported by FAO on behalf of these entities and reconstructed estimates of catch time series for selected Pacific island entities and fisheries (Zeller et al. 2006, 2007b, 2008). Here, we present total time series catch reconstructions for all 25 small island countries, states and territories in the Pacific (Fig. 1; Table 1) based on field work and desk studies conducted by

numerous colleagues over the last decade in Polynesia, Micronesia and Melanesia. Note that we include Papua New Guinea here as a ‘small island’ country, due to its close cultural and fisheries connections with other Pacific island entities. We define four distinct fishing sectors: ‘industrial,’ being large scale and commercial in nature; ‘artisanal,’ being small scale and with a primary intent of commercial operation (i.e., the majority of catch is for sale); ‘subsistence,’ being small scale and non-commercial (i.e., the major reason for fishing is self- or family consumption, although some catch may be sold if catch is large or valuable); and ‘recreational,’ being small scale, non-commercial and largely for leisure (i.e., the main driver for going fishing is pleasure or relaxation, rather than food provision). We realize that there can be overlap between the last two sectors over time (subsistence and recreational), as with an increasing cash economy, fishing activities may gradually turn from a food provision exercise to a leisure activity. We also recognize that ‘large-scale’ versus ‘small-scale’ definitions often differ by country (e.g., using different vessel lengths or gear types), and we remain consistent with each country’s definition, if one exists. However, in line with the general considerations of gear development over the last 60+ yrs, we define any gear that is dragged through the water or across the sea floor (i.e., trawls) as ‘industrial,’ irrespective of vessel size (*sensu* Martín 2012).

These reconstructions focus on domestic fisheries within each country’s own waters, namely national fisheries

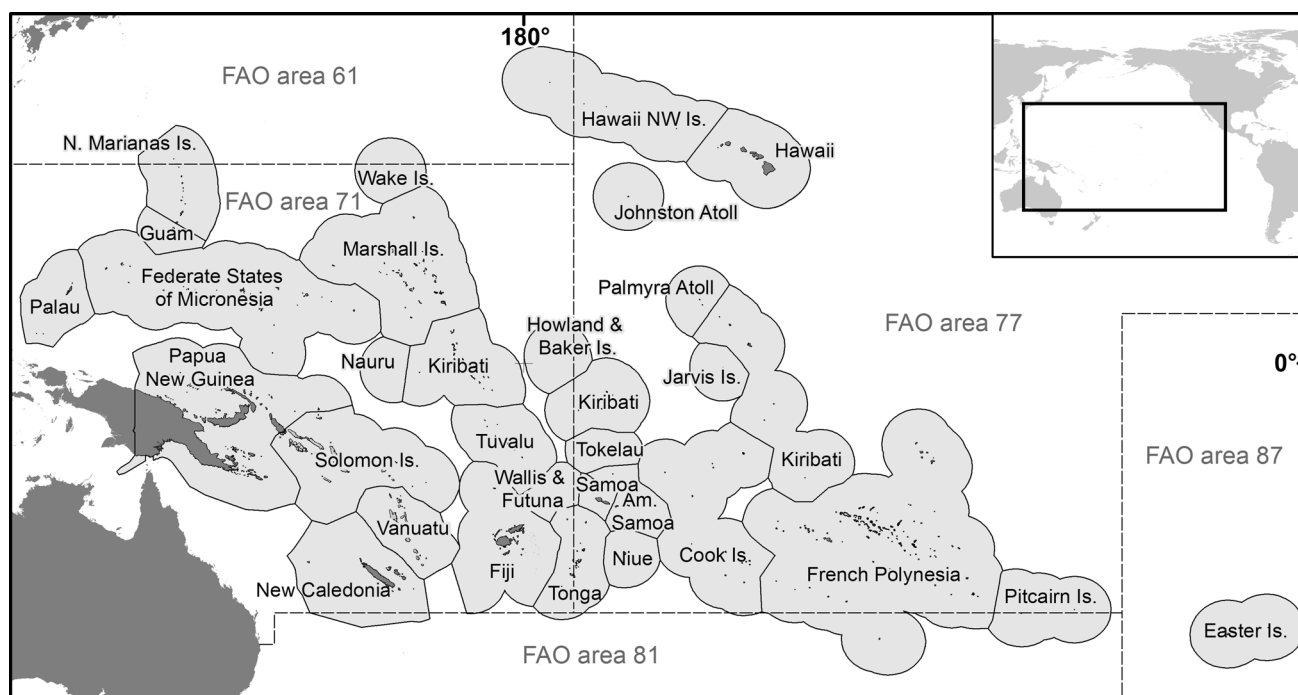


Fig. 1 Map of Pacific island countries, states and territories and their EEZs, as well as FAO statistical area boundaries (areas 61, 71, 77, 81, 87)

Table 1 Basic data on the political/administrative affiliation (if any), the size of the EEZ and the human populations in 1950 and 2010 for the 25 Pacific island countries and territories included in the present synthesis

Name	Affiliation	EEZ (km ²) ^a	Population (1950; 2010)
American Samoa	USA	404,391	18,900; 68,420
Cook Islands	New Zealand	1,960,135	15,000; 15,500
Easter Island	Chile	720,400	1029; 5000
Federated States of Micronesia		2,992,597	32,000; 107,839
Fiji		1,281,122	294,000; 860,000
French Polynesia	France	4,767,242	62,100; 271,000
Guam	USA	221,504	60,000; 179,000
Hawaii	USA	2,474,884	499,800; 1,360,301
Kiribati		3,437,345	33,633; 99,546
Marshall Islands		1,992,232	13,000; 54,038
Nauru		308,502	868; 9,322
New Caledonia	France	1,422,543	59,000; 247,000
Niue	New Zealand	316,629	4,503; 1,496
Northern Mariana Islands	USA	749,268	7,000; 60,917
Palau		604,289	7,074; 20,472
Papua New Guinea		2,396,200	1,613,200; 6,858,900
Pitcairn Island	UK	836,108	162; 54
Samoa		131,812	82,000; 184,000
Solomon Islands		1,597,492	103,000; 538,148
Tokelau	New Zealand	319,031	1,500; 1,135
Tonga		664,853	48,000; 104,000
Tuvalu		751,797	5,000; 10,472
US Pacific small island territories ^b	USA	1,953,800	1,300 ^b ; 150 ^b
Vanuatu		827,891	53,139; 240,000
Wallis and Futuna	France	258,269	7,000; 13,256

