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FISHERIES CATCH RECONSTRUCTIONS: ISLANDS, PART II

Fisheries Centre, University of British Columbia, Canada

FISHERIES CATCH RECONSTRUCTIONS: ISLANDS, PART II

Edited by

Sarah Harper and Dirk Zeller

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DIRECTOR'S FOREWORD

As marine fisheries resources around the world are increasingly threatened by pollution, climate change, and overfishing, it is more important than ever to know the amount and types of fish and invertebrates being extracted from the marine environment. Fisheries resources, particularly for island countries, provide a crucial source of food and income. However, the very fisheries which depend on these natural goods and services—notably small-scale fisheries—are being under-represented in fisheries statistics. In many of the countries highlighted in this report, the majority of seafood consumed is taken via subsistence fisheries. This non-commercial fishing sector is largely overlooked in statistical collection systems, particularly those of several decades ago, but continues to be under-represented today. In some places this is beginning to change, as the importance of small-scale fisheries to national food security is being recognized.

In many developing countries, which lack the infrastructure and resources to fish their own waters for economic development through trade with external markets, foreign access fees are collected as a key source of revenue. In exchange for a modest fee, foreign fleets are allowed to fish their waters for high valued species. While this provides much needed income for the country, it also threatens the availability of these resources for domestic sustenance.

While there is a range in the quality of fisheries reporting from one country to the next, in almost all countries Illegal, Unreported and Unregulated (IUU) fisheries exist. Fisheries landings statistics, as supplied to the United Nation's Food and Agriculture Organization (FAO), represent mainly the commercial and larger-scale fisheries. Artisanal, subsistence and recreational fisheries are mostly overlooked. Discarded bycatch and baitfish associated with certain fishing techniques are also rarely included in the official statistics.

As a follow up to *Fisheries catch reconstructions: Islands, Part I*, this report continues to reconstruct total marine fisheries catches of island countries around the world from 1950 to present. This edition describes fisheries for island countries in the Pacific, Indian and Atlantic Oceans, highlighting the discrepancies that exist between reported landings and likely true catches. The reconstruction approach used here, as in the previous edition, aims to estimate all marine fisheries extractions as a baseline for monitoring and management purposes in the face of continued anthropogenic pressures. The future success of these countries relies, in part, on their ability to keep pace with an increasingly global economy while maintinaing a healthy supply of resources for domestic purposes.

Ussif Rashid Sumaila, Director

UBC Fisheries Centre

August 2011

Preliminary estimate of total marine fisheries catches in Corsica, France (1950-2008)[1]

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Abstract

Corsica is an island in the Western Mediterranean belonging to France, located southeast of the French mainland and west of Italy. The island covers an area of about 8,700 km², is flanked by deep water along its west coast, and by a broad shelf along its east coast. Corsica has fisheries in its coastal lagoons, but its most commercially important fishery is the red spiny lobster (*Palinurus elephas*) fishery, followed by bottom trawling for finfish. Other smaller and poorly documented artisanal and recreational fisheries also occur, but overall fishing pressure appears to be low, and the number of full time fishers is declining. The total reconstructed catch from 1950 to 2008 was 118,700 tonnes - 5 times more than the 23,700 tonnes reported by France to FAO – of which 30% was unreported recreational catch by locals or tourists, 37% was bottom-trawl catch, 10% was associated bycatch (unreported, landed or discarded), and 23% was red spiny lobster and pelagic catches. The estimated mean annual catch in the 21st century was 1,300 tonnes. Field investigations are needed to improve on these data, presented here as a first approximation of total extractions from the waters surrounding Corsica.

Introduction

Corsica is the fourth largest island of the Mediterranean and a part of France. It is located southeast of the French mainland and north of Sardinia (Italy), and west of the Italian Peninsula (42° N and 9° E; Figure 1). Corsica is characterized by a mountainous landscape and a highly disparate underwater morphology, featuring a steep descent to depth along the western part of the island (down to 3,000 m, 10 km offshore). In contrast, wide expanses of shallow waters are present along the east coast, where a depth of only 150 m has been recorded 11 km offshore, and several lagoons important for the Island's marine fisheries are also found along the east coast (Riutort, 1994).

[1] Cite as: Le Manach, F., Dura, D., Pere, A., Riutort, J.J., Lejeune, P., Santoni, M.C., Culioli, J.M., and Pauly, D. (2011) Preliminary estimate of total marine fisheries catches in Corsica, France (1950-2008). pp. 3-14. *In*: Harper, S. and Zeller, D. (eds.) Fisheries catch reconstructions: Islands, Part II. Fisheries Centre Research Reports 19(4). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

Corsican waters host numerous fish and invertebrate species (de Caraffa, 1929; Miniconi, 1989, 2001) and valuable habitats (e.g., meadows of seagrass *Posidonia oceanica*), of which most are protected under European Commission directives or national legislations (Anon., 1975; 1979, 1981, 1987, 1992, 1994, 1999) (Figure 1). The *Réserve Naturelle des Bouches de Bonifacio* is the largest marine protected area (MPA) of metropolitan France, covering approximately 800 km² (Figure 1), including a 13 km² no-take zone and 130 km² with restricted fisheries activities. Regulations and monitoring seem to be effective, as increasing catches have been reported in and around this MPA (Santoni and Culioli, unpub. data)

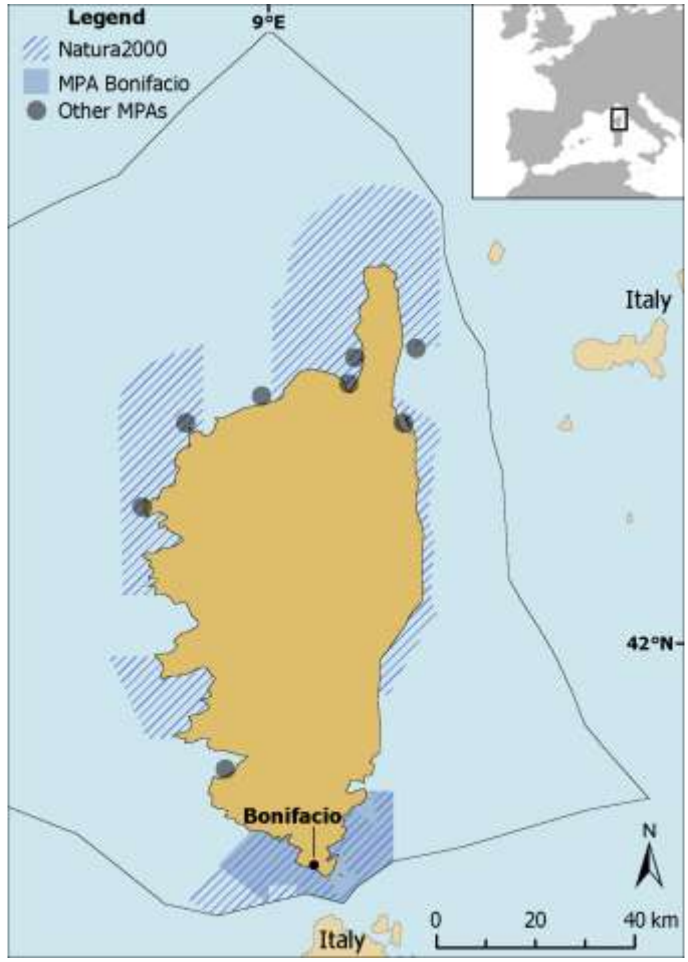

Figure 1: Map of Corsica and its territorial waters (solid black line). Marine Protected Areas (blue areas and grey solid dots) are designated at a state level and aim to protect both habitats and wildlife by controlling, or even excluding human activities (no-take zones). Natura2000 zones (blue stripes) are designated at a European level and aim to protect both habitats and wildlife, without excluding human activities. The level of protection in the Natura2000 zones is lower than for MPAs. Source: www.affaires-maritimes.mediterranee.gov.fr

Since the 1950s, tourists have been attracted to Corsica for its natural beauty and pristine habitats, and the tourist population currently reaches 3 million per year (Anon., 2010), with a resident Corsican population of less than 300,000. The tourism industry has a major impact on seafood consumption and hence on marine resources, as already highlighted in the 1960s (Maurin, 1965). Currently, numerous hotels and/or charter companies offer recreational fishing opportunities, separate or in combination with consumption of local seafood.

Despite its potential attractiveness for fishers, the waters around Corsica have never experienced heavy industrial fishing pressure, and the history of Corsican resource extraction was shaped more by land-based than maritime activities. Therefore, there is almost no export of seafood out of Corsica, and a substantial fraction of the seafood consumed locally by Corsicans is imported from the French mainland or other Mediterranean countries. Currently, the number of professional fishers is declining, and Corsica likely experiences the lowest commercial fishing pressure in the Mediterranean Sea (Riutort, 1994; Relini *et al.*, 1999). As a consequence, fisheries have generally not received much attention, and quantitative analyses of fisheries are scarce, except for the high-profile fishery for red spiny lobster (*Palinurus elephas*) (Pere *et al.*, 2007; 2010) and for MPA fisheries (Rigo, 2000; Santoni, 2002; Mouillot *et al.*, 2007; Rocklin *et al.*, 2009).

Corsica - via France - has only supplied fisheries statistics to the Food and Agriculture Organization of the United Nations FAO since 1970. This study therefore aims to reconstruct Corsican fisheries catches back to 1950, while ensuring that all extractions due to fishing are considered, following the catch reconstruction approach of Zeller and Pauly (2007). Like most countries in the Mediterranean, France has not declared a formal Exclusive Economic Zones for its Mediterranean coast (EEZ; Anon., 1976; Santoni, 2002; Cacaud, 2005). Hense, our estimates of historical catches for the period 1950 to 2008 are deemed to have come from Corsican EEZ-equivalent waters.

Materials and Methods

Baseline data were extracted from the General Fisheries Commission for the Mediterranean (GFCM) section of the FAO FishStat database (FAO, 2009). As Corsica is remote from the French mainland, we assumed that all catches reported by France within the 'Sardinia' FAO fishing area (Division 37.1.3) were Corsican. A bibliographical review of all Corsican fisheries was done to identify the 'anchor points' required for inferences on historical catches back to 1950 (Zeller and Pauly, 2007). Data sources included peer-reviewed scientific articles, reports by local institutions, theses and other unpublished accounts, and local expert knowledge.

Total Corsican population

Population statistics were extracted from the National Institute of Statistics and Economic Studies (INSEE, www.insee.fr/fr/themes/theme.asp?theme=2&sous_theme=1&nivgeo=6&type=3 [accessed: October 15, 2010]). Population data were used here to indirectly estimate total catches by local residents (see 'recreational fisheries: residents and tourists' sub-section; Figure 2a).

Fishers and fishing vessels in Corsica

The time-series of the population of fishers was obtained from Riutort (1994), and linear interpolations were applied between anchor points for years without data (Figure 2b). The number of fishers after the last anchor point (1993) was calculated by applying the trend in the number of fishers per vessel during the period 1950-1993 to the number of vessels for the period 1994-2008. It is worth noting that these

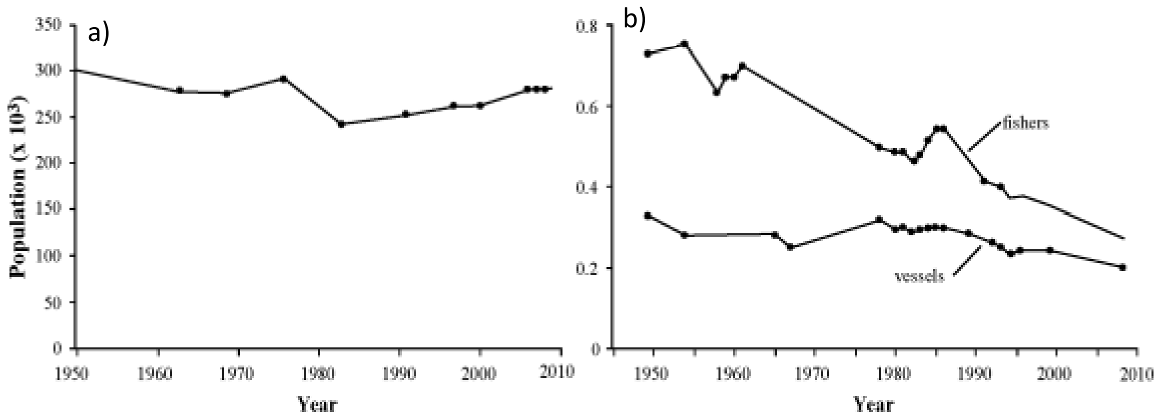

Figure 2. Basic statistics on Corsica: a) total resident Corsican population and b) trends in the number of fishers and vessels in Corsica. Anchor points are represented by closed circles.

vessels are usually smaller than 15 m, and operate close to shore (Miniconi, 1994; Riutort, 1994; Rigo, 2000; Santoni, 2002). The fishing industry in Corsica is therefore more artisanal than industrial, with small vessels (Riutort, 1994), short periods at sea, and a small supply chain (Riutort, 1989). The two time-series in Figure 2b were used to estimate bottom-trawl catches for the 1950-1970 period (see 'artisanal demersal fishery' sub-section).

Lobster fishery

Red spiny lobster (*Palinurus elephas*) is mainly exploited along the west coast of Corsica, where its preferred hard-bottom habitats are found. The fishery for lobster is relatively small, and vessels stay close to the coast, fishing at depths not exceeding 200 m (Marin, 1987). The fishery was profitable very early on (de Caraffa, 1929), but it is not well documented. Thus, official catch data are deemed inaccurate, and is at best a refelction of trends (Marin, 1987). Here, we attempt to re-estimate lobster catches for the entire 1950-2008 period using various sources of information.

Statistics were extracted from the *Office de l'Environnement Corse* (2010) for the 1950-1983 period. The early values (1950s) are in accordance with catches at the beginning of the 20th century, i.e., around 300 t·year^{-1} (Doumenge, 1956). For the 1983-2008 period, values were extracted from studies by Riutort (1999), Marin (1987) and Pere *et al.* (2010).

Changes in gears had an influence on both catch per unit of effort (CPUE) and discard rates (non-marketable lobsters). In the early 1960s, the traps in common use were replaced by trammelnets (Miniconi, 1989), which had higher CPUE, but also generated a higher discarding rate. Discards for traps were estimated to be about 5% during the 1950-1964 period (Riutort, unpub. data). During the 1965-1980 period, fishers were using trammelnets for short trips, and a discard rate of 12.5% was therefore used (Riutort, unpub. data). For the 1981-1994 period, the mean value of 15.7% between the 1965-1980 period (12.5%) and the 1995-1999 period (20%) was used (Riutort, 1999; Pere *et al.*, 2010). For the 2000-2003 period, the same value of 12.5% was used. For the 2004-2007 period, Pere *et al.* (2010) estimated a discarding rate of 11.4%, which was also used for the year 2008.

It is worth noting here that two types of trammelnets are used in Corsica, to target either demersal fish (since before 1950) or red spiny lobster (since the early 1960s). Even when 'lobster trammelnets' are used, a considerable amount of the bycatch is fish. Thus, 55% of total catch were fish species in 2008 (Riutort, 1989; 1994; Santoni and Culioli, unpub. data). This bycatch of fish is retained and landed, and was included in the next sub-section (artisanal demersal fisheries).

Artisanal demersal fisheries

Demersal species are caught in Corsican waters with two types of gears: trammelnets and bottom-trawlers. Trammelnets have been in use for demersal fish for a long time (prior to 1950), while we assumed bottom-trawlers were introduced in the early 1950s (Riutort, 1994). Catches by trammelnets may represent 50% of total fish catches in the province of Bonifacio (Santoni and Culioli, unpub. data), and given that no other studies were available, we used this 50% ratio for the 1965-2008 time-period and the entire island. Thus, the remaining 50% of demersal fish catches were treated as caught by bottom-trawlers as of 1965. For 1950, we set bottom-trawl fish catches as zero, and interpolated linearly to 1965. FAO FishStat contains data on demersal species for the period 1970-1992 only. In the absence of any alternative, we considered these data to be realistic. Indeed, none of the documents available on Corsican fisheries allowed us to make an independent estimate of the bottom-trawl and trammelnet fisheries catches.

Catches per fisher and catches per vessel (CPUE) for the period 1970-1992 were calculated by dividing catches of bottom-dwelling fish reported to FAO by the number of fishers or vessels (Figure 2b). CPUE for the 1950-1970 and 1993-2008 periods were then estimated by extrapolation of the trends of 1970-1992 CPUE time-series. The resulting CPUE data for the 1950-1970 and 1993-2008 periods were then multiplied by the number of fishers or vessels (Figure 2). Our estimate of total catch used the average values of these two catch time-series (one based on CPUE per fisher, one on CPUE per boat), which was then split evenly to create the bottom-trawl and trammelnets components.

<u>Trammelnet fishery</u>

The taxonomic breakdown of trammelnet commercial species in the Bonifacio MPA (Figure 1) was studied by Mouillot *et al.* (2007) from 2000 to 2006. Given that there were no other studies available that included a taxonomic breakdown, we assumed that the percentage of each species remained the same for the entire 1950-2008 time-period, and were similar for the entire island. A recent study concluded that trammelnet discards were representing approximately 10% of total catches, in the MPA of Bonifacio (Rocklin *et al.*, 2009). These discards are composed of damaged, non-marketable fish. We used this study to estimate the taxonomic breakdown of these discards.

Bottom-trawl fishery

We assumed that the species composition of landed bottom-trawl catches were similar to the trammelnet fishery. However, we acknowledge that the species composition can vary significantly between the continental shelf and the slope. For higher depths (on the slope), many other species such as *Nephrops norvegicus*, *Etmopterus spinax*, *Galeus melastomus*, *Merluccius merluccius* or *Trigla lyra* can indeed account for a large part of the catch (Riutort, pers. obs.; Le Manach, pers. obs.). However, as it was not possible to estimate the percentage of each species or the importance of slope bottom-trawling, we did not take these observations into account. To estimate the bycatch by the artisanal bottom-trawl fishery, we used a bycatch rate of 40%, given by Machias *et al.* (2001) and Sanchez *et al.* (2004) for geographically close and similar fisheries. The MEDITS database (Bertrand *et al.*, 1998) - 2009 update - was used to estimate the bycatch taxonomic breakdown. We assumed that non-commercial species occurring in this database were bycatch species, e.g., *Spicara* spp., *Scyliorhinus* spp., *Raja* spp., *Micromesistius poutassou*, *Capros aper*. Furthermore, as fishers land a portion of non-targeted bycatch, notably for their personal consumption and *soupe de roche* ('rockfish soup'), we conservatively assumed that 20% of the bycatch was landed, but unreported, and that the remainder (80%) was discarded.

Recreational fisheries: residents and tourists

To estimate recreational catches by Corsicans, we used a 'Fermi solution', i.e., an approach pioneered by the physicist Enrico Fermi, to estimate unknown quantities from limited data (von Baeyer, 1993; Pauly, 2010). Thus, based on local knowledge (Culioli, pers. obs.; Riutort, pers. obs.), we estimated three anchor points, for 1950, 1980 and 2008. For 1980, we assumed that 30% of the total population, i.e., 76,000 out of 255,000 inhabitants, was potentially recreational fishers. Of these potential fishers, we assumed that 15% were actually fishers, and that they were on average fishing once a month, with yields of 4 kg per trip. For 2008, we used the same assumption that 30% of the total population, i.e., 84,000 out of 280,000 inhabitants, were potentially recreational fishers, but that the proportion of actual fishers increased to 25%. As local residents report that there are less fish now than in the 1980s, we assumed that fishers currently fish on average only 10 times a year, with yields of 1 kg per trip. For 1950, we assumed a stable CPUE and fishing effort compared to 1980, and derived total catches from the total population size.

Similarly, our estimate of recreational catches by tourists was based on the annual number of tourists, and assuming that sport fishing became more attractive in the 1990s. We conservatively assumed that 5% of tourists were catching on average 1 $kg \cdot year^{-1}$ for the 1950-1990 period, and that 8% of tourists were catching on average 1.5 $kg \cdot year^{-1}$ for the 1991-2008 period. Given that each tourist currently stays on average 10.3 days in Corsica, these assumptions seem reasonable (Anon., 2010).

Pelagic fisheries

Three pelagic fisheries are taking place in Corsican waters. However, information is scarce and no studies enabled us to re-estimate their total catches. Therefore, we included data as provided to FAO in our total reconstruction (except for small pelagics – see below).

Swordfish

Swordfish (*Xiphias gladius*) started to be targeted by artisanal longliners in the 1980s (Regional Committee of Corsican Marine Fisheries, 2009; Riutort, unpub. data). However, as tonnages are likely small (15-20 $t \cdot year^{-1}$; Riutort, unpub. data), it is possible that these catches are accounted for in official FAO statistics as 'marine fish nei' (FAO, 2009).

Small pelagics

'Blue fish' (i.e., sardines, anchovies and mackerels) are also fished along the Corsican coast. Several studies report substantial catches during the 1960s and 1970s in Corsica and along the French mainland (Maurin, 1965; Bonnet, 1973; Pichot and Aldebert, 1978). It is worth noting that FAO data include sardine statistics only for 1972-1976 and 2006; data for other years being either non-existent or unrealistically low. However, older Corsican residents remember very abundant sardine and anchovy catches during the 1950-1960s, most of which were exported to the mainland (Riutort, unpub. data). For the period 1950-1971, we therefore used the average catches for the period 1972-1976, and kept the rest of the time-period unchanged.

Tuna

Maurin (1965) reports 100 tonnes of tuna caught in 1963 by Corsicans. However, he suggests that the tourism industry already accounted for a significant part of unreported catches, although he did not elaborate on this topic. Tuna may also be reported to FAO as 'marine fish nei', and annual catches are likely very low or up to 15 tonnes (Riutort, unpub. data).

RESULTS AND DISCUSSION

Lobster fishery

As expected, our lobster catch reconstruction is very different from official statistics: our values are on average 16 times higher than data provided to FAO, and show a very different pattern over time (Figure 3). Lobster catches decreased from 300 t·year^{-1} in 1954 to 80 t·year^{-1} for 1959-1960. Then, catches increased again to 300 t·year^{-1} by 1962. At this time, a new (unspecified) crash occurred and catches dropped to 100 tonnes annually, staying at that level until the late 1970s. By 1984, catches increased to 250 t·year^{-1}. Since then, catches have been decreasing, reaching 80 t·year^{-1} by the early 2000s. However, it is worth noting that catches currently seem to be increasing. Overall, the trend of the number of fishers and vessels (Figure 2b), and lobster catches (Figure 3) show a similar pattern, which confirms that this fishery is of great importance in Corsica and largely accounts for much of the fishing pressure.

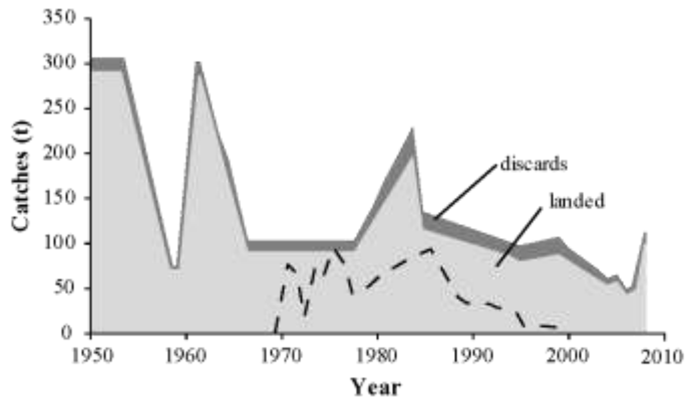

Figure 3: Reconstructed catches of lobsters and associated discards for Corsica, 1950-2008. The dotted line represents official lobster landings data supplied to FAO.

Fluctuations in lobster catches may be partly explained by new policies and gear modifications, along with biological features (e.g., larval migration; Pere *et al.*, 2011). The first crash in the 1950s likely resulted from increasing fishing pressure, and the following increase in catches is likely the result of a gear change from traps to trammelnets, which increased the CPUE. In 1968, policy-makers decided to close the lobster fishery between the 1st of October and 28th of February each year, which probably played a significant role in the stabilization of catches during the 1970s. Finally, new vessels were introduced in the early 1980s and were responsible for increased fishing effort. This increase is likely to have contributed to the increase in catches until 1984, then to the decrease in catches observed until the mid-2000s.

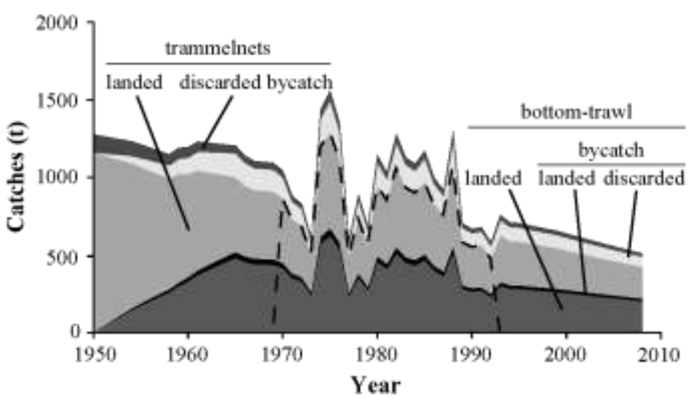

Figure 4: Reconstructed catches and associated bycatch (landed and discarded) for the demersal finfish fishery by the two main gears (trammelnet and bottom-trawler) in Corsica, 1950-2008. The dotted line represents official landings data supplied to FAO.

In the late 1970s, nine small marine protected areas (some of them no longer existing; Figure 1) were created, which also possibly led to the catch increases in the late 1970s early 1980s (Figure 3). The current decrease, which started around 1984, may be due to several factors, such as the decreasing number of fishers, or increasing fishing effort. It seems there is an increase in catches during the last few years. Such an increase could be due to biological parameters (e.g., larval migration), but no data were available to assess the validity of this assumption.

Artisanal demersal fishery

Demersal catches totaled an estimated 56,500 tonnes, compared to only 18,800 tonnes reported to FAO (Figure 4). Catches fluctuated, but declined overall from approximately 1,300 $t \cdot year^{-1}$ in 1950 to 500 $t \cdot year^{-1}$ in the late 2000s. Bycatch followed a different trend, totaling 10,300 tonnes and peaking around 250 $t \cdot year^{-1}$ in the 1980s due to the increasing number of trawlers. Bycatch amounts in the 1950s and the 2000s are similar, slightly above 100 $t \cdot year^{-1}$ (Figure 4).

Unlike our reconstruction for the lobster fishery (above), the reconstruction of artisanal bottom-trawl fishery catches was mainly based on official statistics. The main novelty in this result comes from the gaps in time-series originally supplied to FAO being filled in. Also, a significant part of total catches (18%) were previously unreported and are now reported as bycatch (either discarded or landed; Figure 4).

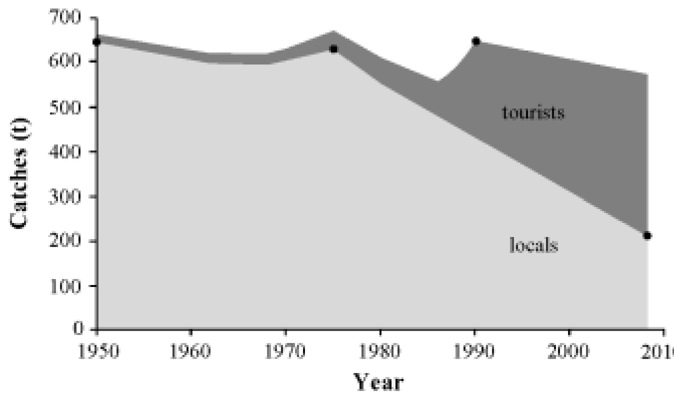

Figure 5: Reconstructed catches by recreational fishers in Corsica, 1950-2008. Anchor points are indicated by closed circles.

Recreational fisheries: residents and tourists

Recreational fisheries were estimated to catch 35,150 tonnes, of which 80% was taken by local resident fishers, and 20% by tourists (Figure 5). These catches were previously not included in statistics provided to FAO.

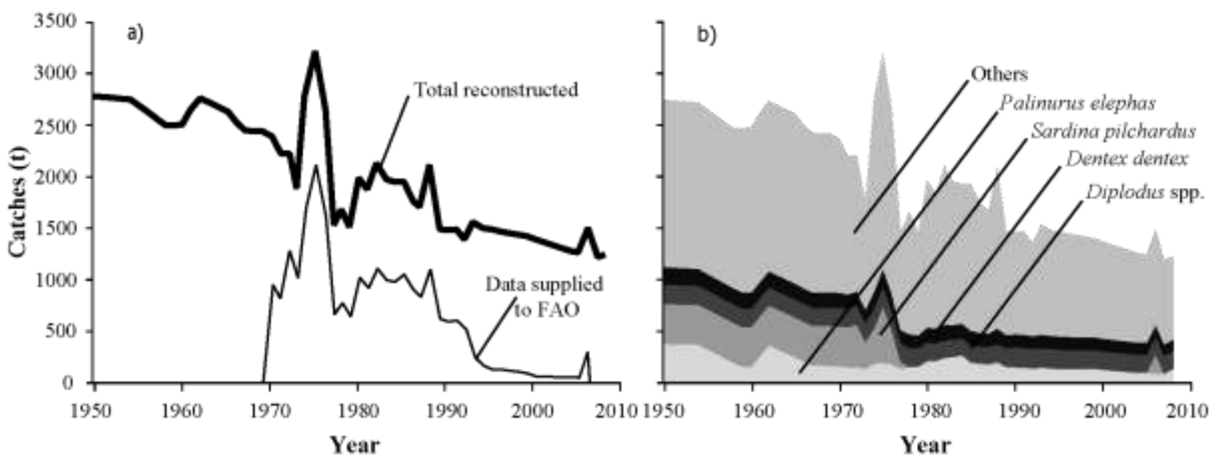

Figure 6: Catches in Corsican waters, showing a) reconstructed total catches versus landings data as supplied to FAO; and b) taxonomic breakdown (top 10 species) of reconstructed total catches in Corsica, 1950-2008. The 'others' group includes *Scorpaena scofa*, *Phycis* spp., *Pagellus*, spp., Labridae, *Serranus* spp., *Seriola dumerili*, *Zeus faber*, as well as other fish species of lower importance in term of percentage, and species of invertebrates.

Based on our assumptions, we estimated that recreational catches by residents were the highest in 1950, with 612 t·year^{-1}, and then declined to 210 t·year^{-1} by 2008 (Figure 5). On the other hand, recreational catches by tourists were estimated to have increased during the last two decades, increasing from 17 t·year^{-1} in 1950 to 360 t·year^{-1} by 2008 (Figure 5).

Overall reconstruction

Reconstructed total Corsican fisheries catches total over 118,700 tonnes since 1950, compared to only 23,700 tonnes reported to FAO by local fisheries authorities. Overall, total catches appear to be steadily decreasing from approximately 2,800 t·year^{-1} in 1950 to 1,200 t·year^{-1} by 2008, interrupted by a peak catch of over 3,000 t·year^{-1} in 1975 (Figure 6a and Appendix Table A1). This decrease seems linked to the decline in both fishers and vessel numbers, but also to declines in fish abundance along the Corsican coast.

Official statistics likely accounted for commercial (artisanal) fisheries only, that is, red spiny lobster and bottom-trawl fisheries. Recreational fisheries by Corsicans, or by tourists, were not considered by official authorities. Finally, we highlighted the existence of discards (for red lobster and bottom-trawl fisheries), which are generally not included in reported statistics (Zeller *et al.*, 2011).

This improved accounting of total catches (versus reported commercial landings) is also evident in the improved taxonomic accounting provided by our study (Figure 6b). Data reported by FAO on behalf of Corsica, besides being of poor quality, also had a poor taxonomic breakdown. Species present in these official data were reported as arbitrary, according to the local fisheries literature. In contrast, we have been able to assign catches to over 30 taxa, of which each had catches allocated in accordance to the literature (Figure 6b and Appendix Table A2).

This study provides an estimate of total fisheries catches in Corsican waters since 1950, and although some sectors such as the pelagic fisheries have not been dealt with in detail, two major conclusions emerge from our work: (1) historical events, changes in gear and emergence of new fisheries illustrate that, despite being assumed to be one of the areas of the Mediterranean with the lowest fishing pressure (Riutort, 1994; Relini *et al.*, 1999), Corsican waters may be exposed to higher fishing pressure than previsously assumed; and (2) our results suggest that Corsicans seem to be much more involved in marine resource exploitation than it appears in the literature and in official statistics.

Acknowledgement

We thank the *Sea Around Us* project, a scientific collaboration between the University of British Columbia and the Pew Environment Group. We also thank Jacques Bertrand (Ifremer) for sharing information and knowledge.

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Appendix Table A1: Annual catches by Corsican fisheries.

Year	Domestic fisheries (t)	
	Data reported to FAO	Reconstructed catches
1950	0	2759
1951	0	2751
1952	0	2744
1953	0	2736
1954	0	2728
1955	0	2666
1956	0	2603
1957	0	2540
1958	0	2475
1959	0	2478
1960	0	2484
1961	0	2634
1962	0	2740
1963	0	2698
1964	0	2657
1965	0	2615
1966	0	2506
1967	0	2427
1968	0	2422
1969	0	2421
1970	945	2373
1971	784	2204
1972	1280	2206
1973	966	1757
1974	1719	2772
1975	2128	3195
1976	1632	2647
1977	625	1457
1978	759	1662
1979	607	1450
1980	1012	1968
1981	899	1836
1982	1100	2109
1983	986	1956
1984	967	1930
1985	1042	1934
1986	895	1746
1987	811	1672
1988	1093	2094
1989	604	1473
1990	574	1462
1991	584	1469
1992	502	1358
1993	220	1540
1994	137	1482
1995	99	1468
1996	96	1448
1997	85	1433
1998	74	1418
1999	59	1404
2000	28	1370
2001	26	1342
2002	22	1314
2003	21	1287
2004	23	1259
2005	15	1243
2006	281	1482
2007	0	1194
2008	0	1226

Appendix Table A2: Six most important taxa caught by domestic fisheries in Corsica's EEZ, 1950-2008.

Year	*Palinurus elephas*	*Sardina pilchardus*	*Diplodus* spp.	*Dentex dentex*	*Scorpaena scrofa*	*Phycis* spp.	Others[a]
1950	375	387	189	171	165	106	1366
1951	373	387	187	169	163	104	1368
1952	372	387	186	167	160	102	1369
1953	370	387	185	165	157	101	1371
1954	369	387	184	164	154	99	1371
1955	325	387	183	161	150	96	1363
1956	281	387	182	159	147	94	1354
1957	237	387	181	157	143	91	1343
1958	193	387	180	154	139	89	1332
1959	153	387	179	156	143	91	1368
1960	153	387	178	155	142	91	1378
1961	259	387	177	156	145	93	1416
1962	363	387	176	154	143	92	1424
1963	324	387	176	153	141	90	1426
1964	285	387	176	153	139	89	1428
1965	246	387	176	152	137	88	1429
1966	204	387	176	148	130	83	1377
1967	163	387	176	146	126	81	1347
1968	163	387	176	146	125	80	1343
1969	163	387	178	147	125	80	1342
1970	160	387	179	145	119	76	1306
1971	150	387	182	137	100	64	1184
1972	146	420	184	136	95	61	1164
1973	133	265	186	125	70	45	933
1974	184	348	189	170	164	105	1612
1975	192	548	191	178	178	114	1794
1976	179	328	188	165	154	99	1534
1977	132	70	184	124	68	44	835
1978	150	2	181	137	102	65	1025
1979	154	3	177	125	78	50	862
1980	199	15	174	147	131	84	1217
1981	209	3	172	140	118	75	1120
1982	241	0	169	152	146	93	1307
1983	248	0	167	143	129	82	1187
1984	263	6	165	140	124	79	1154
1985	191	6	162	143	134	86	1212
1986	178	13	160	133	114	73	1076
1987	169	13	165	131	105	67	1022
1988	190	13	171	154	148	95	1325
1989	150	7	179	126	80	51	879
1990	145	6	188	129	76	49	869
1991	142	7	187	129	77	50	876
1992	133	7	186	124	66	42	799
1993	141	7	185	133	86	55	932
1994	135	6	184	130	81	52	894
1995	128	8	183	129	80	51	888
1996	129	4	182	128	79	51	875
1997	130	4	181	127	78	50	864
1998	132	4	180	125	76	49	852
1999	133	4	180	124	75	48	841
2000	125	0	179	123	73	47	824
2001	118	0	178	122	71	45	809
2002	110	0	177	120	69	44	794
2003	103	0	176	119	67	43	780
2004	95	0	175	118	65	42	765
2005	98	0	174	116	63	41	751
2006	83	192	173	115	62	39	819
2007	88	0	172	114	60	38	723
2008	135	0	171	112	58	37	712

'Others' comprises *Pagellus*, spp., Labridae, *Serranus* spp., *Spicara* spp., *Raja* spp., other clupeiformes, *Mullus* spp., other *Scorpaena*, *Maja squinado*, *Sepia* spp., *Homarus gammarus*, *Lophius* spp., *Capros aper*, *Micromesistius poutassou*, *Scyliorhinus* spp., other miscellaneous marine fish, cephalopods and crustaceans.

A BRIEF HISTORY OF FISHING IN THE KERGUELEN ISLANDS, FRANCE[1]

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ABSTRACT

Catch statistics from around the (uninhabited) Kerguelen Islands, which are part of the French Antarctic and sub-Antarctic Territories, and where distant-water fisheries began in 1970, were obtained from the CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) Statistical Bulletin (Area 58.5.1) and complemented by statistics reported through the French KERPECHE program. Catches originally expressed by fishing seasons were re-expressed as calendar years, which results in a slight between-season smoothing. These catches show a general decline over a 30 year-period and an expansion of the longline fishery to deeper waters in the last 10 years.

INTRODUCTION

The Kerguelen Islands

The Kerguelen Islands (49°30'S, 69°30'E) are part of the French Antarctic and sub-Antarctic Territories, which also include the islands of Crozet, Amsterdam and St. Paul, and the Antarctic district of Terre Adélie (www.taaf.fr). They consist of a main island called 'La Grande Terre' (6,700 km²) and a number of smaller surrounding islets. Kerguelen Island sits in the middle of the combined shelf of the Kerguelen and Heard Islands (Australia), known as the Kerguelen Plateau, which covers an area of 100,500 km² above 500 m depth (Pruvost *et al*., 2005: see Figure 1). The islands are uninhabited both because of their isolated locations and the extreme climate prevailing in the area.

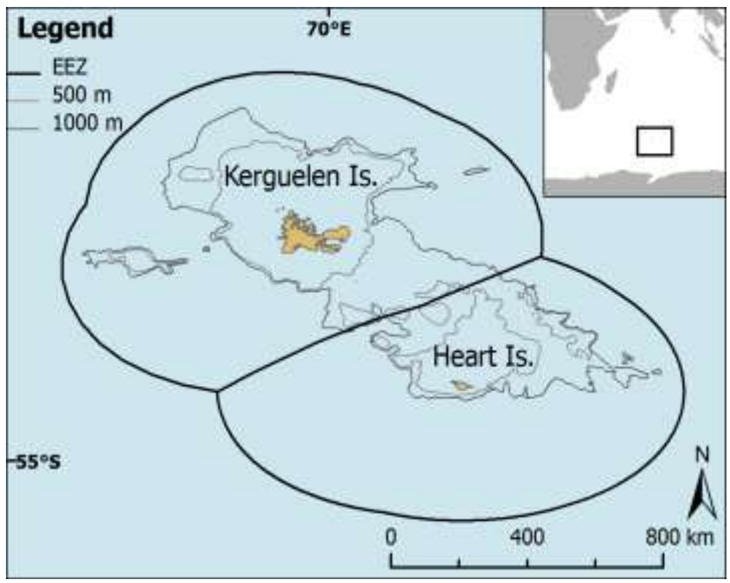

Figure 1. Map of Kerguelen Islands, CCAMLR areas 58.5.1, showing French (Kerguelen Islands) and Australian (Heard Island) Exclusive Economic Zones, as well as 500 m and 1000 m depth contour.

Fisheries and their resource species

Fishery prospecting cruises (mostly by the USSR, i.e., the Ukraine; Zeller and Rizzo 2007) in the 1960s led to the development of a modern fishery in the Kerguelen Islands starting in 1970 with about 10 Ukrainian bottom trawlers operating during 6-month fishing seasons without management or control. They targeted marbled rockcod (*Notothenia rossii*), mackerel icefish (*Champsocephalus gunnari*) and gray rockcod (*Lepidonotothen squamifrons*), and also caught unspecified by-catch species of the plateau, at 200-500 m depths in what is now known as CCAMLR area 58.5.1 (Pruvost *et al*., 2005). This unmanaged fishery continued until France declared an Exclusive Economic Zone (EEZ) around the islands as well as the

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other 'Terres Australes et Antarctiques Françaises' in 1978 (TAAF; see Duhamel, 1995). Since the implementation of the French management scheme in 1980, foreign fleets could access the Kerguelen Islands' EEZ only through access agreements for which the French government granted quotas, limiting to 7 the number of trawlers operating at any one time (Pruvost *et al.*, 2005; Duhamel, 1995).

