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Learning from the Past for Future Policy: Approaches to Time-series Catch Data Reconstruction

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Abstract—Reliable time-series catch and effort data are fundamental for fisheries assessment and management; however, such data are usually not readily available. The Food and Agricultrual Organization (FAO) compiles statistical reports from its member countries, but their reliability is questionable. Several approaches were explored in this study for the reconstruction of time-series catch data using Red Sea fisheries as case studies, starting from 1950. Historical documents, published and unpublished reports, grey literature, databases, surveys, anecdotal information, interviews, and information on processed seafood products were used as sources. When reliable data were available for a number of years, they were used as anchor points to interpolate for missing data, based on transparent assumptions, which use the basic knowledge of the fisheries. Monte Carlo simulations were used to estimate uncertainty in estimates of the means and 95% confidence intervals. The results revealed that actual catches are up to nine times higher than those reported to the FAO. The resulting catch trends provide interesting historical records and important guidance for the development of future fisheries management policies on resource conservation for the benefit of coastal communities.

INTRODUCTION

Throughout the world, many fisheries are still managed – when they are – with explicit reference to Maximum Sustainable Yield (MSY), or variants thereof. This leads to the idea that there is a maximum limit beyond which it is not advisable to fish, which is still useful. Thus, irrespective of criticisms of the MSY concept, not knowing where we are in relation to the MSY, or any other management objective, could lead to inappropriate decisions on appropriate levels of fishing effort. This can lead to damage which is hard or sometimes impossible to reverse, e.g. the collapse in the Cod stock of the North-eastern Atlantic (Fu *et al.*, 2001). This is true of many fisheries, the management of which depends on the notion of a target 'MSY', but for which a basic knowledge of the fishery is lacking, e.g. in form of reliable catch and effort data. Hence, in such cases, it becomes imperative that time-series catch and effort data should be reconstructed as a starting point for any fisheries assessment and management.

A time-series on total catch is the most important information about a fishery (Pauly & Zeller, 2003), more so when it is coupled with effort data. Notably, such time-series are essential for preliminary assessments of the status of populations upon which fisheries depend (Caddy & Gulland, 1983). Catch

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and effort data are fishery dependant, i.e., obtained from a fishing industry (as opposed to experimental fisheries). The most common methods of data collection are: logbook entries by the fishers, observer data collected on-board the fishing vessels, data collection at landing sites and information gathered at the market (e.g. auctions and export). However, proper planning and systematic collection procedures are needed (Gulland, 1975; Sparre, 2000).

A frequent problem encountered when collecting time-series data in developing countries is the institutional instability of most fishery agencies, which may form part of an overall political instability in the country itself. As a result, there are usually inconsistencies and gaps in data collection. In such situations, researchers and managers (local and international) usually refer to data held by regional or international organizations, such as the FAO, that collect global data in a standardized format; these are valuable, despite some drawbacks (Pauly & Zeller, 2003). Though the bulk of such data are submitted by member countries, there are often discrepancies between locally obtained catch statistics and those available from the FAO. There is no incentive for countries to report properly and the FAO does not appear to have a well-developed mechanism to verify submitted data.

Reconstructing time-series catch and effort data from the past to the present is not only useful for historical purposes, it can also be used as the basis for restorative actions, future exploitation and the accurate assessment of the impact of fishing on marine ecosystems (Scott Baker & Clapham, 2004; Pitcher, 2005). Even if a good data collection system is in place, past records are important for comparison (Pauly, 1998). In such data reconstruction, the different components are compiled into one standardized data set. Both quantitative and qualitative data are needed to elucidate the status of stocks, the effects of fishing and the effectiveness of fisheries management. As a fishery expands, there may be change either in the composition of the catch (Pauly *et al.*, 1998), or in its magnitude, or both (Pauly & Watson, 2003). Monitoring these changes provides an insight into what is happening in a fishery and can be the basis for appropriate management actions. The longer a time-series data reaches into the past, the better it is, the point being to avoid the problem posed by 'shifting baselines' (Pauly, 1995). Some reconstructions go back many centuries using archaeological findings (Pitcher, 2005). Once catch and effort data are reconstructed, catch per unit of effort (CPUE) can be calculated, and inferences drawn on stock abundance indices.

