Accurate catches and the sustainability of coral reef fisheries
Daniel Pauly and Dirk Zeller

While there might be differences in details, any definition of ‘sustainability’ must include an element that remains similar over time. For example, this applies to the catches of coral reef fisheries, which cannot be sustainable if exhibiting a strong ascending or descending trend. Thus, despite claims of the efficacy of ‘data-less’ management, at least time series of the catch of coral reef fisheries must be known for valid inferences on their status to be drawn. By contrasting the official and the ‘reconstructed’ coral reef catches of four small island states (Fiji and Tonga in the Pacific, and Jamaica and St Kitts & Nevis in the Caribbean), we show, however, that official catch data, as made available to and by the Food and Agriculture Organization of the United Nations (FAO) not only strongly underestimate catches (from 4 to 17 times for 1950–2010), but also suggest increasing catch trends in 3 of 4 cases, that is, the very opposite of the trend resulting from the bottom-up catch reconstructions. Some implications of these findings, which we think have general currency, are presented.

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Introduction
Research on sustainability has numerous dimensions, one of them being semantics — for example, what does ‘sustainable fishing’ mean, if anything? Clearly, industrial fishing, especially trawling, which began around the English coast at the end of the 19th century, has never been sustainable in the sense that a given stock was exploited at any given place for a long period [1**2]. Rather, trawlers could maintain their unprecedented high catch rates only by expanding the scope of their operation, first to the open North Sea, then the wider North Atlantic all the way to Iceland, where in the 1930s, they began to exploit stocks which Icelanders perceived as theirs [3]. Such expansion is a characteristic of industrial fishing, and has led to a number of distant-water fishing nations to deploy vessels operating even in Antarctic waters [3,4*,5].

Industrial-scale exploitation of coral reef fisheries resources, on the other hand, is quite rare outside of muro-ami operations,1 which however leave only coral rubble in their wake, and therefore do not need to be discussed in the context of sustainability. Thus, the question that could be posed instead is: how sustainable are small-scale coral reef fisheries?

A famous biologist-turned-maritime-anthropologist, Bob Johannes, suggested that coral reef fisheries in the tropical Pacific were sustainably managed, without ‘western science’ [7], because of the deep traditional knowledge of the people who had exploited and managed these resources for centuries [see also 8]. Work by others, for example, in the South Pacific [9,10] and in Hawaii and Florida [11], tends to support this claim.2

However, traditional modes of exploitation of reef resources have faded away, or have been actively suppressed by colonial powers [9,10], and while there are numerous current efforts to revivum throughout the Pacific, the context within which coral reef fisheries operate is generally very different from that of pre-colonial (or pre-contact) times. Thus, these fisheries are currently conducted with motorized boats and modern gear, and can land fish in port cities with airports ready for marketing internationally — a far cry from the situation prevailing before, when lineage or village chiefs could prohibit fishing on certain reefs, and where one’s village was the only outlet for the fish caught during a trip with an un-motorized craft [9,10].

As for the Caribbean, the wholesale replacement of the Amerindian inhabitants by populations initially lacking a connection with the sea (mainly Sub-Saharan farmers) prevented the continuation of any traditional approaches to managing coral reef fisheries. Moreover, in the Caribbean, but to a certain extent also in the Pacific,

1 Muro-ami fishing is a method wherein a coral reef is completely encircled with a fine mesh net and the reef is then smashed to bits with stones attached to ropes, such that the fish previously hidden in the reef’s crevices are caught in the net [6].

2 However, the claim by Johannes that the Palau fisheries he described are sustainable cannot be tested because ‘Words of the Lagoon’; as the title may imply, does not present any numbers to describe actual catches.
profound changes in land tenure created a large number of surplus farmers (i.e. underemployed young men) for whom fishing became, in recent decades, an occupation of last resort [12,13].

Combined with a strong population and income growth, these trends generated, in the last decades an immense demand for fish, both local and international, and a huge increase in fishing effort to meet that demand. Fisheries, which had arguably not needed any sort of scientific input [8] became so intensive that they induced massive changes on the underlying coral reef ecosystem [14].