The discovery of a large stock of Patagonian toothfish, *Dissostichus eleginoides*, by USSR bottom trawlers in the 1984-1985 fishing season on the slopes of the Kerguelen shelf led to the development of this high-value trawl fishery. In 1996, the former USSR stopped trawling in Kerguelen waters and only 2 Ukrainian longliners and 2 French bottom trawlers remained (Pruvost *et al.*, 2005). In the same year, a joint French and Japanese prospecting cruise aboard the M/V *Anyo Maru* established that longlining was an effective method for catching Patagonian toothfish (Duhamel and Hautecoeur, 2009), which led to the development of this fishery, completely replacing the bottom trawl fishery in the 2000-2001 fishing season (Lord *et al.*, 2006). The high initial abundance of this stock encouraged a rapid expansion of the longline fisheries and the subsequent proliferation of non-licensed longliners from non CCAMLR member states (Kock, 2001). The illegal fishery catch peaked between 1996 and 2004, with catches reaching four times that of the regulated catch in 1997 (Agnew, 2000). In 2005, illegal fishing was curtailed and the fishery was limited to 7 French longliners (Pruvost *et al.*, 2005).

Overall, both trawl and longline fisheries in the Kerguelen Islands increased their effort throughout the period considered here, i.e., 1970-2005. Their catch per unit of effort has consequently strongly diminished, in spite of the expansion of the longline fishery from an average fishing depth of 500 m to 1,000 m (Lord *et al.*, 2006). This suggests massive declines in the target fish biomass; the mean individual size of Patagonian toothfish has also declined (Duhamel and Hautecoeur, 2009).

Material and methods

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) catch statistics for CCAMLR area 58.5.1 were used as a basis of this catch reconstruction for the period 1970-2010. These statistics were missing data for the period 1979-1987. Lord (2005) provided statistics for: (*i*) catches of Ukrainian and French trawlers for Patagonian toothfish, marbled rockcod, mackerel icefish and grey rockcod fisheries for the period 1979-2001; (*ii*) longline catches for the Patagonian toothfish fishery and its by-catch (mainly rays and grenadiers) for the period 1990-2003 using the French KERPECHE database (see Lord *et al.*, 2006 and Pruvost *et al.*, 2005); and (*iii*) catch estimates from illegal fishing operations based on recorded arrests for the period 1996-2003. In those cases where the CCAMLR and KERPECHE statistics overlapped, the KERPECHE catches ranged from 73% (marbled rockcod trawl fishery) to 204% (rays as by-catch of the longline fishery) of the CCAMLR statistics. We used the KERPECHE statistics *in lieu* of the CCAMLR statistics for: (a) trawlers for the period 1979-1989 for mackerel icefish, marbled and gray rockcod, and 1979-1991 for Patagonian toothfish; and (b) longliners, notably during the period of expansion for Patagonian toothfish, in order to be able to include some of the unreported catches.

Catches reported by the USSR to the CCAMLR were all assigned to the Ukraine because this part of the world's ocean was exploited by USSR vessels from the Ukrainian SSR during the Soviet era (see Romanov, 2003; Zeller and Rizzo 2007). Also, it is only Ukrainian vessels which exploited the Kerguelen following the breakup of the USSR (see Pruvost *et al.*, 2005).

Results and Discussion

Appendix Table A1 and A2 present a summary of the catch statistics available from the Kerguelen Islands extracted from the CCAMLR (2010) and completed with data from Lord (2005, Annex 3). The catches originally presented by CCAMLR 'season', from the 1st of July of a particular year to the 30th of June of the next year, were converted to calendar years by assuming that the catch in the first half of the season (in a given year) is equal to that of the second half of the season (in the next year). This does not affect cumulative catches and, in fact, corresponds to a slight between-season smoothing.

This brief account of the fisheries in the Kerguelen Islands is meant to present the Kerguelen Island fisheries statistics in such a way that they can be included in the *Sea Around Us* project's (www.seaaroundus.org) catch mapping procedure (see Watson *et al.*, 2004). This is the reason why the catch is reported by calendar years and not as done in the original literature, which account for fishing 'seasons'. Moreover, we include estimates of illegal catches, which although highly tentative, are likely to be more correct than the statistically very precise but inaccurate estimate of zero commonly used as a replacement for difficult to estimate quantities such as illegal catches (see Zeller *et al.*, 2011).

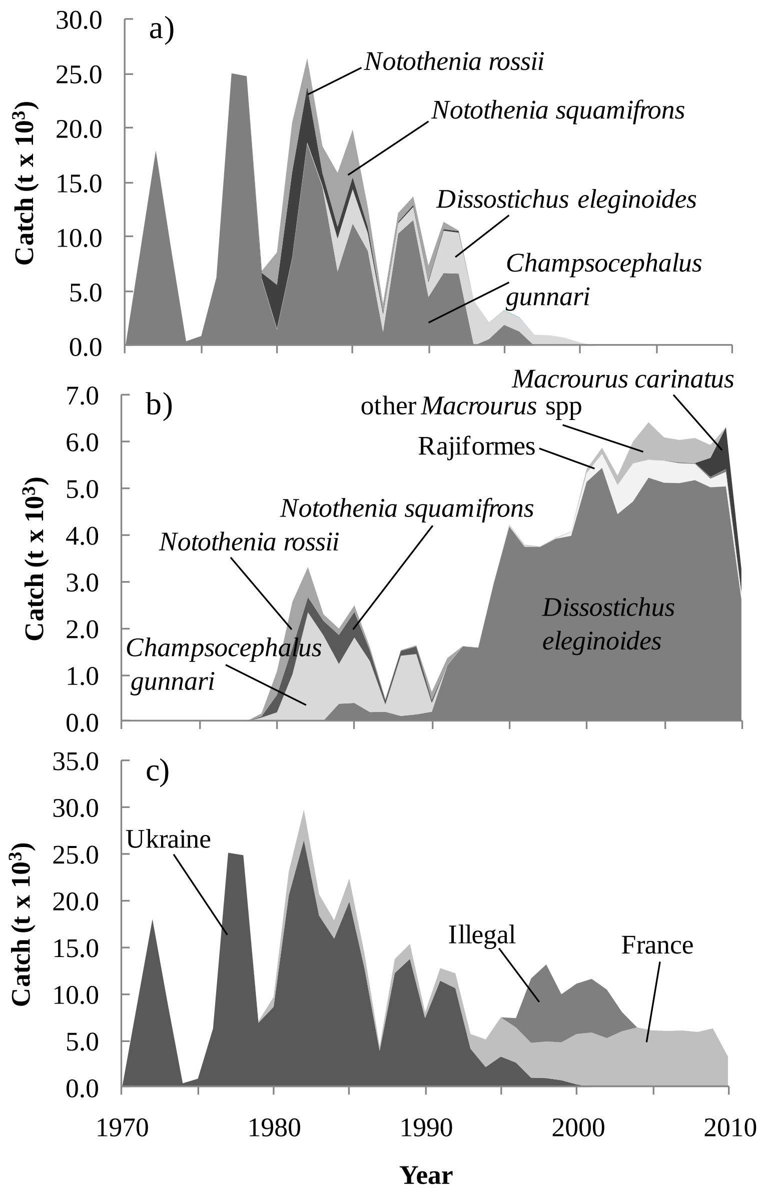

Figure 2. Reconstructed fisheries catches (in metric tonnes) for the Kerguelen Islands (CCAMLR Area 58.5.1) with statistics adapted from CCAMLR (2010) and complemented with data from Lord (2005) for ;(a) Ukrainian (i.e., former USSR and Russian Federation statistics); (b) French trawlers and long-liners; and (c) total catch by country including some estimates of illegal fishing during the period 1996-2003 from Lord (2005).

The resulting catch statistics for the Ukraine (see Appendix Table A2 and Figure 2a), i.e., the fishery which heavily exploited mackerel icefish over three decades, show peaks and troughs similar to patterns reported for South Georgia, South Orkney Islands, Elephant Island and South Shetland Islands (Kock, 1991). Heavy fishing pressure on the strong 1973-1974 year classes may have reduced the stock size to a level that prevented adequate recruitment and thus recovery (Anon., 2001). The trend of the peaks shows a steady decline in the catch, and Kock and Everson (2003) concluded that this decline is the result of a combination of factors, including heavy fishing pressure, changes in the abundance of icefish predators (Antarctic fur seals and penguins) and prey (krill), and warming in the northern parts of the distributional range of icefish. Commercial fishing for mackerel icefish was banned at the end of the 1980s (Kock, 1991) resulting in the tapering off of statistics reported by the Ukraine.

The increasing French catch trend (see Appendix Table A1 and Figure 2b), on the other hand, reflects an exploratory fishery tending towards expansion to deeper waters. Duhamel *et al.* (1997) speculated that the level of longline bycatch (mainly of rays and rattails or grenadiers, Family Macrouridae) have the potential to replace the Patagonian toothfish fishery. Although smaller and subjected to management and monitoring, this expanding fishery has effectively 'counterbalanced' its decreasing catch per unit of effort.

Overall, it is masking the fact that no new fishing grounds have been found since all accessible shallow shelf stocks have been over exploited (Lord *et al*., 2006).

The illegal catch estimates shown in Figure (2c) that were reported both by the CCAMLR (2010) and by Lord (2005) may well be underestimates, i.e., catches may be twice (or more) of those reported to the CCAMLR.

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Appendix Table A1: Kerguelen Islands, CCAMLR area 58.5.1, fisheries catch statistics (t) by French trawlers and longliners from 1970-2010 adjusted from fishing season to calendar year (see text and Figure 2).

Year	France								
	Blue antimora	Mackerel icefish	Unicorn icefish	Patagonian toothfish	Ridge scaled rattail	Rattails[a]	Marbled rockcod	Gray rockcod	Rays[b]
1970-1978	–	–	–	–	–	–	–	–	–
1979	–	75	–	9	–	–	65	247	–
1980	–	136	–	11	–	–	506	597	–
1981	–	952	–	9	–	–	984	574	–
1982	–	2328	–	14	–	–	645	326	–
1983	–	1832	–	15	–	–	143	312	–
1984	–	855	–	379	–	–	136	622	–
1985	–	1407	–	396	–	–	139	548	–
1986	–	1093	–	201	–	–	71	228	–
1987	–	158	–	207	–	–	28	93	–
1988	–	1292	–	118	–	–	16	104	–
1989	–	1295	–	152	–	–	24	163	–
1990	–	188	–	208	–	–	170	67	–
1991	–	8	–	1199	–	–	148	5	0
1992	–	7	–	1611	–	–	0	0	0
1993	–	6	–	1582	–	–	0	0	0
1994	–	6	–	2960	–	–	0	0	1
1995	–	42	1	4178	–	–	0	1	1
1996	–	45	1	3742	–	–	0	1	0
1997	–	3	2	3744	–	0	0	0	6
1998	–	0	3	3919	–	6	0	0	11
1999	–	0	1	3984	–	7	1	0	87
2000	–	0	0	5139	–	87	1	0	189
2001	–	–	–	5443	–	132	0	0	298
2002	–	–	–	4450	–	201	–	–	623
2003	–	–	–	4722	–	472	–	–	815
2004	–	–	–	5231	–	805	–	–	383
2005	7	–	–	5123	–	489	–	–	477
2006	21	–	–	5115	–	476	–	–	428
2007	15	–	–	5179	–	537	–	–	351
2008	35	–	–	5026	409	276	–	–	186
2009	58	–	–	5045	896	–	–	–	313
2010	23	–	–	2620	488	–	–	–	136
Totals	**157**	**11,826**	**6**	**81,727**	**1,792**	**3,487**	**3,077**	**3,443**	**4,302**

[a] *Macrourus* spp.; [b] *Raja* spp. and unidentified Rajiformes, most probably *Bathyraja eatonii* and *Bathyraja irrasa* (Lord, 2005; Lord *et al.*, 2006).

Appendix Table A2: Kerguelen Islands, CCAMLR area 58.5.1, fisheries catch statistics (t) for the Ukrainian (i.e., former USSR and Russian Federation statistics) from 1970-2010 adjusted from fishing season to calendar year and estimates of illegal fishing during the period 1996-2003 (see text and Figure 2).

Year	Ukraine					Illegal Fisheries[b]
	Mackerel icefish	Patagonian toothfish	Marbled rockcod	Gray rockcod	Other finfish[a]	
1970	3	–	–	–	–	–
1971	8982	–	–	–	–	–
1972	17995	–	–	–	–	–
1973	9018	–	–	–	–	–
1974	410	–	–	–	–	–
1975	900	–	–	–	–	–
1976	6275	–	–	–	–	–
1977	25110	–	–	–	–	–
1978	24847	–	–	–	–	–
1979	6118	71	522	1978	–	–
1980	1485	90	4045	4772	–	–
1981	8019	74	7875	4595	–	–
1982	18622	113	5162	2607	–	–
1983	14657	123	1141	2493	–	–
1984	6841	3031	1088	4979	–	–
1985	11253	3170	1113	4388	–	–
1986	8747	1609	571	1824	–	–
1987	1261	1655	225	748	–	–
1988	10338	946	126	829	–	–
1989	11585	1212	172	777	13	–
1990	4494	1354	143	1397	13	–
1991	6699	3902	150	674	–	–
1992	6647	3772	144	51	5	–
1993	16	4096	1	0	12	–
1994	614	1530	1	0	7	–
1995	1926	1311	–	9	31	–
1996	1312	1279	–	8	31	1000
1997	–	1008	–	–	–	6913
1998	–	966	–	–	–	8275
1999	–	739	–	–	–	5163
2000	–	297	–	–	–	5410
2001	–	–	–	–	–	5760
2002	–	–	–	–	–	5213
2003	–	–	–	–	–	2063
2004	–	–	–	–	–	–
2005	–	–	–	–	–	–
2006	–	–	–	–	–	–
2007	–	–	–	–	–	–
2008	–	–	–	–	–	–
2009	–	–	–	–	–	–
2010	–	–	–	–	–	–
Totals	**214,171**	**32,345**	**22,478**	**28,567**	**111**	**39,795**

[a]Osteichthyes reported in the CCAMLR statistics, most probably including incidental bycatch of southern lantern shark (*Etmopterus granulosus*), porbeagle (*Lamna nasus*), Greenland shark (*Somniosus microcephalus*), moray cod (*Muraenolepis marmoratus*) and gray rockcod (*Notothenia squamifrons*) (see Lord *et al.*, 2006); [b]Consisting only of longlines targeting Patagonian toothfish; their bycatch consisting mainly of rays and rattails. Note that the blue antimora (*Antimora rostrata*), unicorn icefish (*Channichthys rhinoceratus*), ridge scaled rattail (*Macrourus carinatus*) and other rattail species and rays are also bycatch of the longline fishery which are sometimes legally reported.

RECONSTRUCTION OF TOTAL MARINE FISHERIES CATCHES FOR MADAGASCAR (1950-2008)[1]

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ABSTRACT

Fisheries statistics supplied by countries to the Food and Agriculture Organization (FAO) of the United Nations have been shown in almost all cases to under-report actual fisheries catches. This is due to national reporting systems failing to account for Illegal, Unreported and Unregulated (IUU) catches, including the non-commercial component of small-scale fisheries, which are often substantial in developing countries. Fisheries legislation, management plans and foreign fishing access agreements are often influenced by these incomplete data, resulting in poorly assessed catches and leading to serious over-estimations of resource availability. In this study, Madagascar's total catches by all fisheries sectors were estimated back to 1950 using a catch reconstruction approach. Our results show that while the Malagasy rely heavily on the ocean for their protein needs, much of this extraction of animal protein is missing in the official statistics. Over the 1950-2008 period, the reconstruction adds more than 200% to reported data, dropping from 590% in the 1950s to 40% in the 2000s. This discrepancy has profound management implications as well as consequences for current understanding of Madagascar's fisheries economy and communities' reliance on wild fish for food security.

INTRODUCTION

Madagascar is located in the western Indian Ocean, and separated from Africa by the Mozambique Channel (Figure 1). With a land area of approximately 587,000 km², it is the fourth largest island in the World and an African biodiversity hotspot, with around 80% of its terrestrial species being indigenous, and its endemic biodiversity threatened by habitat loss (Brooks *et al.*, 2006; Anon., 2008a). Given its great size, spanning 14 degrees of latitude, Madagascar exhibits a range of geological, oceanic and climatic environments, for example, the east of the country is mountainous with a narrow continental shelf facing the prevailing trade winds and oncoming east equatorial current, while the west side is characterised by large plains in a rain shadow, with the coast fringed by a wide continental shelf (Cooke *et al.*, 2003). The southern region is subject to more arid conditions (Jury, 2003), restricting its agricultural potential. These environmental differences have also shaped marine ecosystems: mangroves are almost exclusively present on the west coast (Giri and Muhlhausen, 2008), whereas coral reefs span the southwest, west and northeast coasts, and include one of the largest coral reef systems in the Indian Ocean, totalling approximately 2,230 km² (Spalding *et al.*, 2001). These geographical differences have also resulted in spatial divergence in the distribution of the island's human population with the eastern part of the island having the highest density, while the west coast is home to the majority of fishers and therefore experiences the highest fishing pressure (Guidicelli, 1984; Bellemans, 1989; Rafalimanana, 1991; Laroche *et al.*, 1997).

[1] Cite as: Le Manach, F., Gough, C., Humber, F., Harper, S. and Zeller, D. (2011) Reconstruction of total marine fisheries catches for Madagascar (1950-2008). pp. 21-37. *In*: Harper, S. and Zeller, D. (eds.) Fisheries catch reconstructions: Islands, Part II. Fisheries Centre Research Reports 19(4). Fisheries Centre, University of British Columbia [ISSN1198-6727].

Historically, Madagascar has had several political regimes (Schraeder, 1995). After the Berlin Convention in 1885, which decided the fate of most of the African continent during colonisation, Madagascar was invaded by France in 1896, turning Madagascar into a French colony and finally Overseas Territory in 1946. Although the colonial power invested in national infrastructure such as trains and schools, this period was characterised by protracted political violence, with around 700,000 out of 3 million inhabitants being killed within a few decades (Rousse, 2010). Giving increasing power to national institutions, the French government withdrew step-by-step and in 1960 the First Republic was proclaimed. However, the first Malagasy President was unpopular with the country's people, mainly due to the continuing strong economic and political ties with France. In 1975, the Second Republic aligned itself with the USSR; key sectors of the economy were nationalized and the country experienced a radical socialist and authoritarian political regime. Ten years later, heavy opposition to this regime developed, and in 1992 the Third Republic was proclaimed. Political instability continues to the present day, following a military-backed coup in 2009. Madagascar's current unelected regime faces ongoing economic sanctions and is not recognised by the international community, including the European Union (EU) or the Southern African Development Community (SADC).

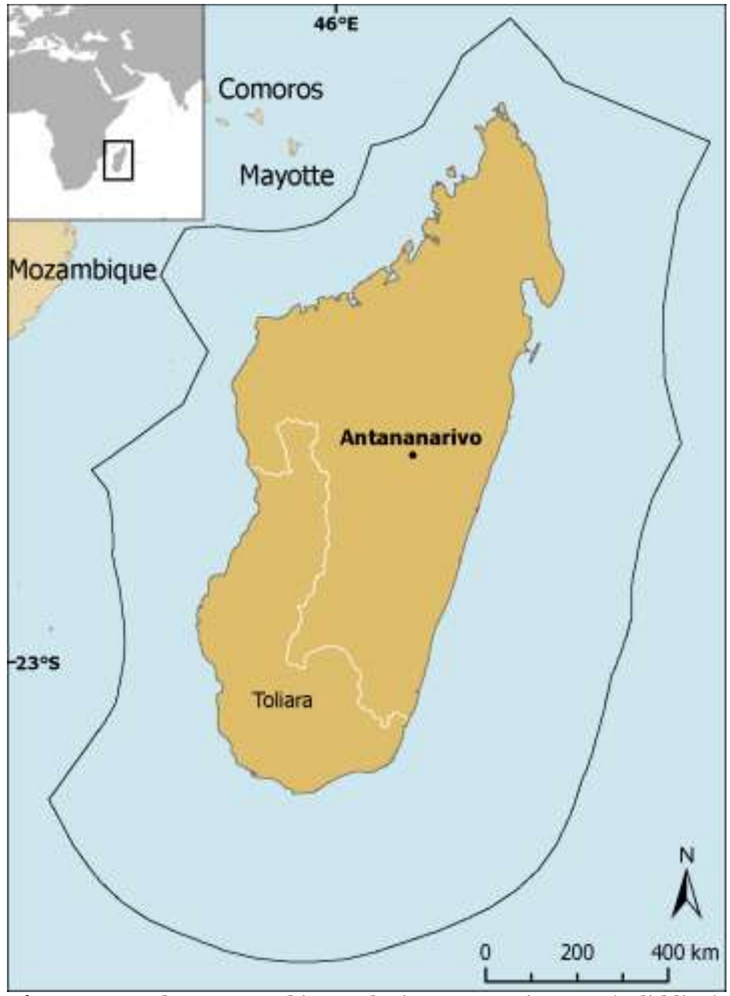

Figure 1: Madagascar and its Exclusive Economic Zone (solid line).

Economically, Madagascar is one of the poorest countries in the world. Per capita GDP has declined steadily since Independence, having never exceeded $410, and currently is at less than $300 (year 2000 USD). Approximately 70% of the population currently lives below the poverty threshold, and over half of the country's population is dependent on the exploitation of natural resources for their livelihoods (World Bank, 2010; Horning, 2008). Subsistence fisheries are of prime importance for coastal communities, especially in the south and west of the country where agriculture is virtually impossible due to aridity.

In developed countries, scientific fisheries assessments such as stock assessments can provide robust data on which to base fisheries management decisions. However, these approaches are expensive, technically complex and often challenged (Murawski, 2010). Developing countries such as Madagascar rarely have adequate scientific capacity or resources to undertake stock assessments. Consequently, poor or incomplete catch data often serve as the only basis for policy and decision making in such countries. In the absence of effective regulations, catch statistics are thought to approximate fluctuations in fish stocks and are therefore viewed as an acceptable proxy for stock assessments. However, catch statistics generally do not account for Illegal, Unreported and Unregulated (IUU) catches, which are widely recognised as a major barrier towards sustainable fisheries management (Sumaila *et al.*, 2006; Hosch *et al.*, 2011). Such IUU catches often result in serious under-estimates of extracted resources and over-estimate of their sustainability (Jacquet *et al.*, 2010). FAO FishStat (FAO, 2009) provides time-series data on marine fisheries landings starting in 1950. These data are based on statistics provided to FAO by member countries. However, it has been shown for many countries that the statistics submitted to the FAO are often incomplete, particularly with regards to artisanal and subsistence fisheries (Zeller *et al.*, 2007; Jacquet *et al.*, 2010; Wielgus *et al.*, 2010). This is likely the case with Madagascar as well, where the importance of seafood for domestic food security has rarely been recognised by the various governments. Here, we re-estimated total marine catches by Madagascar within its EEZ (or EEZ-equivalent waters) for the period 1950 to 2008, with the aim of providing a more accurate baseline for use in policy decisions. This included a review of all fisheries sectors in the country, which allowed us to highlight missing or under-reported components. The present work is also published in Le Manach *et al.* (2012). Note that Le Manach *et al.* (2012) contains a mislabelled Figure (3b), which was corrected through a subsequent errata, and is correctly presented here as Figure (6).

MATERIALS AND METHODS

Human population data

Human population data were obtained from PopulStat (www.populstat.info) and various other sources (Central Intelligence Agency, 2010; Globalis, 2010) and used to derive the number of fishers for the whole time-series (1950-2008). Linear interpolations were made between years of known data (Figure 2a). A fishers' census conducted by the FAO documented the percentage of artisanal fishers among the population in 1988 for each district (Bellemans, 1989). In the absence of more recent estimates, we assumed that these ratios remained stable between 1988 and 2008. It is likely conservative, as the declining per capita GDP during this period would suggest a growing reliance on small-scale artisanal fishing for livelihood and food security. For the 1950-1988 period, the proportion of artisanal fishers among the total population was assumed to have doubled, increasing from approximately 2% to 4%. Indeed, Bellemans (1989) reported that the number of fishers approximately doubled during the two decades preceding the census (Figure 2b). Billé and Mermet (2002) have also indicated a two-fold increase in the number of fishers between the early 1980s and the early 2000s. Based on this, we estimated a fisher population of 100,000 individuals in 2005 (G. Hosch, pers. comm., Fisheries Planning and Management; Gough and Humber, unpub. data). For this study, the coast was divided in two areas: (1) the southwest, comprising the district of Toliara (Figure 1), where the fishing pressure is known to be the highest (Laroche *et al.*, 1997), and (2) the remaining coastal districts, where fishing pressure is consequently thought to be somewhat lower.

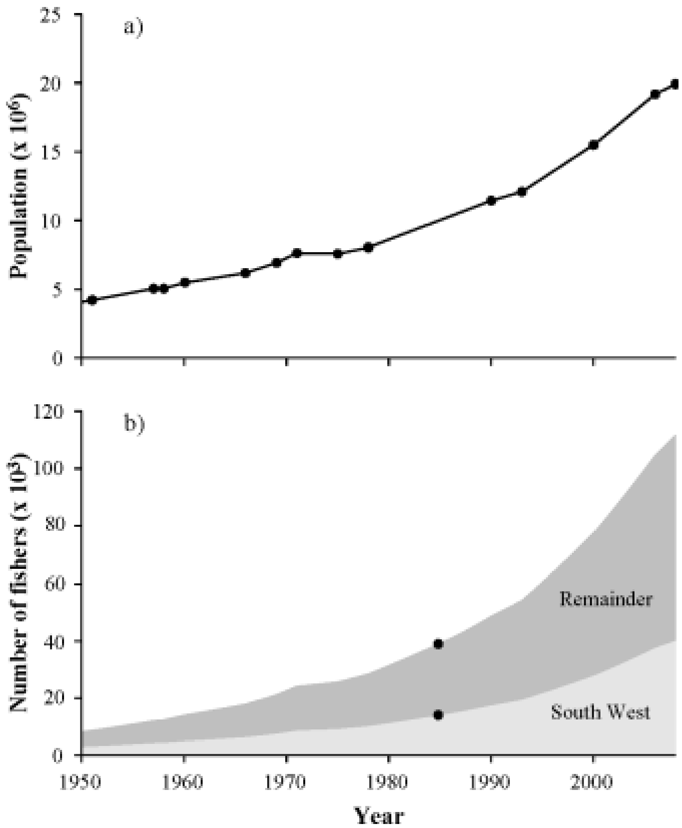

Figure 2: a) Human population of Madagascar with anchor points indicated by solid circles, and b) number of artisanal fishers with the 1987-88 census data foundation (Bellemans, 1989) indicated by dots.

Fisheries sub-sectors

The officially reported landings data which served as the baseline for the study were extracted from the FAO FishStat database (FAO, 2009), and a thorough bibliographic review of fisheries activities in

Madagascar allowed us to determine which sectors were either missing or being under-reported. Data sources included peer-reviewed publications, reports by non-governmental organizations (NGOs), and other grey literature. Expert and local knowledge was collected for each sector in order to formulate the best assumptions possible. For each of these fisheries sectors, catches were then derived for the entire 1950-2008 period, based on anchor points found in the literature and informed knowledge-based assumptions.

Shrimp fishery

The shrimp fishery represents around 4% of Malagasy reported landings for the last decade. However, its market value is significant, reaching almost 70% of the officially recorded marine resource contribution to the GDP, mainly due to important export to Europe, Asia and North America (Soumy, 2006; Anon., 2008b; Kasprzyck, 2008).

The industrial shrimp fishery officially started in 1967, after several years of exploratory trawling (Fourmanoir, 1952a, b; Crosnier, 1965). The number of vessels steadily increased from 11 in 1967 to a maximum of 71 vessels between 1993 and 2003, when the number of licenses started to be controlled. Since then, the number of vessels has decreased, with 47 licensed vessels operating in 2008. Although linked to the economic recession of the 2000s, the increasing price of fuel and the international market being flooded by cheaper Chinese shrimp products, this drop was also due to declines in landed catch and increasing competition with artisanal fishers (Kasprzyck, 2008). Conflict between artisanal and industrial fishers continues to be a serious concern for west coast fishing communities (Cripps, 2009). Despite the intensive exploitation by industrial operators in the past, the decline in the economic viability of the fishery is causing owners to reduce their fleets (Razafindrainibe, 2010; McNeish, 2011). The *Société de Pêche de Morondava* (SoPeMo), a shrimp fishing company based on the west coast, stopped commercial trawling in the region in 2008 (C. Gough, pers. comm.). Unima, the biggest shrimp company in Madagascar is accusing artisanal fishers to have caused the decline in catches (McNeish, 2011).

Artisanal fishers have targeted shrimp since the 1970s. Before then, shrimp was considered incidental bycatch and was used as a complementary food, consumed as an overcooked paste. Since then, artisanal fishers have been attracted by this high-value resource and sell a large portion of their catches to local markets and processors. Due to its rapid expansion, we assumed a yearly growth rate for the artisanal shrimp fishery of 4.5% from 1970 to 2005 (Kasprzyck, 2008; C. Chaboud, pers. comm., Institut de Recherche pour le Développement). The 2005 landings of 3,500 tonnes were used as a basis to carry backward this 4.5% yearly growth rate to 1970.

Bycatch from shrimp fisheries is largely associated with industrial trawl vessels, and is known to be particularly high for tropical shrimp fisheries. Typically, discarded bycatch is not accounted for in reported landings, and we assumed this also applied to Madagascar. One of the earliest estimates for bycatch in the Malagasy shrimp fishery was an amount between 18,000-20,000 tonnes per year in the 1980s (Roullot, 1989). Kelleher (2005) proposed a 1:4.1 bycatch ratio and a discard rate of 72%, which gives tonnage values for the late 1980s similar to Roullot (1989), suggesting that the bycatch was almost entirely discarded. However, it is worth noting that a part of this bycatch is traded to local fishers who fill up their pirogues in exchange for some tobacco or a small amount of money and the local fishers land it and sell it for consumption in the local markets (A. Harris, pers. comm., Blue Ventures Conservation). Here, we applied a discard rate of 72% from 1990 to 2000, and a 90% discard rate for the 1967-1990 period (Table 1), based on Roullot (1989). Lower bycatch ratios and discard rates have been suggested for the last few years (late 2000s). Randriarilala *et al.* (2008) reported a bycatch ratio of 1:2.5 for 2003-2005, which suggests an annual amount of between 8,500 tonnes and 12,700 tonnes per year. This decrease, even stronger since 2005, seems to have been influenced by two developments in Malagasy regulations (Razafindrainibe, 2010). The first development was the introduction of legislation in the 1990s (decree 1999/2000) requiring industrial vessels to retain at least 50% of bycatch to supply fish to local markets. However, the effectiveness of this regulation has been questioned by Randriarilala *et al.* (2008), who assessed a discard rate of 62% for the period 2003-2005. The second development was the introduction of Turtle Excluder Devices (TEDs) and Bycatch Reduction Devices (BRDs) in the Malagasy shrimp fishery in 2003 (Anon, 2003; Razafindrainibe, 2010). Since 2005, all vessels are mandated to be equipped with such BRDs (decree 2003-1101), which considerably reduce the amount of bycatch (Kasprzyck, 2008; Table 1). This reduction is estimated to be approximately 32%, depending on the year, fishing conditions and area (Fennessy and Isaksen, 2007). Therefore, we considered a bycatch ratio of 1:1.7 from 2005 onward, while discard rates were set at 62% since 2001 (Table 1). However, only approximately 30% of licensed boats carry enforcement personnel from the national fisheries surveillance authority, and it is not clear whether crews use TEDs and BRDs when not under surveillance. Indeed, without surveillance, crews have little incentive to follow legislation, since the economic conditions under which crews work create a major incentive to maximise bycatch for private sale at sea. Shrimpers work seven days a week and are paid per tonne of shrimp landed, with base salaries as little as $25 per month.

The bycatch is dominated by fin fish (e.g., *Otolithes argenteus*, *Johnius dussumieri*, *Trichiurus lepturus* and *Pomadasys maculatus*), and to a lesser extent, invertebrates such as sea urchins and jellyfish, which can represent an important component of total bycatch. Chen and Chow (2001) estimated a discard survival rate of 8% for fin fish, 35% for cephalopods and 60% for crustaceans in a tropical shrimp fishery in Asia. We assumed here that all the discarded bycatch had a similar mortality, and thus applied mortality rates of 8%, 35% and 60% to the respective bycatch amounts of fin fish, cephalopods and other crustaceans.
The commercial shrimp fleet also comprises two other sectors of much lower capacity:

- A small fleet of mini-trawlers with engine power less than 50 horse power. This fleet was intended to introduce more efficient gears to the artisanal fisheries. However, they were taken up by industrial fisheries societies to allow them to fish in certain areas otherwise not accessible by their large boats (Kasprzyck, 2008; *Direction des Pêches* in Morondava, pers. comm.). Landings reported to FAO increased from 45 tonnes to 700 tonnes per year from 1975 to 2008 (peak at 750 t in 2003), and were considered reliable and were included without modification in the 'industrial grouping' described above.
- A deep-sea shrimp fishery was initiated in 1992 and ended in 2005 due to technical issues, mainly due to the nature of the sea floor. No information was available concerning associated bycatch. Catches fluctuated between 100 and 150 t·year^{-1} and were also included without modification in the 'industrial grouping'.

Table 1: Summary of data, assumptions and sources used to reconstruct total catches by shrimp fishing fleets in Madagascar.

Time period	Shrimp catches (t·year^{-1})	Associated bycatch and discards		Sources	Comment
		Bycatch ratio	Discards (%)		
1967-2008	300 - 13,300[a]	-	-	Domalain *et al.* (2000); Goedefroit *et al.* (2002); Razafindrakoto (2008), Rokotodratsimba *et al.* (2008) ; FAO (2009)	-
1967-1989		1:4.1	90	Roullot (1989)	
1990-2000		1:4.1	72	Kelleher (2005)	
2001-2004		1:2.5[b]	62	Randriarilala *et al.* (2008)	Decree 1999/2000
2005-2008		1:1.7[b]	62		BRD introduction

[a] Values reported to FAO were kept for the years 1966, 1994, 2000-2003, as they were deemed more representative than those reconstructed. [b] Based on a 32% reduction of bycatch due to BRDs (Fennessy and Isaksen, 2007).

Shark fishery

Although consumption of sharks is common, Madagascar only reports landings of less than 10 tonnes per year for the 2001-2008 period, according to FAO. However, the FAO trade database documents shark exports of up to 85 tonnes per year since 1992, and an independent report suggests that shark meat and fins have been exported since the early 20th century (Petit, 1930). In fact, artisanal fishers target sharks for the export market of fins, but carcasses are rarely discarded, and the meat is either consumed locally or to a lesser extent, sold to Comoros. A number of endangered benthic species, such as the critically endangered sawfish (*Pristis pectinata*), were once commonly caught by artisanal fishers along the mangrove-fringed coast of western Madagascar, but are now considered extremely rare throughout the region (A. Harris, pers. comm., Blue Ventures Conservation).

Sharks are also caught as bycatch in other Malagasy commercial fisheries, such as the shrimp fishery, in which sharks have been reported as representing 1% of the bycatch (C. Chaboud, pers. comm., Institut de Recherche pour le Développement; Table 2). Due to the high price of shark fins, we assumed that all sharks are finned, and that all of the carcasses are retained for local consumption or exported to Comoros (C. Chaboud, pers. comm., Institut de Recherche pour le Développement; A. Harris, pers. comm., Blue Ventures Conservation).

Finally, shark liver oil has also been traditionally used for cooking and to waterproof wooden boats (Cooke, 1997). The quantity of oil used for this purpose is substantial in the Maldives, as Anon. (2001) reports a use of between 54 and 58 kg of oil per year, for each boat. However, as it was impossible to assess the number of sharks required to treat the whole Malagasy artisanal fleet, this component was not considered in this study. Shark liver oil is also a valuable commodity on international markets, with Madagascar's sharks targeted by illegal, unreported and unregulated (IUU) boats for this purpose as well as for the fins. A number of known IUU vessels, which previously targeted Patagonian toothfish in the southern Ocean (see Palomares and Pauly, this volume), are reported to have recently converted to shark fishing in southern and western Madagascar by substituting bottom trawl nets with bottom-set gillnet gear to target nurse sharks for liver oil (mainly *Nebrius ferrugineus* and the vulnerable *Pseudoginglymostoma brevicaudatum*) (SADC, 2008; Anon. 2010a and b).

Table 2: Summary of data, parameters, assumptions and sources used for the reconstruction of shark fisheries catches in Madagascar.

Sector	Timeperiod	dry fin[a] (t)	Sources	Catch (t)	Comment
Targeted	1950-1979	-	Petit (1930)	160 - 570[b]	Exports at least since 1930s. Backward extension of 1980 per fisher catch rate
	1980-1985	-		600 - 3050	Backward extension of 1986-1988 trend in derived catch
	1986-1995	34.5 - 64.7	Cooke *et al.* (2001)	3,430 - 6,440	
	1996-2008	-		5,400 - 3,760[c]	Decrease of 3%·year^{-1}
Shrimp bycatch	1967-2008	-		Up to 385 t (1998)[d]	

[a] Hong Kong and Singapore imports; [b] 1950 value of 60 t derived through keeping the 1980 catch per fisher fixed. [c] Values for this period were based on interpolations from the 1994 fin trade data, and an assumed 3% per year decrease in catches (McVean, 2006; Cooke *et al.*, 2001; Y. Sadovy, pers. comm. University of Hong Kong). [d] Values were based on reconstructed industrial shrimp catches and an assumed 1% of total shrimp bycatch composed of sharks (C. Chaboud, pers. comm., Institut de Recherche pour le Développement).

Cooke (1997) and Cooke *et al.* (unpub. data) review the shark fishery in Madagascar, focusing on exports of fins to the Hong Kong and Singapore markets. Given the high market price of fins, we assumed that all captured sharks were finned, and therefore, trade in fins was the best proxy available to assess the minimum quantity of sharks caught each year. Three approaches were used to reconstruct total shark catches by Malagasy fishers (Table 2). Data on the trade of shark fins were used to conservatively estimate the likely minimum catches of sharks that occurred in Madagascar's waters during the period 1970-1994: dried fins imported between 1986 and 1995 by Honk-Kong and Singapore from Madagascar were converted to whole body, wet weight using a conversion factor of 98.5% (Cortes and Neer, 2006; Jacquet *et al.*, 2008; Y. Sadovy, pers comm., University of Hong Kong). We assumed that the market started to greatly expand in 1980, and therefore linearly extended the 1986-1988 trend backwards to 1980. For the 1950-1979 period, we assumed that the 1980 per fisher catch rate remained constant back to 1950, and expanded it to total catches using fisher population data. For the 1996-2008 period, we conservatively assumed that the 1994 per fisher catch rate decreased by 3%·year^{-1}, based on literature and local knowledge (McVean *et al.*, 2006; Y. Sadovy, pers. comm., University of Hong Kong). Currently, catches are reported to decrease, and fishers catch fewer and smaller sharks, most of the time farther from shore than before (Cooke, 1997 and 2003; McVean, 2006; Cooke *et al.*, unpub. data). The high market demand for shark fin as a lucrative yet diminishing fisheries resource is a key factor driving Madagascar's nomadic

Vezo fishers further afield during their annual migration, with shark fishers exploiting remoter regions of the west coast of Madagascar, further offshore and in larger numbers, than ever before (Cripps, 2010). As an example of this escalation in fishing effort, the recent introduction of new intensive fishing techniques in the offshore Barren Isles archipelago and around Morondava, involves teams of artisanal fishers deploying weighted 'barrage' nets several kilometres in length, targeting sharks and guitarfish (Cripps, 2010). Based on this information, we applied a 3% per year decrease in catches since 1994 (Table 2).

Non-shrimp invertebrate fisheries

The remaining landings data reported to FAO have been aggregated into a miscellaneous invertebrate grouping, which includes cephalopods and other molluscs, crabs and lobsters, shells and sea cucumbers. These species are heavily targeted by men, women and children for both subsistence and commercial purposes (Rasolofonirina and Conand, 1998; Frontier Madagascar, 2003; Anderson *et al.,* 2008; Barnes and Rawlinson, 2009; Cripps, 2009; Gough *et al.,* 2009; Tucker *et al.*, 2010). The under-reporting of invertebrate fisheries is visible in the statistics reported to the FAO, since reported landings are very similar to exported fisheries products (r^2=0.75; not shown). Also, there are no reported invertebrate catches before 1962. However, coastal populations rely heavily on reef gleaning for invertebrates for their daily protein needs, although a significant amount is sold (Cripps, 2009; Gough *et al.,* 2009). Indeed, invertebrate landings account for a major component of fisheries-derived income for artisanal fishers in many parts of Madagascar. Beside holothurian fisheries, octopus is the dominant commercial fishery in much of the southwest and northeast of the country, and lobster plays a crucial role in coastal livelihoods from the rocky shores of the southeast. A thriving trade in marine curios, predominantly molluscs, is also present in most coastal towns. In all these cases, catches are sold to collectors by local fishers for international export. Therefore, we assumed that invertebrate extraction by the local population was happening prior to 1962 and that this sector is missing from the official data.