There is, however, no definite procedure to reconstruct or estimate catch; different approaches are used with one common goal, which is to get as close to accurate numbers as possible. Watson & Pauly, (2001) used statistical modelling, which related oceanographic data to fisheries production, while Zeller & Pauly, (2007) used a variety of approaches. Indeed, most catch reconstruction procedures involve digging deeper into the records of fisheries agencies, academic and research institutes, registers, tax offices, banks or any other sources which may provide direct or indirect clues on fisheries catch. Sometimes proxies, such as human population sizes and per capita fish consumption, are used to estimate total catches (Zeller & Pauly, 2006). Here, a few approaches of catch reconstruction are explored using fisheries data from the Red Sea.

THE FISHERIES AND STUDY METHODS

Four different methods of catch reconstruction are given here, as applied to fisheries in the Red Sea (Fig. 1). The four fisheries were chosen based on their importance (Tesfamichael & Pitcher, 2006) and usefulness as good examples of the various approaches of catch reconstruction.

Catch inferred from processed products

The first example is the beach seine fishery in Eritrea which was this country's most important fishery in the 1950s and 1960s, contributing up to 90% of the total reported catch (Grofit, 1971). The main target species were sardines (*Herklotsichthys quadrimaculatus*) and anchovies (*Encrasi-cho¬lina heteroloba* and *Thryssa baelama*),

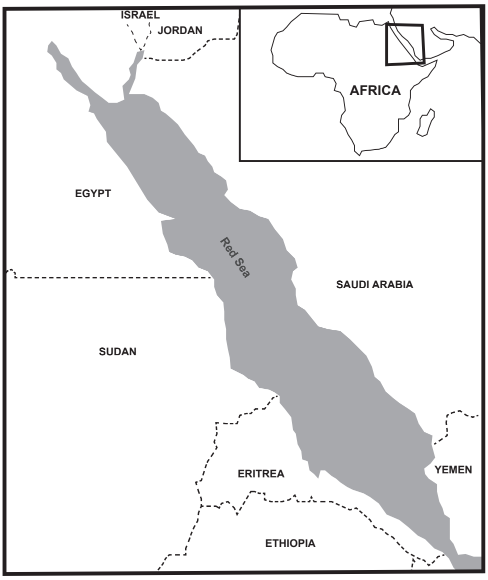

Figure 1. Map of study area showing the Red Sea coasts of Sudan and Eritrea.

used mainly in the production of fish meal for export to Europe and Asia. A small proportion of the catch was also sun-dried for human consumption for markets in Asia (Sanders & Morgan, 1989). Since the main target of this fishery was the export of fish meal, there was a good record of exported quantities, converted to wet weight using a wet weight to processed weight ratio of 4:1 (Ben-Yami, 1964).

On-board observation of discards

The main target of demersal trawlers in the Eritrean Red Sea comprises penaeid shrimps, which do not contribute much to the total catch; however, their high market value makes them lucrative. The total shrimp catch has never exceeded the estimated MSY of 500 tonnes (Giudicelli, 1984). Species commonly caught are: *Penaeus semisulcatus*, *P. japonicus* and *P. latisulcatus*. In addition to shrimps, bottom trawlers also catch finfishes, the dominant species being lizard fish (*Saurida undosquamis* and *S. tumbil*) and threadfin bream (*Nemipterus japonicus*). Indeed, the by-catch of the trawl fishery is much higher than the targeted shrimp; and some is retained, there is significant discarding of fish. On-board observers were placed on the trawlers by the Ministry of Fisheries - Eritrea to record the amount of fish by-catch (both discarded and kept); their reports were compiled to reconstruct the total amount of fish harvested by the trawlers.