We argue that under such conditions (i.e. high-performance modern gear, disappearance of strict traditional fishing rules, and even international marketing of catch), notions of ‘data-less’ management become questionable and likely cannot ensure sustainability, however defined. Indeed, for such fisheries, sustainability is in many cases not an issue any more; the challenge is rather the rebuilding of exploited populations [15]. Moreover, whichever way the challenge is defined, once the notion of ‘data-less’ management is abandoned, the question becomes: which data are necessary for the management of coral reef fisheries?

Given the scarcity of resources (both financial and technical) in most tropical countries that have coral reefs, highly technical and expensive data regimes, such as those required for traditional stock assessments and extensive fisheries-independent surveys, have been and likely continue to be unavailable and unobtainable. This leaves these countries with the most fundamental and most basic of all fisheries data, namely data on total catches (and secondarily, data on fishing effort). However, to date, comparative studies of coral reef fisheries have been generally based on catch (actually ‘landings’) statistics made public by the Food and Agriculture Organization of the United Nations (FAO), themselves based on voluntary questionnaires and spreadsheets submitted annually by FAO member countries [16]. However, these ‘catch’ data supplied by countries are usually highly incomplete and/or inaccurate [17–20,21,22–26], especially for small-scale fisheries such as those exploiting coral-reef fishes.

Here, we document that the scope of the inaccuracies in reported landings data implies that the authorities in question do not know the key variable of the fisheries they are supposed to manage, that is, the catch. Thus, they cannot ensure their sustainability, even if they had otherwise the means to do so (legislation, civil service, budget, etc.).

Materials and methods
The catch from the domestic, small-scale (i.e. artisanal, recreational and subsistence) fisheries of Fiji [27], Tonga [28], Jamaica [29], and St. Kitts & Nevis [30] (Figure 1) were ‘reconstructed’ for 1950–2010 based on the concept in Pauly [31] and the approach outlined in Zeller et al. [21]. The former posits that:

- There is no fishery with ‘no data’, because a fishery, as a social activity with a ‘fish catching’ component, will always impact on other sectors of an economy, such as employment, seafood supply, or fuel requirements. Thus, it is nearly always possible to infer, if grossly, the magnitude of the catches of a fishery.
- It is always worse to put a value of ‘zero’ (i.e. to say nothing about its catch) 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’. This even applies to actual entries of ‘no data’, which subsequently get treated as ‘zero’ catch.

Based thereon, the approach of Zeller et al. [21] for reconstructing catches details a 6-step process, generalized and summarized as:

1) Identification, sourcing and comparison of existing, reported catch times series:
   a. FAO reported landings data by FAO area, taxon and year;
   b. National data series by area, taxon and year.

2) Identification of sectors (e.g. subsistence), time periods, species, gears etc., 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 grey) and consultations with local experts. Information sources include case studies, anthropological and social science studies, reports, data sets and expert knowledge;

4) Development of data ‘anchor points’ in time for each missing data item, 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 non-commercial sectors; and

6) Estimation of total catch times series, combining reported catches (1) and interpolated, country-wide expanded missing data series (5).

The country-specific technical reports cited above (and available under ‘publications’ at http://www.seaaroundus.org/about/) provide details on how the approach of Zeller et al. [21] was applied to each specific island.
The four examples of coral reef fisheries dependent island countries examined here, that is, Fiji [27] and Tonga [28] in the western Pacific, and Jamaica [29] and St. Kitts & Nevis [30] in the Caribbean. Each has an Exclusive Economic Zone (EEZ; black line, medium blue waters) extending beyond the coastal and coral reef areas emphasized here. Maps show the 50 m depth contour (in red) indicative of 'reefy' areas, as well as the Inshore Fishing Areas (IFA, dark blue) defined as those waters that are either less than 50 km from shore, or less than 200 m deep, and whose adjacent land is inhabited. The IFA represents the general area used by small-scale fisheries in a country, which usually extends beyond the areas of living coral reefs. Note that the offshore banks (e.g. Pedro bank) to the south-west of Jamaica are regularly and intensively fished by Jamaican small-scale fishers, and hence are also treated as IFA, despite being more than 50 km from Jamaica.