In order to re-estimate the total extraction of invertebrates, product weight as it appears in the trade data was converted to (whole body) wet weight, using FAO conversion factors (Anon., 2000). A highly conservative export rate of 80% (for sea cucumber, cephalopods, crabs and lobsters) or 20% (for the other products) was then applied for the entire time period for which exports were thought to have occurred (1970s-2008) in order to calculate the domestic subsistence component. Finally, the average subsistence catch rates for the first three years of exports were applied to the number of inhabitants prior to the first year of export, in order to estimate the domestic subsistence component of invertebrate catches back to 1950.

Table 3: Summary of parameters used for the estimation of small-scale catches.

Coastal Area[a]	Time period	Number of fishers	CPUE	Fishing days[b]	Catches (t)	Comment	Source
South-West	1950	2,900	6.7	-	5,155	-	
	1988	16,000	5.8	-	24,110	-	
	1991	18,100	5.0*	-	23,574	-	Laroche (1997)
	1950-1988	-	-	260	-	Stable CPUE	
	2008	40,100	2.1	-	21,853	-	
	1988-2008	-	-	260	-	-5% CPUE·year^{-1}	
The remainder	1950	5,300	6.1	-	8,300	-	
	1988	28,500	5.7	-	42,347	-	
	1950-1988	-		260	-	Stable CPUE	
	2002	55,300	4.3*	-	62,178	-	Doukakis (2007)
	2008	71,600	3.8	-	71,344	-	
	1988-2008	-	-	260	-	-2% CPUE·year^{-1}	

*Anchor points; [a] See Figure 2 for area definitions; [b]Assumed average number of fishing days in Madagascar (McVean, 2006; Gough and Humber, unpub. data; G. Hosch, pers. comm. Fisheries Planning and Management).

Small-scale fisheries: subsistence and artisanal catches

Between 1950 and 2008, landings of tuna-like species, narrow-barred Spanish mackerel (*Scomberomorus commersoni*) and miscellaneous marine fish represented the bulk of the data reported to FAO, accounting on average for 82% of total seafood landings in Madagascar. They are exclusively caught by artisanal fishers, as there are no industrial fisheries targeting these species.Unfortunately, estuarine catches were reported by Madagascar as inland catches until 1989, after which they were accounted for in the marine landings (Stamatopoulos and Rafalimanana, 1991). The same authors also report these estuarine catches to be 30,000 tonnes per year in the late 1980s. Finally, the official records of fish caught in the 1950s would signify a highly unrealistic local consumption of approximately 0.7 kg·person^{-1}·year^{-1} (based on a coastal population representing 90% of the total human population). Considering the change in reporting protocol and this unrealistic consumption rate, we replaced the data supplied to FAO (tuna-like species, mackerel and miscellaneous marine fish) and re-estimated small-scale catches based on CPUE and fishing effort data from independent studies (Laroche and Ramananarivo, 1995; Laroche *et al.*, 1997; Doukakis *et al.*, 2007), in combination with the number of fishers for the two regions as defined in Figure 2. Based on local knowledge and reports, which suggest decreases in CPUE over time (Bellemans, 1989; Laroche *et al.*, 1997; Frontier Madagascar, 2003; Langley, 2006; Doukakis *et al.*, 2007; Gough *et al.*, 2009), we applied different CPUE estimates for areas and time periods as shown in Table 3.

Other fisheries

A commercial joint venture fisheries operation between Japan and Madagascar was established in the 1970s under the name of *Compagnie Malgache Nippone de Pêcherie* (COMANIP) for the exploitation of Madagascar's skipjack tunas, *Katsuwonus pelamis* (Marsac and Stequert, 1984; Gilbert and Rabenomanana, 1996). Independent catch data were not available; therefore we considered the data reported to FAO as reliable and included them in the final result without modification. Thus, we assumed no underreporting of skipjack tuna catches during this period. This is likely conservative, given the known occurrence of substantial and widespread underreporting of tuna catches.

An exploratory deep-sea fishery in the Malagasy EEZ started in 2001. There is only one value provided by the FAO of 4157 tonnes for the year 2002. This sector is described by Soumi (2004) to have increased without any further indication; therefore, we assumed a growth rate of 5% per year between 2002 and 2008.

In the last two decades, fishing tourism has rapidly expanded in Madagascar (Jain, 1995). Most of the catch, dominated by large pelagic species such as marlin and tuna, is not catch-and-release, and is therefore killed and retained. However, none of the 60 people contacted in this study (employees or managers of sport-fishing charter companies) were willing to share information with us. As a result we were unable to quantify extractions made by this sector. In terms of overall tonnage, this sector is likely to be small, but may have effects on the population structure of these species, especially the billfishes.

Foreign fishing in Madagascar's waters

Since 1986, a fishing agreement has been in place with the European Commission, allowing EU purse-seine vessels to catch tuna in Malagasy waters (Gilbert and Rabenomanana, 1996). Catches of 10,000 tonnes have been declared each year since 1986. However, given that licence fees are based on this tonnage, it is highly likely that catches are largely under-reported, and may actually be around 18,000-20,000 tonnes per year (Anon., 2002). It is also interesting to note that a substantial Asian long-line fleet has been fishing in Malagasy waters most of the time illegally without access agreements, with entirely un-reported catches of tuna. Anon. (1995) reported legal catches of 6,000-8,000 tonnes. However, some estimates are up to 50,000 t·year^{-1} (Fowler, 2005). Indeed, Malagasy authorities do not possess the resources to patrol their own EEZ and therefore cannot address the problem of illegal fishing for such high-value species (Jain, 1995; Cooke, 1997; A. Harris, pers. comm., Blue Ventures Conservation; G. Hosch, pers. comm., Fisheries Planning and Management). Given that no formal access agreements exist between Madagascar and these countries, these catches are illegal under international law. For this long-line fleet, 7.5% of the bycatch is composed of sharks (Cooke, 1997; Fowler, 2005), of which only fins are retained. Finally, a longline fleet, whose catches are uncertain (Fowler, 2005), is operating from La Réunion (René *et al.*, 1998) and is targeting tuna and other large pelagic species (e.g., swordfish, marlin). For our purposes, we assumed this longline fleet started fishing in Malagasy waters around 1990 and catches increased linearly to 5,000 t·year^{-1} in 2008. Cases of this sort of unreported fishing are sometimes covered by media journals (Anon., 2010b) but have remained largely unaddressed by Malagasy authorities or Regional Fisheries Management Organizations (Cullis-Suzuki and Pauly, 2010). These catches, important in an ecosystem sense, are estimated here and listed in Appendix Table A1, but are not included in our reconstruction of Malagasy fisheries catches, since they are made by foreign countries.

RESULTS

Reconstructed catches by sector, taxa and year are presented in Appendixes Tables (A1, A2).

Shrimp fishery

Total shrimp catches, which were very low prior to 1967, increased until the late 1990s-early 2000s, with peak catches of 12,850 t·year^{-1} in 2003 (Figure 3a). Industrial landings stabilised in the 1990s at around 8,500 t·year^{-1}, with a peak of 9,850 t·year^{-1} in 1998. They have declined substantially since 2002, with only 5,200 t caught in 2008. Similarly, small-scale catches increased from approximately 300 t·year^{-1} during the 1950s, to 750 t·year^{-1} in 1970 and to 3,500 t·year^{-1} in 2005. Thereafter, they underwent a gradual decline to around 2,700 t·year^{-1} in 2008 (Figure 3a).

Bycatch also followed a similar trend, and reached a maximum of 38,800 t·year^{-1} in 1998, of which 25,500 t were discarded (72%). Since then, bycatch has decreased to around 8,000 t·year^{-1} in 2008, of which 4,400 tonnes were discarded (62%; Figure 3a).

Over the 1950-2008 time-period, the artisanal component represents 27% and the industrial sector 73% of total shrimp catches.

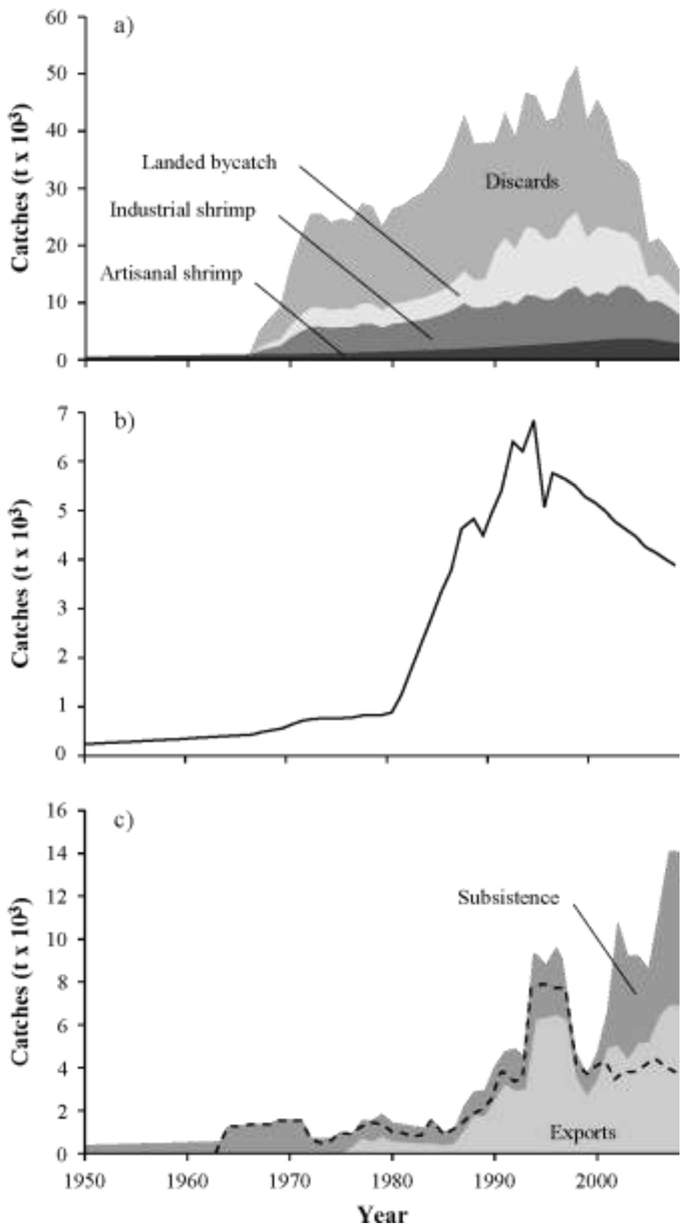

Figure 3: a) Shrimp catches by the industrial and artisanal sectors, and the associated bycatch (landed and discarded); b) total shark catches by small-scale fishers and c) catches for non-shrimp invertebrates, separated by exports or commercial (light grey), and subsistence (dark grey) catches (dotted line represents the data supplied to FAO).

Shark fishery

The reconstructed data for sharks conservatively suggests low catches until 1980, averaging 350 t·year^{-1}, followed by a rapid and substantial increase, from approximately 500 tonnes in 1980 to a peak of almost 7,000 t·year^{-1} in 1992 (Figure 3b). Since then shark catches have decreased to 3,800 t·year^{-1} in 2008 (Figure 3b).

Non-shrimp invertebrate fishery

Total invertebrate catches increased from 1,500 t·year^{-1} in 1950 to 4,000 t·year^{-1} in 1975 and were deemed to be exclusively for subsistence purposes during that time (Figure 3c). Since 1975, total catches have comprised both a subsistence and a commercial (export) component and, although fluctuating over time, have steadily increased to approximately 16,000 t·year^{-1} by 2008 (Figure 3c). Over the 1950-2008 time-period, invertebrate catches have totalled 193,800 tonnes, of which the subsistence component represents 45% and commercial exports 55%.

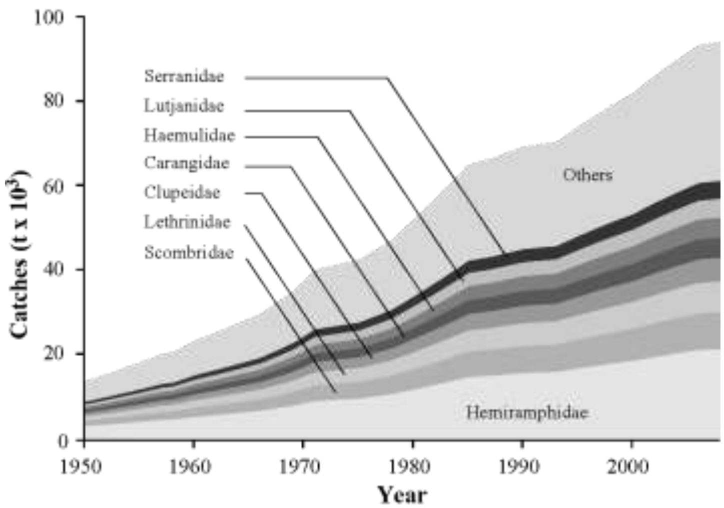

Figure 4: Total reconstructed catches of the small-scale finfish fishery, showing the taxonomic breakdown (based on Laroche *et al.*, 1997). Approximately half of these catches are for subsistence, and the other half for sale on the local market (C. Gough and F. Humber, pers. obs.).

Small-scale finfish fisheries: subsistence and artisanal catches

Reconstructed subsistence and artisanal catches of finfish by small-scale fishers have increased steadily over the 1950-2008 time-period (Figure 4). Total subsistence and artisanal catches in 1950 were around 13,500 t·year^{-1} and have increased to around 93,000 t·year^{-1} by 2008 (Figure 4).

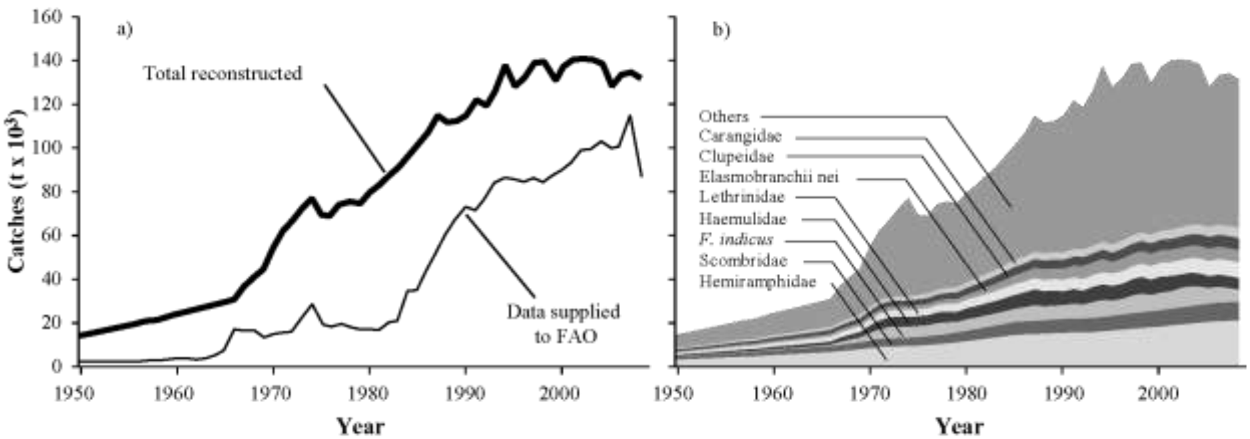

Figure 5: a) Total reconstructed catches versus reported landings as supplied to FAO by Madagascar; and b) Taxonomic composition of the overall reconstructed catches. *Fenneropenaeus indicus* is a shrimp species; all the other groups (except the mixed-group 'others') are from the small-scale, finfish fishery.

Overall reconstruction

Over the whole 1950-2008 time-period, total catches taken by Malagasy fishers in Madagascar's EEZ are estimated at 4.7 million tonnes. Thisreconstructed total is twice as high as the data supplied to the FAO by the government of Madagascar (Figure 5). Significantly, the re-estimation added over 550% for the earlier time-period (1950s), but adjusted the reported data by only 39% for the 2000-2008 period (Figure 5a). The taxonomic composition of reconstructed total catches shows a constant attern over time (Figure 5b).

Foreign fishing in Madagascar's waters

Tuna catches taken by foreign vessels are thought to have increased substantially since the mid-1980s. Current catches are somewhat uncertain due to obvious unreported and illegal catches. A minimum estimate is over 70,000 t·year^{-1} (Figure 6). Catches are likely dominated by Asian longline fleets operating illegally, with catches having increased to 50,000 t·year^{-1} by 2008. The EU purse-seine fleet, although operating legally through access agreement, is known to substantially under-report by at least 100%, with official catches reported as around 10,000 t·year^{-1}, while estimated actual catches are around 18,000 t·year^{-1} (Figure 6). Note that the publication by Le Manach *et al*. (2012) contains a mislabelled version of Figure (6). The present version is labelled correctly.

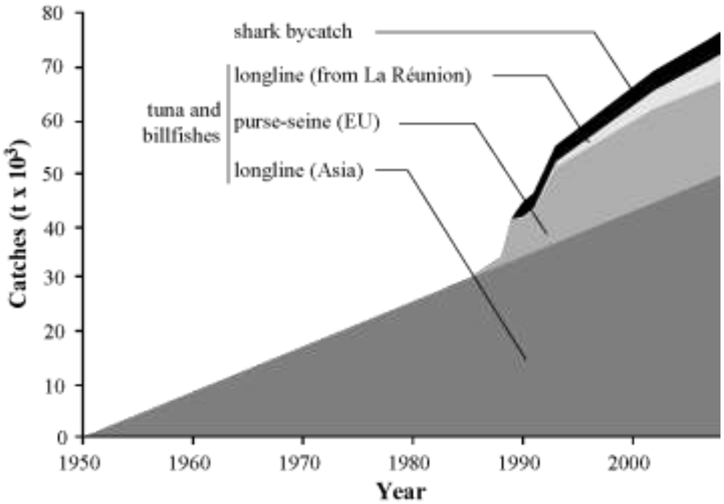

Figure 6: Estimated time-series of tuna catches in Madagascar's EEZ.

Discussion

Overall, reported data show a steady increase in landings, due to the expansion of industrial fleets in the early 1980s. According to our analysis, Malagasy fisheries had been underreported by over 500% in the early time period, and seem to be underreported at present by at least 40%. The reporting is therefore improving, but current values, likely under-estimates, are still very substantial.

Our reconstructed catch time-series shows a levelling off of catches over the last two decades (Figure 5). It is worth noting that this levelling off of total catches is partly related to the improvement of bycatch handling by the shrimp industry causing decreased bycatch/discards since the 1990s. However, it is also certainly due to decreases in catches seen in various invertebrates (including shrimp) and shark fisheries, which suggest that overfishing is likely to be taking place.

The official data also fail to account for a large part of the subsistence fishery, which represents 75% of the total reconstructed catch over the whole period, and 83% for the period 1950-1980. Such marginalization of small-scale fisheries is common (Pauly, 1997), although inclusion in official statistics is crucial. As a consequence of this marginalization, total Malagasy catches may be approaching or even exceeding sustainable yields for coastal stocks, estimated at 180,000 t·year^{-1} (Anon., 2008b), with it remaining undetected.

Another issue that has been dealt with in this report is the poor taxonomic information included in official statistics supplied to FAO. The major group in these official statistics represents over 80% of total catches, and is only described as 'marine fish nowhere else included'. Although we made a taxonomic breakdown of total catches, information related to species composition remains extremely poor. This fact justifies the importance of the implementation by FAO of taxonomic census every three to five years in order to create more reliable species composition times-series.

Although not included in the total reconstruction, we also reviewed foreign fisheries in Madagascar's EEZ. Current catches of tuna, billfishes and sharks are likely to be over 70,000 t·year^{-1}, most of which are made illegally. This situation raises serious legal questions, and also points to the issue of inappropriate low fishing access fees paid by developed countries (Kaczynski and Fluharty, 2002; Hanish and Tsamenyi,

2009) and poor to non-existing monitoring and enforcement of such agreements (e.g., Jain, 1995). Indeed, the monitoring and enforcement system for the entirety of Madagascar is only composed of 3 monitoring vessels, 8 speedboats, 18 inspectors and 22 observers (R. Fanazava, pers. comm., Centre de Surveillance des Pêches). This lack of monitoring and enforcement capability has led to increasing illegal pirate fishing in the waters of Madagascar, as evidenced here, which likely contributes significantly to unsustainable fishing practices in the Western Indian Ocean.

For the large-scale commercial shrimp industry, no real discrepancies exist between landings reported to FAO and our re-estimated landings. However, the overall CPUE is decreasing, possibly because catches have been significantly higher (by up to 5,000 $t \cdot year^{-1}$) than the estimated maximum sustainable yield of 8,700 $tonnes \cdot year^{-1}$ (Kasprzyck, 2008). It is worth noting that no values were reported to the FAO before 1964, when the first exploratory trawls were conducted. Prior to this date, local people were nevertheless fishing and consuming shrimp, and our study has filled this gap by assigning a subsistence component to this sector, although this was negligible compared to total catches. Also, the significant bycatch produced by shrimp trawlers is missing from official data, and this issue needed to be addressed since this bycatch is often made unavailable to the local population, when not collected by artisanal fishers. Our study highlights the importance of such bycatch for Madagascar since the beginning of this fishery.

The reconstructed time-series of shark catches gives a very different picture to the official data. The former considers that an artisanal fishery has existed since at least 1950, while the latter show little indication that a shark fishery exists despite this being fairly well documented in the independent literature (see Petit, 1930; Cooke, 1997). These values are based on the fin trade using strong assumptions and are considered highly conservative given that Hong Kong and Singapore do not account for 100% of the fin market. However, they are likely to be closer to actual catches than the previous assumption in which a lack of data has been incorrectly interpreted as no catch.

Concerning the small-scale finfish fishery, our reconstruction provides very similar estimates to those provided to the FAO for the 1989-2008 period. For 1950-1989, our results however differ greatly, as they fill the gap made by estuarine catches accounted for in reported inland catches before 1989. This misreporting of estuarine catches is documented but has never been incorporated into official statistics. Importantly, there are increasing concerns about the rate of growth in small-scale catches slowing, eventually leading to declining catches by the small-scale, artisanal and subsistence fisheries. This finfish fishery supplies the bulk of local seafood consumption demand, as most of the catches are sold and consumed locally, and declines in catches could have significant impacts on the food security of coastal communities.

Throughout this report, historical events and changes in reporting protocols illustrate the importance of linking historical information and fisheries data to current management plans, especially in maritime developing countries such as Madagascar, where fisheries are of fundamental importance for the food security of the people. The consequences of diminishing fisheries are likely to be particularly severe in an island nation in which over 50% of children under five years of age suffer delayed development due to a chronically inadequate diet, and where chronic food insecurity affects over 65% of the population (Back-Michaud *et al.*, 2009; Anon., 2010c).

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Appendix Table A1: Annual catches by domestic and foreign fisheries in Madagascar's EEZ, 1950-2008.

Year	Domestic fisheries (t)		Foreign fisheries (t)		
	Data reported to FAO	Reconstructed catch	Purse-seine (EU)	Longline (Asia)	Longline (France)
1950	2400	14295	0	0	0
1951	2500	15170	0	847	0
1952	2500	16070	0	1695	0
1953	2600	16995	0	2542	0
1954	2600	17946	0	3390	0
1955	2600	18923	0	4237	0
1956	2600	19925	0	5085	0
1957	3000	20942	0	5932	0
1958	3000	21447	0	6780	0
1959	3500	22811	0	7627	0
1960	4000	24205	0	8475	0
1961	4000	25243	0	9322	0
1962	3500	26304	0	10169	0
1963	4000	27387	0	11017	0
1964	5501	28491	0	11864	0
1965	7801	29617	0	12712	0
1966	17500	30883	0	13559	0
1967	16600	36787	0	14407	0
1968	16900	40937	0	15254	0
1969	13400	44617	0	16102	0
1970	15100	54319	0	16949	0
1971	15800	62029	0	17797	0
1972	16200	66801	0	18644	0
1973	22401	72408	0	19492	0
1974	28701	77014	0	20339	0
1975	19501	69410	0	21186	0
1976	18451	68934	0	22034	0
1977	19760	74354	0	22881	0
1978	18160	75462	0	23729	0
1979	17260	74619	0	24576	0
1980	17373	79804	0	25424	0
1981	16875	83133	0	26271	0
1982	20455	87439	0	27119	0
1983	21195	91293	0	27966	0
1984	35038	96501	0	28814	0
1985	35112	101705	0	29661	0
1986	44353	107033	520	30508	0
1987	52488	114869	1040	31356	0
1988	61141	111675	1550	32203	0
1989	67731	112374	8125	33051	0
1990	73515	115101	7400	33898	263
1991	71438	121887	8000	34746	526
1992	77021	118912	11250	35593	789
1993	84317	126392	14500	36441	1053
1994	86618	137783	14889	37288	1316
1995	85840	128033	15278	38136	1579
1996	84644	132157	15667	38983	1842
1997	86547	138809	16056	39831	2105
1998	84405	139285	16444	40678	2368
1999	87638	129942	16833	41525	2632
2000	90167	137120	17222	42373	2895
2001	93615	140240	17611	43220	3158
2002	99326	140689	18000	44068	3421
2003	99671	140276	18000	44915	3684
2004	103416	138493	18000	45763	3947
2005	99986	128148	18000	46610	4211
2006	100943	133449	18000	47458	4474
2007	115148	134454	18000	48305	4737
2008	87834	131771	18000	50000	5000

Appendix Table A2: Six most important taxa caught by domestic fisheries in Madagascar's EEZ, 1950-2008.

Year	Hemiramphidae	Scombridae	*Fenneropenaeus indicus*	Haemulidae	Lethrinidae	Elasmobranchii	Others
1950	3043	1246	274	677	1049	605	7402
1951	3232	1323	291	719	1114	642	7850
1952	3426	1403	308	762	1181	681	8310
1953	3626	1484	325	806	1249	721	8784
1954	3831	1568	343	852	1320	761	9270
1955	4042	1655	361	899	1393	803	9770
1956	4259	1744	380	947	1468	846	10282
1957	4481	1835	389	996	1544	890	10806
1958	4587	1878	414	1020	1581	912	11054
1959	4882	1999	440	1086	1682	970	11752
1960	5184	2123	459	1153	1787	1030	12469
1961	5409	2215	479	1203	1864	1075	12998
1962	5639	2309	499	1254	1943	1121	13539
1963	5874	2405	519	1306	2024	1167	14091
1964	6113	2503	540	1359	2107	1215	14654
1965	6357	2603	561	1414	2191	1263	15228
1966	6606	2705	689	1469	2277	1313	15824
1967	7002	2867	1436	1964	2413	1395	19711
1968	7407	3033	1856	2284	2553	1477	22328
1969	7823	3203	2183	2554	2696	1561	24598
1970	8367	3426	3522	3388	2884	1675	31057
1971	8926	3655	4489	4022	3076	1790	36071
1972	9065	3711	5271	4460	3124	1821	39348
1973	9203	3768	5309	4491	3172	1849	44618
1974	9341	3824	5068	4369	3219	1875	49318
1975	9478	3880	5242	4450	3266	1902	41190
1976	9818	4020	5107	4475	3383	1970	40162
1977	10164	4161	5603	4857	3503	2041	44025
1978	10515	4305	5466	4885	3624	2110	44556
1979	11050	4524	4823	4647	3808	2214	43554
1980	11595	4747	5296	5074	3996	2324	46771
1981	12152	4975	5340	5249	4188	2621	48608
1982	12721	5208	5503	5502	4384	3003	51119
1983	13300	5445	5581	5708	4584	3381	53294
1984	13891	5687	5846	6043	4787	3758	56489
1985	14494	5934	6078	6380	4995	4141	59683
1986	14653	5999	6539	6823	5050	4394	63574
1987	14803	6061	7216	7366	5102	4860	69461
1988	15022	6151	6427	6905	5177	5013	66980
1989	15232	6236	6438	6952	5249	4834	67432
1990	15432	6318	6415	6283	5318	5156	70178
1991	15530	6358	6973	6713	5352	5411	75549
1992	15608	6391	6419	6363	5379	5969	72781
1993	15681	6420	7477	6991	5404	5824	78596
1994	16095	6590	7884	7042	5547	6258	88369
1995	16494	6753	7003	6764	5684	5257	80078
1996	16878	6910	7211	6890	5817	5829	82622
1997	17248	7062	8200	7421	5944	5809	87125
1998	17605	7208	8561	7744	6067	5788	86312
1999	17948	7348	7537	7047	6185	5756	78121
2000	18278	7483	8195	7405	6299	5736	83725
2001	18743	7674	7990	7011	6459	5735	86627
2002	19193	7858	8942	6172	6614	5728	86182
2003	19620	8033	9098	6203	6762	5727	84834
2004	20031	8201	8363	6144	6903	5725	83124
2005	20427	8363	7189	5415	7040	5715	73998
2006	20807	8519	7233	5558	7170	5714	78449
2007	20902	8558	6554	5463	7203	5665	80109
2008	20991	8594	5717	5323	7234	5615	78298

RECONSTRUCTION OF MARINE FISHERIES CATCHES FOR MAURITIUS AND ITS OUTER ISLANDS, 1950-2008[1]

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ABSTRACT

Total marine fisheries catches by Mauritius and its outer dependencies were estimated from 1950 to 2008, and include unreported catches from the small-scale fisheries carried out around the islands of Mauritius, Rodrigues, Agalega and St. Brandon, recreational marine catches, estimates of catches taken by the Mauritian fleets along the Mascarene Ridge, and discards of the tuna purse-seine fishery. Summed for 1950-2008, total marine fisheries catches for Mauritius and its dependencies were estimated to be 682,392 t, which is 42 percent larger than currently reported landings of 478,305 t presented by FAO on behalf of Mauritius. This discrepancy was largely due to better accounting of small-scale catches carried out around Mauritius and Rodrigues islands by part-time fishers. This study illustrates the need for improved reporting of catches including all fisheries sectors in Mauritius, especially for the small-scale sector, which provides food security and a source of income for a large portion of the local population.

INTRODUCTION

Mauritius is an island of volcanic origin located between 20°10′S and 57°31′E about 850 km east of Madagascar (Figure 1). It covers a land area of approximately 1,860 km² and shelters a population of around 1.2 million people. Mauritius is an island state including several dependencies in the Southwest Indian Ocean, namely the island of Rodrigues, the St. Brandon (or Cargados Carajos) group of islands and islets, and the twin islands of Agalega. Mauritius was uninhabited when it was first colonized by the Dutch in 1638, and it has later been under French (1715-1810) and British (1810-1968) rule. The colonization period coincided with large-scale deforestation of the islands for sugar cane farming and the introduction of alien species which have severely damaged the islands' ecosystems and indigenous species (Paul, 1987; Sobhee, 2004; Turner and Klaus, 2005). At the time of independence in 1968, the economy was dominated by the sugar industry, and it has later undergone rapid growth and diversification with the development of the textile manufacturing industry and tourism.

Mauritius includes a large Exclusive Economic Zone (EEZ) that is approximately 1.7 million km² (Figure 1). The fishing sector includes small-scale fisheries in the lagoon and non-lagoon areas around Mauritius, Rodrigues, Agalega and St. Brandon islands, offshore semi-industrial fishing on the oceanic banks along the Mascarene Ridge stretching from St. Brandon to Saya de Malha and around the Chagos Archipelago, and on the high seas targeting migratory tuna stocks. Of late, a semi-industrial fishery targeting pelagic swordfish resources has been active since 1999, and two local vessels recently operated a deep sea demersal trawl fishery in the Southwest Indian Ocean from 2000 to 2006 (Jehangeer, 2006; Anon., 2007a)

In terms of its contribution to GDP and employment (about 10,000 people), fisheries are of limited economic importance to the national economy. However, the lagoon and inshore fisheries are an important source of employment and food security to many coastal communities of Mauritius and on the island of Rodrigues (Hollup, 2000; Vogt, 2001; Sobhee, 2004; Anon., 2007b; Hardman *et al.*, 2007).

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Tourists, partly through their recreational fishing activities, also add to the fishing pressure on marine resources (Paul, 1987; Sobhee, 2006). However, catches of the recreational and small-scale fishing sectors are often underreported in the official statistics and especially for the Western Indian Region (Van der Elst, 2005). The FAO FishStat database, which currently offers time series data on marine fisheries landings from 1950 to the present, is based on national statistical data supplied by its member countries. Therefore, the quality of the FAO data depends on efficiency of statistical collection within these countries. FAO data have been the basis for many influential fisheries studies (Pauly *et al.*, 1998), but they are, in fact incomplete (Zeller *et al.*, 2006). On Mauritius and Rodrigues Islands, the lagoon and non-lagoon areas are exploited by many people from different sectors, who fish for commercial, subsistence and recreational purposes. Most are not professional but amateurs, people in search of a meal or to supplement what is generally a meager income. In addition, both professional and amateur fishers use illegal and destructive fishing techniques, such as fine meshed nets, illegal spearguns, dynamites and chemical agents (Ardill, 1979; Paul, 1987; Hollup, 2000; Sobhee, 2004, 2006). Although such catches are not ignored and have been mentioned in recent and past studies (Paul, 1987; Pearson, 1988), they have never been estimated over a long time period, even though long time series of fisheries catches are necessary to evaluate the ecological effect of fisheries on the marine ecosystems. In this context, the purpose of the present study is to reconstruct the likely total catches of marine resources for the 1950-2008 time period following Zeller *et al.* (2007), to serve as a scientific baseline in the face of climate change and potential threats to food security.

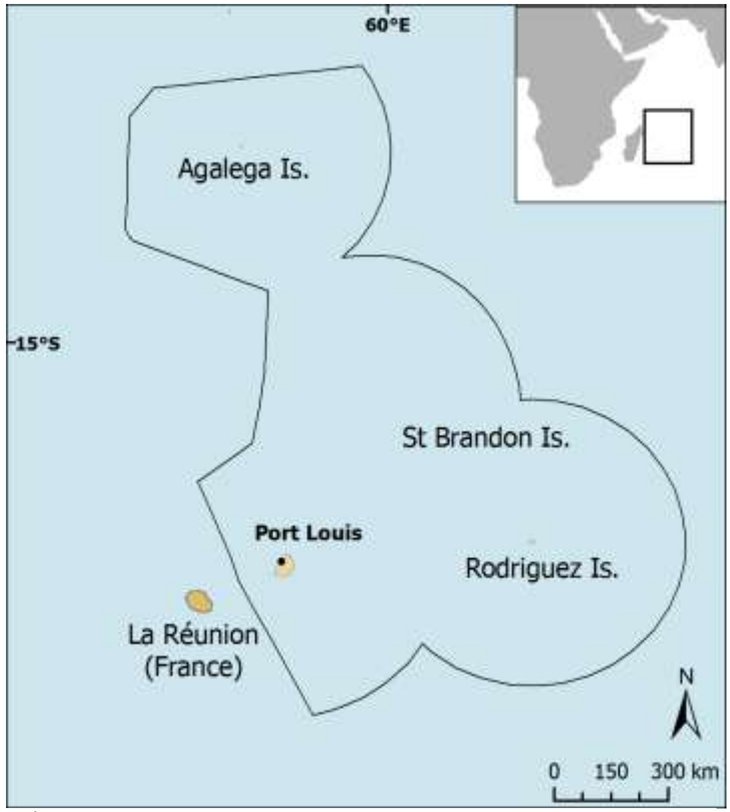

Figure 1. Map of the Mauritius Exclusive Economic Zone which includes Mauritius, Rodrigues, Agalega, and St. Brandon Islands.

METHODS

The existing reported catches were first examined. Such data were extracted from the FAO FishStat database, which currently offers time series data on marine fisheries landings from 1950 to 2008, and from national documents or from the Ministry on behalf of the Albion Fisheries Research Centre. For comparison of pelagic and non-pelagic species catches, we grouped Albacore (*Thunnus alalunga*), Bigeye tuna (*Thunnus obesus*), Black marlin (*Makaira indica*), Indo-Pacific sailfish (*Istiophorus platypterus*), 'Marlins, sailfishes, etc. nei', Striped marlin (*Tetrapturus audax*), Swordfish *(Xiphias gladius)*, 'Tuna-like fishes nei', Skipjack tuna (*Katsuwonus pelamis*) and Yellowfin tuna (*Thunnus albacares*) as 'pelagic species' and the remaining taxa as 'non-pelagic species'. We compared the FAO reported catches with those reported at the national level to identify discrepancies between the two. We then identified the missing components (i.e., sectors, time periods, species, gears) not covered by the existing reported catch time series through literature searches and consultations with local experts. After a search for other available and reliable sources to supply the missing catch data, we developed data anchor points in time for missing data. Time series data were reconstructed using interpolations and extrapolations. Data used to form these anchor points range from fisher and human population data, tourists arrivals, to catch per fisher data.

The marine environment of Mauritius and its outer islands has been exploited since first settlement, but this study is limited to the period of global FAO reporting, i.e., from 1950 onwards. Our reconstruction comprises the following components: a) 'unreported' catches of the small-scale, near-shore fisheries carried out around the islands of Mauritius, Rodrigues and St. Brandon; b) 'recreational' marine catches; c) estimates of the Mauritian banks fishery catches; d) illegal catches taken in the lagoon and non-lagoon waters of Mauritius and Rodrigues islands; and e) 'discards' of the industrial tuna purse-seine fishery. For the purpose of the present study, and according to the data that were available to us, we distinguished between three different categories of local fishers, namely the professional full-time fishers, the part-time professional fishers and the part-time subsistence fishers. Thus, we reconstructed the catches for each of these categories, separating the commercial and subsistence components for each. We reconstructed separately the catches for the different dependencies and fishing areas of the Mauritian state, although FAO data do not distinguish between them.

Human population

Population statistics for Rodrigues and Mauritius Islands were extracted from the Census Statistics Office (CSO) website (www.gov.mu/portal/site/cso) and reports. For years when data were unavailable, population numbers were derived by interpolating linearly between adjacent figures. Thus, a complete time series of the human population was derived from 1950 to 2008 (Figures 2a, b). The numbers of tourist arrivals on Mauritius Island were extracted from several sources (Paul, 1987; Gabbay, 1988; Anon., 2008; Anon., 2009b). Although commercial flights to Mauritius began in 1946, we assumed that tourist's arrivals were zero in 1950. Linear interpolations were used to estimate tourist arrivals for intervening years when no data were available (Figure 2c). While the St. Brandon islands shelter no permanent human population, some 300 people live on the twin islands of Agalega (see below).

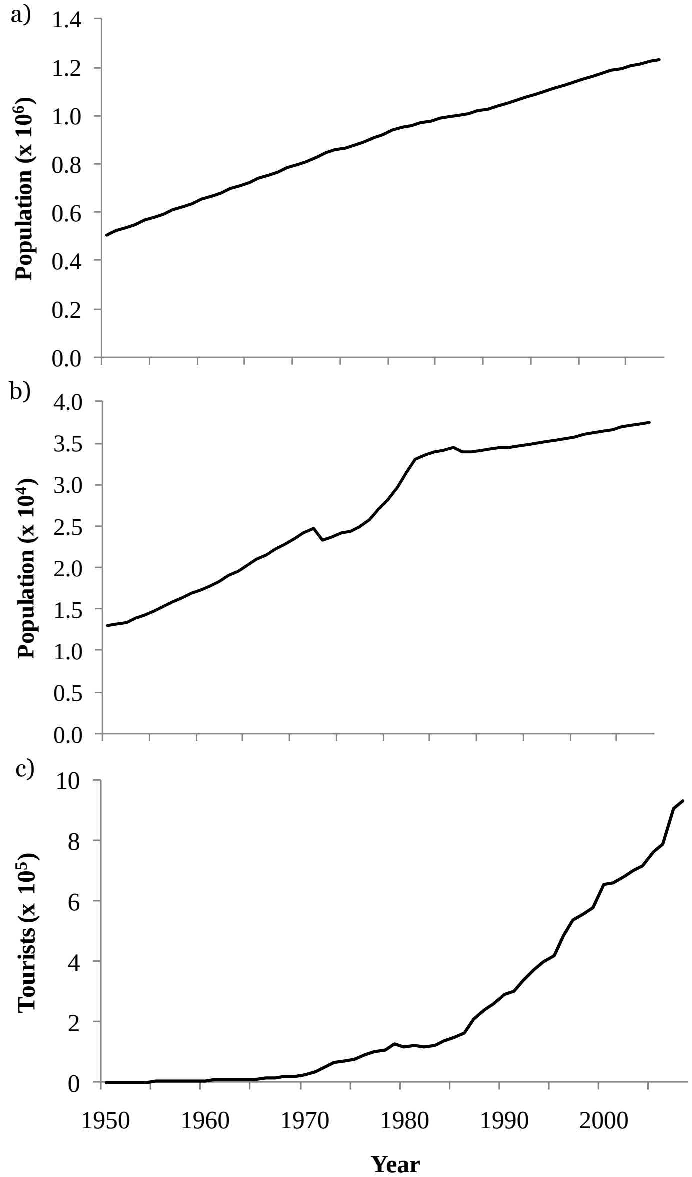

Figure 2. Human population data, 1950-2008 for: a) Mauritius Island; b) Rodrigues Island; and c) Tourist on Mauritius Island.