^a EEZ areas are calculated by the *Sea Around Us* (www.seaaroundus.org) and include territorial waters

^b These 'minor' US islands (comprising Howland and Baker Islands, Jarvis Island, Johnston Atoll, Palmyra Atoll and Wake Island) had no permanent resident population, except for Wake Island and Johnston Atoll that have some government personnel and contractors (installations on Johnston Atoll have been closed since the late 2000s) and Palmyra Atoll which has a small caretaker staff. Thus, it was assumed that no domestic fisheries catches occurred except for some recreational fishing on Wake and Johnston Atoll as estimated by Zeller et al. (2005)

catches taken within a country's own exclusive economic zone (EEZ) waters. Where applicable, catches taken by a country in neighboring EEZs or other non-national waters, or foreign catches taken within a given country's waters, are also documented in the underlying country-specific studies (for references to the extensive technical reports see Electronic Supplementary Material, ESM), but not incorporated in the dataset considered here. This largely applies to the large pelagic fisheries for tuna, billfishes and sharks. Large pelagic fisheries conducted by truly domestic fleets that are mostly owned and crewed by domestic interests are retained within the present dataset when identifiable (e.g., French Polynesia; Bale et al. 2009), while the generally widely roaming, industrial tuna fleet is excluded from consideration. We do this specifically to focus the reader's attention on the truly domestic fisheries for direct food security purposes, without being side-tracked by the often

high volumes of large pelagic catches being assigned to Pacific island flags through either joint venture operations, foreign charters, reflagging or flag of convenience operations. Aside from foreign fishing access fees or charter fees and some joint venture contributions, the majority of beneficial ownership and profit derived from these roaming, industrial tuna fleets do not accrue to host countries, but rather to the distant water fleet countries, mainly in Japan, USA, Korea, Taiwan and more recently China and Europe (Siaosi et al. 2012; Pauly et al. 2013) who hold the majority of beneficial ownership of these fleets, and their associated profits.

Nevertheless, we recognize fully that any such fees being paid to host countries may often be significant or even crucial from the host country's foreign revenue perspective (Gillett 2009; Siaosi et al. 2012), but point out that, for various reasons, such fees substantially undervalue

the actual returns that should be received by host countries (Le Manach et al. 2013a). Therefore, these fisheries are excluded from the present consideration. Furthermore, while official catch records for the large pelagic fisheries are better documented than coastal fisheries (at least for more recent times), considerable and troubling issues of public accountability and transparency exist in these fisheries (Cullis-Suzuki and Pauly 2010; Gillett 2011) despite considerable improvements in some aspects such as access fee data (Gillett 2009).

Incomplete catch time series can have policy and economic implications (Zeller et al. 2007a), especially for marginalized artisanal fisheries and the informal subsistence sector. In contrast to the fisheries for large pelagic taxa, fisheries for inshore and coastal taxa have few if any formal assessments or evaluations of stock or fisheries status (see Houk et al. 2012) and assessments are unlikely to ever be conducted regularly and comprehensively on the large number of stocks and species comprising the artisanal and subsistence fisheries in the Pacific. However, some straightforward and simple methods exist that allow first-order evaluations of fisheries and stock status to be considered using catch time series data alone (Grainger and Garcia 1996; Pauly et al. 2008; Zeller et al. 2009). While assessments using catch time series alone do have their limitations, carefully considered stock status evaluations using comprehensive catch time series do provide very useful and insightful first-order assessments (Froese et al. 2012; Kleisner et al. 2013). Thus, there is need for the comprehensive collection and reporting of accurate catch statistics, the most fundamental of all fisheries data (Pauly 2013), despite ill-advised suggestions that downplay the need for comprehensive catch data in exchange for data collection useable for formal and expensive stock assessments (Hilborn and Branch 2013).

At a time when climate change is beginning to have major and growing impacts on biodiversity (e.g., Cheung et al. 2009) as well as fisheries (Cheung et al. 2008, 2010, 2012; Sumaila et al. 2011), and where climate change projections paint an increasingly challenging picture for coastal small-scale fisheries in the Pacific (Bell et al. 2011a, b), it is particularly important that clearly documented information on historical catch levels and trends is available to assist national governments and regional agencies to ensure the sustainability of domestic artisanal and subsistence fisheries. Our study (and the underlying country-/territory-specific technical reports) presents such data and information for all Pacific small island countries and territories.

The overall aim of the present study is to summarize and document the extent of unreported catches taken from coastal fisheries in the 25 Pacific island countries and territories over the last 60 yrs and thereby to reset the historic

baseline of coastal fisheries catches (both commercial and non-commercial) that is of relevance for developing sustainable food security policies for Pacific islands going forward in the twenty-first century.

Methods

The catch reconstruction approach utilized by the 25 comprehensive studies underlying the present synthesis was first applied in a technical investigation conducted for the US Western Pacific Regional Fishery Management Council located in Hawaii (Zeller et al. 2005), subsequently published in Zeller et al. (2006, 2008) and described in detail in Zeller et al. (2007b). Here, we summarize the generalized six-step process of reconstructing total historical catches for island countries presented in Zeller et al. (2007b) and present a new seventh step addressing the uncertainty of reconstruction estimates:

1. Identification and sourcing of existing, reported catch times series to validate the quality of national–international data transfer:
 - (a) FAO reported landings data by FAO statistical area, taxon and year (obtained from www.fao.org);
 - (b) National data series by area, taxon and year for years and countries for which such data were available (sourced either from national agencies, national reports or regional reports and sources);

Note that in many instances, the catch amounts reported to FAO match closely those in official national sources (when available). However, there are commonly taxonomic differences, with national data sources often containing better taxonomic information and detail.