two (Fiji and Tonga) of the four examples had original reconstructions ending before 2010, these reconstructions were carried forward to 2010:

**Fiji:** To update the reconstruction for Fiji [27] to 2010 from the original end year of 2009, the 2010 FAO data were used as the reported catch baseline. In recent years, essentially all target-species catches that were landed were also reported, thus only large-scale commercial by-catch and discards were unreported for 2010. Landed by-catch and discards for 2010 were calculated based on the proportion of 2009 landed by-catch and discards, respectively.

**Tonga:** The reconstruction for Tonga [28] originally went to 2007, and required carrying forward to 2010 by using the FAO data as the reported landings component. The ratio between the FAO reported component and total reconstructed catches for 2007 was applied to the FAO data for 2008–2010 to estimate the total reconstructed catches for these years, that is, proportionality was assumed. The unreported catches for 2008–2010 were then assumed to be the difference between the reported FAO data and the estimated total catches.

The key references used for the reconstruction of catches of each country (Table 1) are presented by fisheries component, these being large-scale commercial (or ‘industrial’), small-scale commercial (i.e. artisanal), subsistence, discards and recreational/tourist. This allows for rapid comparison of the source type. Since the reconstructions were conducted by these fisheries components, and
then summarized for the present purpose into coral reef and no-reef fisheries using taxonomic affiliation with coral reefs, we refrained from presenting the data anchor points graphically, as this would create a disconnect with regards to the present reef versus non-reef emphasis.

Results and discussion
Each of the four islands had small-scale (coral reef) catches that were strongly underreported in official statistics. Irrespective of how one feels about the methods and assumptions used in the catch reconstruction

Table 1

<table>
<thead>
<tr>
<th>Fisheries component</th>
<th>Fiji</th>
<th>Tonga</th>
<th>Jamaica</th>
<th>St. Kitts &amp; Nevis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large-scale commercial</td>
<td>[40, 41]</td>
<td>[42–44]</td>
<td>[45–48]</td>
<td>N/A</td>
</tr>
<tr>
<td>Small-scale commercial</td>
<td>[49–51]</td>
<td>N/A</td>
<td>[48,54–57]</td>
<td>[58–61]</td>
</tr>
<tr>
<td>Discards</td>
<td>[62]</td>
<td>N/A</td>
<td>[63]</td>
<td>N/A</td>
</tr>
<tr>
<td>Subsistence</td>
<td>[50,64–67]</td>
<td>[50,68–74]</td>
<td>[75–77]</td>
<td>[78]</td>
</tr>
<tr>
<td>Recreational</td>
<td>N/A</td>
<td>N/A</td>
<td>[79,80]</td>
<td>[91–94]</td>
</tr>
<tr>
<td>Other</td>
<td>[85–87]</td>
<td>[88]</td>
<td>[89,90]</td>
<td>[91]</td>
</tr>
</tbody>
</table>

Figure 2

Time series of fisheries catches from 1950 to 2010 for Fiji and Tonga in the Pacific (top), and Jamaica and St. Kitts & Nevis in the Caribbean (bottom), showing in each case the reconstructed coral reef fisheries catches (light grey), as well as non-reef fisheries catches (mainly large pelagic tuna and billfish catches; dark grey), with official catches as reported by FAO on behalf of each country overlaid as a solid line.
summarized in Figure 2, the scale of official underreporting was substantial. This is especially true for earlier time periods, where the reconstructed total catches were between nearly 4 fold higher for St. Kitts & Nevis to over 17 fold higher for Fiji compared to reported catches (Table 2, Figure 2). However, even by the 2000s, three of the four countries continued to miss substantial coral reef fisheries catches in their reported data (between 50% and >100%; Table 2, Figure 2). Fiji, whose more recent reporting efforts are commendable, was the exception.