Mauritius Island small-scale fisheries

Mauritius Island is almost totally surrounded by a fringing coral reef enclosing a lagoon of more than 300 km². Small-scale fishing takes place within the lagoon and non-lagoon areas beyond the reef on the narrow shelf area around the island. Fishers use a wide spectrum of fishing gears which ranges from hand collecting to large nets, gill nets, canard nets, hooks and lines, basket traps and harpoons. To this must be added unreported catches taken by illegal fishing methods such as dynamite and pesticides. The main taxa caught include Serranidae (groupers), Siganidae (rabbitfish), Lethrinidae (emperors), Lutjanidae (snappers), Scaridae (parrotfish), Mullidae (goatfish), Mugilidae (mullets), Acanthuridae (surgeon fish), octopus and lobsters. With the use of hands, sticks and other simple gears, part-time fishers can take small fishes, molluscs, crustaceans and other edible marine species. Many use small cast and mosquito nets to catch large numbers of immature fishes (Paul, 1987).

Professional full-time fishers

Professional full-time commercial catches: On Mauritius Island, artisanal fishery landings have been monitored since 1946 (Ardill, 1979). However, the method employed as well as the managerial efficiency has fluctuated over the years, thus changing the reliability of the reported landings over time. Therefore, in order to provide a more accurate estimate of total artisanal catches, we retained the more reliable estimates, which we used as anchor points for our reconstruction of the artisanal fishers commercial catches. Linear interpolations were used between anchors points to derive a complete catch time series for the artisanal catches from 1950 to 2008.

1950-1958: From 1946 to 1958, officials have added to the "controlled catch" an estimated amount of 560 t for the uncontrolled yield. This quantity included "*(1) an amount of fish artisanal fishermen retained for their own consumption, for their 'curry' or somewhere between 1 and 1.5 kg daily per fisher, (2) some 200 t thought to be landed at some 17 minor but uncontrolled landing stations and, (3) an estimated 50 t taken by sport fishers and countless amateurs*" (Paul, 1987). Therefore, we used the official estimates of total catch presented by Paul (1987), from which we subtracted the official estimated amounts retained by the fishers for their own consumption (310 t) and the official estimated catch of the sport and countless amateur fishers (50 t). These will be considered separately (see below).

1959-1976: Two different samples of catch data were available to us. The first represented the artisanal catches estimated from 1960 to 1970 by multiplying the catches gathered by the Protection Service by the raising factor of 1.7. The second referred to a later method, in which the total catch was estimated from 1960 to 1977 by multiplying the controlled catch by 3.44, a correction factor arbitrarily chosen to bring total yield to 'expected' levels (Ardill, 1979; Paul, 1987). Therefore, and given that the coverage of the landing stations became sporadic after 1967 (Ardill, 1979), we assumed that the earlier estimation method provided the more accurate and conservative estimates of catch from 1960 to 1966 and we retained those estimates as anchor points. For 1974, Moal (1975 in Paul, 1987) reported an estimate of 1,100 t, which was not consistent with our other data, so we assumed that this only represents a fraction of the total catch.

1977-2008: For this time period, we retained the artisanal catches estimated by the Fisheries Division as the more reliable estimates. Indeed, since 1977, a frame survey system for the collection of statistics on fish landings has been operational (Ardill, 1979), and the method was described in the literature (FAO, 1983; 1987; Samboo and Mauree, 1987; Anon., 2007b). Catch and effort data are collected on a monthly basis by a team of enumerators covering randomly selected landing stations divided into several strata, and raising factors are used to estimate catch and effort for each stratum separately. For 1982, Paul (1987) estimated the total catch of the professional artisanal fishers at 1,373 t. However, once the subsistence part of the catch was removed, the remaining amount, namely the commercial catch, was consistent with that reported by the Ministry for the same year. Therefore, landings collected by the Fisheries Division were taken as the best estimates for the artisanal commercial catches for this time period.

To estimate the taxonomic composition of the professional fishers' commercial catches, we used data from Paul (1987) which provided the estimated changes in species composition of total controlled catch from 1957 to 1982 (Table 1).

Table 1. Estimated species composition of total professional full-time fishers' catches on Mauritius Island, based on estimated changes in species composition of total controlled catch (Paul 1987).

Taxon Name	Common Name	1950 - 1957	1958 – 1964[a]	1965 - 1971	1972 - 1981[a]	1982 - 2008[a]
Lethrinidae	Capitaine	3.9	3.4	2.0	2.2	-
Lethrinidae	Dame Berri	5.4	4.4	4.0	3.1	9.9
Lethrinidae	Battardet/Caya	5.3	5.4	3.1	4.4	-
Siganidae	Cordonnier	17.4	17.0	19	10.9	12.8
Mullidae	Rougets	5.2	3.9	4.1	3.1	4.1
Mugilidae	Mulets	4.5	3.3	2.9	4.1	7.9
Serranidae	Vieilles	4.9	5.4	5.2	5.2	7.1
Acanthuridae	Licornes	8.6	8.6	9.6	15.6	7.0
Octopodidae	Octopus	13.2	16.4	17.5	15.8	11.7
Lobsters	Langoustes	1.8	2.1	1.6	0.5	0.3
Miscellaneous	Others	29.8	30.1	31.0	35.1	39.2

[a]Note change in time period coverage.

The 'others' category (Table 1) includes pelagic fishes. In the 1950s, the catch of clupeoids constituted an important seasonal activity of traditional fishers, but catch of those species followed a sharp decline while the catch of scombroid type fishes increased. Capture of sharks also occurred from the 1950s and 1970s, and 74 t of shark was caught in 1963 (Paul, 1987).

Professional full-time subsistence catches: The custom is for professional fishers to keep a small amount of their daily catch for their own consumption (Gonzalez Manero, 1971; Paul, 1987). This amount has been estimated between 1946 and 1958 as part of the uncontrolled landings. However, we assumed that this amount would not have been included in the official reported catches since 1958. The amount retained by fishers is fairly constant, independent of the size or value of the catch (Gameiro, 2003). Therefore, for the 1959-2008 period, rather than using a percentage of the total commercial catch, we used the number of artisanal fishers, an effort of 176 fishing days per artisanal fishers, and the average amount of 1.25 kg retained per fisher per day as reported by Paul (1987). For 1974 and 1982, we used 1,000 and 1,500 professional artisanal fishers, respectively, as reported in Paul (1987), while the number of active professional fishers from 1999 to 2008 were provided by the CSO (Anon., 2009a). For the period 1950-1958, we rely on the description of the uncontrolled catch by Paul (1987), and we concluded that a total standard of 310 t was yearly retained by the artisanal fishers during this time period for subsistence purposes.

We used linear interpolations between the figures reported or calculated as above to establish the subsistence catches of the artisanal fishers from 1950 to 2008.

Professional part-time fishers

In addition to the professional full-time fishers, numerous part-time fishers exploit the lagoon and non-lagoon environment. The common species in their catch are from the families Siganidae (rabbitfish), Serranidae (groupers), Lethrinidae (emperors) and Carangidae (jacks) (Samboo, 1987). A report by Roullot *et al.* (1988) mentioned that part-time fishers also visit Fish Attracting Devices (FADs), catching pelagic fish using trolling and hand lining. From 1977 to 2008, the official reported catches for the so-called 'amateur fishery' consisted of the constant amount of 300 t. In a recent survey, the Ministry of Fisheries on Mauritius found that 23,400 persons were involved in "recreational" fishing in the lagoon of Mauritius, from which about 1,000 were owners of a boat. Indications were that their catch could be more than the current estimate of 300 tonnes annually (Jehangeer, 2006). (Samboo and Mauree, 1987) mentioned that "*the quantities caught by the part-time fishers may exceed the catch by the commercial fishers*". Paul (1987) and Moal (1975 in Paul, 1987) differentiated between two categories of part-time fishers. The first represents people who directly consume as well as sell a part of their catch; the second consists of local people who fish only for their own consumption. For clarity purposes, we will use the terms part-time professional fishers and part-time subsistence fishers for the first and second categories, respectively. Furthermore, in his estimate of catches for the part-time subsistence fishers in 1982, Paul

(1987) included catches from the fishing tourist population, but excluding the pelagic sport fishery catches. However, as we aimed at discriminating between the commercial, subsistence and recreational sectors, we rather included the fishing tourist catches in the recreational catches.

Part-time professional fishers fish for their own consumption and sell the surplus of their catch. However, we assumed that their commercial catches are not included in the recorded commercial landings, for the following reasons. First, they are fishers who generally do not operate through a middleman[2] and many have developed their own sales outlets to commercialize the surplus of their catch (Paul, 1987). There are some indications that many hotels and restaurants which cater to the tourist trade are provisioned directly by contracted fishers, and that their catch escapes detection by the fisheries authorities and are unaccounted for in landings statistics (Paul, 1987; Sobhee, 2004). Moreover, many of them use illegal fishing gear. To respond to an increasing demand for seafood, reduced catches, and new regulations, many amateur fishers have currently resorted to illegal fishing methods, using fine meshed nets, illegal spearguns and landing of undersized fish (Paul, 1987; Hollup, 2000). Therefore, it was assumed that their commercial catches were not included in the reported artisanal catches.

Table 2. Data sources and method used to estimate the part-time professional fishers population of Mauritius Island from 1950 to 2008. These data were converted to percentage of the total population which we used, together with assumptions and the total human population time series, to derive estimates of the part-time professional fishers population from 1950 to 2008.

Year	Number of part-time professional fishers	Human population	Ratio (%)	Source and method
1950	1,566	506,663	0.31	25% decrease in ratio from 1950 to 1974
1974	2,000	857,063	0.23	Moal 1975 (in Paul, 1987)
1982	2,000	960,994	0.21	Paul (1987)
2008	2,562	1,230,995	0.21	1982 ratio maintained unaltered

Professional part-time fishers' population: Paul (1987) and Moal (1975, in Paul, 1987) reported 2,000 part-time professional fishers in 1974 and 1982. We converted these figures to ratios of the total population for the corresponding years. The calculated ratios, together with the total island's population time series and assumptions as described below, were used to derive complete time series estimates of part-time professional fisher population from 1950 to 2008 (Table 2). We assumed that the proportion of the Mauritian population involved in such fishing activities decreased by 25% from 1950 to 1974. A greater proportion of the population likely relied on fishing for food or income purposes in the earlier time period. The progressive diversification of the economy away from sugar cane after independence in 1968 (Paul, 1987; Houbert, 2009), together with new and cheap supply of frozen fish from the offshore banks fishery in the late 1960s (Christy and Greboval, 1985; Ardill, 1986) would have contributed to reduce the need to fish for food or income complement. We also assumed that the same proportion of the population was involved in this activity from 1982 to 2008. This is a conservative estimate when we consider the ever-growing population and worsening poverty in the coastal regions (Sobhee, 2004). A high unemployment rate was also of concern in the 1980s as well as in the more recent period (Paul, 1987; 2010).

Professional part-time fishers' catch rate: According to Moal (1975 in Paul, 1987), 2,000 part-time fishers caught 700 t in 1974. This suggests a catch rate of 0.35 $t \cdot fisher^{-1} \cdot year^{-1}$ in 1974. Paul (1987) presented the change of the average catch rate for an artisanal fisher from 1948 to 1982. From the catches and number of artisanal fishers reported by the CSO (Anon., 2009b), we derived estimates of catch rates for the period 1999-2008. We assumed that the productivity of the part-time fishers would have changed similarly to that of the professional. Indeed, it is very likely that their productivity has declined similarly, as a consequence of increasing numbers of fishers exploiting the same areas. To the reported and calculated catch rates, we applied an exponential model. Using the growth constant of this model and the

[2]On Mauritius, a large number of professional fishers are dependent on middlemen for equipment. Middlemen usually buy the entire catch, and finance the fishers who are then indebted due to these cash advances. Locally named *banyan*, middlemen are usually Muslim traders from the urban areas.

catch rate of 0.35 t·fisher^{-1}·year^{-1} for 1974, we derived estimates for part-time professional fisher's catch rates for the whole time period (Figure 3), declining from 0.56 tonnes·fisher^{-1}·year^{-1} in 1950 to 0.18 tonnes·fisher^{-1}·year^{-1} in 2008.

Finally, using the fisher population and catch rates as estimated above, we derived the catches of the part-time professional fishers from 1950 to 2008.

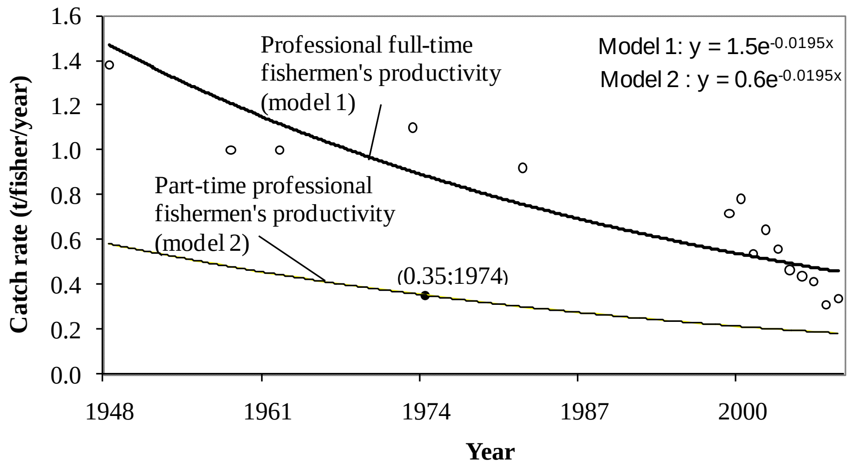

Figure 3. Data points and fitted models used to estimate part-time professional fishers' productivity for Mauritius, 1950-2008. Data points are represented by open circles (for professional full-time fishers) or dark circles (for part-time professional fishers). Data sources: Paul (1987); Moal (1975 in Paul 1987); Anon. (2009a).

Professional part-time fishers' commercial vs. subsistence catches: For 1974, Moal (1975 in Paul, 1987) divided the part-time professional fishers' total catch into subsistence and commercial components, being 29 and 71 percent of the total catch, respectively. We assumed that the subsistence part of the catch was higher in the earlier time period, thus reflecting the increasing development of the tourism industry which likely provided new employment opportunities as well as new sale outlets for the part-time fishers. Also, in the late 1960s, the development of the banks fishery contributed to provide a supply of local frozen fish at relatively low prices (Christy and Greboval, 1985; Ardill, 1986) which would have reduced the need to fish for subsistence by the low income population. Therefore, we inverted those percentages for 1950 so that the subsistence and commercial catches represented 71 and 29 percent of the total part-time professional fishers' catch in 1950, respectively. Linear interpolations were used to estimate the percentages for 1950-1974, while the 1974 percentages was carried unaltered to 2008.

Part-time subsistence (only) fishers

Part-time subsistence fishers fish only for their own consumption. Most of them are coastal residents. This category of fishers likely comprises a substantial proportion of owners of the many houses along the island's shores (Paul, 1987). They usually fish close to shore with rod and reel or as a group on a boat.

Part-time subsistence fishers' population: In 1982, a sample survey of the entire coast indicated that about 10,000 people were fishing only for their own consumption (Paul, 1987). This amount was taken as a percentage of the total human population of Mauritius Island for the same year and came to about 1 percent. Moal (1975 in Paul, 1987) reported a larger estimate of 65,000 people or 7.6 percent of the island's population. However, Moal's estimate was considered unreliable. Indeed, to obtain this figure, Moal (1975 in Paul, 1987) simply added the coastal population based on the 1972 census and subtracted the estimated size of the vegetarian and artisanal fishing population. Therefore, we retained the one percent figure as the more conservative estimate. However, while we applied this percentage for 1982-2008, we assumed that it would have decreased from 1950 to 1982, similarly to that of the part time professional fishers, where the percentage of the number of part-time professional fishers to the total population declined from 0.31 to 0.21 percent from 1950 to 1982. This proportional decline of 67 percent was then applied to the reported 1 percent figure for 1982 back to 1950, so that the percentage of local people fishing only for their subsistence declined from an assumed 1.55 percent in 1950 to a reported 1 percent in 1982. Linear interpolations were used to estimate the percentages in the intervening years.

Using the human population data for Mauritius Island, we derived the number of local people fishing only for their own consumption for each year from 1950 to 2008.

Part-time subsistence fishers' catch rates: For 1982, Paul (1987) estimated the catch rate of a local part time subsistence fisher at 10 kg·fisher^{-1}·year^{-1}. We maintained this catch rate unaltered from 1982 to 2008. However, we assumed that it would have been decreasing since 1950. From our precedent calculations, we derived that the part-time professional fishers' catch rate declined from 0.56 to 0.30 t per fisher per year from 1950 to 1982. This proportional declined of about 54 percent was then applied to the reported rate of 10 kg per fisher per year for 1982 back to 1950, so that the catch rate of the local people fishing for their subsistence declined from an assumed 18.7 kg·fisher^{-1}·year^{-1} in 1950 to a reported rate in 1982 of 10 kg·fisher^{-1}·year^{-1}. Linear interpolations were used to estimate the catch rates in the intervening years. Using the fisher population as estimated above, these derived annual catch rates were expanded to determine the part time subsistence fishers' catches from 1950 to 2008.

<u>Other unreported catches</u>

Catches taken by illegal methods are common on Mauritius Island and are largely unreported (Ardill, 1979; Paul, 1987; Hollup, 2000; Sobhee, 2004). Ardill (1979) mentioned that sampled landings, aside from ignoring part-time fishers' catches, also excluded estimates of catch taken in illegal nets and by dynamite fishing, which are landed all along the coast. Other illegal and destructives fishing practices include fine meshed nets, illegal spearguns, night fishing, capture and landing of undersized fish, and pesticides. These practices involve both part- and full-time fishers, and have been rising due to the dwindling resources, reduced catches and new regulations (Hollup, 2000; Sobhee, 2004). In the absence of quantitative information specific to Mauritius Island, we relied on the knowledge acquired for Rodrigues (see below). We assumed that these illegal fishing methods evolved similarly on the two islands, and therefore used the same method as we did for Rodrigues to estimate this component of the unreported catch. Although underwater fishing was forbidden in 1982 in Mauritius, this practice is still used today (90 interventions occurs in 2006). Underwater fishers are also said to be responsible for the use of dynamite and anesthetics, and fishing at night (Paul, 1987). Estimated catches ranged from 150 t in 1974 (1975 in Paul, 1987) to 397 t in 1982 (Paul, 1987), but we assumed that such catches were included in our estimates of unreported catches.

Rodrigues Island small-scale fisheries

Rodrigues Island (19°43'S-63°25'E, 110 km², 37,500 inhabitants) is located some 586 km northeast of Mauritius and it is a semi-autonomous island since 2001. Unemployment, poverty and illiteracy are high compared to the main island of Mauritius, and tourism is in its infancy. As a consequence, the lagoon fisheries are very important to Rodrigues, but they are currently severely overexploited (Blais *et al.*, 2007). The island is surrounded by 90 km of fringing coral reef, enclosing a shallow lagoon of 240 km². Small-scale fishing takes place within and outside the lagoon, with the use of seine nets, hand-lines, basket traps and spears or harpoons for octopus and large fish.

<u>Professional fishers</u>

Professional commercial fishers: Total catches reported by the FAO on behalf of the Ministry do not distinguish between Mauritius and its outer dependencies. Nevertheless, comparison of the FAO data with other reports (Fisheries Division annual reports, 2003-2007; Harris, 1988) indicated that from 1977 to 2000, artisanal catches for Rodrigues have been estimated between 1,200 and 1,500 t annually. In Rodrigues, monitoring of artisanal catches started in 1994 (Reshad Jhangeer-Khan, Shoals Rodrigues, pers. comm.). Broad catch and effort data are collected at fish landing stations around the island on a regular basis by the Fisheries Research and Training Unit (FRTU), collated annually and transmitted to the Albion Fisheries Research Centre (Anon., 2007b)(E. Hardman, Shoals Rodrigues, pers. comm.). For the period 1994-2008, we obtained sampled catch data from the CSO annual digests of statistics on Rodrigues and from Dr Emily Hardman (for the octopus and lagoon fish catches reported by the CSO from 1994 to 2006). However, these reported catches refer to the registered fishers catches, and do not include unofficial catches landed by the amateurs and illegal catches (Anon., 2009c) (Dr Emily Hardman, Shoals Rodrigues 2005-2008, pers. comm.; Reshad Jhangeer-Khan, Shoals Rodrigues, pers. comm.), and we retained those sampled catches as anchor points for the professional fishers' catches. For the earlier period, professional fishers' catches were compiled from various sources, using the more reliable estimates as anchor points. For 1955, 1962 and 1968, catches reported by Pearson (1988) were equivalent to the export data. Therefore, those amounts were only used as minimum. We interpolated linearly between our anchors points, in order to estimate the professional fishers' catches for the whole time period.

Taxonomic breakdown: In order to determine the taxonomic composition of the artisanal commercial catches taken on Rodrigues Island, we used data from the Fisheries Research and Training Unit (FRTU) (unpublished data) and Central Statistics Office reports. The FRTU data provided the species composition of the seine net fishery for the years 1994 to 1999, and 2004 to 2006. We interpolated linearly between the 1999 and 2004 available figures to estimate the species composition of the seine net fishery for the period 2000-2003, while the 2006 figures were maintained unaltered until 2008. For the period 1994-2008, CSO data provided the total controlled catch on Rodrigues, discriminated by type of fishery, namely the octopus, lagoon and non-lagoon fisheries. This allowed us to calculate their respective contributions as percentages of the total controlled catch from 1994 to 2008. Similarly, for the period 1994-2006, FRTU data provided the seine net controlled catch, which we converted into percentage of the total controlled catch on Rodrigues. The calculated percentage for 2006 has been carried forward to 2008. Thus, knowing the respective contribution of the seine net, octopus, lagoon (other than seine net) and non-lagoon fisheries, we adjusted the FRTU data on the seine net species composition to estimate a breakdown of the total artisanal commercial catch on Rodrigues for the period 1994-2008 (Table 3). Furthermore, Sauer *et al.* (2011) indicate that the octopus fishery on Rodrigues is dominated by *Octupus cyanea* with the remaining catch being mainly *O. vulgaris*. The catches presented in Sauer *et al.* (2011) correspond to the CSO data for octopus.

Professional fishers' subsistence catches: Registered fishers will also keep some of the fish and octopus that they catch for their own consumption (Dr Emily Hardman, Shoals Rodrigues, pers. comm.). Therefore, these retained amounts were estimated and added to our total subsistence catches. We used the estimate of 1.25 kg of fish retained by each fisher per fishing day, which we multiplied with Paul's estimate of 176 fishing days for the professional fishers to obtain a catch rate of 0.22 $t \cdot fisher^{-1} \cdot year^{-1}$. This number of fishing days was consistent with these reported by (Pearson, 1988). Indeed, for 1987, he mentioned that the number of fishing days for the trap and handline fisheries rose to about 290 and 238 days, respectively, while that of the seine-net fishery fell from about 200 days in the earlier time period to 163 in 1987, due to regulations being implemented for this fishery. The professional fishers' population was reconstructed using various sources (Gonzalez Manero, 1971; Moal, 1971 in Paul 1987; Ardill, 1979; Paul, 1987; Pearson, 1988; Anon., 2010). Finally, the 0.22 $t \cdot fisher^{-1} \cdot year^{-1}$ catch rate estimate as calculated above, together with the artisanal fisher population data, were used to derive the subsistence catches amounts for the whole time period.

<u>Part-time fishers</u>

Fishing by part-time fishers, mainly for subsistence, on Rodrigues Island is unmonitored, although it is likely to be considerable, and it currently includes in and off-lagoon fin fishing using lines and traps, in-lagoon octopus fishing and shell fishing (Reshad Jhangeer-Khan, Shoals Rodrigues, pers. comm.). In addition to the registered fishers, there are many part-time fishers (Gonzalez Manero, 1971; FAO, 1983; Paul, 1987; Anon., 2009c). Some of them are regular fishers who fish to feed their family or to sell, while others have a full-time job and fish for pleasure and their own consumption (Dr Emily Hardman, Shoals Rodrigues, pers. comm.). Therefore, their catches likely comprise commercial as well as subsistence components. However, catches of the part-time fishers were assumed to be mostly of subsistence purpose. In order to estimate these catches, we first assessed the annual number of part-time fishers, then we estimated the catch rates of those fishers, based on Pearson (1988).

Table 3. Estimated taxonomic composition of the total small-scale commercial catch for Rodrigues Island. Sources: Fisheries Research and Training Unit (FRTU) (unpublished data), Anon (2009a), Central Statistics Office of Mauritius.

			Portion of total catch (%)														
Fishery	**Common name**	**Taxon**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Seine net	Rabbitfish	*Siganus* spp.	1.7	1.1	1.5	1.9	2.6	2.1	2.6	2.8	4.7	3.4	4.8	3.2	5.0	5.0	5.0
	Spangled emperor	*Lethrinus nebulosus*	2.1	1.1	1.3	1.1	1.0	0.2	0.6	1.0	2.3	2.1	3.8	4.1	3.3	3.3	3.3
	Unicornfish	*Naso* spp.	1.6	0.9	1.6	1.0	1.1	0.4	0.9	1.3	3.0	2.8	4.9	2.4	4.1	4.1	4.1
	Mullet	Mugilidae	2.2	3.3	1.6	1.5	1.9	2.7	2.9	2.8	4.1	2.5	2.9	1.8	2.7	2.7	2.7
	Trevally/jacks	Carangidae	1.8	2.2	1.0	1.6	1.0	1.0	1.1	1.1	1.6	1.0	1.3	1.1	1.3	1.3	1.3
	Strongspine silver-biddy	*Gerres longirostris*	1.8	1.1	0.8	0.5	0.3	1.2	1.3	1.3	2.0	1.3	1.7	1.4	2.1	2.1	2.1
	Goatfish	Mullidae	1.0	1.7	1.0	0.7	0.4	1.3	1.4	1.4	2.2	1.4	1.7	1.7	3.2	3.2	3.2
	Parrotfish	Scaridae	0.9	0.2	0.5	0.3	0.2	0.1	0.2	0.2	0.4	0.3	0.5	0.6	0.9	0.9	0.9
	Blackspot emperor	*Lethrinus harak*	0.8	0.4	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	Yellowfin bream	*Rhabdosargus sarba*	0.9	0.2	0.5	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Rudderfish	*Kyphosus* spp.	0.8	0.5	0.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Milkfish	*Chanos chanos*	0.8	0.7	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
	Striped threadfin	*Polydactylus plebeius*	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Others	Misc. marine fishes	0.6	0.6	0.9	0.4	0.2	0.0	0.1	0.3	0.8	0.8	1.4	1.7	2.2	2.2	2.2
Octopus	Octopus	*Octupus* spp.[b]	51.1	51.1	42.4	44.7	31.9	23.7	23.6	17.0	27.3	34.7	26.9	27.4	25.0	16.7	16.0
Other	Lagoon fishes	Lagoon fishes	31.0	34.0	43.0	45.0	48.0	53.0	50.0	46.0	39.0	41.0	46.0	36.0	35.0	33.0	36.0
	Non-lagoon fishes	Pelagic and non-pelagic species[a]	1.0	1.0	2.0	-	11.0	15.0	15.0	25.0	13.0	9.0	4.0	18.0	15.0	25.0	23.0

[a]including Serranidae, Lethrinidae, Lutjanidae, Acanthuridae, Labridae, sharks and pelagic species such as small tunas or barracudas (from Rodrigues' Offshore Cooperative Society Landings, 1982-1983, in Paul, 1987); [b] *Octopus* spp. caught were *O. cyanea* (80%) and *O. vulgaris* (20%) based on Sauer *et al.*(2011).

Part-time fishers' population: 1950-1979: We used the estimate of 7,000 part-time fishers given by (Ardill, 1979). This represented about 26% of the island population in 1979. We assumed that this percentage would also apply to the years before 1979, as most of Rodriguan people likely relied on subsistence fishing and agriculture at this time, and thus we maintained this percentage unaltered from 1950 to 1979.

1980-2008: For 1987, Pearson (1988) estimated that 10 percent of the population practiced occasional line-fishing (or about 4,000 Rodriguans). However, it is very likely that part-time fishers also used other gears such as traps and harpoons to catch fish and octopus and so that their population was underestimated by Pearson (1988). A more recent estimate consisted of 2,000 part-time fishers in 2008 (Blais *et al.*, 2007) or about 5% of the island's population. However, some believe that more than twice the number of full-time professional fishers are engaged in part-time fishing activities (Anon., 2009c), which would give an estimate of more than 3,500 people. To remain conservative, we retained the estimate of 2,000 part-time fishers provided by Blais *et al.* (2007) and we interpolated linearly between the percentages of the total population in 1979 (26%) and 2008 (5%). Using the total island's population, we estimated the number of part-time fishers on Rodrigues Island from 1982 to 2008 (Table 4).

Table 4. Data sources and method used to estimate the population of part-time fishers for Rodrigues Island from 1950 to 2008.

Year	Number of part-time fishers	Human population	Ratio (%)	Sources and method
1950	3,353	12,971	25.8	1979 ratio maintained
1979	7,000	27,081	25.8	Moal (in Paul, 1987)
2008	2,000	37,570	5.3	Blais *et al.* (2007)

Part-time fisher's catch rates: 1987-2008: We used the catch rate of 0.1 t·fisher^{-1}·year^{-1} estimated by Pearson (1988). We maintained this catch rate unaltered for the period 1987-2008, assuming that the productivity of the part-time fishers would not have changed during the last two decades. This is likely to be a conservative estimate, as Pearson's catch rate estimate for 1987 referred to line-fishing, while subsistence fishers also use traps and fish octopus inside the lagoon (Reshad Jhangeer-Khan, Shoals Rodrigues, pers. comm.).

1950-1986: Over-fishing in Rodrigues may date from the 1800s (Bunce *et al.*, 2008). The island has been affected by intensive land erosion and its heavy impact on the lagoonal fauna has been reported as early as 1962 (Baissac, 1962 in Paul, 1987). It has also been illustrated by a sharp downfall in exports to Mauritius since the 1970s (Paul, 1987; Pearson, 1988; Bunce *et al.*, 2008). Therefore, we assumed that the average productivity of the part-time fishers declined from 1950 to 1986 by a half, so that in 1950 it was equal to 0.2 tonnes·fisher^{-1}·year^{-1}. Therefore, we applied a catch rate of 0.2 t·fisher^{-1}·year^{-1} for 1950-1987 and 0.1 t·fisher^{-1}·year^{-1} for 1986-2008.

Other unreported catches

Additional catches taken in reserves, during the closed seasons (implemented for the seine net and sea cucumber fisheries) and using illegal gears such as undersized seine net mesh sizes, spearguns to catch octopus were unreported (Anon., 2009c) (Dr Emily Hardman, Shoals Rodrigues, pers. comm.; Reshad Jhangeer Khan, Shoals Rodrigues, pers. comm.). These catches are either consumed by the fishers themselves or sold - on the beach or directly to the markets (Reshad Jhangeer Khan, Shoals Rodrigues, pers. comm.). To estimate these unreported catches we assumed that illegal gears were not used prior to the 1960s (Reshad Jhangeer Khan, Shoals Rodrigues, pers. comm.). For 1987, Pearson (1988) estimated that 150 illegal nets may have been operating within the lagoon. Pearson (1988) conservatively estimated unreported catches taken by illegal methods amounted to 10% of total legal landings in the lagoon. In contrast, these catches may be equal to or greater than legal landings (Reshad Jhangeer Khan, Shoals Rodrigues, pers. comm.). To remain conservative, and to take into account the fact that illegal fishing practices are used by both part-time and full-time fishers, we assumed that most of this catch would be included in our total reconstructed catch from the small-scale fishery carried out around the islands. Therefore, for the 1987-2008 period, we estimated additional unreported catches in the coastal waters of Rodrigues island as 10% of our total reconstructed small-scale fisheries catches, including both professional and part-time fishers' catches. Finally, we interpolated linearly between zero catch in 1960 and our first calculated value for 1987.

Recreational fisheries

Mauritius is well-known as a tourist destination. While it creates job opportunities for the local population, it also represents a potential threat to marine life (Paul, 1987; Sobhee, 2004). In Mauritius, the recreational fishery can be divided into two components, namely the extraction of marine resources for leisure purposes inside or close to the lagoon environment, and the pelagic sport fishery, which operates with boats in deeper waters. We estimated these catches separately.

Pelagic sport fishery

Mauritius is a popular destination for big game sport fishers. A number of leisure and sports fishers operate successfully around FADs (Roullot *et al.*, 1988; Venkatasami and Sheik Mamode, 1995). For this activity, a number of lines are used with rods and outriggers baited for the large migratory carnivorous species. The catch comprises mainly blue marlin (*Makaira mazara*), black marlin (*Makaira indica*), Indo-Pacific sailfish (*Istiophorus platypterus*), striped marlin (*Tetrapturus audax*) and yellowfin tuna (*Thunnus albacares*), albacore (*Thunnus alalunga*) and bigeye tuna (*Thunnus obesus*). Other species like wahoo (*Acanthocybium solandri*), shortbill spearfish (*Tetrapturus augustirostris*), skipjack tuna (*Katsuwonus pelamis*) – used as bait for marlins, sharks (*Sphyrna zygaena*, *Isurus oxyrinchus*, *Carcharinus albimarginatus*, *Carcharinus melanopterus*) and dolphinfishes (*Coryphaena hippurus*) are also caught (Cayre and Stequert, 1988; Norungee *et al.*, 2004; Jehangeer, 2006). Recently, a system of data collection has been set up at the Albion Fisheries Research Centre (Norungee *et al.*, 2004). However, examination of the Ministry reports showed that the currently reported sport pelagic catches consist of the constant amounts of 400 t from 1977 to 1987 and 650 t from 1988 to 2008. Such amounts do not reflect the increasing trend of the tourist population that reaches the island each year. Thus, catches from the sport fishery were re-estimated. We first extracted catch estimates for the sport fishery from other reliable sources. For each reported value, we calculated a per tourist rate using the time series of number of tourists arrivals. Sport fishery likely already existed in 1950. According to Paul (1987), the sum of the countless amateurs and sport fishermen catches were estimated at 50 t by the officials from 1946 to 1958. However, to remain conservative (and in the absence of more detailed information), we assumed that the pelagic sport fishery catches were null in 1950. For the period 1950-1987, we interpolated linearly between the per tourist rates. Between 1974 and 1988, the calculated per tourist rates declines from 2.9 to 2 kg per tourist arrival. In order to reflect the decreasing catches of pelagic species since the 1990s, we carried this decreasing trend forward from the 1988 catch rate figure to derive the catch rates for the 1988-2008 period. Pelagic sport catches were finally deduced by multiplying the catch rates as estimated above by the number of tourist arrivals.

Recreational catches in the lagoon

In addition to the tourists involved in big game fishing, a substantial part of the tourist population is involved in recreational fishing in the lagoon of Mauritius. For 1982, Paul (1987) assumed that a conservative estimate of the total number of fishing tourists involved in the exploitation of the island's waters would be approximately 20,000 people, or about 17% of the tourist arrivals during the year. We assumed that the number of fishing tourists was proportional to the tourist arrivals, and we carried the 17 percent figures for the whole time period. Thus, using the number of tourist's arrivals time series, we established the number of fishing tourists from 1950 to 2008. For 1982, Paul (1987) estimated the catch rate of a fishing tourist at 5 $kg \cdot tourist^{-1} \cdot year^{-1}$. We assumed that this catch rate would not have changed from 1950 to 1982, but that the increasing degradation of marine resources of the island, together with an increasing number of people fishing in the lagoon area, would have caused the tourist's catch rates to decrease from 1982 to 2008. Therefore, we used the proportional decline of 60% between the part time professional fishers catch rates of 1982 and 2008, so that the tourist catch rates decreased from a reported

5 kg·tourist^{-1}·year^{-1} in 1982 to an assumed 3 kg·tourist^{-1}·year^{-1} in 2008. We then established the catches using the fishing tourist population time series.

Agalega Islands

The twin islands of Agalega are located some 982 km north of Mauritius between 10°28'S and 56°40'E. The islands are of coralline origin and cover a total land area of 70 square kilometers. Colonization took place in the early part of the 18th century and fishing was the mainstay of the settlement's diet (Paul, 1987). Since then, the exploitation of the coconut trees for copra production began, and it is still the main economic activity. Fish production being very limited due to the steep drop-off outside the reef, is only sufficient for consumption of the local workers. The current reported catches for Agalega consist of the constant amount of 30 t from 1977 to 2008. To arrive at these figures, it has been assumed that the *per capita* consumption of fish was 100 kg·person^{-1}·year^{-1}, giving an annual catch of 30 tonnes for a population of 300. The species composition of the catches is believed to be similar to that of Mauritius Island but this remains to be examined (FAO, 1983). As the population did not change much over the 1950-2008 period (Paul, 1987; Anon., 2006, Anon., 2010) and in the absence of contradictory information, we assumed that the current reported amount was accurate and we carried it back unaltered to 1950.

Table 5. Estimated taxonomic breakdown of the Mauritian banks handline fishery catches on the Nazareth, Saya de Malha, St Brandon and Chagos banks modified from Samboo 1989 (in Mees, 1996). In the Chagos, although it is avoided due to the potential of ciguatera, the red snapper *Lutjanus bohar* can represent up to 50 percent of the catch.

Taxon	Nazareth & Saya de Malha	St Brandon	Chagos
Lethrinus mahsena	88.00	84.0	50
other Lethrinidae	2.00	2.0	2
Serranidae	4.00	1.5	26
Carangidae	2.00	2.0	4
Aprion virescens (Lutjanidae)	1.00	-	6
Siganidae	-	2.5	-
Scaridae	-	2.0	-
Mugilidae	-	0.5	-
Naso spp. (Acanthuridae)	-	0.5	-
Lutjanus bohar (Lutjanidae)	0.75	-	(50)
Pristipomoides spp. (Lutjaidae)	0.75	-	10
Tuna	0.75	-	2
Others	0.75	5.0	-

The Mauritian Banks fishery

An important Mauritian fishery occurs on the shallow oceanic banks of the Mascarene Ridge. In addition to the banks located within Mauritius EEZ, the Mauritian fishing fleet fishes on the Saya de Malha bank (much of which is in international waters), and exercises traditional fishing rights within the EEZ of the British Indian Territory (BIOT, Chagos Archipelago). Since the 18th century, fishing on these grounds has been carried out by vessels engaged in inter-island trade, but it was not before the twentieth century that more systematic exploitation began when the Mauritius Fishing Development Company and its sister company the Raphael Fishing Company Limited gained control of the St. Brandon group. In the earlier years, the demersal stocks were exploited mainly for salting purposes, but since the Wheeler and Ommaney (1948-49) pioneer survey, these banks have gradually started to be the main suppliers of frozen fish to Mauritius (FAO, 1983; Ardill, 1986). Fishing on the banks is practiced using handlines from 7-8 m dories carried by refrigerated mother-vessels, 20-60m in length. The main targeted species is Dame Berri (*Lethrinus mahsena*) which contributes about 80% of the total catch, while the remainder of the catch is made up of serranids, lutjanids, siganids, and carangids. The catch is mostly gilled, gutted and frozen on board. In St. Brandon, however, temporary settlements of fishers continue to fish in the lagoon using seine nets and basket traps while the mother ships are away. Their catches are salted and dried while awaiting shipping to Mauritius (Moal, 1971 in Paul 1987; Samboo and Mauree, 1987). Also, 17 vessels are allowed to operate a semi-industrial chilled fishery on the Soudan, Albatross, St Brandon, Hawkins, Saya de Malha and Nazareth Banks. Their catch is either frozen or chilled at sea and comprises mainly emperors, snappers, groupers and tunas. Catch data for the banks fishery were obtained from the Ministry on behalf of the Albion Fisheries Research Centre (AFRC). However, such data only covered the

1977-2008 period. When compared to other sources, it also appeared that they represented landings in frozen weight, and for the greatest part of the time period, catches of salted-dried fish from St. Brandon were not included. Therefore, in order to assemble the most accurate estimates for the total banks fishery catches, we used data of the Ministry converted to wet weight, complemented or adjusted with data extracted from other reliable sources to supply the missing years and areas (Gonzalez Manero, 1971; Moal, 1971 in Paul 1987; Ardill, 1979; Paul, 1987; Samboo and Mauree, 1987; Mees, 1996; Anon., 2009a). Conversion factors of 1.2 and 2 were used to convert the frozen weight and salted-dried weight respectively, to wet weight as reported in Paul (1987), Gonzalez Manero (1971) and in the Conversion Factors FAO software. Although the Chagos Archipelago is part of the British Indian Ocean Territory (BIOT), we included catches from the Chagos' EEZ by the Mauritian fleet in our reconstruction of the banks fishery catches.

Table 6. Estimated taxonomic breakdown of the salted-dried fish catches taken in the St Brandon lagoon (Anon., 1971; 2009a).

Family or group	Taxon name	Common name	Catch (%)
Lethrinidae	*Lethrinus mahsena*	Dame Berri	75.0
Lethrinidae	*Lethrinus nebulosus*	Capitaine Gueule Longue	10.0
Siganidae	*Siganus* spp.	Cordonnier	2.5
Acanthuridae	*Naso* spp.	Licorne	2.5
Scaridae	*Callydon* spp.	Cateau	2.5
Serranidae	*Epinephelus* spp.	Vieilles/Babones	5.0
Octopus	-	-	2.0
Lobster	-	-	0.5

The estimated species composition of the Mauritian banks fishery catches was based on a report by Samboo (1989 in Mees, 1996) for the Nazareth, Saya de Malha, St Brandon, Albatross and Chagos banks (Table 5), while the taxonomic breakdown of the St Brandon salt and dried fish, octopus and lobsters catches was based on Gonzalez Manero (1971) and Anon. (2009a; Table 6).