2. Identification of fishing sectors (e.g., artisanal, subsistence, recreational), components (e.g., discarding), time periods, species, gears, etc. not covered by (1): This step identifies missing catch items (i.e., sector, time periods, taxa and tonnages) and is conducted through the evaluations of (1), in-depth literature searches and consultations with available experts of each fishery and country;
3. Sourcing of available alternative information sources dealing with missing catch items identified in (2), via extensive literature searches and consultations with local experts: We look for any source of information, including case studies, anthropological and social science studies, health studies, household surveys, reports, datasets and expert knowledge. Of particular utility for Pacific islands was the work conducted by R. Gillett and colleagues over the last 15 yrs, as well as

library archival searches (including colonial archives). If local or regional sources on discarding were not available, we considered the global study by Kelleher (2005). Note that we only estimated major discards and generally only associated with industrial fisheries;

4. Development of data ‘anchor points’ in time for each missing catch item based on data and information sources derived in (3), and their expansion to country-wide catch estimates for each catch item using clearly stated and conservative assumptions: Assumptions may vary between sectors, time periods and islands and reflect general knowledge of each situation based on all information available. Thus, most assumptions are location and data-specific and are detailed in the underlying technical reports for each island entity. However, several consistencies exist in the assumptions used. For example, for years with missing data within a sector, we assumed that this sector continued to exist and hence generate catches (unless clearly documented evidence to the contrary existed). Thus, we generally interpolated tonnages for years with missing data between years with available data. Furthermore, in cases where sources indicated impacts of environmental disturbances, e.g., major impacts of cyclones, we derived adjustments based on simple assumptions of likely percentage reductions in catches due to damaged fishing gears and boats. A further consistent underlying assumption relates to subsistence catches, where we generally assumed that trends and patterns over time were closely linked to human population numbers and trends on the given islands over time and that, in general, per capita subsistence rates were higher in 1950 than in 2010, due to more limited availability of cash markets and cash economy in the 1950s compared to the 2000s. We explain the specific assumptions more clearly in the underlying technical reconstruction reports which are all available online at www.seaaroundus.org (see also ESM);
5. Interpolation for time periods between data anchor points for each catch item, either linearly or assumption-based for industrial and artisanal (i.e., commercial) fisheries, and generally via per capita (or per fisher) catch rates for non-commercial sectors (i.e., subsistence, recreational), taking into account major political, socioeconomic and environmental impacts;
6. Estimation of final total catch times series, combining reported catches (1) and interpolated, island-wide missing catch data series (5): The final data series identifies catch by fisheries sector, taxon and year. We define the following ‘sectors’ using country-specific definitions or regional equivalent definitions: ‘industrial’ (large-scale, commercial), ‘artisanal’ (small-scale, commercial), ‘subsistence’ (small-scale, non-

Table 2 ‘Score’ for evaluating the quality of time series of reconstructed catches, with their confidence intervals (IPCC criteria from Figure 1 of Mastrandrea et al. 2010)

Score		Confidence interval		Corresponding IPCC criteria ^a
		−%	+ %	
4	Very high	10	20	High agreement and robust evidence
3	High	20	30	High agreement and medium evidence or medium agreement and robust evidence
2	Low	30	50	High agreement and limited evidence or medium agreement and medium evidence or low agreement and robust evidence
1	Very low	50	90	Low agreement and low evidence

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

commercial) and ‘recreational’ (small-scale, non-commercial); and

7. We developed a seventh step to address and express uncertainty in our reconstructions. However, given the very inconsistent nature of data and information sources (as well as assumptions) that form the basis of all catch data reconstructions, we did not find it appropriate to estimate/apply standard measures of uncertainty to our anchor point values (such as sample variances). Instead, the method we developed is based on scoring the level of uncertainty in data sources, assumptions and methods used in each case, by time period and fishing sector. This method, based on multiple independent scoring of each reconstruction, uses criteria inspired by the Intergovernmental Panel on Climate Change (Mastrandrea et al. 2010) and requires, for each reconstruction, that its underlying data and assumptions be reviewed independently by several experienced scientists, and relative uncertainty scores (Table 2) were attributed by sector and time period. Note that this table has no ‘medium’ score—this is a deliberate decision. Scores are then averaged between score reviewers and the catch-weighted sector average upper and lower confidence limits calculated for each of three time periods: early (1950–1969), mid (1970–1989) and late (1990–2010). We applied this method to all reconstructions presented here during a full-day workshop in which 15 review participants (all with experience in catch reconstructions) each (independently of each other) scored five countries/territories’ reconstructions, for a total of three sets of scores for each reconstruction. This allowed us to calculate weighted average confidence limits as defined in

Table 2. We present these confidence limits for the mid-year in each of the three time periods (i.e., 1960, 1980 and 2000).

Detailed reconstructions, including technical details, for each island entity are given in the technical reports underlying the present synthesis (see ESM, Appendix Table A1), which are available under ‘publications’ at <http://www.seaaroundus.org/about/>. Here, we present some examples in detail, by first presenting the officially reported time series data (1950–2010) as reported globally by FAO on behalf of each country or territory (Garibaldi 2012), and adjusted where necessary to reflect domestic EEZ-level catches as best as possible (i.e., by excluding catches taken by a given country/island entity in waters other than its own EEZ waters). Then, we present the reconstructed total catches (i.e., reported and unreported) by the above-defined fisheries sectors for 1950–2010, including discards (generally only for high discard-prone fisheries or gear types). Lastly, we compare total reconstructed catch time series with the reported data. Note that we consider discarded catch as part of total catch; however, discards were generally only estimated as major discards of industrial fisheries and are thus likely very conservative estimates. Whenever available, local or regional studies on discarding were utilized, although this was supplemented by information from the global review on discarding conducted for the FAO by Kelleher (2005).

Finally, we present reconstructed total domestic catches (by sectors) for all 25 small island countries, states and territories combined and compare these to the officially reported data presented to the global community by FAO on behalf of these countries, states and territories.

All comparisons with FAO data (we utilized the 2011 version of FAO FishStat, fully recognizing that FAO data may change over time, even retroactively; see ESM for adjustments made due to such retroactive changes in FAO data over time) require the disaggregation of FAO FishStat data (www.fao.org) from the very large spatial scale of FAO statistical reporting areas (areas 61, 71, 77, 81 and 87 for the Pacific; Fig. 1) to country-specific EEZ waters. Specifics and assumptions on how this was accomplished differ by country and territory (see underlying technical reports for details, ESM, Appendix Table A1), but generally, after excluding from reported data, the industrial large pelagic landings taken by or with the majority of foreign beneficial ownership, most of the remaining reported landings data generally relate to domestic coastal or near-coastal fisheries undertaken in local (i.e., EEZ) waters. Most of the Pacific small island countries and territories do not have their own industrial large pelagic fishing fleets, although domestic large pelagic fleets did exist in the past in some countries, e.g., Palau (Lingard et al. 2011), or have

been developed more recently in others, e.g., French Polynesia (Bale et al. 2009) or Cook Islands (Haas et al. 2012). However, most other countries’ ‘lease’ or ‘charter’ foreign fleets, develop so-called joint venture operations or engage in foreign access agreements, neither of which are deemed truly local, domestic fisheries for direct food security purposes in the present study. We do recognize, however, the economic importance of the cash contributions to host countries derived from such ventures or foreign fishing access agreement fees (but see Le Manach et al. 2013a).