Formal and informal markets

The Sudanese artisanal fishery is dominated by hook and line fishing on the well-developed coral reef ecosystem off the coast of Sudan. There is a major fish market in Port Sudan, Sudan's main port. However, like many other countries, not all fishes caught are sold in the market. Some of them are sold directly to buyers and others are given to family members or friends. The Fishery Administration of Sudan collects its catch data mainly in the fish market in Port Sudan, which means that fishes that do not go through the market are unrecorded. Surveys have revealed that only half of the fish sold goes through the market (Chakraborty, 1983) and a multiplication factor is used to obtain a better estimate of the total catch. In addition, 300 tonnes are estimated to be consumed by the crew and their family members or given away. The main species targeted are groupers (*Epinephelus* spp.), snappers (Lutjanidae) and emperors (Lethrinidae).

Interviews

Unlike the above three approaches, no attempt is made in this method to calculate the actual catch, but rather to estimate catch rates over a long period of time, based on interviews with fishers of different ages. A semi-structured questionnaire was thus used to interview fishers in the Red Sea in 2006 and 2007 to fill gaps in the data, e.g. on the amount of fish consumed by crew or given away, the latter being a socially important and common activity. The latter can be substantial; based on the interviews, it may amount to 50% of the catch, none of which is recorded in official catch statistics. Interviews were also used to estimate temporal changes in catch rate. In total, 45 hook and line fishers from Sudan and 78 Shark fishers from Eritrea, aged from 15 to 82 years, were asked about the best catch they ever caught. The Sudanese fishers reported that they target coral reef fishes - mainly groupers, snappers and emperors - for direct human consumption. The shark fishers in Eritrea use mainly deep water gill nets to catch sharks and, to a lesser extent, they use hook and line. Once they catch the sharks, they usually cut off the fins and throw back the bodies. The fins are dried and sold for a good price for export to markets in China. Sometimes the meat of sharks is salt-dried for sale in the local market or export to Yemen. Most of the shark fishers reported their catch in dry fin weight (DFW in packs 16 kg, locally called '*farasila*'). The DFW was converted to total wet weight (TWW) using data on dried and wet fin weights from Fong (1999), an assumption that the fins accounted for 5% of the dressed shark weight (NMFS, 1993) and the estimate that heads and guts accounted for 10% of the total wet weight. The empirical relationship between DFW and TWW (in kg) was: TWW = 14.93*DFW – 0.13.

It has been argued that this equation is too general and that different models should be applied to different species (Cortes & Neer, 2006). However, during the interviews, fishers indicated that their catch would contain different species and they usually reported on the total catch and not according to its composition. Based on the interview data, catch rates were calculated as catch per crew per day, providing a good estimate of changes in abundance of the species.

Apart from the interviews, data were not available for all these fisheries over the years. When data were missing, they were interpolated using nearby data points as anchors, taking into consideration changes in the fishery during that time. A linear change was assumed between neighbouring anchor points during interpolation, the slope being determined by these anchor points. While simple linear connections between anchor points can be criticized, we believe that, given the qualitative information obtained from interviews and documents, these interpolations roughly reflect what happened in intervening years when catch data were not available. Such estimates, even when based on qualitative information, are better than recording zero catches when quantitative data are not available, as is often done.

Statistical analysis

Where different catch and effort estimates were available from various sources for different years, the highest and lowest values were selected as upper and lower limits, respectively, in uncertainty analyses. Similarly, where data were interpolated, upper and lower bounds were calculated by linear interpolation between upper and lower neighbouring anchor points. The true catch (X) was assumed to fall somewhere between the lower (A) and upper (B) range estimates such that:

$$P[A \le X \le B] = \int_a^b f(X)dX = 1 \qquad \dots(1)$$

For values of *X* between *A* and *B*, the probable density function *f(X)* of the triangular distribution is given by:

$$f(x) = \begin{cases} \dfrac{2(X-A)}{(B-A)(C-A)} & if\ A \le X \le C \\ \dfrac{2(B-X)}{(B-A)(B-C)} & if\ C \le X \le B \end{cases} \qquad \dots(2)$$

where (*C*) is the mode of the distribution, the peak of the triangle. It was determined by experts who knew each fishery and its associated data, either as the most likely value of the catch, or a percentage of its range between the upper and lower limits:

$$C = A + \big(D(B-A)\big) \qquad \dots(3)$$

where (*D*) is the percentage range that the mode will vary from the lower limit.