Mauritian purse seine fishery

Large-scale commercial purse seining was introduced in the Indian Ocean in 1979 as a Mauritian and Japanese joint venture, using a traditional Japanese technique of fishing schools of tuna associated with logs, developed in the Pacific Ocean. The reported landings from Mauritian purse seiners reached a peak of over 10,000 t in 1991. Since then, there has been a gradual decline of this fishery until 2001 when production dropped to zero, as all the seiners left the fishery (Jehangeer, 2006). Catch data for the Mauritian purse seiners were provided by the Indian Ocean Tuna Commission (IOTC). Amande *et al.* (2008) provided estimates of tuna discards and bycatch by large groups of species of the European purse seiners operating in the Indian Ocean for the 2003-2007 period. Discards and bycatch were presented as tuna production ratios, for three different fishing methods. As the Mauritian purse seiners operated exclusively on artificial logs (Norungee and Lim Shung, 1995), we used the discards and bycatch ratios corresponding to the FAD-associated fishing mode. To estimate discard rates for each group of species, we multiplied the percentage of bycatch to tuna production by the percentage of discarded bycatch (Table 7). As no indications were provided regarding the amount of discarded bycatch for shark, and to remain conservative, we assumed that sharks species were accounted for in the landings and thus we did not

Table 7. Data and methods used for estimating discards of the Mauritian tuna purse seine fishery from 1979 to 2000. To calculate the discard rate (ratio to tuna production) for the bycatch species, we converted the bycatch rate expressed in tuna production ratio into a percentage, which we multiplied by the reported percentage of discarded bycatch specific to each species group (except sharks). Source: Amande *et al.* (2008).

Species or group	Bycatch/tuna production (t/1000 t)	Discarded bycatch (%)	Discard rate (%)
Tuna nei	26.5	100	2.65
MMF[a]	19.7	80	1.58
Sharks	6.0	-	0.00
Billfishes	0.7	65	0.05
Rays	0.2	100	0.02

[a] MMF = miscellaneous marine fishes

include them in our discard estimates. Through this method, our total estimated discards for the Mauritian tuna purse seiner was consistent with the discard rate of 5% reported by Kelleher (2005).

Shark fishery

Shark catches were presented by the FAO for the years 1977-2008. A review of the independent literature found no information regarding a shark fishery in Mauritius. These might have been incidental catches associated with the longline fishery, but which do not appear in the IOTC data. However, we accept the FAO landings data for the 'sharks, skates and rays' category as it is presented in FAO FishStat and add it to the industrial component of our total reconstructed catch.

Sea cucumber fishery

On Mauritius, the commercial exploitation of sea cucumbers started on a trial basis in late 2005 (Conand, 2008) and around 2006 on Rodrigues (Dr Emily Hardman, Shoals Rodrigues, pers. comm.). Species harvested are *Actinopyga echinites* (brownfish), *A. mauritiana* (surf redfish), *Bohadschia marmorata* (brown sandfish), *Stichopus chloronatus* (green fish), *S. variegatus* (curry fish), *Holothuria scabra* (sandfish), *H. nobilis* (black teatfish) and *Holothuria* spp. (Anon., 2009d). Although fishers regularly collect sea cucumbers in Mauritius Island mainly for domestic consumption (Laxminarayana, 2005), the harvesting is done by a limited section of the Mauritian population – mainly local Chinese people – and those catches were thus thought to be negligible (Chantal Conand, pers. comm.). Current management measures of the commercial sea cucumber fishery include collection restrictions, both spatial and temporal, and size limits (Anon., 2007a) (Dr Emily Hardman, Shoals Rodrigues, pers. comm.) although illegal fishing continues to occur in the closed season on Rodrigues (Dr Emily Hardman, Shoals Rodrigues, pers. comm.). We accepted the sea cucumber landings data presented by FAO on behalf of Mauritius, although it likely that this is an underestimate of actual catches.

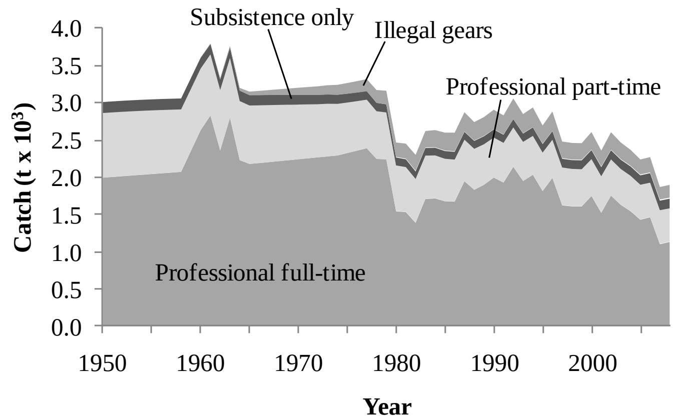

Figure 4. Reconstructed small-scale fisheries catches for Mauritius Island. Professional full- and part-time catches include both artisanal and subsistence components.

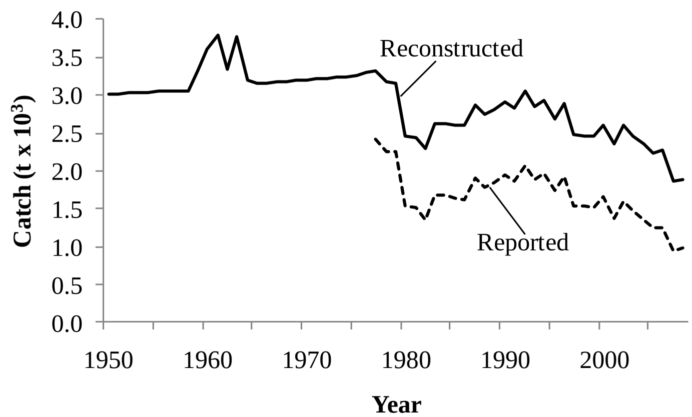

Figure 5. Reconstructed small-scale fisheries catches for Mauritius Island compared to reported national landings data.

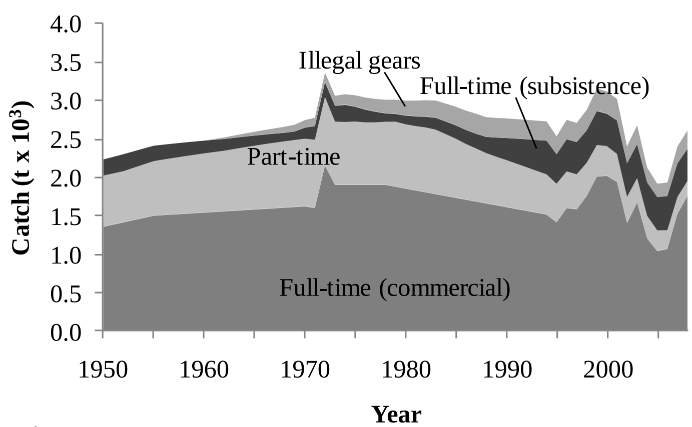

Figure 6. Reconstructed small-scale fisheries catches for Rodrigues Island, with commercial and subsistence catches taken by full-time fishers, catches taken by part-time fishers whose catch is for subsistence purposes only and unreported catch from illegal gears.

Results

Total reported landings by the FAO from 1977 to 2008 followed the same pattern as those of the Ministry reports, implying a good data transfer mechanism between the Mauritius national level and FAO. The same conclusion was drawn from the comparison of the non-pelagic reported catches from both sources. The catch rate data combined with the fisher population data yielded the reconstructed small-scale catches for 1950-2008, which are presented here for Mauritius and Rodrigues Island. Also represented are estimated catches for the recreational sector including both pelagic and lagoon fisheries, the Banks fishery, and tuna catches and associated discards from the purse seine fishery. Finally, we compare our total reconstructed catch estimate for the Republic of Mauritius for 1950-2008 to total marine landings presented by the FAO on behalf of Mauritius.

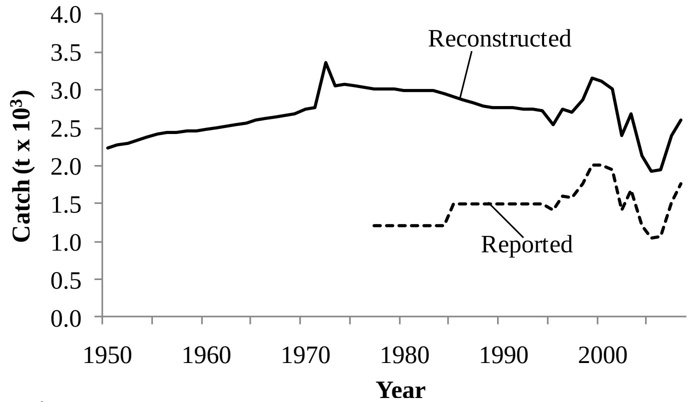

Figure 7. Total reconstructed catch for the small-scale fisheries of Rodrigues Island, 1950-2008 compared to the nationally reported landings, which start in 1977.

Mauritius Island

Reconstructed small-scale fisheries catches for Mauritius Island, including catches by professional full-time and part-time fishers, part-time subsistence (only) fishers and unreported catches taken by illegal gears and methods was estimated to be 170,825 tonnes over the 1950-2008 time period (Figure 4). Unreported catch taken by illegal gears and methods represented approximately 8,500 t over the period 1960-2008 (Figure 4). For the 1977-2008 period, our total reconstructed catches for the small-scale sector are about 1.6 times greater than nationally reported landings (Figure 5). Catches by part-time fishers' (professional and subsistence only) made up a substantial part of the reconstructed catch representing, for the whole time period, 27% of our total reconstructed catches for the small-scale sector on Mauritius Island.

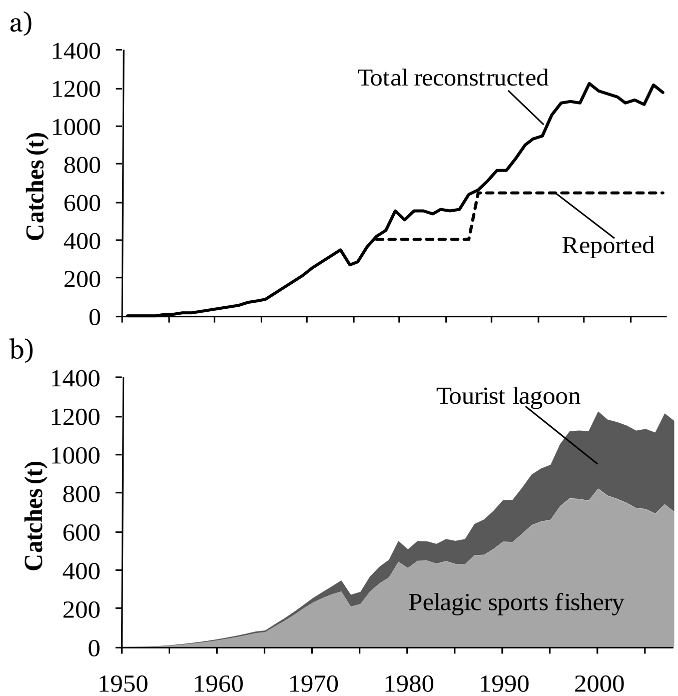

Figure 8. a) Reported and total reconstructed recreational catches for Mauritius state 1950-2008; b) Components of total recreational catch.

The time series of catches taken by professional full-time fishers, the majority of which are artisanal, has two main periods. The first (1950-1977) represents a period where data were scarce, the second (1977-2008) corresponds to a period of improved sampling and collection of fisheries landings. Thus, the catch variability that appears in the latter time period may be more representative of a trend in catch levels. Catches taken by professional full-time fishers decreased substantially in 1979 from approximately 2,200 t to 1,500 t the following year (1980; Figure 4). The cyclone of 1980 may have played a role in this decrease e.g., through its impact on fishing effort. However, given that the sampling methods for monitoring artisanal catches were implemented in 1977, these dropping catches could also be the result of adjustments to the method by the officials between 1977 and 1980.

Rodrigues Island

Catches by small-scale fishers on Rodrigues Island were estimated over the 1950-2008 time period to be approximately 159,000 t (Figure 6). This estimate included commercial catches by professional full-time fishers which amounted to about 96,000 t, subsistence catches taken by full-time and part-time fishers amounting to almost 54,000 t and unreported catch from illegal gears estimated to be 8,600 t. Subsistence catches taken by part-time fishers (i.e., people who fish only for subsistence purposes) were over 2.5 times larger than subsistence catches taken by full-time fishers as the 'take-home' portion (i.e., non-commercial) of their catch (Figure 6). However, this is mainly an artifact of the much larger number of part-time fishers than professional full-time fishers. The number of part-time fishers was up to 7 fold greater than the number of professional full-time fishers.

Summed for 1977-2008, reconstructed small-scale fisheries data suggested a 1.9 fold difference between reconstructed estimates and the statistics reported by the Ministry (Figure 7). As for Mauritius Island, this discrepancy between the reported and our reconstructed catches is mainly due to the inclusion of our estimated catches by part-time fishers, which, for the whole time period, represented 25% of our total reconstructed catches for the small-scale sector.

Recreational fisheries

Our total reconstructed recreational catch for Mauritius from 1950 to 2008 was estimated to be over 30,000 t, which is 1.7 times larger than the reported recreational catch (Figure 8a). Pelagic sports fishery catches accounted for approximately 21,800 t and tourist catches from the lagoon fishery representing the remaining 8,700 t (Figure 8b). It is worth noting the difference in the overall trend of the reported compared to the reconstructed recreational catch, especially since 1990 (Figure 8a). Due to the method employed, estimated catches of the fishing tourist population reflected the growing number of tourists visiting the island each year, thus showing an increasing trend for the whole time period (Figure 8b). Estimated pelagic sports fishery catches increased constantly from 1950 to a peak of 825 t in 2000, after which catches have been decreasing.

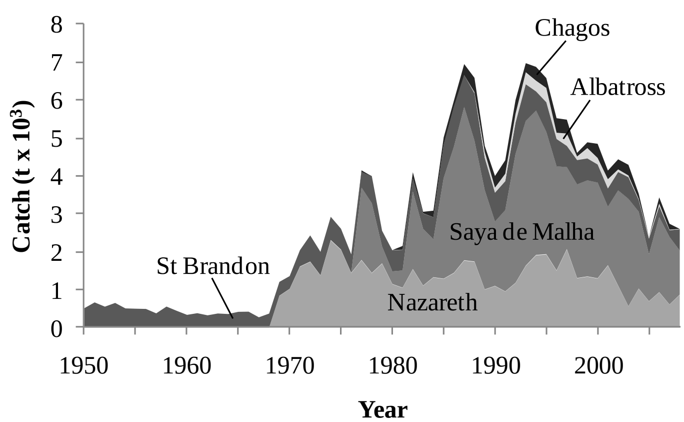

Figure 9. Total catches estimated for the Banks fisheries of Mauritius, 1950-2008. These include fisheries on St. Brandon, Chagos, Albatross, Saya de Malha and Nazareth banks.

Banks fishery

Total estimated catches from the banks fisheries were estimated to be approximately 167,000 t over the study period. The St Brandon banks fishery operated from 1950-2008, the Nazareth bank fishery started in 1969 and the Albatross, Chagos and Saya de Malha banks fisheries started in the late 1970s. The Saya de Malha and Nazareth banks fisheries were the largest with catches of over 70, 000 t and 54,000 t, respectively over the study period (Figure 9).

Mauritian purse seine fishery

Total catches of tuna taken by the Mauritian purse seine fishery were estimated for the period 1977-2008 to be approximately 127,000 t (Figure 10). The discarded bycatch associated with the tuna purse seine fishery were estimated to be 4,472 t (Figure 9).

Shark and sea cucumber fisheries

Total catches of shark and sea cucumber, taken directly from the FAO data were estimated to be 2,043 t and 1,055 t, respectively, over the 1950-2008 time period. Shark catches were considered part of the industrial sector while the sea cucumbers originate from the artisanal sector.

Total reconstructed catches

Total reconstructed marine fisheries catches for Mauritius and its outer dependencies was estimated for the 1950-2008 time period to be 682,392 tonnes. This suggests our reconstructed estimate was 42% higher than the landing statistics reported by FAO on behalf of Mauritius. The discrepancy between our total estimated catches and those currently reported is most substantial for 1950-1970 (Figure 11). Summed for this period, our total reconstructed estimates represent about 2.4 times the reported catches. This implies that under-reporting of catches was particularly substantial for the earlier time period.

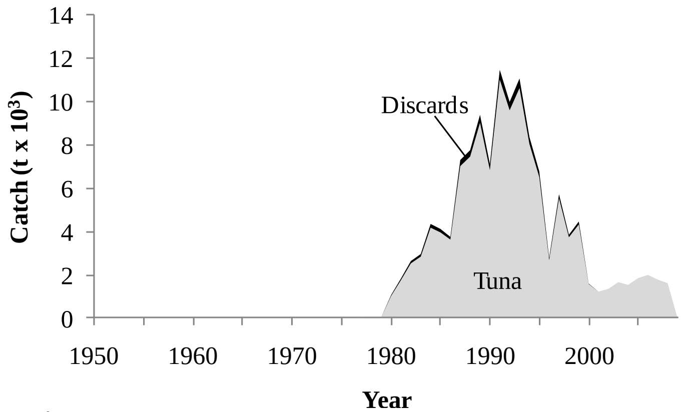

Figure 10. Total catches of tuna and associated discards from the Mauritian purse seine fishery, 1950-2008.

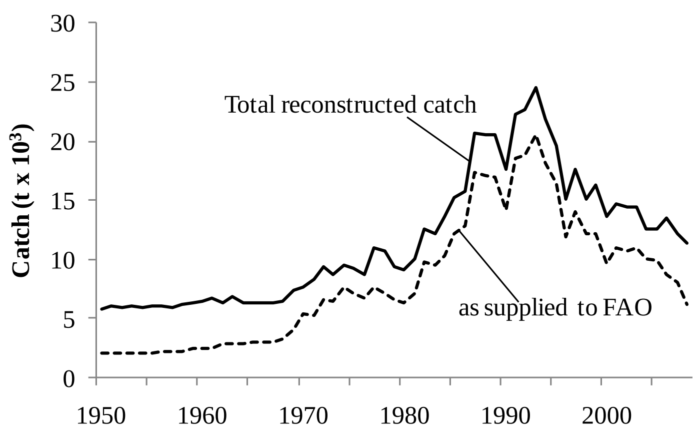

Figure 11. Total reconstructed catch for Mauritius Island and its dependencies and catches presented by the FAO on behalf of the Republic of Mauritius, 1950-2008.

Discussion

For a better understanding of the fisheries impact on marine ecosystems, there is a great need for improved reporting and verification of landings and catches. The present study represents an alternative approach to estimate a more comprehensive total catch for the island state of Mauritius, including estimates of unreported landings of the small-scale fisheries sector, recreational catches, and discards. Summed for 1950-2008, marine fisheries catches for Mauritius and its dependencies as estimated in our reconstruction was 682,392 t, which is 42% larger than currently reported total catches of 478,305 t presented by FAO on behalf of Mauritius. This was largely due to the under-reporting of small-scale catches for Mauritius and Rodrigues islands. Estimated small-scale catches for Mauritius and Rodrigues islands represented respectively 25% and 23% of the total reconstructed catch, thus implying an important contribution of those fisheries to total national catches. Thus, our results confirmed that currently reported catches for the Republic of Mauritius are incomplete, and especially underrepresented catches from the small-scale fishing sectors. This situation of underreporting of catches for the small-scale sector is not specific to Mauritius and has been demonstrated for other countries (Zeller *et al.*, 2006; Jacquet and Zeller, 2007). Indeed, although they are highly important in terms of income and food security, small-scale tropical fisheries are often marginalized world-wide (Pauly, 1997). Consequently, their contribution in terms of catches is also often substantially underreported.

Nevertheless, it should be mentioned that the Mauritius government made efforts to decrease the pressure on lagoon fish stocks and to improve the fishers' livelihoods (such as the bad weather or closed net season allowances). Mauritius is also one of the few countries which accounts for recreational and 'amateurs' fisheries catches in their total reported catches, even though they are represented by constant estimates over the years. However, as demonstrated in the present study, more efforts should be dedicated to monitoring recreational and small-scale fisheries.

High levels of uncertainty are associated with reconstructions such as ours. However, as long as estimates for unaccounted catches are not substantially overestimated, the catch reconstruction will present a more accurate picture of total extractions in the marine environment compared to current practices of essentially allocating 'zero catch' to IUU components (Illegal, Unregulated and Unreported catches) for which no hard time series data are available.

The time series data presented do not include catches by foreign vessels which fish heavily – legally or illegally - the waters off Mauritius, which would likely add great amounts to the total extractions of marine resources in the Mauritius' EEZ. The Banks of the Mascarenes Ridge, for instance, have been, over the years, exploited by a number of foreign fishing units from diverse countries such as Korea, Japan, France (Reunion), Seychelles, Spain, Russia, Panama and Malaysia (Paul, 1987). Réunion based boats were fishing in the Soudan, Nazareth and Saya de Malha zone as early as 1962. Not all foreign vessels fishing on the banks use handlines but also longlines and trawls. The total catch of these foreign fishing vessels on the banks is not reported but estimated to be well in excess of 10,000 tonnes per year (Ardill, 1986; Paul, 1987).

Discards of the deep-sea demersal trawlers are also considered to be high in many deep-sea fisheries (Kelleher, 2005) and therefore they would likely add important amounts to our estimated total catches. Kelleher (2005) reported a discarding rate for deep water trawls of 39.6%. However, this discarding rate was from fisheries operating in the Northeast Atlantic and Chile, and no similar estimate has been made for the Western Indian Ocean. Therefore, attempts have not been made to quantify trawl discards.

In Mauritius as in Rodrigues Island, depletion of the marine lagoon resources is of concern and indications of growth overfishing were drawn early. One of the characteristics of growth overfishing is a decline in the mean size of a fish population, and this problem has been noted for Mauritius as early as the 1920s (Paul, 1987). Pearson (1988) also defined the lagoon of Rodrigues as clearly overfished, while (Bunce *et al.*, 2008) mentioned that overfishing in Rodrigues could have occurred since the 1800s. In Mauritius, the reduced catches have to some extent been compensated for by rising prices and a high demand for fresh fish, and as a result there has been no substantial reduction of the fishing effort (Hollup, 2000). An ever growing population and increasing tourist arrivals is leading to a greater demand for seafood, and subsequent increased pressure on fish stocks. Fishers have also resorted to illegal fishing practices that are highly destructive for the marine environment (i.e., dynamite and fine mesh nets). Combined, population pressure and destructive fishing practices suggest that 'Malthusian overfishing' (Pauly, 1997) is occurring on Mauritius Island. Although regulations have existed in the legislation since the colonial days, they only concern limitations on the use of specific gears, fish reserves and closed seasons for nets (Hollup, 2000). Pearson (1988) and Hollup (2000) both mentioned that regulations should include the limitation of access to the fish resources of the lagoon area. However, alternatives are needed for the numerous fishers who depend on these resources for their livelihoods.

This study illustrates the need for better reporting of catches for all the different fisheries sectors of Mauritius state. Accounting for all fisheries components is fundamental to effectively managing the fisheries, which provide food and income for a large coastal population. We hope that the present study will encourage management agencies and policy makers to work in this direction.

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Appendix Table A1: FAO landings vs. total reconstructed catch (in tonnes) for Mauritius, 1950-2008.

Years	FAO landings	Total reconstructed catch
1950	2,000	5,786
1951	2,000	5,982
1952	2,000	5,913
1953	2,000	6,057
1954	2,000	5,958
1955	2,000	5,995
1956	2,200	6,013
1957	2,200	5,920
1958	2,200	6,121
1959	2,500	6,300
1960	2,501	6,486
1961	2,501	6,757
1962	2,801	6,263
1963	2,801	6,783
1964	2,801	6,238
1965	3,000	6,274
1966	3,001	6,343
1967	3,000	6,258
1968	3,300	6,421
1969	4,001	7,328
1970	5,400	7,586
1971	5,200	8,337
1972	6,600	9,347
1973	6,400	8,663
1974	7,679	9,536
1975	7,038	9,248
1976	6,660	8,649
1977	7,667	10,932
1978	7,108	10,697
1979	6,525	9,362
1980	6,348	9,109
1981	7,132	10,032
1982	9,780	12,638
1983	9,434	12,222
1984	10,346	13,613
1985	12,175	15,248
1986	12,848	15,817
1987	17,279	20,656
1988	17,116	20,604
1989	16,896	20,530
1990	14,098	17,603
1991	18,576	22,298
1992	18,861	22,687
1993	20,576	24,595
1994	18,145	21,911
1995	16,395	19,620
1996	11,870	15,104
1997	14,025	17,707
1998	12,093	15,068
1999	12,205	16,264
2000	9,615	13,684
2001	10,986	14,748
2002	10,706	14,414
2003	10,968	14,836
2004	9,971	13,126
2005	9,855	12,995
2006	8,681	13,653
2007	8,087	12,627
2008	6,152	11,430

Appendix Table A2: Total reconstructed catch (in tonnes) by major taxa for Mauritius, 1950-2008. Others grouping includes 38 taxa.

Year	*Lethrinus mahsena*	Octopodidae	*Katsuwonus pelamis*	*Thunnus albacares*	Siganidae	*Thunnus alalunga*	Serranidae	Acanthuridae	Mugilidae	Others
1950	332	1,544	-		534	-	152	261	187	2,465
1951	460	1,563	-	0	539	0	155	262	188	2,503
1952	367	1,582	-	0	538	1	153	263	189	2,511
1953	449	1,602	-	0	542	2	155	264	191	2,543
1954	329	1,621	-	0	539	3	153	264	191	2,547
1955	322	1,640	-	1	540	5	154	265	192	2,566
1956	318	1,649	-	1	541	9	154	265	192	2,575
1957	220	1,656	-	2	538	12	152	265	192	2,571
1958	339	1,762	-	3	531	17	170	266	157	2,566
1959	257	1,813	-	4	574	22	183	289	165	2,682
1960	180	1,864	-	5	618	28	196	312	174	2,799
1961	226	1,907	-	6	653	35	208	329	181	2,903
1962	158	1,840	-	7	572	42	182	289	166	2,698
1963	218	1,925	-	8	647	50	206	327	181	2,912
1964	181	1,844	-	10	551	58	175	278	163	2,668
1965	215	1,883	-	10	607	63	167	305	149	2,565
1966	218	1,896	-	14	609	87	168	306	150	2,584
1967	128	1,909	-	18	608	110	167	307	150	2,590
1968	177	1,922	-	22	612	136	168	308	151	2,614
1969	895	1,937	-	27	613	163	202	309	152	2,699
1970	1,027	1,969	-	31	614	189	209	310	154	2,749
1971	1,568	1,986	-	34	617	208	233	311	155	2,826
1972	1,884	2,229	-	37	362	224	243	507	208	3,268
1973	1,520	2,079	-	39	362	236	229	510	202	3,118
1974	2,344	2,090	-	28	363	172	266	511	203	3,205
1975	2,083	2,088	-	30	365	183	257	514	203	3,187
1976	1,506	2,077	-	39	366	235	233	518	203	3,149
1977	3,460	2,072	0	46	368	270	333	523	204	3,346
1978	3,333	2,043	15	71	360	296	304	500	199	3,283
1979	2,055	2,042	41	59	350	362	253	498	197	3,183
1980	1,553	1,926	1,004	67	277	336	192	389	169	2,851
1981	1,589	1,923	1,746	76	274	367	217	387	168	2,907
1982	3,505	1,806	2,430	78	299	368	351	163	249	3,079
1983	2,684	1,842	1,421	1,191	342	361	304	185	275	3,344
1984	2,680	1,823	2,537	1,430	349	373	332	186	276	3,377
1985	4,212	1,798	2,080	1,081	348	360	402	184	273	4,081
1986	5,063	1,773	1,899	1,039	352	359	426	184	273	4,003
1987	5,917	1,785	4,397	1,845	383	443	519	203	293	4,439
1988	5,550	1,747	5,049	1,492	377	440	505	194	284	4,551
1989	4,085	1,749	5,614	1,955	379	476	397	199	288	5,007
1990	3,360	1,758	4,195	1,624	390	480	408	206	295	4,522
1991	3,716	1,744	6,735	3,043	382	472	429	200	289	4,940
1992	5,152	1,766	6,126	2,419	415	484	509	216	308	4,969
1993	6,047	1,736	7,074	2,768	394	522	500	201	292	4,765
1994	5,961	1,742	5,209	1,987	394	536	543	208	297	4,755
1995	5,720	1,614	3,936	1,891	372	544	483	191	303	4,313
1996	4,787	1,504	1,589	727	390	601	491	204	277	4,297
1997	4,737	1,503	3,150	1,281	338	640	459	175	242	4,966
1998	4,091	1,209	1,692	1,576	333	648	368	174	253	4,550
1999	4,328	1,037	2,481	1,333	336	685	391	174	283	5,060
2000	4,208	1,042	425	835	349	725	455	184	302	4,960
2001	3,627	791	140	769	319	716	376	167	275	7,393
2002	3,936	964	140	752	348	693	420	184	309	6,529
2003	3,816	1,221	140	784	332	779	409	175	267	6,808
2004	3,215	853	140	786	313	876	344	168	252	6,099
2005	2,240	792	133	787	299	853	258	158	216	7,184
2006	3,088	752	133	838	300	838	342	161	235	6,862
2007	2,491	622	133	823	246	866	293	132	215	6,758
2008	2,449	643	133	841	260	788	252	134	225	5,705

Reconstruction of Nauru's fisheries catches: 1950-2008[1]

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Abstract

Nauru is a small, single island country located in the western Pacific Ocean with a relatively large population. Historically, phosphate mining has destroyed much of the island's land surface. We reconstructed total fisheries catches for Nauru (1950-2008). The reconstructed catch consists of small-scale fisheries, including both commercial and subsistence components, as well as the offshore domestic catch. For 1950-2008, total reconstructed catches were 23,150 t, being 3.4 times higher than data supplied to FAO on behalf of Nauru. Of these catches, 9,000 t, 12,300 t and 1,850 t were small-scale commercial, small-scale subsistence and offshore catches, respectively.

Introduction

The Republic of Nauru is a small, single raised limestone island located at 0° 32' S latitude and 166° 55' E longitude, with a land area of approximately 21 km² (Figure 1) and an Exclusive Economic Zone (EEZ) of 308,000 km² (www.seaaroundus.org).

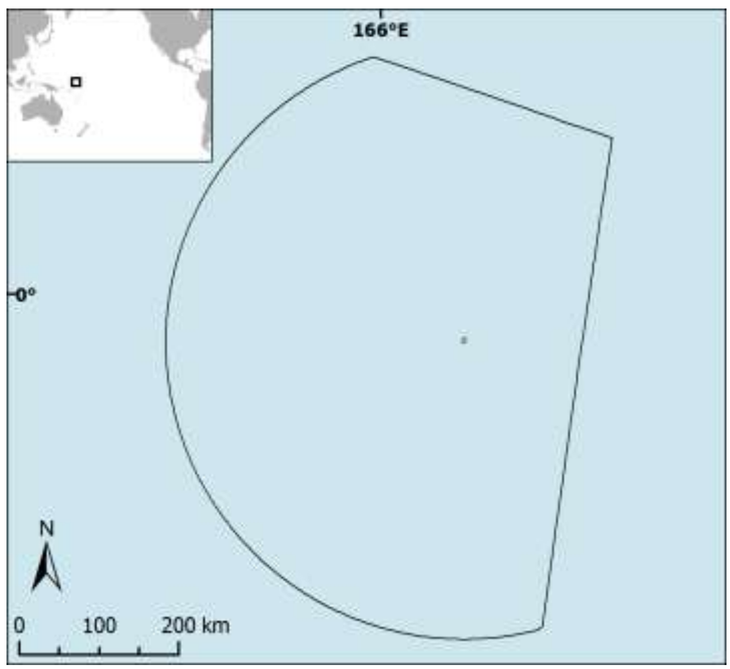

Figure 1. Map of Nauru and its Exclusive Economic Zone (solid line).

The island has an average height of 50 m above sea level, with an interior plateau that once held extensive deposits of phosphate bearing rock, resulting from the accumulation of seabird droppings over millenia. Phosphate mining was the island's largest source of revenue, but due to heavy mining the resource is now virtually depleted. This has left an estimated 80% of the land area uninhabitable, along with substantial environmental degradation from silt and phosphate runoff, which is believed to have impacted large parts of the island's marine life (Jacob, 1998). With an already degraded terrestrial environment and an eroding coastline, the impact of global sea level rise for a small island such as Nauru may be devastating (Stephen, 2011)

The original inhabitants of the island relied heavily on marine resources a source of animal protein. Nauru is surrounded by a coral belt that becomes exposed at low tide, ranging from 150 to 300 m in width, and the waters surrounding Nauru hold an abundance of both reef and pelagic fish species (Dalzell and Debao, 1994; Jacob, 1998).

[1] Cite as: Trujillo, P., Harper, S. and Zeller, D. (2011) Reconstruction of Naurru's fisheries catches: 1950-2008. pp. 63-71. *In*: Harper, S. and Zeller, D. (eds.) Fisheries catch reconstructions: Islands, Part II. Fisheries Centre Research Reports 19(4). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

The colonial period

In 1888, Germany annexed the island as part of the *Marshall Islands Protectorate*. At the turn of the century, a British company discovered phosphate, and mining for the deposits began in 1906. Immigration to the island, starting with the European influx during the colonial period (between 1889 and 1913), followed by migrant workers to labour in the phosphate mining operation, changed the island's traditional make-up. These immigration patterns were linked to the mining developments of the Nauru Phosphate Corporation (NPC), yet were also relevant to the island's fishing capacity and history.

Initially, workers were brought to the island from other German-administered Micronesian islands, as well as New Guinea and China. Later, when Australia took control of the island in 1914, an increasing number of Chinese labourers were hired, and by 1939 their numbers (1,512) nearly equalled those of the native Nauruan population (1,733). This demographic make-up did not change until, during World War II, the Japanese occupiers of the island forcibly exiled Nauruans to Truk, where nearly 500 of them died (Underwood, 1989).

At the start of the 1950s, virtually every able-bodied Nauruan adult male was gainfully employed both and once again began to receive their respective phosphate mining royalty payments. This enabled the inhabitants to purchase imported foods as well as improving their living conditions (Viviani, 1970). This purchasing power brought on numerous changes in the structure of the island population, differentiating it from other Pacific islands.

Independence

At the time of its independence in 1966, Nauru had attained an economic status similar to that of rich oil-producing countries of the Middle East (Underwood, 1989; Vunisea *et al.*, 2008). This in turn increased the immigration of labourers to the island to compensate for the growing number of retiring Nauruan nationals (Figure 2). The population is largely concentrated along a narrow coastal strip. Most of the non-native Pacific islanders (largely from Kiribati and Tuvalu) that worked for the Nauru Phosphate Corporation (NPC) were also at least part-time fishers (Underwood, 1989; Dalzell and Debao, 1994).

Nauru's economic prosperity translated into profound cultural changes. This was also reflected in the diet, not only in terms of dietary preferences, but also in the means by which dietary goods were acquired. Until the mid 1980s, the majority of fishing was done by the non-Nauruan Pacific islanders. Nonetheless, the economic decline that occurred in the early 1990s, following the downscaling of phosphate production, reduced the population's ability to purchase high-valued fish, and contributed to the subsequent emigration of non native fishers from the island.

The development and management of the marine resources within the Republic of Nauru falls under the jurisdiction of the Nauru Fisheries and Marine Resources Authority (NFMRA). The NFMRA does not enforce the reporting of catches or issue any fishing quotas. Marine resources are open access, and records of catches are sparse (Dalzell and Debao, 1994). The NFMRA attempted to pursue industrial-scale fisheries by purchasing two purse-seine vessels. However, one ship was lost at sea, while the other was used sparsely due to inadequate fishing gear, and was subsequently sold.

The aim of the present study was to gather available information on fisheries catches and fishing practices to reconstruct Nauru's total fisheries catches for the period 1950-2008. The catch reconstruction approach used here is based on the approach developed by Zeller *et al.* (2006; 2007).

METHODS

At present, small scale marine fisheries in Nauru can be separated into two categories:

1) Subsistence fisheries, dominated by coastal reef fisheries, beach seining and reef gleaning (mainly by women [Chapman, 1987]), are known to be traditional fishing methods practiced throughout the

Pacific islands (Gillett, 2003). I-Kiribati, Tuvaluan and Nauruan fishers commonly operate outboard powered boats ranging from 3–7 m in size, using trolling and shallow-water bottom handlining as their main fishing methods. Some Nauruans carry out spear fishing equipped with scuba gear. This type of fishing may also be done at night, using battery powered flashlights (Chapman, 1998). These coastal fishing activities do overlap with commercial fisheries, if part of the catch is sold; and

2) Commercial fisheries, using fishing methods such as mid-water handlining and drop stone fishing, targeting offshore tunas and other pelagics (Gillett, 2003). The fishers involved in this type of fishery are generally Nauru Phosphate Corporation (NPC) workers from Tuvalu and Kiribati who fish whenoff from work. This fishing is often concentrated around the NPC's mooring buoys used for phosphate vessels that act as Fish Aggregation Devices (FADs) (Chapman, 1998).

Data sources

Human population

Human population numbers (1950-2008) were derived with assistance from G. Beccalossi; Programme Assistant at the Demography and Statistics division of the Secretariat of the Pacific Community (SPC), complemented with data from UN databases[2] and work by Underwood (1989). Every decade had at least one demographic composition anchor point, with linear interpolations performed between anchor points (Figure 2).

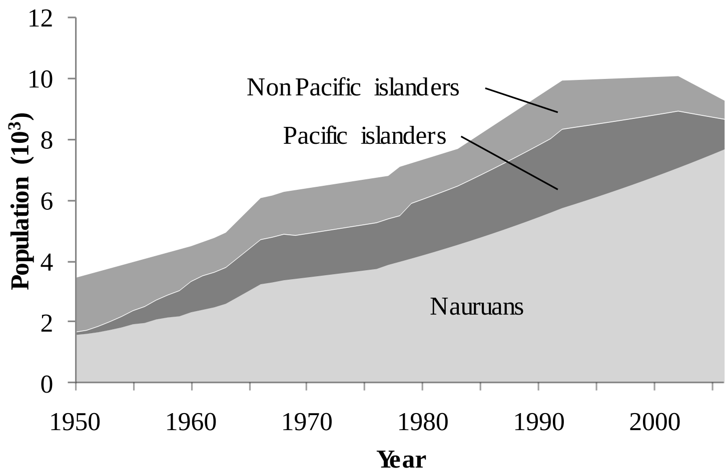

Figure 2. Population composition of Nauru, 1950-2008.

Catch data

Data estimates of fisheries catches, and used here as anchor points, were obtained from Dalzell and Debao (1994), Gillett and Lightfoot (2002), Vunisea *et al.* (2008), as well as Bell *et al.* (2009), for the period between 1991 and 2008. Linear interpolations were used for time periods between anchor points.

To reconstruct the 1950-1990 times series, we assumed that the *per capita* consumption rate for 1950 was twice the 1991 *per capita* catch rate of 45 kg·person^{-1}·year^{-1} for Nauru, taken from Dalzell and Debao (1994). Hence, we assumed a consumption rate of 90 kg·person^{-1}·year^{-1} for 1950. We also assumed negligible seafood imports for 1950. Nauruans, like most Pacific islanders, have traditionally relied on fish as a main protein source (Petit-Skinner, 1981; Sokimi and Chapman, 2001) and the assumed 1950 rate is in line with other data for Micronesia (Bell *et al.*, 2009). We linearly interpolated rates between 1950 and 1991 and derive total catch estimates in conjunction with population data (Figure 2).

Table 1. Fishing sector estimates for late 1990s, used as anchor points, from Gillett and Lightfoot (2002).

Fishing sector	Catch (t)
Coastal subsistence	110
Coastal commercial	315
Offshore locally based	50
Offshore foreign based	41,000
Total	41,475

For the 1990s, Gillett and Lightfoot (2002) estimated offshore and domestic commercial landings (accounting for approximately 77% of domestic supply) as well as subsistence catches (23%; Table 1). In addition, they documented offshore pelagic catches of around 41,000 t, taken by foreign vessels in the late 1990s. This breakdown by fishing sector provides a proxy for local *per capita* catch rates as well as domestically sourced consumption rates. Domestic fish landings were estimated based on coastal catch

[2] United Nations Department of Economic and Social Affairs Population Division: http://www.un.org/esa/population/ [Accessed: February 2010]

estimates by Gillett and Lightfoot (2002) (425 t) summed with domestic offshore catch (50 t) for a total of 475 t (Table 1).