Results

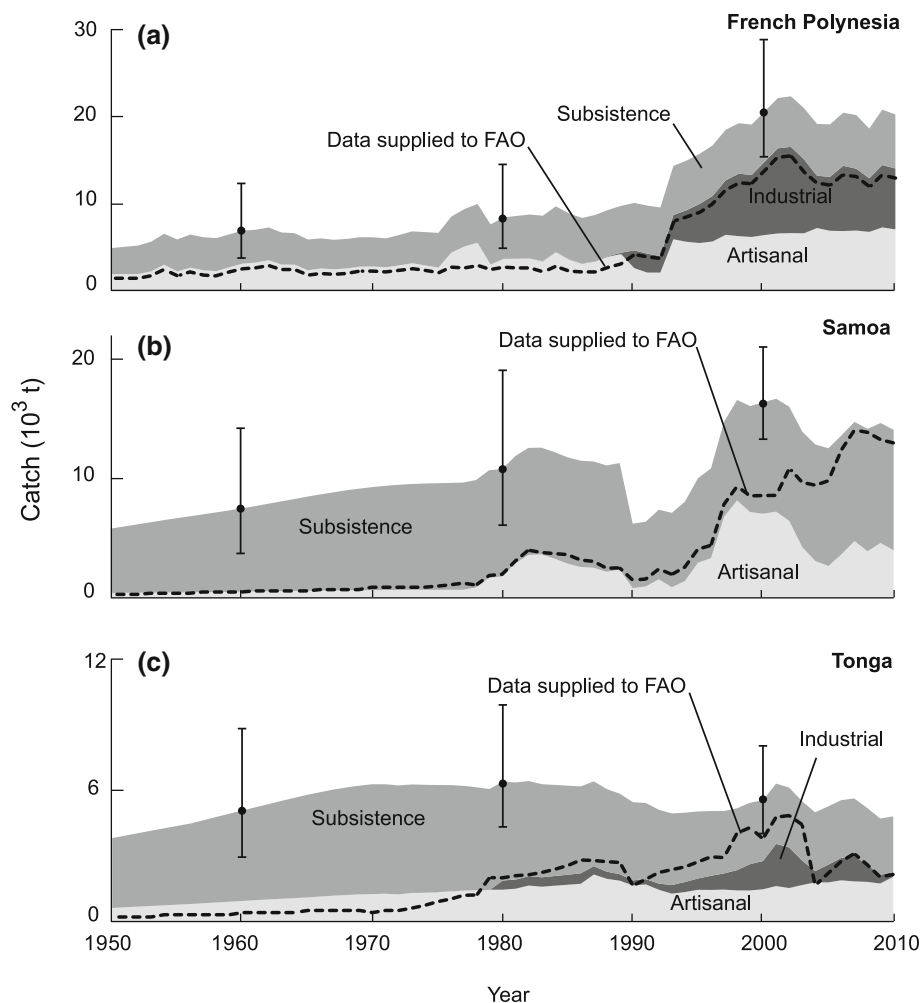
We initially illustrate the range and variability in data and reported data omissions via three catch reconstruction examples (i.e., French Polynesia, Samoa and Tonga), before providing a summary for all 25 Pacific small island countries and territories combined. We chose these three examples specifically because they are illustrative of major points noted throughout our reconstruction work: (1) good coverage of commercial catches, but complete absence of subsistence catches in the reported data (e.g., French Polynesia); (2) misleading time series trend due to the recent improvements in data collection and reporting without retroactive adjustments to earlier time periods, thus undervaluing earlier time periods (e.g., Samoa), and (3) time-variant quality of reporting consistency (e.g., Tonga). Overall, discarded catches are never included in officially reported data.

Examples

French Polynesia

The total marine fisheries catches for French Polynesia were reconstructed from 1950 to 2007 by Bale et al. (2009) and updated to 2010 by *Sea Around Us* (see ESM). The catch reconstruction included truly domestic industrial, artisanal and subsistence sectors in its estimation, and separate approaches were used for each of the major island groups (Society, Austral, Tuamotu-Gambier and Marquesas Islands), reflecting differences in fishing activities between the islands. Overall, the reconstructed total catch for French Polynesian fisheries summed for 1950–2010 was 2.5 times the landings reported by the FAO on behalf of French Polynesia, but followed similar trends over time (Fig. 2a). Reconstructed catch per year increased from just under 5,000 t yr⁻¹ in 1950 (compared to a reported catch of 1,500 t yr⁻¹) to a peak catch of nearly 23,000 t yr⁻¹ in 2002, before settling to around 20,000 t yr⁻¹ by 2010 (Fig. 2a). The data supplied to the FAO reflect only

Fig. 2 Examples of country-specific catch reconstructions forming the foundation for the Pacific-wide total catch time series: **a** French Polynesia, **b** Samoa and **c** Tonga, showing reconstructed catches by the fisheries sectors artisanal (small-scale, commercial), industrial (large-scale, commercial) and subsistence (small-scale, non-commercial), with the official reported data as presented by FAO on behalf of individual countries overlaid as line graphs. Confidence intervals of the reconstruction are shown for 1960, 1980 and 2000 based on a scoring method adapted from the IPCC (Mastrandrea et al. 2010). Note that industrial fisheries for large pelagic species (e.g., tuna and billfishes) are excluded from the present consideration unless they are conducted by truly domestic fleets



commercial landings, covering the domestic industrial tuna fisheries as well as most of the artisanal catches, while our reconstructed catch also accounted for non-commercial subsistence fisheries (Fig. 2a). The strong increase in reported (i.e., FAO) and reconstructed catches in the 1990s was driven by the developing domestic industrial tuna fisheries. In general, both reported statistics and reconstructed data followed similar patterns over time, suggesting that official data, while underestimating the actual volume of catches, do represent overall trends.