An asymmetrical triangular distribution was chosen because the limits were probably neither symmetrical nor normally distributed, i.e. extreme values far from the median were less likely (Kalikoski *et al.*, in press). Means and 95% confidence intervals were calculated in 5000 iterations of the asymmetrical triangular distributions using Monte Carlo simulations. Reconstructed catch were compared with FAO data.

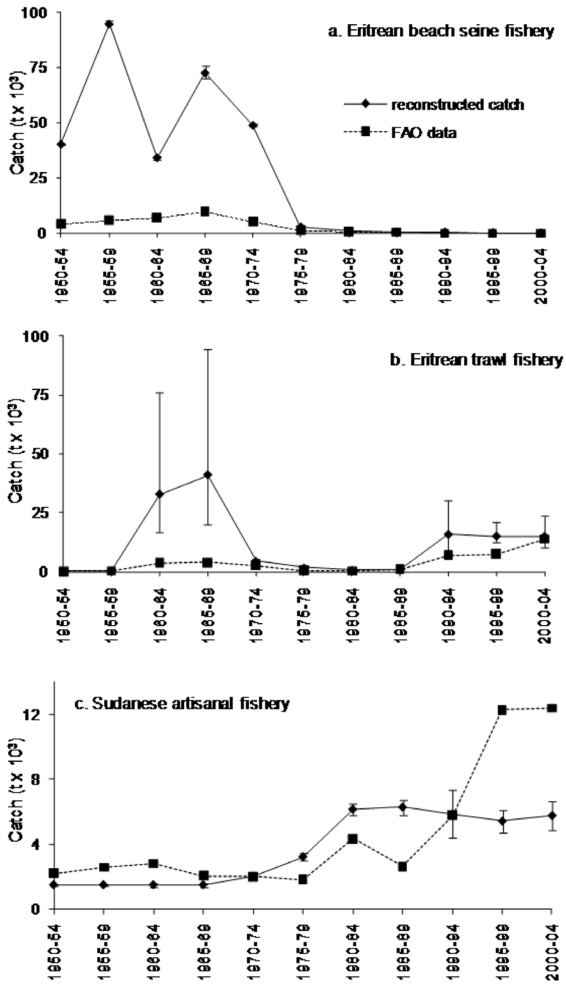

Figure 2. Reconstructed and FAO catch data for a) the Eritrean beach seine and b) trawl fisheries and c) the Sudanese artisanal fishery in five-year averages with error bars showing the 95% confidence intervals for the reconstructed data.

RESULTS AND DISCUSSION

Reconstructions revealed clear differences between reconstructed catches and what is reported (Fige 2). The analysis in Figure 2 was undertaken in five-year blocks, i.e., the data points on the graph are averages of five years. Catches reconstructed here may not reflect the exact quantities of fish harvested by the different types of fishing gear. However, given the evidence, we believe our estimates are closer to actual catches than data reported by the FAO. It is necessary to account for unreported catches to understand the effects of fisheries in an ecosystem (Tesfamichael & Pitcher, 2007). Figure (2a) shows the reconstructed catch for the beach seine fishery of Eritrea. The difference between the reconstruction and FAO report can clearly be seen in the 1950s and 1960s when the fishery was active and the catch larger. Starting early in the 1970s, the catch declined drastically because the Eritrean war of independence intensified and affected most of the infrastructure in the country until it ended 1991. On average, the officially reported catch was only 12% of the reconstructed catch.

Two peaks occurred in the Eritrean trawl fishery, one in the 1960s and a second commencing in the early 1990s; this pattern is evident in both the reported and reconstructed catches (Fig. 2b). Trawling was introduced in the 1960s and initial catches were very high. After Eritrea's independence in 1991, the trawl fishery recovered better than the beach seine fishery. The 95% confidence intervals of mean estimates of reconstructed catches were high in the 1960s because disparate catches were reported by different sources and it was difficult to verify which ones were more reliable. However, even the lower limit of the interval is higher than the FAO data.