The economic downturn of 1999 greatly diminished the population's purchasing power, decreasing their ability to pay for commercially sold fish. This is reflected in the increasing proportion of fish sourced via the subsistence sector which increased to 84% of the total domestic landings by 2004 (2008). In addition, a reduction in imported fish (22 t) was reported by Gillett and Lightfoot (2002) for 1999, which is considerably lower than the 55 t of imported canned and salted fish reported a few years earlier by Dalzell and Debao (1994). Nonetheless, a two month survey of the island's fishers and families in 2005 estimated that canned fish consumption had risen to an average of 16 kg·person^{-1}·year^{-1} (Vunisea *et al.*, 2008). Because Bell *et al.* (2009) report that Nauruan fish consumption rates range between 55.8 and 62.3 kg·person^{-1}·year^{-1} for the period between 2001 and 2006, we chose the latter rate to account for the canned fish consumption, along with the 425 t of small scale catch reported by Gillett and Lightfoot (2002), which translates into a demand of approximately 600 t of fish per year for Nauru in more recent years.

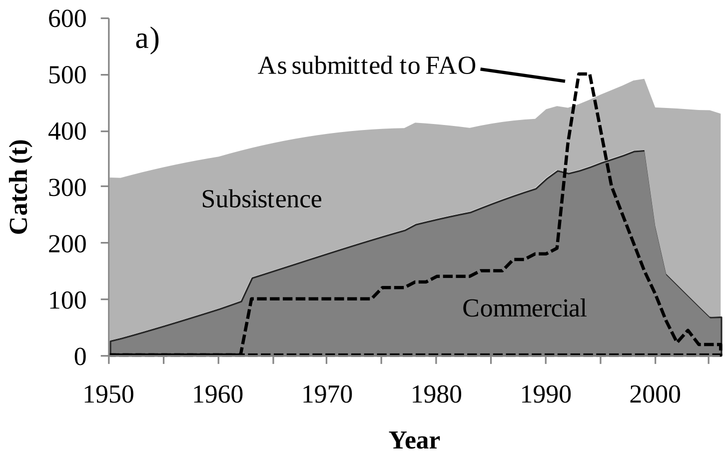

Figure 3a. Reconstructed catches breakdown for Nauru, compared with that reported to FAO from 1950 to 2008.

Catch composition

Dalzell and Debao (1994) list over 180 species of fish observed and reported in the waters of Nauru. They also report a catch breakdown by gear type collected over an eight month period between July 1992 and February 1993 where at the time, approximately 75% of the fishing was done by migrant workers and where approximately 70% of the total landings were commercially sold. Approximately 60% of the total landings were taken by trolling gear, highlighting a high prevalence of tunas (41% of total catch), mainly skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*). Another 30% of the landings were caught using mid-water handlines, almost exclusively catching Carangidae such as rainbow runner (*Elagatis bipinnulata*) and using demersal handlines, that target various species such as squirrelfish (Holocentridae) and bluestripe snapper (*Lutjanus kasmira*). The Mid-water and demersal handline fisheries comprise 26% and 7% of the total landings, respectively. The remaining 7% corresponds to inshore reef fishing activities that are regarded as subsistence or semi-artisanal (Vunisea *et al.*, 2008), where catches were composed predominantly of surgeonfish (Acanthuridae, 38.5%), squirrelfish (Holocentridae, 12.1%), groupers (Serranidae, 7.7%) and rainbow runners (Carangidae, 5%). More recently, lesser valued reef fish such as surgeonfish and triggerfish as well as many invertebrates found during beach and reef gleaning (octopus, turban shell and sea cucumbers etc.), account for an increasing

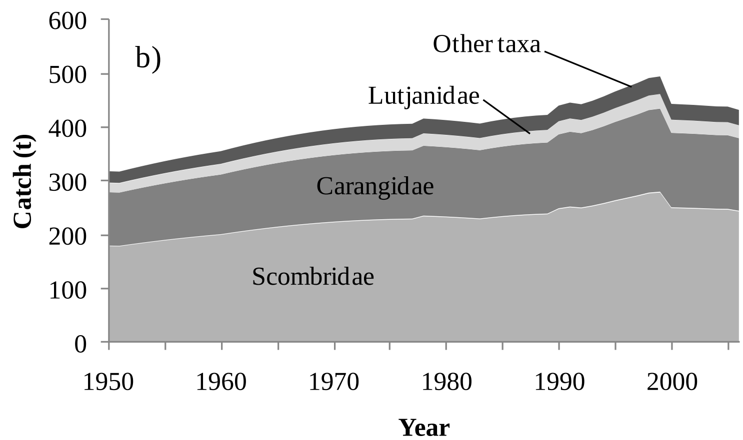

Figure 3b. Taxa layout for Nauru's landings for the period between 1950-2008. Scombridae species 56% of total catch by weight with substantial catches from the Carangidae (31%) and Lutjanidae (6%) families. Within the Scombridae family 90% of the catch were comprised of Skipjack (*katsuwonus pelamis*) and Yellowfin tuna (*Thunnus albacares*)

proportion of inshore subsistence catches (Vunisea *et al.*, 2008). Those species were not necessarily favoured by the Nauruan locals a decade earlier (Dalzell and Debao, 1994; Gillett and Lightfoot, 2002). Presently, fishers indicated that most of their target species required further distances and hours at sea to catch, but regardless of where it came from, it was intended for their family consumption. Incidentally, all family members participated in one way or another in fishing activities (Vunisea *et al.*, 2008; Gillett, 2009) and the increasingly important reef gleaning activity is generally undertaken mainly by women (Chapman, 1987). Overall, the more detailed breakdown by Dalzell and Debao (1994) was applied to the total catch throughout the 1950-2008 time period.

Results

Data supplied to FAO for Nauru would suggest incorrectly that essentially no fish were caught prior to the early 1960s (Figure 3a). Reported landings increased steadily from 100 t·year^{-1} in 1963 to around 190 t·year^{-1} in 1991, before increasing substantially to around 500 t·year^{-1} in 1993 and 1994 (Figure 3a). Thereafter, data supplied to FAO suggested a rapid decline throughout the 1990s to around 40 t·year^{-1} in the early 2000s.

Reconstructed catch estimates suggested a distinctly different picture (Figure 3a). Overall, the 1950-2008 total catches were estimated at 23,150 t, being 3.4 times greater than the data supplied to FAO on behalf of Nauru. Note the slightly lower total estimates for 1993 and 1994 compared to data supplied to FAO. Reconstructed commercial catches increased from around 30 t·year^{-1} in 1950 to around 360 t·year^{-1} in 1999, before declining rapidly to just under 70 t·year^{-1} by 2008 (Figure 3a). Conversely, reconstruction suggested a decline in subsistence catches from 290 t·year^{-1} in 1950 to a low of around 110 t·year^{-1} in 1991, before increasing rapidly to over 350 t·year^{-1} by 2008 (Figure 3a).

The taxonomic breakdown applied to Nauru's reconstructed fisheries catches (Figure 3b) is based on the reported catch composition given by Dalzell and Debao (1994) for the commercial catches, and on Vunisea *et al.* (2008) for the subsistence sector. Commercial catches were dominated by Scombridae (56%), composed of 80% skipjack (*Katsuwonus pelamis*) 10% yellowfin tuna (*Thunnus albacares*) and 10% other scombrids, followed by Carangidae (30%, mainly rainbow runner, *Elagatis bipinnulata*) as well as Lutjanidae (6%, mainly *Lutjanus kasmiri*), followed by coastal reef species such as surgeonfish (5%) and triggerfish (3%). Other taxa have been increasingly targeted more recently, due to ever more intensive fishing pressure. Overall, there is a predominance of pelagic species in local landings (Figure 3b). Nonetheless, far less of these landings are sold commercially; rather, they are intended for family consumption or sharing with other family members and neighbours. This shift to increasingly non-commercial basis was driven by the recent economical crisis and the weaker financial power of the Nauruan people (Vunisea *et al.*, 2008; Gillett, 2009).

Discussion

Nauru's total domestic fisheries catches for the period 1950-2008 were estimated to be 23,150 t. This amount illustrates the historical importance fisheries have in meeting the island's dietary requirements, a fact which cannot be readily inferred from the data reported to FAO on behalf of Nauru. Small-scale fisheries are fundamental to many Pacific islands, nonetheless widespread lack of information on subsistence sector catches undervalues the social and economical importance of this sector (Zeller *et al.*, 2006; Gillett, 2009) and may impact any successful form of ecosystem-based fisheries management (Pauly *et al.*, 2002).

The landings reported to the global community on behalf of Nauru substantially underestimate total catches as estimated here for all but two years during the early 1990s. We assume that this peak in reported landings coincides with the publication of the seminal work by Dalzell and Debao (1994) and Dalzell *et al.* (1996), who presented estimates of *per capita* catch rates. These studies were likely used to estimate Nauru's 1993 and 1994 fisheries landings that were reported to FAO. However, the human population counts for that decade were overestimated (Underwood, 1989), likely resulting in the higher reported landings estimates as presented by FAO compared to our reconstructed estimates. We identified that for the early 1950s, population statistics were underestimated by as much as 60% (Underwood, 1989) and in the most recent decade, the population was overestimated by 20% to 40%, due to the rapidly increasing emigration of foreign NPC workers (Vunisea *et al.*, 2008). Hence it is noteworthy to mention that the *per capita* fish consumption of 56 $kg \cdot person^{-1} \cdot year^{-1}$ reported by Bell *et al.* (2009), which we used for recent time periods, is likely underestimated, due to it being based on inflated population estimates.

Despite the economic surge provided by the island's phosphate earnings during earlier decades, Nauru's fisheries did not develop in similar fashion, due in part to the absence of natural harbours to moor vessels. Three man-made channels and a small boat harbour have been excavated through the coral fringing reef, allowing only small outboard powered vessels to be launched. Industrial-scale fishing was attempted in the early 1980s involving two purse-seine vessels, but was not successful due to ineffective gear and through market loss which led to the sale of one vessel while the other was lost at sea (Chapman, 1998).

Nauru has been a party to the US Multilateral Fisheries Treaty since it came into effect in June 1988. In July of 1994, Nauru entered into a bilateral fishing access agreement with Japan, granting four Japanese fishing vessels access to Nauruan waters and in June 1997, the first fishing access agreement was signed with the Philippines (Chapman, 1998). It is estimated that Nauru received about US$3.4 million in access fees in 1999 (Gillett and Lightfoot, 2002) and US$5.4 million in access fees in 2008 (Gillett, 2009), with 131 foreign fishing vessels (10 countries), licensed to fish in Nauru's EEZ, catching approximately 66,000 t of tuna.

Attempts to farm milkfish (*Chanos chanos*) and tilapia (*Oreochromis mossambicus*) in the past had failed; these fish were introduced into the Baduan Lagoon. Milkfish, although part of the traditional Nauruan diet and culture, were used as bait for tuna fishing (Spennemann, 2002). Tilapia was introduced in the early 1960s but was not accepted as a staple food option and eventually infested all the milkfish ponds causing many farmers to abandon their traditional practice of raising milkfish (Gillett, 2009). Programs to eradicate the introduced fish from the island's lagoon have failed (Dalzell *et al.*, 1996). In 2000, 10,000 milkfish fry from Kiribati were introduced into Buada Lagoon, reaping 5,000 adult fish (Gillett, 2009). At present, several milkfish grow-out ponds exist; these are backyard and mostly subsistence operations. No accurate production estimates exist (Gillett, 2009).

Inshore fishing pressure appears to have increased dramatically since the late 1990s, with almost all households involved in fishing; women and children glean the beaches and reefs, collecting all invertebrate and finfish species they come across. Vunisea *et al.* (2008) surveyed invertebrate catches, estimating the total catch to be 23 $t \cdot year^{-1}$, dominated by genera such as *Etisus, Octopus, Turbo, Thais, Tripneustes* and *Cardisoma* and to a lesser extent *Actinopyga, Panulirus, Grapsus*, and *Cypraea*. All species and types are targeted and consumed, with the exception of lobsters, which are destined for sale (Vunisea *et al.*, 2008). All sizes of fish are caught and consumed, however fishers have observed a decrease in size and volume of catches (Vunisea *et al.*, 2008), suggesting that overfishing is occurring. There has been a steady increase in the intensity and frequency of fishing since the economic crisis in 1999, driven mainly by increasing subsistence efforts. Presently, pelagic fishing is dominated by canoes operated by Tuvaluans and I-Kiribati (Vunisea *et al.*, 2008).

Fish continue to form a large part of the Nauruan diet, increasingly so with the island's recent economic downturn. Food security may be jeopardized, leading to substantial dietary changes. Imported produce such as meat and poultry have been replaced with canned sardines and mackerel from abroad, seafood provides the main source of protein for more than 98% of Nauruan households (Vunisea *et al.*, 2008). The Nauru Fisheries and Marine Resource Authority (NFMRA) have the responsibility of overseeing, managing and conserving the country's natural marine resources and environment. Yet, with fishing being the only major fallback option for the population, the task presents several challenges, especially when marine resources are vulnerable to overexploitation and the livelihoods of an entire nation are at risk.

ACKNOWLEDGEMENTS

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Appendix Table A1: Total FAO landings vs. total reconstructed catch for Nauru, 1950-2008, in metric tonnes.

Year	FAO landings	Total reconstructed
1950	0	296
1951	0	301
1952	0	306
1953	0	311
1954	0	315
1955	0	319
1956	0	323
1957	0	327
1958	0	331
1959	0	334
1960	0	337
1961	0	342
1962	0	347
1963	100	352
1964	100	356
1965	100	360
1966	100	364
1967	100	367
1968	100	370
1969	100	373
1970	100	375
1971	100	378
1972	100	380
1973	100	381
1974	100	382
1975	120	384
1976	120	384
1977	120	385
1978	130	394
1979	130	392
1980	140	391
1981	140	389
1982	140	387
1983	140	385
1984	150	388
1985	150	392
1986	150	394
1987	170	397
1988	170	398
1989	180	399
1990	180	452
1991	190	444
1992	377	441
1993	500	447
1994	500	455
1995	400	464
1996	300	472
1997	250	481
1998	200	490
1999	150	493
2000	109	443
2001	61	442
2002	22	440
2003	44	438
2004	19	437
2005	39	437
2006	39	447
2007	39	447
2008	39	447

Appendix Table A2: Total reconstructed catch (t) by major taxa for Nauru, 1950-2008. Others category contains 7 taxonomic groups including miscellaneous marine fishes.

Year	*Katsuwonus pelamis*	*Elagatis bipinnulata*	*Thunnus albacares*	Scombridae	Carangidae	*Lutjanus kasmiri*	Crustaceans nei	Others
1950	130	72	16	16	18	14	6	24
1951	132	73	17	17	18	14	6	25
1952	134	74	17	17	19	14	6	25
1953	136	75	17	17	19	15	6	25
1954	138	76	17	17	19	15	6	26
1955	140	77	17	17	19	15	6	26
1956	142	78	18	18	20	15	7	26
1957	143	79	18	18	20	15	7	27
1958	145	80	18	18	20	16	7	27
1959	146	81	18	18	20	16	7	27
1960	147	82	18	18	20	16	7	28
1961	150	83	19	19	21	16	8	28
1962	152	84	19	19	21	16	8	28
1963	171	73	21	21	18	14	8	25
1964	173	74	22	22	18	14	8	25
1965	175	75	22	22	19	14	8	25
1966	176	75	22	22	19	15	9	26
1967	178	76	22	22	19	15	9	26
1968	179	77	22	22	19	15	9	26
1969	180	78	23	23	19	15	9	26
1970	181	78	23	23	20	15	10	27
1971	182	79	23	23	20	15	10	27
1972	183	79	23	23	20	15	10	27
1973	183	79	23	23	20	15	10	27
1974	184	80	23	23	20	15	10	27
1975	184	80	23	23	20	15	11	27
1976	185	80	23	23	20	15	11	27
1977	185	80	23	23	20	15	11	27
1978	188	82	24	24	21	16	12	28
1979	188	82	23	23	20	16	12	28
1980	187	81	23	23	20	16	12	28
1981	186	81	23	23	20	16	12	28
1982	185	80	23	23	20	16	12	27
1983	184	80	23	23	20	15	13	27
1984	185	80	23	23	20	16	13	28
1985	187	81	23	23	20	16	13	28
1986	188	82	23	23	20	16	14	28
1987	188	82	24	24	21	16	14	28
1988	189	82	24	24	21	16	15	28
1989	189	83	24	24	21	16	15	28
1990	213	96	27	27	24	18	15	33
1991	209	93	26	26	23	18	16	32
1992	207	93	26	26	23	18	16	32
1993	210	94	26	26	24	18	16	32
1994	214	96	27	27	24	19	16	33
1995	218	98	27	27	25	19	16	34
1996	221	100	28	28	25	19	16	34
1997	225	102	28	28	26	20	16	35
1998	229	105	29	29	26	20	16	36
1999	230	105	29	29	26	20	16	36
2000	190	105	24	24	26	20	16	37
2001	190	105	24	24	26	20	16	37
2002	189	105	24	21	26	20	16	39
2003	189	104	24	12	26	20	16	48
2004	188	104	24	21	26	20	16	38
2005	188	104	24	21	26	20	15	39
2006	193	107	24	21	27	21	15	39
2007	193	107	24	21	27	21	15	39
2008	193	107	24	21	27	21	15	39

MARINE FISHERIES OF PALAU, 1950-2008: TOTAL RECONSTRUCTED CATCH[1]

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ABSTRACT

The small Pacific Island nation of Palau has a long history of human settlement. Palau maintained a predominantly traditional lifestyle until the post-war modernization after 1950s, with fishing being a pre-occupation for the majority of its male population. This study estimated Palau's total marine fisheries catches for the 1950-2008 period to be just over 200,000 tonnes. This total was 43% higher than the official reported data as presented by the FAO on behalf of Palau. The discrepancy was mainly due to subsistence catches which were under-reported in the official statistics. The total coastal catches including subsistence and artisanal, were estimated to be 103,480 t 45% higher than the 46,615 t of coastal catches reported over the period. Our findings illustrate the importance of the subsistence sector, with catches representing 60% of coastal fisheries catches. Better monitoring or at least regular comprehensive estimation of the subsistence sector is key to properly account for the social and economic importance of fishing in Palauan society.

INTRODUCTION

Palau, a small country in the Western Pacific, is comprised of 340 islands which lie between 131°-135°E and 2°-8°N, 500 kilometers east of the Philippines (Figure 1). Palau is located within FAO statistical area 71, the Western Central Pacific, has a land mass of approximately 488 km² and an exclusive economic zone (EEZ) of around 604,289 km² (www.seaaroundus.org). The five main inhabited islands of Palau are Kayangel, Babeldoab, Korror, Peliliu, Angaur, and it has two de-populated outer islands, being Sonsorol and Hatohobei (Figure 1). The history of human settlement in Palau is long, with the earliest archaeological findings in Palau dating back over 2400 years (Clark, 2005). In recent human history, Palau has been successively colonized and under external stewardship by different states; Palau was ruled by Spain in the 1880s, Germany from 1899-1913 and Japan from 1914-1944. Following World War II, Palau was administered by the United

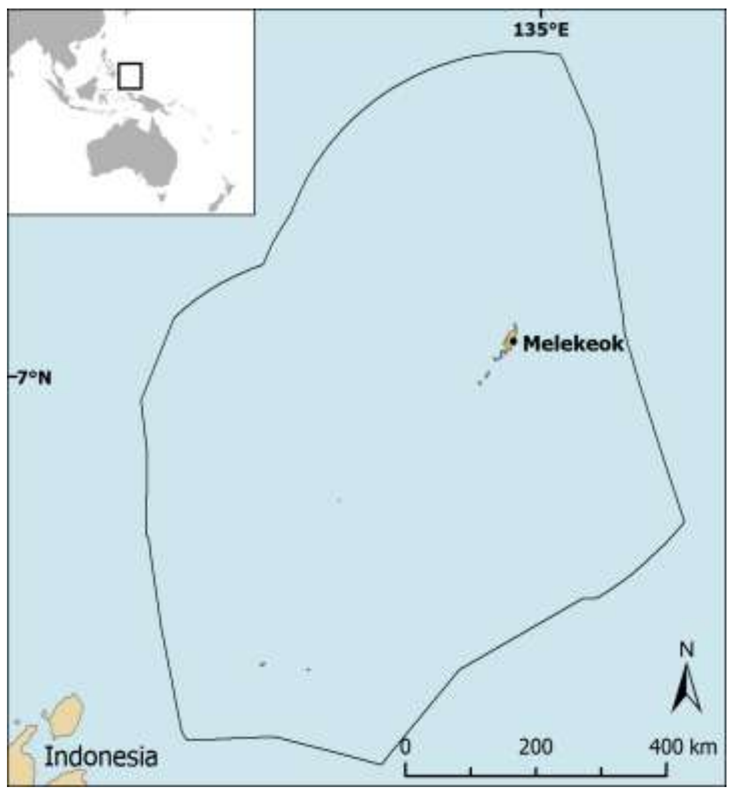

Figure 1. Map of Palau and its Exclusive Economic Zone (solid line).

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States. In 1994, Palau was designated as an independent country under the Compact of Free Association (Anon., 2003a) (Ota, 2006). The Compact of Free Association entails the United States providing military defense to Palau, development aid in the form of annual grants, and scholarship programs for Palauan residence to attend pos- secondary education in the United States. Due to this external support gradual development of some local industries, such as the tourism sector, Palau has the highest per capita GDP among Micronesia, and higher than most small island states in other Pacific region[2].

Traditionally, Pacific islanders have relied on marine resources as their main source of food, and fishing skills and knowledge were recognized as the status symbol of both wisdom and masculinity among many Pacific cultures (Johannes, 1981; Colbert, 2000). Likewise, in Palau, fishers were highly esteemed members of the community (Ota, 2006). Both Johannes (1981) and Ota (2006) have described fishing to be central to the organization of Palauan communities, embodying the gender dichotomy and social stratification, which still supports the basis of the socio-cultural dynamics of the society. In Palauan tradition, for instance, women have traditionally engaged in reef gleaning activities (Chapman, 1987), and farming of taro, while men capture fin fish which make up the majority of Palauan diet (Johannes, 1981; Mathews and Oiterong, 1991). Sharks and larger pelagic species are usually only caught for special occasions (Johannes, 1981).

Prior to colonization, Palauan society was organized into separate communities, each with its own respective chief. Between communities, land and sea barriers were continuous, and each community had proprietorship of sections of the coast line and reef. From ownership of and responsibility for a defined geographical area came a natural conservation ethic (Johannes, 1981). With the succession of colonizing countries, this system was increasingly disturbed by external political control and eventually replaced by modern democracy, which maintains the traditional chieftainship merely as a façade (Ota, 2006). More recently, the increase in the importance of the cash economy has led rapid urbanization of the country as people started seeking work in the capital, Koror (Johannes, 1981; Ota, 2006). In 1990, an estimated 70% of Palauans were living in Korror (Nichols, 1991). Even in the midst of this modernization, fishing has remained both economically and culturally important and is practiced regularly for subsistence purposes, though not commercially, by many Palauans both in their urban and rural settings. However, the centralization of marine resource management to the contemporary governing body has had negative effects on Palauan fishing culture and fish populations from the early days of the Palauan modernization as it slowly replaced the power of traditional community based management (TCBM) system which was based on the indigenous chieftainship (Johannes, 1981). For instance, Johannes (1981) reports that species of the Serranidae (e.g., groupers) were quickly overexploited due to fishers targeting spawning aggregations, which were previously controlled through the traditional community-based management (TCBM) system. Dynamite, poison, and other unsustainable fishing practices have also been employed since the breakdown of the TCBM, resulting in negative impacts on the reef fisheries of Palau (Johannes, 1981).

Since the Japanese occupation of Palau in 1914, tuna have been exploited in Palauan waters, and in recent decades, this has provided an important source of income for Palau, as fishing access fees for foreign vessels were introduced. Gillett(2009) estimated that in 2007 approximately 1.2 million USD were paid to Palau for access to fish in their waters. However, during WWII, all off-shore tuna fishing was halted until 1964 when an American company, Van Camp Seafoods, opened a processing facility in Koror (Lawson, 1991). Van Camp Seafoods operated until 1982. Since then, there has only been one locally based off-shore pole-and-line vessel operating under the Palauan Flag (Nichols, 1991).

The subsistence fishery has been largely unaccounted for in the FAO data for many island countries, despite its significant contribution to food security and local economies (Zeller *et al.*, 2006). It has been noted that Palau's inshore coral reef fishery continues to provide the main source of protein, and financial income for the majority of Palauan people (Johannes, 1981; Ota, 2006). In the recent period it has been estimated that 87% of Palau's population is engaged in coastal artisanal and subsistence fishing activities (Palau International Coral Reef Center, unpublished data in Golbuu *et al*, 2005). The artisanal and subsistence reef fisheries are carried out with a variety of gears. Fish pots, drop lines, trolling, hand

[2] http://www.adb.org/Documents/Fact_Sheets/PAL.pdf [accessed June, 2011]

spears, spear guns, gill nets, set nets (kesokes), and cast nets are the major gear types employed. The major species fished for in the small-scale fishery are snappers (Lutjanidae), emperors (Lethrinidae), groupers (Serranidae), parrot fishes (Scaridae), wrasses (Labridae), rabbitfishes (Siganidae), surgeon fishes (Acanthuridae), trevallies (Carangidae) and herring (Clupeidae) (Nichols, 1991).

Invertebrate fisheries are important components of the local diet and economy, but are poorly represented in official fisheries statistics. In earlier time periods most of the invertebrate fisheries were reported as being handled by women and children, predominantly for subsistence use (Johannes, 1981; Mathews and Oiterong, 1991), but they are now caught by commercial fishers and were largely sold at the local market mainly to the tourism sector (Anon., 2003b; Pakoa *et al.*, 2009). Bêche-de-mer is an important part of the Palauan diet, and is often collected by women during reef gleaning activities (Johannes, 1981; Mathews and Oiterong, 1991; Pakoa *et al.*, 2009). Bêche-de-mer is considered a boom and bust fishery, as the catches can fluctuate substantially year-to-year due to its ease of harvest and the open access nature of this fishery (Dalzell *et al.*, 1996). Other important invertebrate resources in Palau are the mud crab (*Scylla serrata*), land crab (*Cardiosoma hirtipes* and *Cardisoma carnifex*), and coconut crab (*Birgus latro) (*Johannes, 1981; Nichols, 1991; Dalzell *et al.*, 1996).

Since the 1990s, there have been some improvements to the documentation of the offshore and artisanal sectors of Palauan fisheries also reflected in better taxonomic breakdown in FAO data; however, to date no studies exist that include all fisheries components in a single estimate with a complete estimated time series (although Gillet [2009] does provide a very comprehensive estimate for the recent time period). The aim of this study is to make a comprehensive estimate of total marine fisheries catches for Palau that includes the invertebrate, subsistence, artisanal, offshore, and baitfish fisheries sectors over the 1950-2008 time period.

METHODS

For this report, officially reported landings were acquired from FAO (FishStat), and data were obtained from government reports, and independent reports published by the Secretariat of the Pacific Community (SPC) and Asian Development Bank (ADB). For the time period 1990-2007, several estimates of subsistence, artisanal and offshore commercial fisheries catches were available for some years (Nichols, 1991; Adams and Dalzell, 1994; Kitalong and Dalzell, 1994; Dalzell *et al.*, 1996; 2001; Gillett and Lightfoot, 2002; Gillett, 2009). Prior to 1990, few studies on commercial reef and off-shore fisheries were available (Johannes, 1981; Perron *et al.*, 1983; 1984). Data for certain years and for certain sectors were taken from Johannes (2009), Kitalong and Dalzell (1994), Dalzell *et al.*(1996), Gillett and Lightfoot (2002), and Gillett (2009). To derive a complete time series of data (1950-2008), we interpolated linearly between years of known data. Human population data and *per capita* fish consumption rates were used to calculate total seafood demand and secondarily derive subsistence sector catches for the 1950-2008 time period.

Human population

Human population census data were obtained from the Palau Office of Planning and Statistics (http://www.palaugov.net/stats) and used in combination with *per capita* consumption rates to calculate Palau’s seafood demand. Linear interpolations were used to create a continuous time series of human population data from 1950 to 2008, as data were not available for all years (Figure 2). To account for the temporary increase in population due to tourists, we converted number of tourists

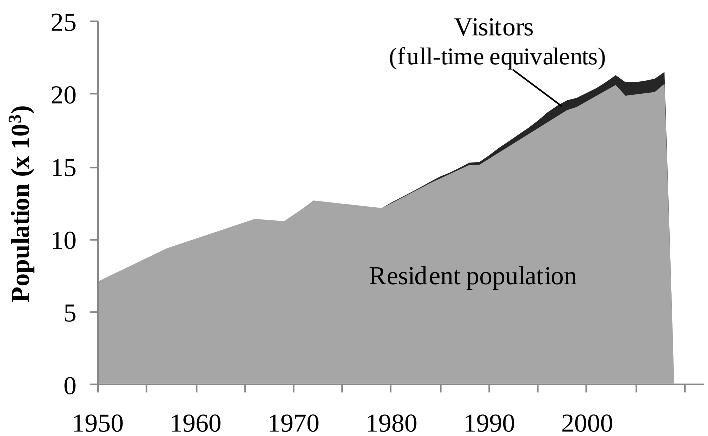

Figure 2. Population of Palau, 1950-2008 with the resident population and the number of visitors converted to full-time equivalents.

into full-time equivalents (Figure 2). To do this, we multiplied the number of visitors by the average number of nights stayed. The length of stay was derived from the estimated number of full-time equivalents presented in Gillette (2009) for the 1990s and the average number of annual visitors for the 1990s taken from the Palau Visitors Authority, published in Yamashita (2000). We estimated the average length of stay to be 3.6 days·visitor^{-1}·year^{-1} and applied this to the time series of visitors, which was for the period 1980-2008. The number of full-time equivalents was added to the resident human population and the total population was then used in conjunction with *per capita* seafood consumption rates to calculate the total demand of fishery products over the study period.

Commercial Fisheries

Inshore fisheries

Several independent studies on commercial inshore fisheries estimate annual catches (Table 1). The PCS (2000) estimate of 865 t has been the most widely agreed upon estimate for coastal fish production in Palau (Gillett, 2009). This estimate was compared to total catches presented by FAO for all species except large pelagics (tuna and billfishes). In 2007, FAO (non-pelagic) landings were found to be 11% higher than the PCS estimate of 865 t·year^{-1} of coastal commercial catch. We assumed that this additional catch (11%) presented in the FAO data was an estimate of non-commercial (subsistence) catches. Therefore, we assumed that 89% of FAO reported landings (excluding large pelagics) represent the coastal commercial (artisanal) catch, while the remaining 11% were considered the reported or estimated component of subsistence catches.

Table 1. Comparison of commercial inshore fisheries catch estimates for the recent period (1990s & 2000s) from various independent sources.

Catch (t/year)	Source
300-400	Shimada (1987 in Nichols, 1991)
250	Kitalong and Dalzell (1994)
865	PCS (2000 in Gillett and Lightfoot, 2002)
736	Anon. (1993 in Dalzell *et al.*, 1996)

Offshore fisheries

Palau's offshore fishery began in the 1920s when Japan occupied the islands. After WWII, tuna fisheries in Palau ceased and it was not until the early 1960s, after a fisheries development program was launched to jump start Palauan offshore fisheries, that tuna fishing resumed. In 1964, a joint-venture company (Van Camp Seafood of the United States) began operating a pole-and-line tuna fishery in Palau, which lasted until 1982 (Anon., 1984). These catches were considered domestic as they were caught and landed by Palau, even though the financing for this fishery was from the United States. Aside from Van Camp Seafood, offshore tuna fisheries in Palau have been mainly foreign fleets, which land their catches outside Palau (Anon., 1944; Gillett and Lightfoot, 2002). After the closing of Van Camp Seafood, only a single domestic pole-and-line vessel remained in operation. Based on our comparison of FAO tuna and billfish landings with other reports (e.g., Gillett, 2010), we concluded that the FAO data were the best available representation of domestic, large pelagic fishery catches.

Due to the minimal bycatch associated with pole-and-line fisheries (Bailey and Williams, 1996; Kelleher, 2005) we did not estimate bycatch, either landed or discarded. However, pole-and-line fisheries do require considerable amounts of live bait which are often caught in reef areas adjacent to the tuna fishing grounds. These catches are rarely accounted for in catch statistics, and we assumed that these were not estimated or included in the FAO data. Therefore, we estimated the amount of fish that was likely caught in order to provide bait for the domestic tuna fishery. Gillette(2011) gives an average tuna-to-baitfish ratio of 26:1 for Palau's pole-and-line fishery between 1964 and 1972. We assumed a similar ratio for the entire 1964-1982 period, when Van Camp Seafood was in operation. This ratio was applied to the total tuna landings from 1964-1982. In 1982, the bait fishery in Palau ceased operations, likely as a result of Van Camp Seafood discontinuing operations in Palau (Anon., 1984). Although one domestic tuna vessel continued to fish after 1982, we did not make any further estimates of baitfish catches. Catch of baitfish was likely dominated by short head anchovy (*Encrasicholina heteroloba*), delicate round herring (*Spratelloides delicatulus*), and Samoan silverside (*Hypoatherina temmincki*). From the estimated catch by species given in the SPC (1984) report on the bait fishery, we derived a species breakdown of 56% *Encrasicholina heteroloba*, 21% *Spratelloides delicatulus* and 8% *Hypoatherina temminckim,* with the remaining 15% being Clupeiformes.

Subsistence fishery

To independently estimate the subsistence catch in Palau, we used *per capita* fish consumption estimates for three separate years, and interpolated linearly between these to derive a complete time series of *per capita* fish consumption rates. The *per capita* consumption rates used were 122 kg·person^{-1}·year^{-1} for 1974 (Johannes, 1981), 135 kg·person^{-1}·year^{-1} for 1999 (Gillett and Lightfoot, 2002), and 115 kg·person^{-1}·year^{-1} for 2007 (Gillett, 2009). Johannes' (1981) estimate of *per capita* fish consumption was calculated using the weight of protein consumed daily, and the landed weight of fish (with weight of bones and scales removed). The estimate from Gillett and Lightfoot (2002) was calculated using the PCS (2000) in-shore catch estimate of 2,115 t adjusted for imports, exports and full time visitor equivalents. The consumption rate calculated from Gillett (2009), which used the same methodology as the Gillett and Lightfoot(2002) and population and visitation data from 2007, was adjusted for imported and exported fishery products and excluded pelagic species which do not form a significant portion of the Palauan diet. Other estimates of *per capita* fish consumption were available (Perron *et al.*, 1983; Preston, 1990) but were general estimates for the South Pacific region or were partially derived using FAO or commercial landings data. We disregarded these estimates based on information regarding the Palauan diet which suggested that although imported food, pigs, and bats contribute in small parts to the Palauan diet, fish still remains the main source of protein (Johannes, 1981; Anon., 2003b; Ota, 2006). Our earliest estimate of *per capita* fish consumption (Johannes, 1981) was carried back fixed from 1974 to 1950 and linear interpolations were used between 1974 and the two later estimates to derive a complete time series of *per capita* fish consumption rates. These rates were then multiplied by the annual human population to derive the total domestic seafood demand. This was then used to determine whether the demand was met through the supply of reported landings. The discrepancy found between these two numbers was then considered unreported subsistence catch. To this we added the 11% of FAO non-pelagic catches that were considered reported subsistence catches. The total subsistence catch (reported + unreported) was then compared to our estimate of reconstructed coastal commercial catches. On average, subsistence catches represented approximately 60% of the total coastal catches (subsistence and artisanal combined). For the South Pacific in general, the ratio of subsistence to total catch can be as high as 80% (Adams and Dalzell, 1994) with the average being around 70%(Gillett, 2009). We thus considered our approach to be conservative.

Table 2. Taxonomic composition of the non-pelagic catches (as proportion of total catch) by family or grouping based on Kitalong and Dalzell (1994) for 1950-1990 and Friedman *et al.* (2007) for 2007-2008. A linear interpolation was used to derive a complete time series between 1990 and 2007.

Family	1950-1983	1984-1990	1991-2006	2007-2008
Acanthuridae	0.141	0.129	linear interpolation	0.104
Carangidae	0.026	0.040	linear interpolation	0.022
Gerridae	0.007	0.002	linear interpolation	0.011
Haemulidae	0.002	0.001	linear interpolation	0.015
Holocentridae	0.004	0.001	linear interpolation	0.011
Labridae	0.010	0.008	linear interpolation	0.008
Lethrinidae	0.119	0.139	linear interpolation	0.268
Lutjanidae	0.085	0.135	linear interpolation	0.140
Mugilidae	0.019	0.005	linear interpolation	0.024
Mullidae	0.010	0.012	linear interpolation	0.023
Scaridae	0.163	0.187	linear interpolation	0.154
Serranidae	0.091	0.093	linear interpolation	0.105
Siganidae	0.116	0.105	linear interpolation	0.105
Others	0.185	0.123	linear interpolation	0.005
Crustaceans	0.020	0.020	linear interpolation	0.005

Invertebrate fisheries

Estimates of invertebrate fisheries catches were not readily available; however, sea cucumber (bêche-de-mer) has been a component of the Palauan diet for centuries (Pakoa *et al.*, 2009). Sea cucumber fisheries often fluctuate considerably from year-to-year (Dalzell *et al.*, 1996); however, catches reported by FAO for this fishery are minimal (<0.5 t), despite it being an important component of the subsistence fishery. Sea cucumber and invertebrates are collected in reef gleaning activities by women (Mathews and Oiterong, 1991). Sea cucumber landings were estimated to be 11.3 t·year^{-1} between 1989 and 1998 (Pakoa *et al.*, 2009). Over 50% of this was for subsistence consumption, 48% was sold in local markets and less than 1%

was exported. Pakoa *et al.* (2009) estimate that in 2007, sea cucumber catches were approximately 65.5 t·year^{-1}. Given the substantial fluctuations characteristic of sea cucumber fisheries and the limited catch data, we used the average of Pakoa *et al.*'s (2009) estimate for the 1990s (11.3 t) and for 2007 (65.5 t). The average of these two was approximately 38.4 t (19.2 t each from artisanal and subsistence sectors), which we applied as the catch for the year 2000. This was converted to a *per capita* rate, and using the population time series, sea cucumber catches were estimated for the entire study period. Sea cucumber catch estimates were then subtracted from the 'other species' category of the artisanal and subsistence catch. (Anon., 2003a)

Crustacean fisheries are also an important part of subsistence and, to a certain extent, commercial fisheries in the South Pacific (Dalzell *et al.*, 1996). Palau's catches of crustacean in the early to mid-1990s were estimated by Dalzell *et al.* (1996) to be 14.4 t·year^{-1}, which represents approximately 2% of artisanal catches. Prior to 1990, FAO catches for Palau present all catches as either miscellaneous marine fishes or pelagic fish species. As of 1990, the FAO provides greater taxonomic detail, which includes several invertebrate categories. Between 1990 and 2008, FAO crustacean categories represent on average 0.8% of the total non-pelagic landings. Crustacean catches were subtracted from the 'other species' category of the artisanal and subsistence catches.

Table 3. Species composition of the families, which dominate the coastal fisheries of Palau based on Friedman *et al.* (2007).

Family	Taxonomy	Proportion of catch by family
Acanthuridae	*Acanthurus xanthopterus*	0.22
	Naso lituratus	0.34
	Naso unicornis	0.21
	Acanthuridae	0.23
Carangidae	*Caranx ignobilis*	0.24
	Caranx melampygus	0.43
	Carangidae	0.33
Gerreidae	*Gerres macrosoma*	0.97
	Gerreidae	0.03
Haemulidae	*Plectorhinchus albovittatus*	0.51
	Plectorhinchus spp.	0.49
Holocentridae	Holocentridae	1.00
Labridae	*Cheilinus undulatus*	0.30
	Choerodon anchorago	0.70
Lethrinidae	*Lethrinus harak*	0.09
	Lethrinus olivaceus	0.19
	Lethrinus rubrioperculatus	0.06
	Lethrinus xanthochilus	0.15
	Lethrinidae	0.51
Lutjanidae	*Aprion virescens*	0.09
	Lutjanus bohar	0.15
	Lutjanus gibbus	0.63
	Lutjanidae	0.13
Mugilidae	Mugilidae	1.00
Mullidae	Mullidae	1.00
Scaridae	*Cetoscarus bicolor*	0.17
	Hipposcarus longiceps	0.45
	Scarus ghobban	0.15
	Scarus oviceps	0.11
	Scaridae	0.12
Serranidae	*Plectropomus areolatus*	0.22
	Plectropomus leopardus	0.25
	Epinephelus spp	0.44
	Serranidae	0.09
Siganidae	*Siganus lineatus*	0.57
	Siganus spp.	0.43

Taxonomic composition

FAO data for Palau have poor taxonomic resolution until the 1990s. For the period 1950-1989, landings are mainly reported as the aggregated grouping, 'miscellaneous marine fishes (MMF)'. Perron (1983) presents a breakdown of the artisanal fishery by family, but these estimates were highly variable. Dalzell *et al.* (1996) has a partial breakdown of the 1992 artisanal fishery including an estimate for the crustacean fishery. Kitalong and Dalzell (1994) have a taxonomic breakdown by family for the years 1976-1990, with two separate breakdowns for the periods 1976-1983 and 1984-1990. Friedman *et al.* (2007) have the most detailed breakdown of the artisanal fishery including species-level composition for catches in four major fishing districts in Palau. Here, we used the breakdown in Kitalong and Dalzell (1994) for the period 1950-1990 and Friedman *et al.* (2007) for 2007 and 2008 (Table 2).