Total artisanal catches over the full time period considered here accounted for 67 % of total commercial (i.e., artisanal plus industrial) catches. With the development of the domestic industrial tuna fisheries starting in the 1990s, however, industrial catches increased substantially and by 2010 accounted for nearly 50 % of total commercial catches (Fig. 2a). Overall, subsistence catches accounted for 43 % of the time series of total catches (Fig. 2a). Therefore, commercial fishing (artisanal plus industrial) dominates in French Polynesia, at least during the last 2–3

decades, largely driven by the recent development of the industrial large pelagic fisheries.

Samoa

The total marine fisheries catches for Samoa were reconstructed from 1950 to 2010 by Lingard et al. (2012). Samoa has a long history of marine resource use and today maintains a strong connection to the marine environment. Despite the acknowledged importance of marine resources for food security, Samoan fisheries catches have been underreported since FAO started reporting fisheries landings data on behalf of Samoa in 1950. Reconstructed total marine fisheries catches summed for the 1950–2010 period were 2.8 times the landings reported by FAO on behalf of Samoa (Fig. 2b). Catches are particularly underreported in the early years, and reporting has improved considerably since the late 1990s, with over 90 % of the total catches estimated by Lingard et al. (2012) being accounted for in the officially reported data (Fig. 2b). Reconstructed catch

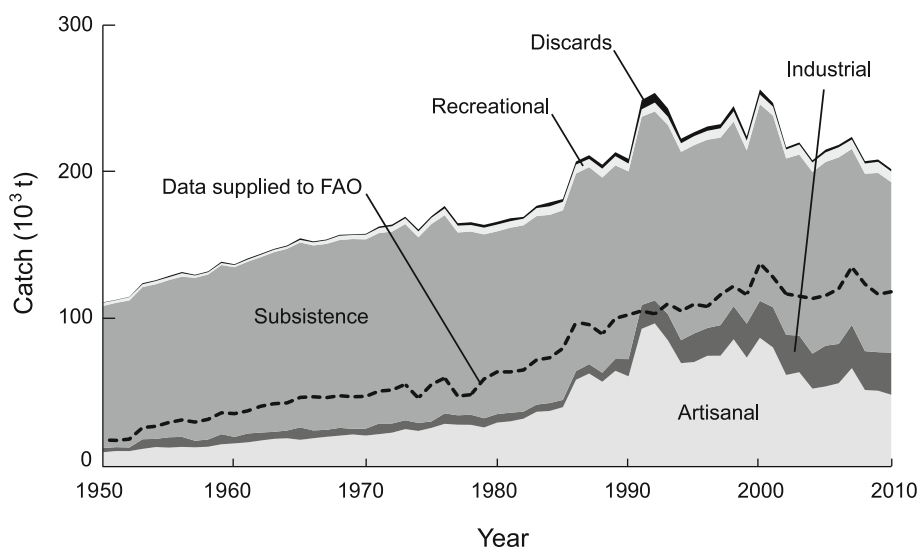


Fig. 3 Catch reconstruction for all 25 Pacific island countries, states and territories by the sectors artisanal (small-scale, commercial), industrial (large-scale, commercial), subsistence (small-scale, non-commercial) and recreational (small-scale, non-commercial), with discards shown separately, and the official reported data as presented

per year increased from around $5,800 \text{ t yr}^{-1}$ in 1950 (of which only 300 t were reported by FAO on behalf of Samoa) to around $11,000 \text{ t yr}^{-1}$ in the mid-1980s, before declining substantially to a low of just over $6,000 \text{ t yr}^{-1}$ in the early 1990s, due to the impacts of two cyclones in consecutive years (Lingard et al. 2012). Catches reached an all-time high in the early 2000s at well over $16,000 \text{ t yr}^{-1}$ before declining slightly to around $14,000 \text{ t yr}^{-1}$ by 2010 (Fig. 2b).

Reconstructed artisanal catches were estimated to have increased from around 400 t yr^{-1} in 1950 to over $4,000 \text{ t yr}^{-1}$ by 2010. Thus, commercial catches accounted for only around 21 % of total catches, while subsistence catches accounted for 79 % of total catches (Fig. 2b). Therefore, non-commercial subsistence fishing dominates in Samoa, both historically as well as at present.

Tonga

The total marine fisheries catches for the Kingdom of Tonga were reconstructed from 1950 to 2007 by Sun et al. (2011) and updated to 2010 by *Sea Around Us* (see ESM). Total catches were estimated for Tonga by accounting for all fisheries sectors, including industrial, artisanal and subsistence fishing. The reconstruction for Tonga estimated a reconstructed total catch summed for the 1950–2010 time period that was over 3.3 times the data reported by FAO on behalf of Tonga (Fig. 2c). For the most recent period (i.e., 2000s), this discrepancy has decreased to around two times, with reconstructed catches in 2010 estimated at around $4,800 \text{ t yr}^{-1}$ compared to $2,150 \text{ t yr}^{-1}$ reported by FAO on

by FAO on behalf of these entities overlaid as a line graph. Note that industrial fisheries for large pelagic species (e.g., tuna and billfishes) are excluded from the present consideration unless they are conducted by truly domestic fleets

behalf of Tonga. Overall, reconstructed catch per year increased from just under $4,000 \text{ t yr}^{-1}$ in 1950 (of which only 200 t were reported) to over $6,000 \text{ t yr}^{-1}$ by the early 1970s, which was maintained to the late 1980s, before beginning a gradual decline (although interrupted by a short-lived increase in the early 2000s) to less than $5,000 \text{ t yr}^{-1}$ by 2010 (Fig. 2c).

Artisanal catches suggest a steady increase from around 600 t yr^{-1} in the 1950s to around $2,000 \text{ t yr}^{-1}$ by 2010, while subsistence catches (around $3,200 \text{ t yr}^{-1}$ in 1950) initially grew to around $5,000 \text{ t yr}^{-1}$ by the early 1970s (due to general population increase), before beginning a gradual but steady decline to around $2,500 \text{ t yr}^{-1}$ by 2010 (Fig. 2c). Truly domestic industrial fisheries (i.e., excluding any foreign-owned but Tongan-flagged large pelagic catches taken throughout the Pacific) appeared to start in the 1980s with around 400 t yr^{-1} and grew to a peak of around $1,900 \text{ t yr}^{-1}$ in the early 2000s before declining substantially to around $200\text{--}300 \text{ t yr}^{-1}$ by the end of the current time period (Fig. 2c). The majority of catches that were unaccounted for in the reported data were from the subsistence sector, which represented 69 % of the total reconstructed catch (Fig. 2c). This illustrates the substantial underrepresentation of the small-scale, non-commercial subsistence fisheries in the data reported by FAO on behalf of Tonga.