In the Sudanese artisanal fisheries, major change occurred in the early 1970s with the introduction of outboard engines through an aid programme from the United Kingdom's Overseas Development Agency (ODA). Until then, the catch of the fishery was estimated to be 300 tonnes per year (Chakraborty, 1983), hence a catch of 1.5 thousand tonnes is inferred for the 5 year period up to the end of the 1960s. The catch then peaked until it stabilized in the 1980s (Fig. 2c). In contrast, FAO data for the Sudanese artisanal fisheries fluctuates drastically. There is no

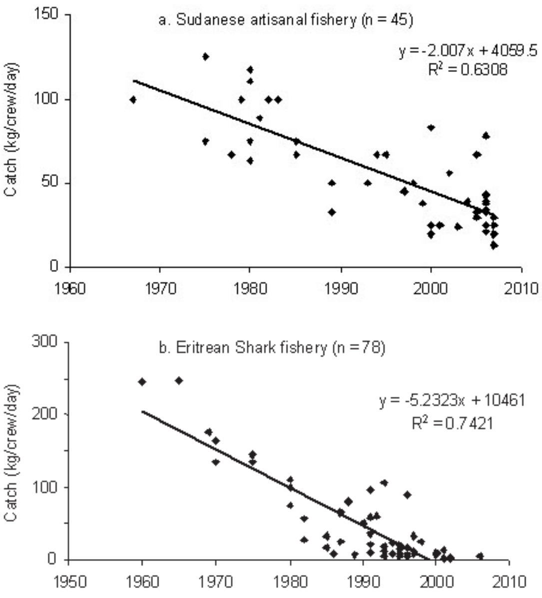

Figure 3. Fishers' recall of best catches in a) the Sudanese artisanal and b) the Eritrean shark fisheries.

historical development in the fisheries to explain these fluctuations and we believe it was due to irregularities in reporting, i.e., the fishery data reports to the FAO were incorrect.

However, even if the total catch in Sudan increased after 1970, the catch rate decreased according to interviews with fishers (Fig. 3a). This means more effort was needed for each added unit of catch. The catch rate in the Eritrean shark fishery decreased even more drastically than the Sudanese artisanal fisheries (Fig. 3b). Sharks are highly vulnerable to fishing because the high value of fins encourages fishers to keep fishing even when their abundance diminishes. Sharks also mature at a late age and have few offspring (Frisk *et al.*, 2001). When compared to other fisheries in tropical and subtropical marine ecosystems, shark fisheries rely on few species (Bonfil, 1994) which tend to become over-exploited, as no other species provide a similar product, i.e., shark fins.

Another factor in the decline of sharks lies in the operation of the Eritrean fleet. In many tropical fisheries, ice is a factor that limits the length of a fishing trip. Ice melts quickly in the hot climate and fishers are obliged to return to landing sites quickly before the catch is spoiled. In a shark fishery, no ice is needed. The fins are cut and dried, and do not take up much space, which allows fishers to stay weeks and sometimes months out at sea. They also often have bigger mother boats that resupply smaller fishing boats.

It is clear from these examples that any decisions made regarding the management of such fisheries can lead to erroneous conclusions, if based only on official reports. In many developing countries, fishery development programmes are undertaken by non-local NGOs that often use FAO data as a starting point in designing their projects and plans of action. Closer examination of such catch data could save many of these projects from failure, a not uncommon fate. Every effort should thus be made to get accurate catch information. Alternatives must be found if catch data are unavailable, at least in the form of rapid interview surveys which provide information on the status of a fishery. Reconstructed time-series of catches constitute a better tool for their assessment and management but are not by any means definitive or absolute. However, we believe that they yield better estimates of the actual catch than many official reports. Decision-makers should be involved in such catch data reconstructions from the start, as this will improve managers' understanding of the process and gives them a greater chance of making informed decisions. The outcome will be improved resource management for generations to come.

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