Using Friedman *et al.* (2007) we calculated the taxonomic composition using the weighted average of each fishing district as a proportion of the total catch in the study, and each area (lagoon, sheltered reef, outer reef) as a proportion of the total in each district. The proportion of each species in each region was then weighted according to the fishing area and district. The proportion each species represented in the total catch was taken as the sum of the proportion of the catch by weighted area. To compare this breakdown with that presented in Kitalong and Dalzell (1994), we grouped the species by family (see Table 3). In order to derive a complete time series between 1990 and 2007, we interpolated linearly between the Kitalong and Dalzell (1994) and Friedman (2007) estimates for each taxonomic family. The 1976 estimate was carried back, unaltered to 1950 and the 2007 estimate was carried forward unaltered to 2008.

Using Dalzell *et al.*'s (1996) estimate of crustacean catch for the early 1990s, we assumed 2% of artisanal catches were crustaceans for the period 1950-1990. This was incorporated into our artisanal sector taxonomic breakdown by subtracting 2% from the 'others' category in the original breakdown. In 2007, we assumed a lower proportion of crustaceans (0.5%) in the artisanal breakdown as after 1990 crustacean categories begin to appear in the FAO data. The taxonomic breakdown with crustaceans incorporated was then applied to the unspecified portion of the artisanal catch (miscellaneous marine fish category in the FAO data). We assumed the same species breakdown for the subsistence catch. Sea cucumber catch which was estimated using a *per capita* rate was then subtracted from the 'others' category for the artisanal and subsistence catch in all years.

For each family, a species-level breakdown was derived using Friedman's (2007) estimates (Table 3). This species breakdown was applied to each family group throughout the 1950-2008 time period for the artisanal and subsistence fishery catches.

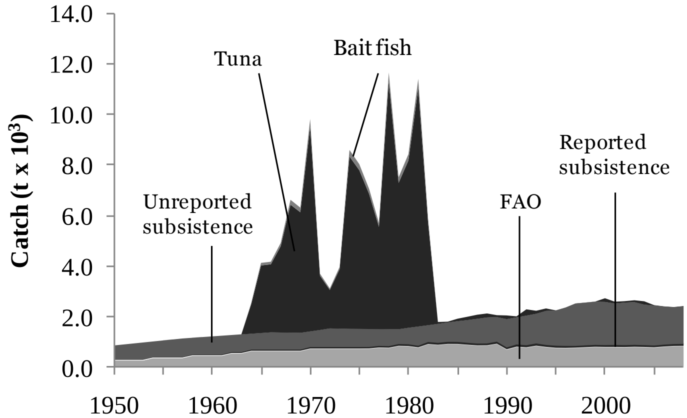

Figure 3. Palau total reconstructed catch including subsistence, artisanal, locally based tuna, baitfish, 1509-2008.

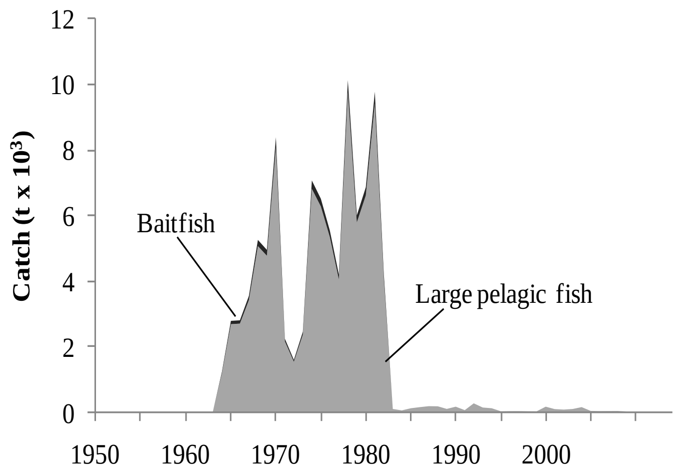

Figure 4. Total catch of large pelagic species and the baitfish associated with the main gear used in this fishery: pole-and-line.

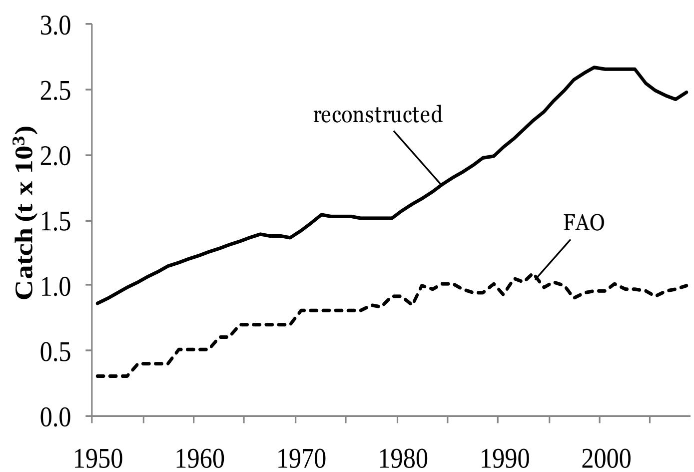

Figure 5. Palau reconstructed and FAO coastal catches 1950-2008.

Results

Our estimate of the total reconstructed catch for Palau, which includes subsistence, artisanal, locally-based tuna fisheries and baitfish totalled 200,817 t for the 1950-2008 time period. This estimate was 43 % higher than the total landings presented by FAO on behalf of Palau for 1950-2008, which was estimated to be 140,483 t (Figure 3). The FAO reports 93,868 t of pelagic species, which were considered to be from the domestic offshore fisheries (Figure 4).

The remaining 49,609 t reported by the FAO were considered to be the coastal fisheries catches. Of the coastal catches presented by the FAO, 89% were considered to be from the commercial (reported artisanal) sector, while the remaining 11% were considered to be non-commercial (reported subsistence) catches (Figure 3). Reported artisanal catches totalled approximately 41,488 t and reported subsistence catches were just over 5,000 t (Figure 5). In addition to the reported subsistence, we estimated another 56,800 t of unreported subsistence (Figure 3). Subsistence catches were estimated to be almost 62,000 t for the 1950-2008 time period. Total coastal catches were estimated to be 103,480 t, 45% higher than the total reported coastal catches (Figure 5.) Thus, total subsistence catches accounted for 60% of total coastal catches. Subsistence catches in 1950 represented 70% of the total coastal catch (total artisanal + total subsistence), decreasing to approximately 50% during the 1970s and 1980s and increasing again to approximately 65% in the recent period (1990s and 2000s; Figure 6).

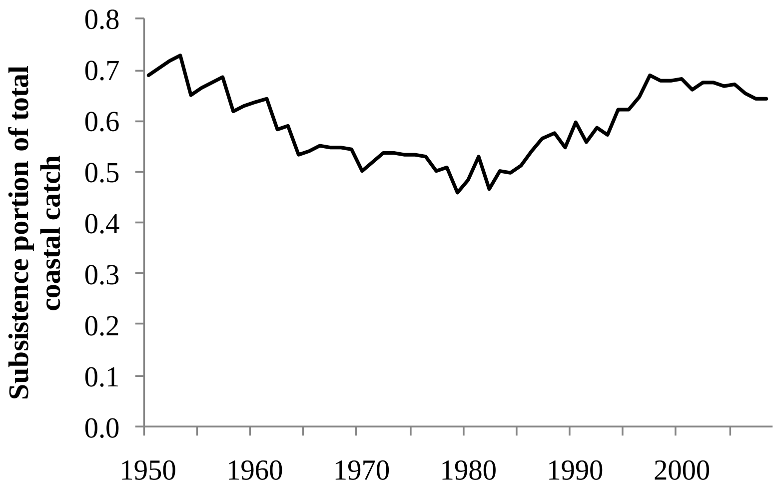

Figure 6. Subsistence portion of the total coastal catch, which includes artisanal and subsistence catches, 1950-2008.

The amount of baitfish caught for use in the pole-and-line fishery was estimated to be almost 3,500 t over the period 1964-1982 (Figure 4).

Discussion

The total reconstructed catch for Palau from 1950-2008 was estimated to be 200,817 tonnes. This estimate is 43% higher than the landings reported by FAO on behalf of Palau for this same period (140,483 tonnes). The difference between these two estimates is mainly attributed to the addition of subsistence catches, which were predominantly unaccounted for in the reported data.

Our work showed that subsistence catches represented an average of 60% of the total domestic catch. For the Pacific Islands region, in general, Adams and Dalzell (1994) estimate that the subsistence catch can represent as much as 80% of the total catch. Currently, an estimated 87% of people are involved in the fishing industry in Palau (Palau International Coral Reef Center, unpublished data in Golbuu *et al.*, 2005). In recent years there has been an increase in the amount of imported food in the Palauan diet (Johannes, 1981; Ota, 2006), but the results of this study show reliance on local reef fish remains high in Palau. The subsistence catch has increased, since 1950, mostly attributed to increase in population size. The subsistence catch will likely continue rising due to a growing population (Anon., 2003a). The majority of the domestic supply of fish in the 1950s was from the subsistence sector (70%) and although the portion of the total domestic catch supplied by subsistence fisheries declined during the 1970s and

1980s,—likely due to an increase in commercial exploitation of fisheries resources—the subsistence sector continues to dominate domestic fisheries catches. The under-reporting of subsistence catches may adversely affect food security in Palau given the importance of this sector to the Palauan culture and diet. Nichols (1991) notes that one species in particular, the humphead wrasse (*Cheilinus undulatus)*, is rarely sold due to a strong preference for this fish in the local diet. It is caught in unknown amounts and usually kept for home consumption. A lack of monitoring and reporting of species important to the subsistence fishery, such as *C. undulatus*, could lead to the silent extirpation of species from Palau's reefs.

The commercial offshore catches in Palau were well documented from 1937-1944 by the Japanese Office of the Chief of Naval Operations. The average catch during this time was approximately 3000 tonnes (Anon., 1944). During WWII, all commercial offshore fishing ceased. Catches prior to WWII, while being quite substantial, are not included as they fall outside the time period considered for this study. Recording of pelagic species, mostly skipjack, began in 1964. From 1964-1982 Van Camp Seafoods operated in Palau, and the catches are well documented in Lawson (1991).

Our estimate of total catches is likely still an under-representation of the actual annual catch due to the conservative approach employed in our estimations and the omission of the recreational fishery sector. The South Pacific Commission (1999) estimates roughly 8.3 t of billfish are taken annually in game fish tournaments in Palau. The major species taken in this fishery are blue marlin (*Makaira nigricans*), black marlin (*Makaira indica*), striped marlin (*Tetrapturus audax*), and sailfish (*Istiophorus platypterus*). Recreational fishing is on the rise in Palau as tourism increases (Nichols, 1991). Better documentation of this fishery is recommended for the conservation of billfish in Palau's EEZ.

Multiple studies have estimated Palau's offshore, artisanal, subsistence and invertebrate fisheries separately; however, this study is the first to combine all these sectors into one comprehensive estimate with a continuous time series from 1950-present. This study revealed some major deficiencies in the availability of fisheries data covering all sectors, with a particular scarcity of data on the subsistence sector, which could be argued is the sector most important to day to day existence of the Palauan people. Our comprehensive estimate of total marine fisheries catches for Palau will hopefully serve as a more realistic baseline from which fisheries management options and tradeoffs can be assessed.

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Appendix Table A1: FAO landings vs. total reconstructed catch for Palau, 1950-2008, in metric tonnes.

Year	FAO landings	Total reconstructed catch
1950	300	863
1951	300	903
1952	300	942
1953	300	982
1954	400	1,021
1955	400	1,061
1956	400	1,100
1957	400	1,140
1958	500	1,167
1959	500	1,195
1960	500	1,222
1961	500	1,250
1962	600	1,277
1963	600	1,304
1964	1,866	2,542
1965	3,370	4,130
1966	3,386	4,174
1967	4,106	4,915
1968	5,756	6,621
1969	5,462	6,309
1970	8,882	9,811
1971	2,943	3,703
1972	2,319	3,118
1973	3,150	3,971
1974	7,608	8,588
1975	7,069	8,026
1976	6,136	7,051
1977	4,883	5,705
1978	10,602	11,647
1979	6,699	7,507
1980	7,516	8,423
1981	10,276	11,396
1982	5,053	5,874
1983	1,041	1,796
1984	1,037	1,808
1985	1,100	1,926
1986	1,100	2,002
1987	1,100	2,083
1988	1,100	2,132
1989	1,090	2,065
1990	1,076	2,201
1991	1,093	2,170
1992	1,271	2,447
1993	1,211	2,388
1994	1,086	2,436
1995	1,027	2,421
1996	1,000	2,512
1997	913	2,585
1998	952	2,640
1999	962	2,672
2000	1,097	2,807
2001	1,086	2,727
2002	1,030	2,714
2003	1,050	2,740
2004	1,081	2,685
2005	935	2,517
2006	969	2,473
2007	986	2,437
2008	1,008	2,492

AppendixTableA2: Total reconstructed catch (t) for Palau by major taxa.Others category represents 58 taxonomic groups including miscellaneous marine fishes.

Year	*Katsuwonus pelamis*	Lethrinidae	*Hipposcarus longiceps*	*Lutjanus gibbus*	*Thunnus albacares*	*Siganus lineatus*	*Siganus* spp.	Others
1950	-	53	63	46	-	57	43	601
1951	-	55	66	48	-	60	45	629
1952	-	58	68	51	-	62	47	657
1953	-	60	71	53	-	65	49	684
1954	-	62	74	55	-	67	50	712
1955	-	65	77	57	-	70	52	739
1956	-	67	80	59	-	73	54	767
1957	-	70	83	61	-	75	56	794
1958	-	71	85	63	-	77	58	814
1959	-	73	87	64	-	79	59	833
1960	-	75	89	66	-	81	60	852
1961	-	76	91	67	-	83	62	871
1962	-	78	93	69	-	84	63	890
1963	-	80	95	70	-	86	64	909
1964	1,025	81	97	72	141	88	66	972
1965	2,497	83	99	73	173	90	67	1,048
1966	2,615	85	101	74	71	92	69	1,068
1967	3,354	84	100	74	52	91	68	1,090
1968	5,039	84	100	74	17	91	68	1,148
1969	4,629	84	99	73	133	90	68	1,133
1970	8,081	87	103	76	1	94	70	1,297
1971	2,133	90	108	79	10	98	73	1,112
1972	1,463	94	112	83	56	102	76	1,132
1973	2,309	94	111	82	41	101	76	1,157
1974	6,647	93	111	82	161	101	75	1,319
1975	5,971	93	111	82	298	101	75	1,297
1976	4,911	93	110	82	412	100	75	1,268
1977	3,592	93	110	81	420	100	75	1,234
1978	9,391	92	110	81	303	100	75	1,495
1979	5,687	92	110	81	1	100	75	1,361
1980	5,580	96	114	84	996	104	77	1,372
1981	6,931	99	117	87	2,480	107	80	1,495
1982	3,438	102	121	90	615	110	82	1,316
1983	75	105	125	92	-	114	85	1,199
1984	32	126	148	151	-	106	80	1,164
1985	82	130	152	156	15	110	82	1,199
1986	112	133	156	159	19	112	84	1,227
1987	139	136	160	164	22	115	86	1,260
1988	119	140	165	168	38	118	89	1,295
1989	72	141	166	169	5	119	89	1,303
1990	80	161	159	162	8	114	86	1,428
1991	-	168	163	169	-	119	89	1,460
1992	61	177	167	175	62	123	92	1,588
1993	-	189	171	182	39	127	95	1,583
1994	-	206	178	192	31	134	100	1,592
1995	-	220	178	193	3	135	101	1,594
1996	-	234	184	203	2	142	106	1,640
1997	-	253	195	217	1	151	113	1,654
1998	-	278	195	221	1	154	115	1,677
1999	-	283	196	225	1	156	117	1,694
2000	-	290	193	225	63	156	116	1,762
2001	-	296	187	220	41	152	114	1,721
2002	-	305	187	223	3	154	115	1,728
2003	-	317	186	225	19	155	116	1,733
2004	-	313	177	217	28	149	112	1,689
2005	-	317	172	214	0	147	110	1,557
2006	-	321	167	211	-	144	108	1,521
2007	-	325	163	209	-	143	107	1,491
2008	-	336	166	212	-	145	109	1,525

RECONSTRUCTION OF SRI LANKA'S FISHERIES CATCHES: 1950-2008[1]

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ABSTRACT

Sri Lanka has a long history of reliance on the sea for the nutritional and economic well-being of its people. Fishing has long been an important industry and, while detailed fishing records exist dating back to the early 1900s, they are incomplete. In this study, we estimated total marine fisheries catches for the 1950-2008 time period by accounting for all fisheries sub-sectors and components and compared this to the reported landings as provided to FAO. Our total reconstructed catch which included commercial and subsistence catches, and discarded bycatch was estimated at almost 18 million tonnes over the 1950-2008 time period. This estimate was over 2 times larger than the total landings reported by Sri Lanka to the FAO. The majority of this discrepancy was due to catches from the subsistence sector and discarded bycatch associated with shrimp trawl fisheries. Improved monitoring of, and record-keeping for, these fisheries components is crucial to the longterm management of Sri Lanka's fisheries and to maintaining livelihoods and food security of the Sri Lankan people.

INTRODUCTION

The Democratic Socialist Republic of Sri Lanka is an island country southeast of India within the Bay of Bengal (Figure 1). The climate is tropical with seasonal monsoon and cyclones, but no upwelling. In 2009, the population was 20 million (Anon, 2009) with 32 percent living in coastal areas (UNEP, 2001). The Sri Lankan Exclusivity Economic Zone (EEZ) lies within FAO statistical area 57 (FAO, 2011).

The island was colonized by the Portuguese and the Dutch, but most influentially by the British. Sri Lanka, or "Ceylon" as it was known prior to 1972, was a strategic military and trade link between West Asia and Southeast Asia. It acquired independence from the British Empire as the Dominion of Ceylon in 1948, just after World War II. In 1972, Ceylon became a republic and the name was changed back to the pre-colonial name: Sri Lanka (De Silva, 1981).

Attempts to record fisheries data in Sri Lanka may have begun during British rule; however, a rigorous island-wide attempt to estimate total landings did not start until after independence. Since 1910, general fisheries information was recorded by the resident marine biologist as part of an annual fisheries administration report. These reports included descriptions of traditional fisheries, destructive practices, fisheries regulations, results of test fisheries, policy changes, and financial record keeping; yet, information regarding landings on the island was incomplete (Pearson, 1911; 1922). By the 1930s, the importance of quantifying total landings was recognized, and by the 1940s, efforts to quantify landings were well underway with the appointment of 12 fisheries inspectors (FIs) within 20 fisheries districts. In the early 1950s, the number of FIs was increased to 24. The first comprehensive annual report of total landings was published in 1952 by the Department of Fisheries (DOF); the reports were, from then on, published annually (reviewed in Sivasubramaniam, 1997).

Records of landings in the 1950s focused mainly on the traditional practice of beach seining as it accounted for approximately 40% of total landings (Canagaratnam and Medcof, 1956). The use of the large beach seine, *madella*, began in the mid to late 1800s and continued to be the most commonly used traditional fishing techniques throughout the twentieth century (Alexander, 1977). Gillnetting began in the 1950s, and eventually took over as the most widespread fishing method for small-scale fishers. Incidents of

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illegal dynamite fishing and fish poisoning were also reported. The DOF showed great interest at this time in test fisheries, with special attention to experimental dredging for pearl and windowpane oysters, as well as trawler surveys (Sivalingam, 1961).

Artisanal and traditional fisheries in the 1950s could not meet the island's domestic demand for marine fish. Thus, markets were supplemented with cheap imports of predominantly dried fish products from Pakistan, Japan, and India. Sri Lanka was not a large exporter of marine fish with the exception of a small market in Thailand and Singapore for shark fins, sea cucumbers and ornamental shells called 'chanks' (*Turbinella pyrum*). Domestic marine fish production and export capacity were limited by poor infrastructure, most importantly the lack of ice and salt at landing sites, and inefficiencies attributed to the traditional nature of the fishery. In an attempt to improve upon traditional methods, the DOF imported nylon nets and implemented the development of a craft motorization program (Canagaratnam and Medcof, 1956). Subsidies for 11,000 outboard motors and the introduction of 17-23 foot fibre-reinforced plastic (FRP) boats were credited for the subsequent high annual growth rate of Sri Lanka's fisheries that lasted until the beginning of civil war in 1983 (RAPA, 1989). In the last few decades, there has been an effort to augment pelagic fisheries though government assistance to increase the number of multiday vessels capable of fishing offshore and in international waters.

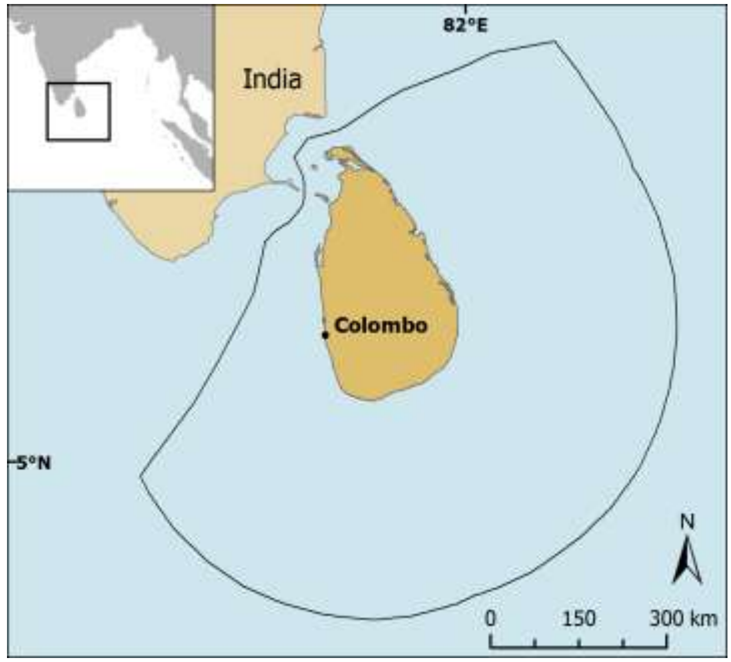

Figure 1. Map of Sri Lanka and ts Exclusive Economic Zone.

With the aid of the FAO, statistical methods again improved in the 1970s with the removal of the position of statistical officer and the appointment of an additional 143 FIs, while a new sampling system was also adopted that utilized landing centers as primary sampling units, and boats as secondary sampling units. In 1981, the National Aquatic Resources Research and Development Agency (NARA) was established with the mandate to improve research and development, with an emphasis to better understand tuna biology and catch statistics by way of a collaborative effort with the Indo-Pacific Tuna Programme (IPTP), the Bay of Bengal Programme (BOBP), the Food and Agriculture Organization (FAO) and the Asian Development Bank (ADB) (Dayaratne and Maldeniya, 1996). Gillnetting, a practice that had become popular in the 1960s, continued as a favorite of Sri Lankan fishers and by the 1970s, was accountable for 60% of reported fisheries catches.

Shortly after the establishment of NARA, civil war broke out between the Liberation Tigers of Tamil Eelam (LITE) and the Government of Sri Lanka (GoSL). The effect of the war on fisheries was considerable, especially in the north where restrictions (e.g., a ban on outboard motors greater than 40 hp, Maldeniya, 1997b) on fishers were put in place to prevent fuel and weapons from being illegally brought from India by the LITE. Additionally, the conflict led to the destruction of boats, gear, and infrastructure which included ice making facilities and highways important for fish transport to distant markets (Silucaithsam and Stokke, 2006). The northern fishing grounds, once responsible for producing over 40% of the country's reported landings, were the most productive and accessible fishing grounds in Sri Lanka due to the presence of a large continental shelf and a trawlable bottom (Engvall *et al.*, 1977).

The 1990s saw an increase in reported landings due to improvements in the security situation in some areas of the north and the expansion of the fishing fleet offshore and internationally. By the 1990s, government officials recognized coastal resources were fully exploited, and efforts were shifted to expanding the potential of deep sea fisheries by providing boat and equipment subsidies (Mallikage, 2001). For billfish, this was attributed to improvements in gear and the expansion of fisheries into offshore and deep sea areas (Maldeniya *et al.*, 1996).

Methods for improvement of catch statistics have been made in the 2000s, but overall, they remained the same since the changes made in 1981. The demand for marine fish has remained high, with a catch that was insufficient to meet demand. Despite the increase in multiday fishing vessels and other larger craft a large component of the marine fishing fleet continues to consist of small FRP boats with outboard motors as well as non-motorized traditional craft (FAO, 2006). The tsunami in December 2004 seriously affected 90% of the fishing community through losses of boats, fishing nets, housing, and lives. Eighty percent of fishing villages were completely destroyed, along with 12-14 fishing harbors (ITDG, 2005). Post-tsunami efforts to rebuild fisheries have resulted in an overabundance of fishing boats in some areas raising concerns for overfishing (Jayasuriya *et al.*, 2005).

With the end of the civil war in 2010, efforts to increase fisheries production in the north were a high priority for the DOF. Growing domestic demand for seafood and the potential for substantial earnings from seafood exports appear to be the driving force behind current fisheries policy, with plans to double marine fisheries production in the future. Apart from increasing landings, offshore fisheries have been identified as a more viable source of high value export oriented species such as tuna. The lack of adequate offshore fishing capacity has been seen as a major obstacle to fisheries expansion, and there have been initiatives to allow commercial fishing by foreign vessels in exchange for access fees and prescribed landings in order to increase domestic fish supply (Anon., 2010).

Small-scale subsistence fisheries are often not considered when collecting fisheries statistics; however, they can constitute a large portion of actual catches (Zeller *et al.*, 2007). The goal of this study was to more accurately quantify total marine fisheries catches, by taking into account all fisheries sub-sectors and components, including subsistence catch and discarded bycatch. The importance of fisheries to the livelihoods of Sri Lankan's, particularly coastal dwellers, requires a more comprehensive estimate and accounting of the true magnitude of fisheries extractions.

METHODS

Total marine fisheries catches were estimated using information obtained from national reports, independent studies, local experts and grey literature. Landings data presented by the FAO on behalf of Sri Lanka were compared to national landings data, and household surveys were used to estimate total demand for domestic seafood as compared to local supply. We also estimated discarded bycatch for the shrimp trawl and tuna longline fisheries. In this report we refer to 'landings' as the amount of fish caught, brought to shore and recorded, while 'catch' refers to the total amount of fish caught, and includes Illegal, Unreported and Unregulated (IUU) catches and discarded bycatch.

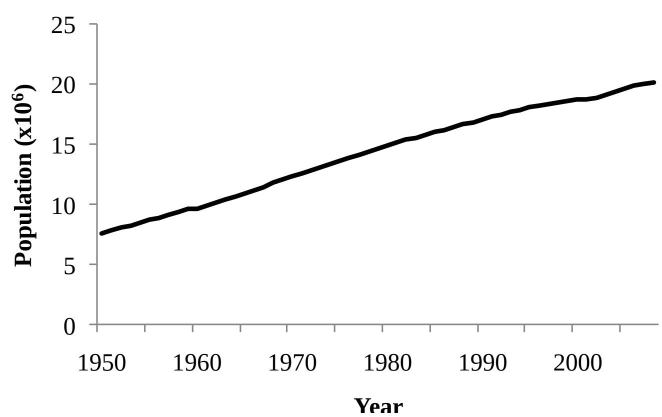

Figure 2: Human population trend for Sri Lanka. Data source: www.populstat.info and World Bank (Anon, 2009).

Population

Human population data were obtained for the 1950-1959 period from Populstat (www.populstat.info) and for the 1960-2008 time period from the World Bank (Anon, 2009). Population estimates were used to derive *per capita* marine supply and subsistence catch rates. The population of Sri Lanka has increased steadily from 7 million in 1950 to over 20 million in 2008 (Figure 2).

Commercial fisheries

Total commercial landings for Sri Lanka were available in nationally published reports as well as by the FAO; however, the national data contained a statistical error causing landings to be high for years prior to 1970 (Pathirana, 1972); landings reported to FAO and obtained from FAO FishStat were lower than nationally reported landings prior to 1970 (Figure 3). Therefore, it was assumed that the statistical error in the national data was accounted for and corrected in landings presented in FAO's FishStat. Landings presented by the FAO were also more complete from 1980-1990, where national landings data were sparse. FAO data for crustaceans were compared to prawn and lobster landings presented by NARA. For the 1994-2002 time period, prawn and lobster landings were used in place of the FAO's 'miscellaneous marine crustaceans' grouping, as they were deemed to be a better representation of total crustacean catches (Figure 5). Marine crab fisheries, although known to occur in Sri Lanka, were assumed to be contained within a new, but smaller miscellaneous crustaceans category as no data was available to determine catch. With the exception of the amendment to crustaceans landings, the remainder of the FAO data was considered a good representation of commercial fisheries landings, both for the artisanal and industrial sectors. These landings were used as a baseline, to which we added components not accounted for in the officially reported data. Noteworthy are two non-fishery related events which are correlated with a noticeable decrease in landings over the time period considered; the beginning of the civil war in 1983 and the tsunami which occurred on December 26th, 2004.

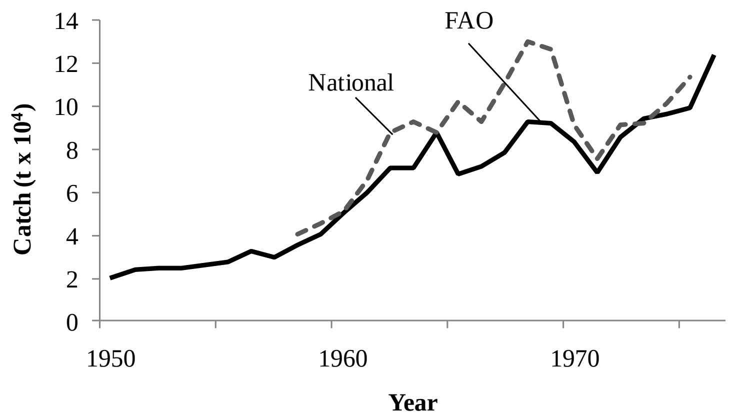

Figure 3: Comparison of landings data as presented by FAO and the national data source, indicating the statistical error in the national data, and its correction in data presented by FAO on behalf of Sri Lanka.

Discards

Shrimp trawl fisheries are typically associated with considerable bycatch, which can either be landed or discarded at sea. A study in the late 1970s estimated bycatch associated with the shrimp fishery in two of Sri Lanka's main shrimp trawling grounds, Jaffna and Mannar (Subasinghe, 1981). The study provided estimates for both the landed and discarded components of the bycatch. Subasinghe (1981) presents discard rates for both areas, which gave an average rate of 10.2 kg of discards per kg of shrimp landed for 1979 (Discard rates for Mannar and Jaffina were 8.92 and 11.48 kg discarded per kg landed, respectively). These two regions were responsible for 60% of the commercial production of shrimp that year (Subasinghe, 1981; Saila, 1983). Therefore, we assumed that this discard rate was representative of Sri Lanka's shrimp trawl fisheries and applied the rate of 10.2 kg discards per kg of shrimp landed across the entire time period. Discards may have been even higher in earlier time periods due to greater benthic biomass and/or less storage capacity on vessels for non-target species; however, to remain conservative we held the discard rate constant back in time to 1950. For the recent time period, we carried the 1979 discard rate forward, unaltered, to 2008. This same study reported that over 80% of the discarded catch was silverbellies (Leiognathidae); we considered the remainder to be miscellaneous small pelagic fishes and miscellaneous sharks.

Table 1. Estimated seafood consumption rates derived from the Department of Census and Statistics 2007 Household Income and Expenditure Survey.

Year	***Per capita* demand ($kg \cdot person^{-1} \cdot year^{-1}$)**
1981	19.39
1986	18.24
1991	14.64
2002	19.86
2005	24.12
2007	24.12

Depending on the type of gear used, bycatch is also of concern for tuna fisheries. The majority of tuna catches in Sri Lanka are skipjack tuna (*Katsuwonus pelamis*), representing roughly 60% of tuna catches and yellowfin tuna (*Thunnus albacares*), representing approximately 20% of the tuna catches. Tuna are predominantly caught using gillnets, although, longlines are becoming increasingly popular for catches aimed at the export market (Maldeniya, 1997b). Kelleher (2005) estimates discards by tuna longline in Sri Lankan waters to be 0.05%. Given that this was a very low discard rate, and given that we were unable to determine the portion of the tuna catch taken by longline, we did not estimate this component of the bycatch. As for bycatch associated with the tuna gillnet fisheries, information was also quite sparse. Due to the size of the nets used, incidental catch in the tuna gillnet fishery is mainly seerfish, billfish and shark. Given that these are marketable species, we assumed that the majority of the non-targeted catch for the tuna gillnet fishery was retained and that this portion of the catch was accounted for in the landings data.

Subsistence fisheries

We assumed that the subsistence component of small-scale fisheries was unaccounted for in the reported data. To estimate this component of the total catch, we calculated the island-wide marine seafood demand using *per capita* consumption data from the 2007 Department of Census and Statistics Household Income and Expenditure Survey (Anon, 2007); and compared this to the reported (commercial) landings presented by the FAO. We considered the difference between the supply of marine products for human consumption and the demand for seafood to be the subsistence catch.

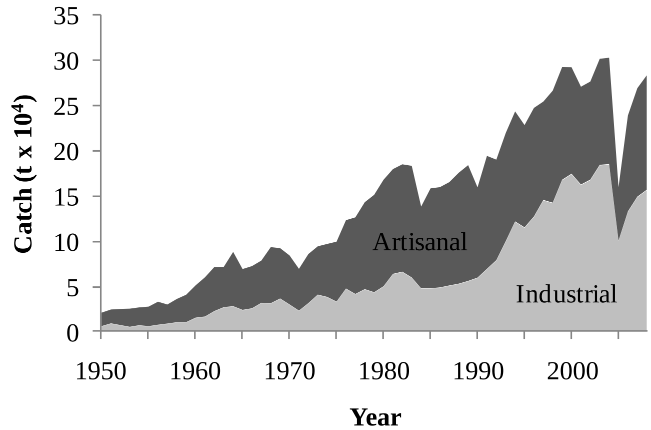

Figure 4: Total commercial fisheries catches for Sri Lanka, separated by industrial and artisanal fisheries, 1950-2008.

The supply of marine products available for consumption by the local population was estimated as the commercial landings (FAO data) adjusted for imports and exports (W. Swartz, unpublished data, UBC Fisheries Centre). These adjusted landings were then converted to *per capita* supply rates using human population data.

To estimate marine demand, the *per capita* marine fish consumption was obtained from the 2007 Sri Lanka Department of Census and Statistics Household Income and Expenditure Survey (HIES). A detailed breakdown of *per capita* consumption of marine products was available for 2007 only. The *per capita* consumption of fish, which included aquaculture and freshwater products, was summarized in the 2007 survey for the years: 1981, 1986, 1991, 2002, and 2005. In order to remove aquaculture and freshwater consumption and calculate marine consumption, we assumed that the ratio of freshwater and aquaculture consumption to marine fish consumption remained the same over the entire survey period. This assumption resulted in a conservative estimate of *per capita* marine consumption as aquaculture and freshwater fish consumption have likely increased since the 1980s. However, in order to remain conservative, the amounts removed were assumed to be proportional to those in 2007. Conversion factors provided by the FAO for Indonesia (FAO, 2000) were used to convert product weight from the 2007 HIES into live weight. The resulting *per capita* seafood consumption rates for 1981, 1986 and 2007 were used as anchor points to derive a complete time series of consumption rates for the 1950-2008 study period (Table 1). We did not use the 1991 and 2002 estimates of *per capita* consumption since these points exactly matched FAO reported landings when they were multiplied by the human population. These points were likely estimates of *per caput* consumption (reported landings divided by the population) and hence left out

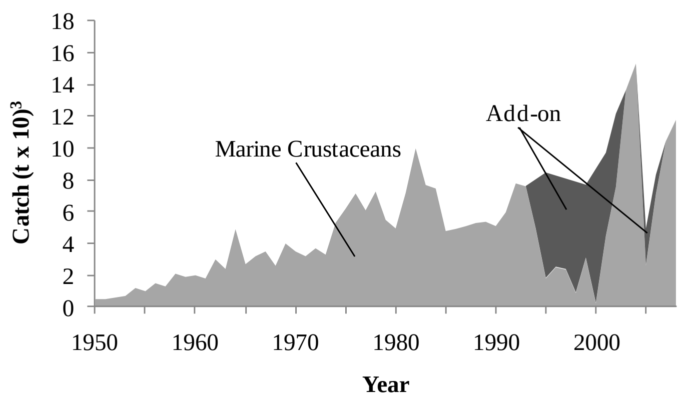

Figure 5: Reported landings of marine crustaceans (light colour) and the additional estimated catches during the 1990s and early 2000s.

of the analysis. We assumed that the consumption rate in 1950 was the same as that in the 1980s, and therefore carried the 1981 rate of 19.39 kg·person^{-1}·year^{-1} back, unaltered to 1950. The 2007 estimate was carried forward to 2008. Years between anchor points were interpolated linearly. Finally, we subtracted the *per capita* marine supply (FAO landings adjusted for imports and exports) from the total *per capita* seafood demand to determine the *per capita* subsistence catch rate. Human population data were then used to convert *per capita* subsistence catch rates into total subsistence catch amounts. This calculation was not done for 2005 since, although the 2005 consumption estimate was thought to be reasonable, the reported landings were low due to the tsunami, which was likely the result of both fewer catches and poor reporting. The subsistence catch rate for the year following the tsunami (2005) was estimated by linear interpolation between the 2004 and 2006 subsistence catch rates and then was reduced by the same percent decline in catch (42%) as reported by the FAO for landings between the years 2004 and 2005. It is possible that subsistence was underestimated for anchor points following the beginning of civil conflict in 1983 as it is unlikely surveys included regions at war. The 2007 HIES states that Trincomalee and the Northern Province, known for high marine productivity and possibly higher *per capita* consumption, were not sampled in 2007 due to active conflict in these areas; consequently, it is likely the *per capita* consumption and hence the subsistence catch estimates are conservative.

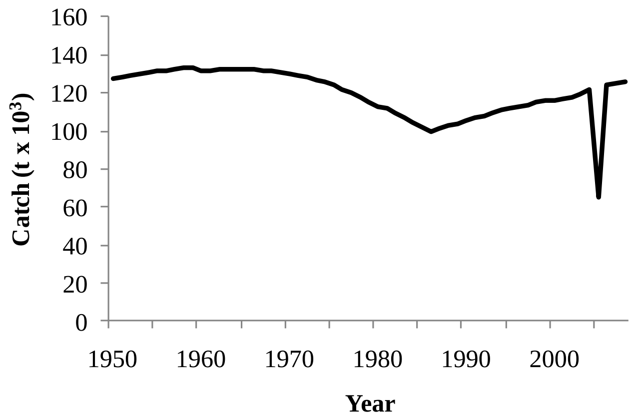

Figure 6: Reconstructed total subsistence catches for Sri Lanka, 1950-2008.

Subsistence catches were assumed to be composed of small pelagic species (50%), demersal species (40%) and invertebrates such as crabs and cephalopods (10%). The small pelagic species caught were mainly clupeids and scombrids, with the most common species being *Sardinella gibbosa*, *S. albella, Amblygaster sirm, A. clupeoides, Rastrelliger kanagurta,* and *Auxis thazard*. Demersal species catches were mainly represented by Lethrinidae, Carangidae, Myliobatidae, Sciaenidae, Haemulidae, Leognathidae, and Acanthuridae (Canagaratnam and Medcof, 1956; Maldeniya, 1997a; MFAR, 2008). Industrial and artisanal catches were also improved for FAO "crustaceans nei" utilizing assumptions based on Jayawardane *et al.* (2003). The species breakdowns for lobster and sea cucumbers were also improved based on local expert opinion (N. Perera, pers. obs., Linnaeus University)

Other IUU components

While catches of sea cucumbers and sharks are reported in the official landings data, they are likely under-estimates. Unreported catches of sea cucumbers and sharks are common in Sri Lankan waters; however, data on these were not readily available. Although we were unable to account for this unreported component as part of the reconstructed catch, it should be noted that IUU fishing is known to occur in Sri Lanka and should be further investigated (P. Ganapathiraju, pers. comm., UBC Fisheries Centre).

RESULTS

Commercial fisheries

Total marine fisheries catches by the commercial sector (artisanal and industrial) were estimated to be 8.4 million tonnes over the 1950-2007 time period (Figure 4). Catches in 1950 were approximately 20,000 t·year^{-1} and increased steadily to over 300,000 t·year^{-1} in 2004. This was followed by a substantial decrease in catches to around 15,000 tonnes in 2005, the year after the tsunami devastated Sri Lanka. Total commercial catches were composed of small- (artisanal) and large-scale (industrial) sectors, which represented 55% and 44%, respectively of the total commercial catch. The total commercial catch included over 50,000 tonnes of additional crustaceans, which were not represented in the reported landings as presented by FAO (Figure 5). Catches of marine crustaceans were estimated to be 320,000 tonnes for the period 1950-2008. These were mainly shrimp (75%) and lobster (9%), with the remainder being miscellaneous marine crustaceans. Discards associated with the shrimp trawl fishery were estimated over the study period to be approximately 2.4 million tonnes (Figure 8).