Pacific islands combined

Reconstructions for all 25 Pacific small island countries, states and territories considered here (Fig. 1; Table 1) from 1950 to 2010 suggest that reconstructed total domestic

Table 3 Summaries of catch reconstructions for 25 Pacific island countries, states and territories, showing for the year 1950 and 2010, the reported catch, the reconstructed total catch (by sector), the difference between reported and reconstructed catch (for the 1950–2010 time period), the percentage change in reconstructed total catch from 1950 to 2010 and the year of peak catch

Country	Year	Reported catch ^a (t)	Reconstructed catch (t)				Difference reconstructed versus reported 1950–2010 (factor)	Change (%) 1950–2010	Peak catch year ^a
			Industrial ^a	Artisanal	Subsistence	Recreational ^b			
American Samoa	1950	0	0	0	752	0	752		
	2010	24	0	24	139	0	163	15.7	
Cook Islands	1950	700	0	207	1,860	0	2,067		
	2010	3,835	3,040	322	620	0	3,982	2.3	
Easter Island	1950	0	8	16	10	0	35		
	2010	143	46	97	48	0	191	12.6	
Federated States of Micronesia	1950	0	0	166	4,921	0	5,087		
	2010	6,845	0	2,913	9,425	0	12,337	6.7	
Fiji	1950	2,000	0	356	37,723	0	38,079		
	2010	12,678	12,678	8,973	18,413	0	40,064	3.2	
French Polynesia	1950	1,477	0	2,000	2,970	0	4,970		
	2010	12,963	6,950	7,098	6,164	0	20,212	2.5	
Guam	1950	0	0	345	490	123	957		
	2010	55	0	20	7	28	55	3.6	
Hawaii	1950	3,780	3,041	990	0	1,809	5,841		
	2010	14,046	14,009	793	0	2,215	17,017	2.0	
Kiribati	1950	1,000	0	0	8,408	0	8,408		
	2010	18,769	0	7,849	14,576	0	22,425	1.2	
Marshall Islands	1950	0	0	79	874	0	954		
	2010	2,400	0	1,029	2,842	0	3,871	8.2	
Nauru	1950	0	0	29	267	0	296		
	2010	200	0	68	379	0	447	2.6	
New Caledonia	1950	400	0	400	2,176	0	2,576		
	2010	3,772	3,038	734	3,974	3,671	11,416	4.9	
Niue	1950	0	0	0	535	0	535		
	2010	114	203	10	139	0	352	71.0	
Northern Mariana Islands	1950	0	0	0	364	91	456		
	2010	69	0	69	20	79	168	5.9	
Palau	1950	300	0	267	596	0	863		
	2010	1,001	15	877	1,583	0	2,475	2.3	
Papua New Guinea	1950	5,948	1	3,103	17,165	0	20,268		
	2010	4,058	1,715	5,675	31,759	991	40,140	4.1	

Table 3 continued

Country	Year	Reported catch ^a (t)	Reconstructed catch (t)			Difference reconstructed versus reported 1950–2010 (factor)			Change (%) 1950–2010	Peak catch year ^a
			Industrial ^a	Artisanal	Total	Subsistence	Recreational ^b	Total		
Pitcairn Island	1950	0	0	5	23	0	0	28		
	2010	3	0	5	8	0	0	13	6.4	1950
Samoa	1950	300	0	416	5,406	0	0	5,822		
	2010	12,999	0	4,782	10,038	0	0	14,820	2.8	2001
Solomon Islands	1950	1,000	0	113	6,180	0	0	6,293		
	2010	35,197	14,249	9,351	16,202	0	0	39,802	1.6	1992
Tokelau	1950	0	0	0	384	0	0	384		
	2010	54	0	0	400	0	0	400	4.4	1960
Tonga	1950	200	0	623	3,207	0	0	3,830		
	2010	2,150	214	1,936	3,374	0	0	5,524	3.3	1981
Tuvalu	1950	0	0	0	813	0	0	813		
	2010	1,082	0	209	1,399	0	0	1,608	5.4	2007
US Pacific small island territories ^c	1950	0	0	0	0	7	0	7		
	2010	0	0	0	0	2	0	2	No reporting	1985
Vanuatu	1950	300	0	118	1,262	0	0	1,380		
	2010	438	0	529	2,859	0	0	3,388	1.6	2009
Wallis and Futuna	1950	0	0	0	441	0	0	441		
	2010	828	0	347	669	0	0	1,016	4.6	2010

^a Industrial fisheries for large pelagic species (e.g., tuna and billfishes) are excluded from the present consideration unless they are conducted by truly domestic fleets

^b Not always actively estimated in every country/territory

^c The US Pacific small island territories as considered here consist of Howland and Baker Islands, Jarvis Island, Johnston Atoll, Palmyra Atoll and Wake Island. However, domestic fisheries (recreational) only exist on Wake Island and Johnston Atoll

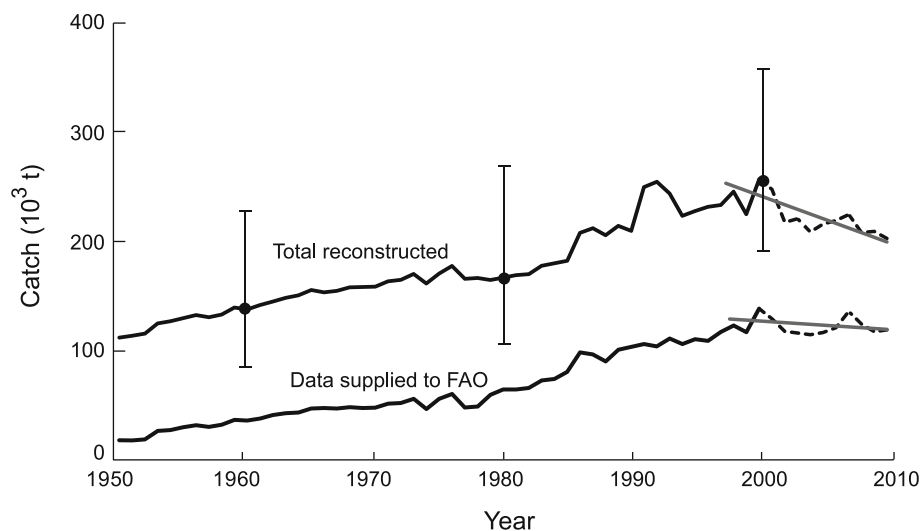


Fig. 4 Reconstructed total catch for all 25 Pacific island countries, states and territories (*upper line*), and data submitted to FAO on behalf of the same 25 entities (*lower line*). Confidence intervals of the reconstruction are shown for 1960, 1980 and 2000 based on a scoring method adapted from the IPCC (Mastrandrea et al. 2010). Note that industrial fisheries for large pelagic species (e.g., tuna and billfishes)