Besides the quantity of unreported catches, the difference in the trends could not be starker. In contrast to the FAO data, which in three of the four countries show a steady and gradual increase in catches over time (Figure 2), the reconstructed coral reef catches show distinct, early time period peaks, ranging from the late 1950s (St. Kitts & Nevis) to the late 1970s (Jamaica), followed, in all cases, by a strong decline.

In other words, the actual trajectory of coral reef fisheries catches over time of our four countries, and by inference, of other coral reef islands (see e.g. [19,22,26]), will usually be radically different than suggested by official (FAO) data. Thus, we suggest that inferences on the sustainability of reef fisheries based on FAO data, however sophisticated their rules for identifying the coral reef fraction of the catch that countries report may be (as done, e.g. in [32]), cannot provide the basis for detailed comparisons and/or inferences on the status of reef fisheries.

Rather, assessment and comparisons of coral reefs fisheries, in term of their sustainability or other metrics, should rely — until the FAO member countries supply better catch data on their coral reef fisheries — on primary catch data [33,34], on carefully filtered secondary data [35] or on bottom-up reconstructed data, as presented here.

Although there are some diverging opinions, as there are on any issue, it is widely agreed that catch data are the first and most important type of information one can obtain about a fishery, for a number of reasons, the primary ones being:

1) Catches, when expressed as a weight per time for a number of taxa, provide a scale for the fishery, and anchor it onto the biology of the species reported in the catch;
2) Catches, when re-expressed in terms of the ex-vessel value of the catch, allow the economic contribution of the fishery in question [36] to be evaluated and assessed against the potential cost and benefits of management intervention; and
3) Time series of catches allow, under certain conditions and assumptions, for preliminary assessments of a fishery using catch-data methods [37,38].

However, for these properties of catch time series to apply, catches must be accurate, which is the real point of this contribution. We suggest that authors, before conducting comparative studies on coral reef fisheries, should perform catch reconstructions as summarized here, and as detailed in the cited papers.

Finally, we would like to argue that coral reef fisheries can be made sustainable, as they are generally small-scale in nature (with few exceptions, such as export oriented live reef fisheries or muro-ami1 fisheries), and therefore they have more local community linkages compared to large-scale fisheries. This allows for community based initiatives and local-scale management or co-management [39], which can ensure sustainability. But again, this requires that catch is regularly and comprehensively monitored/estimated and accounted for [21*].

Acknowledgements
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References and recommended reading
Papers of particular interest, published within the period of review, have been highlighted as:
• of special interest
  ** of outstanding interest


### Table 2

<table>
<thead>
<tr>
<th>Country</th>
<th>EEZ (km²)</th>
<th>IFA (km²) a</th>
<th>Human population</th>
<th>Mean coral reef catch (t)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiji</td>
<td>1,280,000</td>
<td>43,300</td>
<td>287,000</td>
<td>905,000</td>
<td>1950s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2000s</td>
</tr>
<tr>
<td>Tonga</td>
<td>665,000</td>
<td>7800</td>
<td>46,000</td>
<td>106,000</td>
<td></td>
</tr>
<tr>
<td>Jamaica</td>
<td>263,000</td>
<td>13,400</td>
<td>1,380,000</td>
<td>2,700,000</td>
<td></td>
</tr>
<tr>
<td>St. Kitts &amp; Nevis</td>
<td>10,200</td>
<td>630</td>
<td>44,000</td>
<td>50,000</td>
<td></td>
</tr>
</tbody>
</table>

* The Inshore Fishing Areas (IFA) is defined as those waters that are either less than 50 km from shore, or less than 200 m deep, and whose adjacent land is inhabited. This definition is a slight modification from that in [92].


Environmental change issues


64. Gillett R: Small island developing states of the Southwest Pacific. In *Review of the State of World Marine Capture Fisheries Management: Pacific Ocean*. Edited by De Young C. Food and Agriculture Organization of the United Nations (FAO); 2003:121-140.