are excluded from the present consideration unless they are conducted by truly domestic fleets. Trends after 2000 differ significantly (regression, comparison of slopes, $p = 0.026$) between reconstructed (reconstructed catch = $-3,957.1 \times \text{year} + 243,890$ t) and reported data (reported catch = $-713.5 \times \text{year} + 126,270$ t)

catches (excluding clearly identifiable foreign-dominated yet domestically flagged large pelagic fisheries) summed for 1950–2010 were 2.5 times the data officially reported by national or FAO sources on behalf of these countries and territories (Fig. 3), although there were country-/territory-specific differences (Table 3). As one would expect, the discrepancy between reported and estimated total catches was largest in the early time period (1950: 6.4 times), while for the more recent times, reconstructed catches were 1.7 times the reported data (Fig. 3). Noteworthy is the subtle but significant difference in trend that can be observed between reported and reconstructed catches between 2000 and 2010 (Fig. 4; regression, comparison of slope; $p = 0.026$). While reported data present a steady increase in catches over time until 2000, followed by indications that a plateau has been reached in the 2000s (2000–2010: reported catch = $-713.5 \times \text{year} + 126,270$ t, $r^2 = 0.082$; Fig. 4), the reconstructions suggest that catches have actually peaked in 2000 and have been steadily decreasing ever since (2000–2010: reconstructed catch = $-3,957.1 \times \text{year} + 243,890$ t, $r^2 = 0.604$; Fig. 4). While 76 % of individual Pacific island countries, states and territories showed an increase in total catches between 1950 and 2010 (some as little as +4 %, maximum increase of +530 %; Table 3), the pattern of year with peak catch was consistent between individual Pacific island countries, states and territories, with 60 % of entities having the year of peak catch prior to 2000, and all but one entity (Wallis and Futuna), prior to 2010 (Table 3).

Reconstructed catch per year for all Pacific island countries, states and territories increased from around $110,000 \text{ t yr}^{-1}$ in 1950 (of which $17,400 \text{ t}$ were reported) to a peak of over $250,000 \text{ t yr}^{-1}$ in 1992 and again in 2000, before gradually declining to around $200,000 \text{ t yr}^{-1}$ by 2010 (Figs. 3, 4). This decline seems to be driven by a declining artisanal catch, which was not compensated for by gradually increasing domestic industrial fisheries (Fig. 3). Industrial catches as defined and considered here were dominated by the domestic large pelagic fisheries in Hawaii and French Polynesia (but recall that we did not consider large-scale fleets with the majority of foreign beneficial ownership). The artisanal fisheries that primarily supply domestic markets (although export-oriented artisanal fisheries exist, e.g., Lingard et al. 2012) appear to be declining from a peak of around $97,000 \text{ t yr}^{-1}$ in 1992 to less than $50,000 \text{ t yr}^{-1}$ by 2010 (Fig. 3).

Overall, total catches in these 25 small island countries, states and territories were dominated by subsistence fisheries (i.e., small-scale and non-commercial), which accounted for 69 % of total catches as estimated by the numerous detailed studies underlying this synthesis, with the vast majority of subsistence catches missing entirely from the reported data (Fig. 3). Artisanal catches accounted for 22 % of total catches, while truly domestic industrial fisheries, as could best be identified, accounted for only 6 % of total catches. The smallest component is the recreational sector (2 % of total catches), most of which was contributed by the recreational reef and bottom

fisheries in Hawaii (see Zeller et al. 2005, 2008). Recreational fisheries, although small in catches, are likely of substantial economic importance in some areas due to their direct link to tourism income and may become a growing issue for other countries in the region in the future.

Discussion

National, and, by extension, international, fisheries statistics report primarily, or often exclusively, on commercial fisheries, while underestimating small-scale and non-commercial fisheries. While we demonstrate this clearly here for Pacific island countries and territories, we would like to point out that this is not only a Pacific islands issue, as even developed countries have such reporting issues (e.g., Zeller et al. 2011a, b; Ulman et al. 2013; Coll et al. 2014). Here, we demonstrate that this underreporting has been substantial for all 25 Pacific island countries and territories considered. Even in the most recent time period, reconstructed total catches were 1.7 times the reported data, while in the past, the difference was substantially larger. Much of this difference is accounted for by the underrepresentation of subsistence fisheries in the data reported to or by the FAO on behalf of countries. Such consistent underreporting, especially if associated with marginalized small-scale fisheries (Pauly 2006), has implications for policy development and management of fisheries resources, as management in the absence of even the most fundamental of information, namely the catch that is taken, is counterproductive for potential sustainability for this basic food security resource (Pauly and Zeller 2014).

The importance of small-scale fisheries, and notably non-commercial subsistence fishing, to remote populations is substantial and thus represents a fundamental cultural, food security and human rights issue (De Schutter 2010a, b). While subsistence dependence on marine resources has decreased over the years for many Pacific small island countries and territories due to increased international transport and availability of goods and processed foods, subsistence fishing is still prominent on more remote islands, i.e., those that are not commercial or administrative hubs. As shown by estimates in this synthesis, subsistence fishing accounted for over 90 % of total catches in 1950 and at present still accounts for nearly 63 % of reconstructed domestic catches for Pacific islands (in some instances accounting for 100 %, as in the case of Tokelau; Zyllich et al. 2011). Thus, coastal and near-coastal marine resources are far more important for basic food security in the Pacific than national and global reported data would suggest (Pauly and Zeller 2014). At their 2014 meeting, the FAO Committee on Fisheries and Aquaculture (COFI) endorsed the Voluntary Guidelines for Securing

Sustainable Small-scale Fisheries in the Context of Food Security and Poverty Eradication (COFI 2014). Such an endorsement by the international community requires to be followed by increased and improved accounting of catches taken by the small-scale fisheries sectors around the world (including non-commercial catches). As we have shown here, this has not been the case until now, with small-scale fisheries (especially subsistence fisheries) accounting for the vast majority of the unreported catches (see Fig. 3).

It is possible that the dependence of Pacific island communities on coastal and near-coastal resources may increase in the future, as climate change will negatively impact most coastal resources in the Pacific (Bell et al. 2011a, b) and tropical regions in general (e.g., Cheung et al. 2010). This may be further exacerbated by rising fuel costs which will increase transportation costs and thus may reduce availability and accessibility of imported and processed food resources for all Pacific islands. While domestic pelagic (i.e., tuna) fisheries may compensate for such losses in some instances (Bell et al. 2011a, b), this will require additional financial and technical resources and expertise for the development and long-term maintenance of pelagic vessels and fleets, or an ongoing diversion of some catches from foreign licensed vessels into lower-valued local markets. However, even at present, much of this resource pool is already exploited at or even above sustainable levels (Sibert et al. 2012; Anon. 2014). Furthermore, pelagic stocks may in future also suffer from range shift, lower stock productivity and average maximum body size due to eco-physiological effects of climate change (Cheung et al. 2011, 2012). Thus, in order for Pacific islands to better meet future domestic food security needs through these pelagic resources, large-scale foreign-owned fleets may either see their access being curtailed, and thus reducing foreign exchange income earnings for many tuna-host countries in the Pacific, or foreign access fees increased substantially (see also Le Manach et al. 2013a, b) even above the recent increases in fees, to ensure sufficient national funding to subsidize food imports (a less than ideal situation). Either option would require massive investment in monitoring and enforcement resources by Pacific host countries to reduce and control otherwise increasing illegal fishing trends.

Our study indicated that the ‘plateauing’ of the officially reported data for the Pacific islands is not the correct trend for catches, which appear to be declining rapidly (Fig. 4). The same ‘plateauing’ of catch trends is also suggested in global statistics, with the FAO indicating in their biannual State of World Fisheries and Aquaculture report (SOFIA) that global landings have ‘stabilized’ (FAO 2014). It remains to be seen whether the differing and declining trend of total catches documented here for Pacific islands will also be reflected in global reconstructions.

In order to better account for the presently underrepresented small-scale catches in official statistics, we suggest that regular, non-annual survey or census-driven data collections be implemented across all Pacific island countries (Zeller et al. 2007b; Bell et al. 2009) to derive country-wide raised annual estimates for fisheries sectors not captured by current data collection systems. Such surveys, conducted every 3–5 yrs, and the resultant country-wide raised estimates interpolated between survey years, once incorporated in the officially reported data, can serve as a foundation for comprehensive accounting of domestic fisheries. The Household Income and Expenditure Surveys (HIES), conducted by many Pacific island countries, are likely the best and most cost-efficient mechanisms to incorporate such fisheries data collection approaches, if done appropriately (Gillett 2009; de Graaf et al. 2014). Concerns about such data not being ‘precise’ enough for national or international consideration are unfounded, as they are far superior to the current default where ‘no data’ are automatically substituted in the official data series as ‘zero’ catches, resulting in Pacific reported data being considered of such poor quality as to be unusable (Gillett and Preston 2000). Furthermore, while data as reconstructed here or via household survey approaches may be statistically less ‘precise’ than data collected, for example, by onboard observers or at commercial landings sites, they are more ‘accurate’ than the current default practice of unintentionally substituting ‘zero’ reported catches for ‘no data.’ It is hoped that after implementation of the above-proposed approaches to comprehensively but intermittently estimating actual total catches, such data may be superior in quality to the reconstructed data synthesized here based on numerous technical studies.

Such catch surveys should be complemented by equally regular assessments of the taxonomic composition of artisanal, subsistence and recreational catches, also repeated in non-annual increments, using a stratified sampling approach that permits application to country-wide total catch estimates derived from the above surveys.

As financial and human/technical resources are understandably limited for many of the small island countries and territories, such catch and taxonomic surveys should be facilitated by a regional approach, for example, under the guidance and coordination of the Secretariat of the Pacific Community (SPC). Pacific countries could task the SPC with establishing and training a rotating task force of national staff from all Pacific island entities (to ensure comprehensive representation) as part of SPCs regular work program, whose task is to develop, design, execute (at a rate of several countries and territories each year), analyze and publish (in collaboration with each country’s government) such small-scale survey results (including the

contribution of women to fisheries, Harper et al. 2013), on a rotational country basis within, e.g., 5-yr time windows. This should focus exclusively on creel surveys in line with and in close collaboration with HIES. Regionally, Pacific islands should seriously consider funding this initiative outside of the default donor-funding schemes common in the region and instead fund this through a fisheries levy added onto all foreign and joint venture tuna fishing fees. The same team can separately census the taxonomic composition of landed catches using a well-designed random stratified sampling approach for both artisanal (small-scale, commercial) and subsistence catches. Such a Pacific-wide team effort by a geographically representative team can also enhance regional coordination and collaboration in many aspects of food security and would send a strong signal for the need for regional collaborations in sustainable marine resource use for others to follow (see, e.g., Le Manach et al. 2013a, b).

While conducting and coordinating country reconstructions around the world over the last 10 yrs, the senior author has repeatedly been advised that countries or regional agencies have better or more detailed data than what are being reported to FAO. However, the onus is on country representatives who report data to FAO to ensure that FAO receives the best data available to address and avoid the considerable data deficiencies presently inherent in the data FAO reports on behalf of its members (Garibaldi 2012), as these data represent a country in the global sphere (Ward 2004). Unfortunately, the electronic data request form sent annually to country representatives by FAO does not make it readily transparent that every country has the right to retroactively (back to 1950) change both catch quantities and taxonomic resolution of the data it reports to FAO. For FAO to modify this data spreadsheet to enable easy modification and changes to the taxonomic composition and/or past tonnages (combined with clear instructions as to FAO’s mandate to improvements in data) may go a long way toward further improving international accounting practices.

Finally, the data and approaches presented here are currently being applied globally to all countries in the world, with the aim of improving global databases on fisheries catches (Pauly and Zeller 2003). The data presented in the present synthesis will form part of these global datasets and thus contribute to improved baselines for fisheries conservation and management policy.

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