Subsistence Fisheries

Total catches by the subsistence sector were estimated to be over 7 million tonnes from 1950-2008 (Figure 6). Subsistence catches remained relatively stable over the entire study period with an average annual catch of around 120,000 t·year^{-1} (Figure 8). A decrease in subsistence catches was observed for the late 1970s and early 1980s, but they increased again after that.

Total reconstructed catch

The total reconstructed catch of marine fisheries in Sri Lanka was estimated to be almost 18 million tonnes over the 1950-2008 time period (Figure 7). This estimate of total catches was 2.13 times larger than the landings officially reported by Sri Lanka to the FAO. Reported landings, as presented by the FAO on behalf of Sri Lanka were 8.4 million tonnes. The subsistence catch represented 40% and discards represented 13% of the total estimated catch (Figure 8). The remainder of the total catch was from the artisanal (26%) and industrial (21%) sub-sectors of commercial fisheries. The estimate for commercial catch was almost entirely based on reported landings, while the subsistence and discards were entirely unreported components. Major contributing taxa in the reconstructed catch included silverbellies (Leiognathidae), skipjack tuna (*Katsuwonus pelamis*), herrings, sardines, and anchovies (Clupeoids), jacks (Carangidae), and yellowfin tuna (*Thunnus albacares*; Figure 9).

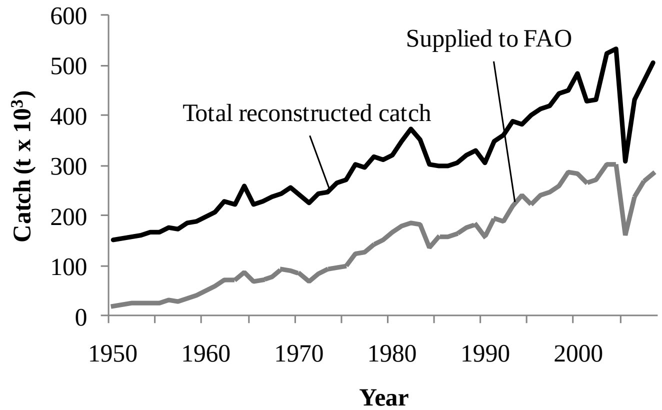

Figure 7: Total reconstructed catches compared to the data submitted by Sri Lanka to FAO, 1950-2008.

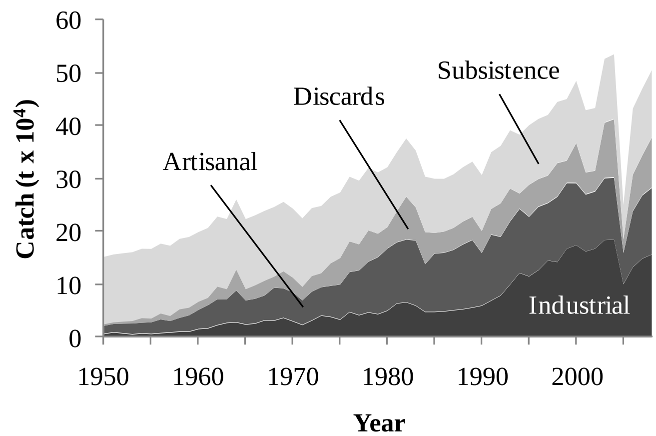

Figure 8: Total reconstructed catches for Sri Lanka by component or fisheries sector, 1950-2008.

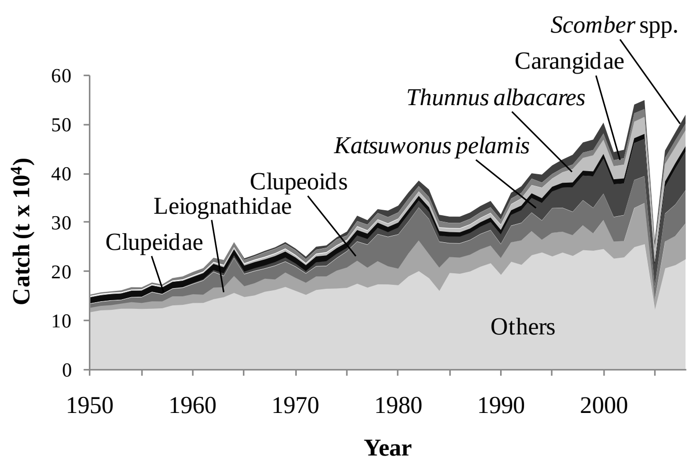

Figure 9: Total reconstructed catches with main taxa caught. All other taxa (88 total) were grouped into 'Others' category.

DISCUSSION

Total marine fisheries catches for Sri Lanka were estimated to be approximately 18 million tonnes over the 1950-2008 time period. This estimate was over 2 times larger than the landings reported by Sri Lanka to the FAO, which was approximately 8.4 million tonnes. This large discrepancy indicates a clear need for improvements in the collection and reporting of fisheries statistics in Sri Lanka. Our investigation into the fisheries of Sri Lanka revealed that information on subsistence fisheries, discarded bycatch and other IUU components was quite limited, even though these fisheries components contributed substantially to overall marine fisheries catches. Subsistence fisheries catches were the largest unreported component of the catch, and represented 40% of the total reconstructed catch.

Discards from the shrimp trawl fishery were also a substantial contributor (13%) to the total catch, and was unaccounted for in the official data. The high rate of discarding in Sri Lankan shrimp trawl fisheries has been attributed to the limited cold storage facilities on multi-day boats. Economically important species are often stored while other less valuable species are discarded. However, the majority of the bycatch consists of low-valued species of Leiognathidae, which are typically discarded (Subasinghe, 1981). Tuna longline fisheries, on the other hand, have a much lower discard rate (0.05%) according to Kelleher (2005). This low rate of discarding is thought to be due to fishers targeting and landing multiple species of high economic importance, thus reducing the amount of discarded fish (Kelleher, 2005). Beach seining in the early period (1950s) was reported to have few discards, with the exception of jellyfish which were known to seasonally clog nets (Canagaratnam and Medcof, 1956).

The year following the tsunami, reported landings were significantly lower, even though seafood consumption remained constant. Although DOF offices were badly damaged by the tsunami and efforts were directed into emergency measures rather than accounting for landings, it is likely catches also decreased, especially in small-scale and subsistence fisheries as they sustained a large amount of damage. An assessment of the impacts of the tsunami on coastal fishers suggested that fishing pressure may have initially decreased in 2005, but then increased to pre-tsunami levels caused by excessive replacement gear and vessels donated to local fishers as part of the relief effort (De Silva and Yamao, 2007).

Illegal, unreported and unregulated fisheries are known to occur in Sri Lankan waters. For example, the transshipments of shark fins caught in Sri Lanka's EEZ occur regularly. Most Sri Lankan vessels lack adequate refrigeration capacity and will therefore trade sacks of shark fins to foreign vessels at sea, which allows them to empty their hold and continue fishing while at sea. Such catches are not included in any reporting mechanism. Sri Lankan vessels also participate in the poaching of sharks and sea cucumbers, which are caught illegally outside of Sri Lanka's EEZ in the poorly regulated waters of Somalia, Madagascar, and the Seychelles, and are then landed in Sri Lanka. These catches are reported as domestic landings, but this is not necessarily the case. A lack of enforcement and proper reporting has allowed these IUU fisheries to continue and possibly expand over time (P. Ganapathiraju, pers. comm., UBC Fisheries Centre). Additionally, foreign vessels, in particular Indian vessels, engage in illegal fishing within Sri Lanka's EEZ and these catches are not reported for Sri Lanka.

Previous attempts to estimate the potential sustainable yield in Sri Lankan waters suggested harvest rates of 250,000 $t \cdot year^{-1}$, with around 80,000 t allocated to demersal species catches and 170,000 t for pelagic species (RAPA, 1989). Our reconstructed catches indicate that this level was likely surpassed as far back as 1974. In this study we highlighted the lack of proper accounting for total fisheries catches, which in the case of the subsistence sector accounted for almost half of the domestic marine food supply. Without a realistic estimate of what is being extracted, fisheries are likely to be mismanaged and possibly overexploited. Although human and financial resources may not be available to establish and maintain in depth monitoring programs, regular surveys conducted every few years have been found to be very effective in estimating subsistence and small-scale catch in other developing countries (Brouwer *et al.*, 1997; Zeller *et al.*, 2006).

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Appendix Table 1. FAO reported landings vs. total reconstructed catch for Sri Lanka, 1950-2008, in metric tonnes.

Year	FAO landings (t)	Total reconstructed catch (t)
1950	20,622	151,813
1951	24,103	156,210
1952	24,709	158,421
1953	25,016	160,496
1954	26,433	166,998
1955	27,265	166,716
1956	32,702	176,616
1957	29,638	172,670
1958	35,737	185,640
1959	40,434	189,190
1960	50,775	198,438
1961	59,717	206,182
1962	71,137	227,544
1963	71,256	222,926
1964	87,796	259,676
1965	68,836	222,888
1966	72,083	230,049
1967	78,225	238,398
1968	93,080	245,640
1969	91,936	255,295
1970	83,855	242,466
1971	69,074	224,345
1972	85,438	243,631
1973	93,972	247,627
1974	96,608	264,940
1975	99,110	273,005
1976	122,870	302,695
1977	126,000	295,302
1978	142,768	319,436
1979	150,934	310,821
1980	167,594	320,543
1981	179,398	348,908
1982	184,664	374,713
1983	183,005	352,116
1984	137,909	302,847
1985	158,065	298,884
1986	159,437	298,798
1987	164,998	307,197
1988	175,347	320,621
1989	183,773	331,133
1990	159,173	305,788
1991	193,989	349,006
1992	189,939	360,916
1993	219,447	390,223
1994	240,307	381,993
1995	222,170	399,668
1996	242,031	411,686
1997	248,790	419,199
1998	259,746	443,709
1999	288,301	449,153
2000	284,314	483,307
2001	265,749	428,117
2002	271,927	432,235
2003	302,082	524,880
2004	303,168	533,482
2005	160,142	251,821
2006	239,292	432,512
2007	270,176	468,803
2008	285,028	503,501

Appendix Table 2. Total reconstructed catch (t) by major taxa for Sri Lanka, 1950-2008. Clupeoids include herrings, sardines, and anchovies. Others includes 86 taxa

Year	Leiognathidae	Clupeoids	*Katsuwonus pelamis*	Clupeidae	*Thunnus albacares*	Carangidae	*Scomber* spp.	Others
1950	10,457	8,000	771	12,715	774	2,543	0	116,553
1951	10,511	8,000	890	12,807	1,150	2,561	0	120,290
1952	11,125	9,000	807	12,887	903	2,577	0	121,122
1953	11,748	7,100	723	12,983	655	3,697	0	123,591
1954	14,638	9,500	720	13,087	606	4,717	0	123,730
1955	13,537	11,600	717	13,137	557	4,027	0	123,140
1956	16,390	18,300	981	13,180	720	3,436	0	123,609
1957	15,303	14,100	1,245	13,253	883	3,351	0	124,536
1958	19,852	14,900	1,410	13,294	970	4,859	0	130,356
1959	18,749	17,000	1,576	13,341	1,055	5,968	0	131,502
1960	19,200	20,400	2,063	13,151	1,347	7,030	0	135,247
1961	18,094	28,400	2,551	13,192	1,639	6,838	0	135,467
1962	24,895	31,500	3,960	13,217	2,493	8,443	0	143,036
1963	21,509	22,400	5,369	13,228	3,348	9,846	0	147,226
1964	35,647	36,300	5,227	13,230	3,222	10,146	0	155,905
1965	23,203	24,200	5,084	13,224	3,096	6,545	3,000	147,536
1966	26,023	24,300	5,830	13,212	3,515	6,342	3,000	150,828
1967	27,706	20,000	6,576	13,190	3,931	8,638	3,000	158,357
1968	22,596	27,500	7,448	13,156	4,416	8,631	3,000	161,893
1969	30,482	21,700	8,322	13,105	4,901	8,621	4,000	168,164
1970	27,612	22,300	6,554	13,034	3,841	9,007	3,600	160,118
1971	25,861	18,400	4,785	12,942	2,783	7,588	5,100	151,986
1972	28,621	20,100	8,250	12,830	4,266	7,566	6,200	161,997
1973	26,281	20,600	9,919	12,700	5,244	8,440	4,900	164,443
1974	37,502	24,900	8,792	12,552	4,610	11,610	4,300	164,974
1975	42,447	32,530	6,937	12,387	3,771	8,637	7,994	166,294
1976	47,751	38,541	12,392	12,207	6,908	10,076	11,018	174,819
1977	41,644	46,278	11,583	12,010	5,806	11,192	9,179	166,788
1978	48,182	54,412	12,933	11,795	5,915	12,717	7,747	173,482
1979	37,957	59,276	9,692	11,557	6,555	12,440	13,388	173,344
1980	34,769	69,061	14,117	11,296	7,304	12,307	13,888	171,689
1981	47,292	64,479	15,196	11,151	8,068	12,796	12,906	189,926
1982	63,048	66,764	14,172	10,935	8,682	10,579	11,302	200,533
1983	49,864	70,971	14,649	10,705	9,264	10,726	15,518	185,937
1984	48,481	52,153	12,348	10,465	6,694	12,594	12,773	160,112
1985	33,183	27,682	13,699	10,217	7,160	10,139	13,000	196,803
1986	33,794	28,471	13,697	9,962	7,416	10,319	13,000	195,139
1987	34,848	29,460	14,442	10,108	7,785	10,638	13,000	199,916
1988	36,061	30,608	15,004	10,255	8,089	11,003	13,000	209,601
1989	36,590	31,064	16,500	10,400	8,727	11,165	13,000	216,687
1990	35,154	27,958	19,495	10,543	9,929	9,831	10,500	192,878
1991	40,141	33,426	21,990	10,683	11,934	11,112	12,000	219,721
1992	50,504	35,097	25,786	10,820	14,185	11,112	13,557	213,413
1993	49,542	37,379	29,692	10,951	16,478	13,068	10,854	233,113
1994	26,277	38,870	35,755	11,075	21,045	10,215	16,450	238,756
1995	48,498	49,785	33,915	11,190	16,499	9,148	17,642	230,633
1996	42,941	48,221	41,000	11,296	21,308	8,347	17,700	238,573
1997	42,681	47,200	50,012	11,393	27,094	9,179	20,000	231,641
1998	50,824	50,800	50,124	11,481	26,122	10,796	20,900	243,562
1999	35,840	51,370	64,316	11,562	32,767	10,992	21,350	242,307
2000	59,392	53,250	70,957	11,636	29,512	12,777	22,180	245,783
2001	35,461	49,270	66,692	11,698	26,522	12,290	16,760	226,183
2002	33,768	52,310	64,425	11,786	28,085	13,117	17,250	228,743
2003	79,929	56,390	75,146	11,954	34,425	17,331	17,760	249,705
2004	83,900	54,410	75,795	12,146	35,512	16,009	18,440	255,711
2005	21,620	24,870	44,938	6,489	24,887	7,248	9,680	121,769
2006	55,219	56,230	54,341	12,433	35,842	12,057	15,570	206,391
2007	59,779	63,520	73,240	12,524	32,998	13,885	16,290	212,857
2008	73,544	66,890	78,860	12,618	33,027	13,684	18,260	224,878

FROM LOCAL TO GLOBAL: A CATCH RECONSTRUCTION OF TAIWAN'S FISHERIES FROM 1950-2007[1]

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ABSTRACT

Taiwan's coastal fisheries were considered overfished in the 1950s, and, as a result, Taiwan expanded its fisheries into offshore areas and to distant-waters beginning in 1959. Taiwan's fisheries catches within its own EEZ increased until 1980, and total catches were estimated to grow from approximately 95,000 tonnes in 1950 to 575,000 tonnes in 1980. However, since 1980, total catches taken by Taiwan within its own EEZ have been in decline and were estimated to be only 290,000 tonnes in 2007. Although the catches taken within the EEZ have been in decline, the distant-water fisheries (DWF) have expanded into all major oceans. By the 2000s, they were 3 to 5 times larger than those from its own EEZ. Total catches of the distant-water fleet were estimated to increase from 110,000 tonnes in 1959 to 1.5 million tonnes in 2007. However, the continued expansion of the DWF is not likely sustainable due to the increased pressure on fisheries stocks globally, and because of the large amount of fuel subsidies the DWF receives.

INTRODUCTION

Taiwan ("Republic of China") is an island country located off the southeast coast of the People's Republic of China in the South China Sea (Figure 1). The west coast of Taiwan is separated from China by the relatively shallow Taiwan Strait and its east coast lies along the much deeper Philippines Sea. Taiwan has always relied on the sea for resources, and its fisheries are well developed and provide an essential source of food and income for its people.

Figure 1. Map of Taiwan and the exclusive economic zone (EEZ) it claims.

The population of Taiwan grew from approximately 7.5 million people in 1950 to approximately 23 million people in 2007 (Anon., 2009). The increasing population, and its seafood demand, the decline of near-shore resources, and the high level of pollution of inshore areas, have resulted in Taiwan's fisheries expanding into offshore waters and eventually to distant waters. Taiwan's diplomatic isolation has often caused problems during negotiations with neighbouring countries resulting in territorial disputes. Consequently, Taiwan's exclusive economic zone (EEZ) is highly disputed and frequently challenged (Figure 1; Chen, 2007).

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It is widely suspected that Taiwan, like a number of other countries, tolerates extensive Illegal, Unreported and Unregulated (IUU) fisheries, and thus the annual catches reported to the Food and Agriculture Organization (FAO) are minimum estimates that may omit significant catches. This report aims to provide a more accurate estimate of Taiwan's annual fisheries catches from 1950–2007 by including estimates of unreported catches and discards. Some catches, which contribute to the local or global supply of seafood, are often unreported for tax avoidance purposes, and are usually not included in assessments or quota considerations, which undermine fisheries management policies. Discards increase economic benefits for fishers by increasing profits, and are a form of fishing mortality that may not be accounted for, and therefore may lead to detrimental effects on exploited fish populations.

EEZ fisheries

Taiwan's fisheries have traditionally been considered as two distinct fisheries—the coastal and the "distant-water fisheries". The coastal fisheries operate up to the 12 nm territorial sea boundary, whereas the distant-water fisheries operated past the 12 nm demarcation of the coastal fisheries. However, Taiwan's definition of 'distant-water' changed with the expansion of the fisheries into all of the major oceans beginning in 1959, using gears such as trawl, longline, and purse seine. Thus, the distant-water fisheries were re-categorized as those operating in the far seas, and the fisheries around the waters of Taiwan were re-defined as 'coastal' and 'offshore'. Throughout this report we refer to the coastal and offshore fisheries as those operating in what is today considered to be within the Taiwanese exclusive economic zone (EEZ), and reserve the term distant-water fleet (DWF) for those fisheries operating outside the EEZ.

As an island country, Taiwan has extensively developed its fisheries for food security, but it has also used its fisheries to gain political influences. After World War II, Taiwan was faced with a growing population, food shortages, and a heavily damaged fishing industry (Huang and Chuang, 2010). During that time, Taiwan's inshore fishing grounds were already considered to be overfished, and in order to meet domestic demand, Taiwan began to expand its fisheries into distant waters because of the declining fisheries resources within its local waters (Chen, 2007).

Distant water fisheries

The growth of the post-war Taiwanese distant-water fishery after WWII was dictated by urgent economical and political needs. During the post-war period, there was a push towards an "Every Fisher Has His Boat" policy. As part of this policy, the government offered subsidies to encourage the purchase of fishing boats and to stimulate the launching of more boats (Chang *et al.*, 2010). The government also attracted investors for the DWF with the support of the United States Agency for International Development (USAID) and the World Bank during 1953 – 1973 (Chang *et al.*, 2010). Beginning in 1961, investments were directed towards Taiwan's DWF to support the production of large-scale longliners and trawlers (Chang *et al.*, 2010). At the same time, the construction of small trawlers was suspended in 1967 because of the drastic increase of fishing boats in the coastal region and depletion of coastal fisheries resources.

During the mid-1970s to early 1980s, the DWF was affected by two international oil crises, which increased the costs of operation and resulted in decreased landings in some years (Chang *et al.*, 2010). Also, many coastal nations declared EEZs starting in the late 1970s or early 1980s, and Taiwan's offshore fleets were prevented access to former areas of operation (Chen, 2007). Consequently, Taiwan began to focus on further expansions of the DWF resulting in an increase in landings from this fleet, while at the same time there was a decrease in landings from the offshore area of the Taiwanese EEZ.

From the mid-1980s to 1990s, the Taiwanese government continued to push for the growth of the DWF (Chang *et al.*, 2010). In 1983, a policy was implemented to suspend the building of all small-scale fishing vessels (< 1000 GRT) in order to develop the large-scale distant-water vessels (Chang *et al.*, 2010), i.e., high seas capable vessels. Beginning in the 1980s, the Taiwanese DWF also explored new gear types such as the squid drift net and tuna purse seine. The main fishery gear types consisted of tuna long line, purse seine, squid jig, saury stick held dip net, trawl, and large-scale tuna drift net fisheries (Chang *et al.*, 2010). The main species targeted during this time were yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), albacore (*Thunnus alalunga*), skipjack (*Katsuwonus pelamis*), and argentine squid

(*Illex argentinus*) (Chang *et al*., 2010). The massive deployment of drift nets, however, was short-lived as drift net fishing was banned by the UN in 1992 (Chen, 2007).

From the mid-2000s to the present, due to increasing problems of IUU fishing and vessels operating under flags of convenience, the Taiwanese longline fishery was sanctioned by the International Commission for the Conservation of Atlantic Tunas (ICCAT) in 2005. This was devastating to the Taiwanese distant-water fisheries, since longline vessels targeting bigeye tuna had their quota substantially reduced and Taiwan also lost its Cooperating Status in ICCAT. The sanctions imposed by ICCAT can, however, also be seen as an opportunity for Taiwan to reform its fisheries policies (Chang *et al*., 2010).

Discards

Discarding is a common practice within the fishing industry, and unwanted fish that have been caught are simply thrown back to sea. Discards can include damaged fish, non-target species, spoiled fish, and undamaged target species that are discarded to make room for more valuable ones (i.e., 'high grading'). Much of the global discards currently are influenced by economic incentives, especially in DWFs. Depending on the markets of the fishing country, catches may be fully retained or largely discarded. For Taiwan, only a rough estimate of discards is possible, as neither the FAO nor the Taiwanese Fisheries Agency (FA) documents discards.

Materials and Methods

FAO reports, on behalf of Taiwan, annual landings statistics through their fisheries capture database (Fishstat) since 1950. Internally, Taiwan has two sets of data relating to fisheries. National landing statistics by area and gear are available from 1959 to 2007 through Taiwan's Fisheries Agency (FA; www.fa.gov.tw) and a separate set of statistics are available from the Taiwanese Council of Agriculture, Executive Yuan that describe the food balance for the country from 1984 to 2007 (www.ttdais.gov.tw/view.php?catid=20242). The food balance statistics include the human population, domestic production for fish and seafood, imports, exports, and domestic supply, and are expressed in live weight equivalents. The sub-categories under the domestic production for fish and seafood include 'fish', 'shrimps and crabs', cephalopods, 'shell fish', 'others', and 'dried (salted) fish'.

A comparison between the national landings and FAO landings was conducted to determine the quality of data transfer from the Fisheries Agency (FA) to FAO. Freshwater fishes, corals, marine mammals, and seaweeds were removed from FAO landing statistics for the purpose of this comparison. Similarly, we excluded the freshwater fisheries and all aquaculture statistics from the FA national landings. The data from FA were also compared to the food balance data for the period 1984 – 2007 when published statistics are available.

The domestic production from the food balance data was converted into estimates of annual national catches by the following formula:

Catch = Domestic Production + Export - Import - Marine Culture - Freshwater Culture - Inland Catch ...1)

The marine culture, freshwater culture, and inland catch statistics were taken from the FA's national landing statistics. The annual catch determined from equation (1) was compared to the annual FAO and FA total landings to check for inter-agency discrepancies.

Unreported catches

We assume that discrepancies found between the food balance data and that supplied to the FAO via the FA represent unreported catches. For the years 1954–1983, when there are no data available from the FA, we use the average rate of unreported catches (~33%) reported from 1951 to 1953 (Sung, 1972) to estimate unreported catches. We further assume that the unreported catches are proportional to the spatially reported landings. Unreported catch rates were applied to the reported landings from the coastal, offshore and distant water fisheries. The unreported catches for each FAO area are distributed in proportion to the reported taxa, except in FAO area 61 and 71. For FAO 61, the "sharks, rays, skate, etc, nei" category were distributed in proportion to the species reported in Lawson (1997). The unreported catch rates for FAO area 71 were applied in proportion to the species reported for the Taiwanese distant water longline catch (Lawson, 1997).

Discards

The discard portion of the Taiwanese catch reconstruction is based on estimates, since no official records of Taiwanese discards exist. Discard rates were applied to the sum of the reported and unreported landings. Longline discard rates were based on data presented in Kelleher (2005; Table 1). The average rates of longline discards calculated from this publication were applied according to their reported areas and year. The discard rate of purse seine, trawl, squid jig, and nets are rates provided for other countries operating in the same area (Kelleher, 2005). We used reported discards by gear and target species as a proportion of retained catches by gear and target species to derive discard rates. We applied these derived discard rates to the sum of the reported and unreported landings to estimate discard amounts.

Table 1. Summary table of discard rates used for the various oceans and gear types of the Taiwan fisheries fleets.

Year	Ocean	Gear	Discard rate	Source
1950-1997	Pacific	longline	0.113	Mejuto *et al.* (1997)
1998-2007	Pacific	longline	0.124	Mejuto *et al.* (1997) and Kelleher (2005)
1950-1994	Atlantic	longline	0.160	Cramer 1998 and Mejuto *et al.* (1997)
1995-2004	Atlantic	longline	0.400	Kelleher (2005)
2005-2007	Atlantic	longline	0.130	Mejuto *et al.* (1997)
1950-1989	Indian	longline	0.340	½ the 1990-1999 rate
1990-1999	Indian	longline	0.680	Mejuto *et al.* (1997)
2000-2004	Indian	longline	0.460	Mejuto *et al.* (1997)
2005-2007	Indian	longline	0.390	Mejuto *et al.* (1997)
1950-2007	all	purse seine	0.040	Amande *et al.* (2008) and Anon. (2003)
1950-2007	all	shrimp trawl	0.970	Clucas (1997)
1950-2007	all	demersal trawl	0.123	Kelleher (2005)
1950-2007	all	squid jig	0.500	Kelleher (2005)
1950-2007	all	other nets	0.014	Kelleher (2005)

The discard rates thus derived were applied spatially to each major fishery based on gear type. The longline and purse seine discards were assigned to both the EEZ and distant water fisheries. Discards associated with squid jigging in the Pacific and net discards (excluding purse seines), which are almost exclusively used in coastal and offshore areas, were assigned to EEZ fisheries only. The longline and purse seine fisheries within the EEZ had discard rates applied in proportion to the reported landings by the two gear types using the FA's national statistics. For the DWF, the longline and purse seine discards were also assigned proportionally, based on reported landings by the two gear types. Discards from the trawl fishery and the squid fisheries in oceans other than the Pacific were assigned to the DWF.

An additional 279 t·year^{-1} of whale shark catches are applied from 1990 to 2000, and 126 t·year^{-1} applied from 2001 to 2007 to the offshore catches due to the unregulated nature of the whale shark fisheries (Chen *et al.*, 1997; Chen and Phipps, 2002). Whale sharks are usually sold outside of the market system to avoid fees, and only two markets have recorded landings statistics for whale sharks (Chen *et al.*, 1997).

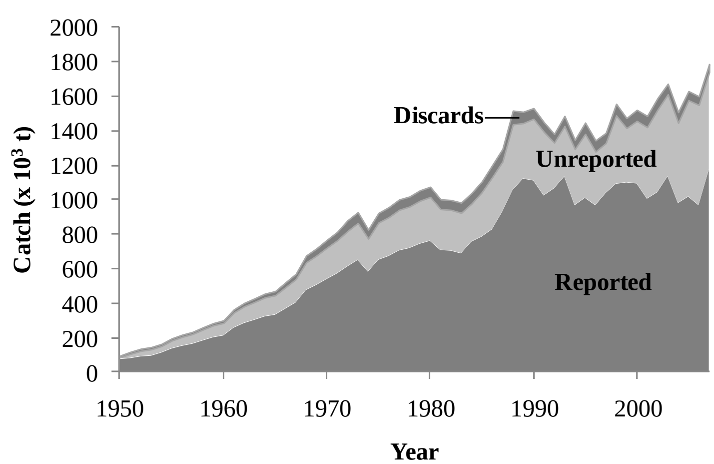

Figure 2. Total reconstructed catches including reported landings, unreported catches and discards.

RESULTS

The total reconstructed catches amount to 54.7 million tonnes from 1950-2007, as compared to the landings reported to FAO of approximately 38.2 million tonnes. The difference of 16.5 million tonnes is estimates of IUU in the form of unreported catches and discards. Unreported catches are the dominant form of IUU accounting for 84% of the IUU catches assessed here (Figure 2).

Total unreported catches

The FAO landings statistics and the FA national landings statistics are largely indistinguishable (Figure 3), indicating that the data transfer between FA and the FAO was efficient. However, discrepancies in landings were found between 1950 and 1953, and from 1984 onwards using alternative sources. Catches for Taiwan from 1950 – 1953 were, on average, about 28% higher than the national FA statistics (Sung, 1972) and the discrepancies increased from approximately 11% in 1950 to 38% in 1953. Discrepancies between the food balance data and the FA data for the later time period (1984-2007) averaged 37%, and also showed an increasing trend through time (Figure 4). Over the entire period (1950-2007), unreported catches estimated from the discrepancies between the food balance data and the FA amount to 13.6 million tonnes. Although the yearly discrepancies were relatively small during the first 4 years (1950 -1953 average: ~25,000 t·year^{-1}), after 1983, these differences increased over time and range from 225,000 t·year^{-1} to 567,000 t·year^{-1}.

Total discards

Our estimated total discard amounts were fairly constant from 1950 to 1959 and averaged 12,000 t·year^{-1}. However, with the expansion of the DWFs, discards increased and peaked at 80,000 tonnes in 1988, representing 5% of the total reconstructed catch. Total discards declined to approximately 47,000 tonnes in 2007 and represent 3% of the total reconstructed catches. From 1959 onwards, the average discard rate applied to reported landings and unreported catches was 5.3%. We estimate that between 1959 and 2007, the highest rate of 8% occurred in 1972, but has since dropped to 3% in 2007.

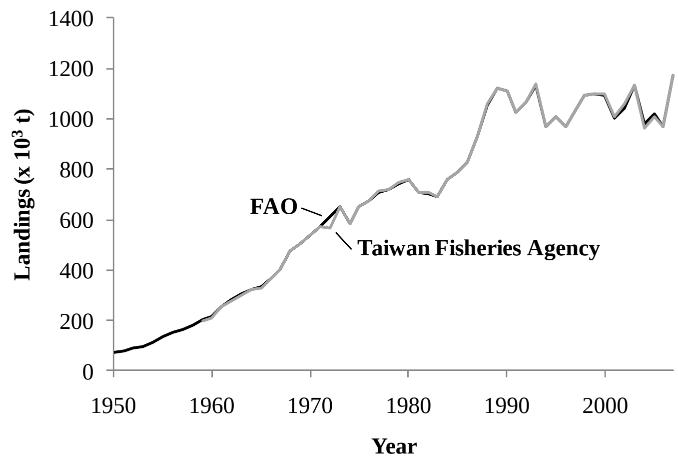

Figure 3. National statistics as reported by FAO and by the Fisheries Agency of Taiwan.

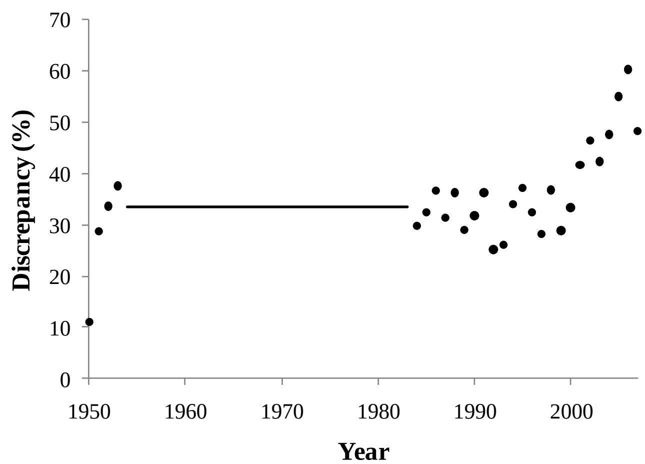

Figure 4. Discrepancies (%) between the food balance data and reported landings. Dots are reported values and the solid line indicates an estimated value (mean of 1951-1953).

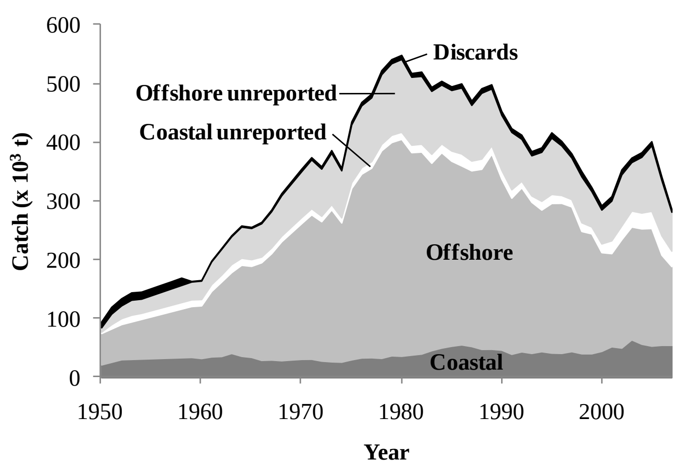

Figure 5. Catches taken within the EEZ waters of Taiwan, including coastal (with catches considered here to be taken by the small-scale sector) and offshore fisheries, unreported catches and discards.

EEZ fisheries

Fisheries in the EEZ of Taiwan, which consist of the coastal and offshore sectors, increased from the 1950s until the 1970s by approximately 100,000 t·decade^{-1}(Figure 5). Reported landings increased from 75,000 t·year^{-1} in 1950 to 401,000 t·year^{-1} in 1979. Annual catches within the EEZ peaked in 1980 at 407,000 t·year^{-1}, but have steadily declined and were only 190,000 t·year^{-1} in 2007. The declines in landings from the EEZ waters have occurred in the offshore waters. Coastal fisheries, relying mostly on fixed nets, have been subject to overfishing since the 1950s (Chen, 2007) and apparently may also have been affected by the expansion of aquaculture. Coastal fisheries, roughly corresponding to small-scale fisheries, averaged reported landings of approximately 31,000 t·year^{-1} between 1950 and 1979, and increased to average 47,000 t·year^{-1} between 1980 and 2007 (Figure 5). Offshore reported landings increased from 55,000 tonnes in 1950, peaked in 1980 at about 370,000 tonnes, but have since declined to 135,000 tonnes in 2007 (Figure 5).

From 1950 to 2007, unreported catches within the EEZ were estimated to be over 5 million tonnes (Figure 5). Unreported catches increased from 8,400 tonnes in 1950, peaked at about 136,000 tonnes in 1980, and declined to 92,000 tonnes in 2007. Discards within the EEZ were estimated to be highest in the first decade due to the amount of trawling. Trawl landings declined from 89% to 33% of reported landings between 1950 and 1959, but due to the increased landings trawl discards were estimated to average 12,000 t·year^{-1} between 1950 and 1958. With the expansion of fleets into distant waters beginning in 1959, we estimate that the discards within the EEZ waters declined, but those from DWF began to increase. Discards were estimated to average approximately 21,000 t·year^{-1} from 1959-2007, but increased from 7,600 tonnes in 1959, peaked during the 1980s at 33,000 t·year^{-1} before declining to 8,000 t·year^{-1} in 2007 (Figure 5).

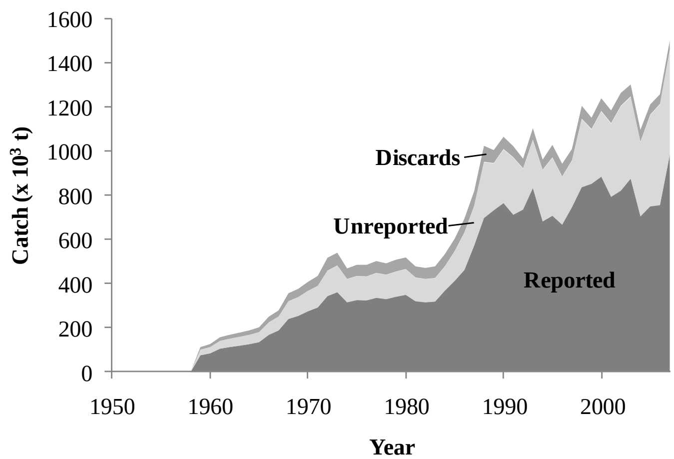

Figure 6. Total reconstructed catches for the DWF, including reported landings, unreported catches and discards.

Distant water fisheries

Ine more recent times, distant-water fisheries represent the most significant component of Taiwanese fisheries. The DWF accounts for approximately 62% of the total reported Taiwanese landings from 1950 to 2007, and mainly targets tunas and squids using longline, purse seine and jig. Since 1985, the DWF have consistently been the largest, contributor to Taiwan's reported total landings. With decreased access to other neighbouring countries waters starting in the late-1970s due to the increasing declaration of EEZs, the DWF was rapidly developed in the 1980s, and reported landings from these fisheries during the 2000s are now 3 to 5 times larger than those from the EEZ in terms of annual reported landings (Figure 6).

Unreported catches from the DWF were estimated to contribute over 8.7 million tonnes to the total catches from 1959-2007 (Figure 6). Unreported catches increased from 26,000 tonnes in 1959 to 97,000 tonnes in 1971. Between 1972 and 1987, unreported catches were between 100,000 and 200,000 tonnes, and averaged 120,000 t·year^{-1}. Unreported catches have increased from 253,000 tonnes in 1988 to 477,000 tonnes in 2007. Discards from the DWF were estimated to have increased from 5,000 tonnes in 1959, peaked at 53,000 tonnes in 2002, but have since declined to approximately 39,000 tonnes in 2007.

DISCUSSION

From 1950-2007, the total reported landings were over 38 million tonnes. Reported landings increased from about 75,000 tonnes in 1950 to over 900,000 tonnes in 1987. Since 1988, annual reported landings have been approximately 1 million t·year^{-1}. Unreported catches from 1950-2007 were 13.7 million tonnes, and increased from about 8,000 tonnes in 1950 to 568,000 tonnes in 2007. Discards rose from 10,000 tonnes in 1950 to 80,000 tonnes in 1988 and then began to decline, amounting to approximately 47,000 tonnes in 2007. As estimated here, our total reconstructed catches including reported landings, unreported catches and discards amount to 54.7 million tonnes and are 43% larger than reported landings. This estimation is probably conservative. While the unregulated portion of IUU catches in Taiwan may be small, the unreported illegal portion may be large, leaving out a potentially significant portion of IUU catches.

The unreported catches that we estimated, based on the food balance data, may represent unreported by-catch from the EEZ fisheries and DWF. With the exception of FAO fisheries statistical area 61, the only species reported from other fisheries statistical areas were tunas, marlins, squids, unidentified sharks, and unidentified marine fishes ("marine fishes nei"). The "marine fishes nei" category accounts for a small proportion of the overall catch statistics in FAO, and thus would be an underestimate because it doesn't account for all bycatch. It was not until 1991 that the government enforced an observer and vessel monitoring program to track fisheries catches (Chang *et al.,* 2010). However, the fact that most of the reported DWF landings are high-value target species (e.g., tunas) makes it possible that the estimates of unreported catches reported here are mainly comprised of bycatch species.

The expansion of Taiwan's fishing fleet into offshore areas of the EEZ beginning in 1959 increased annual landings until many of Taiwan's neighbours declared EEZs, increasingly limiting the fishing areas accessible by Taiwan. The loss in catches from traditional fishing grounds caused a fairly rapid expansion of the DWF in the early years, but has since slowed. As estimated here, the total reconstructed DWF catches doubled from 113,000 tonnes to 251,000 tonnes in 8 years (1959-1966), doubled again from 251,000 tonnes to 500,000 tonnes in 7 years (1966-1972), but it took 17 years for DWF catches to double from 500,000 to 1 million tonnes (1972-1988). Total reconstructed DWF catches were estimated to be 1.5 million tonnes in 2007.

Taiwan's fisheries contribute to national food supply, and presently the DWF catches compensate for the declining catches from the Taiwanese EEZ. However, the DWFs are highly vulnerable to fluctuations in the energy sector in the form of rising fuel costs. Decreased catches were the result of the oil crisis in the 1970s and again in the 1980s. Fuel used by the DWF is subsidized by the Taiwanese government, and in the year 2000 the \$US 0.09·litre^{-1} subsidy amounted to \$US 120 million (Sumaila *et al.*, 2008). With increased pressure on fisheries stocks worldwide, this strategy is not likely to be sustainable, and the Taiwan DWF may thus experience difficulties expanding, or even maintaining their present catch volumes.

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APPENDIX

Appendix Table A1. Total Taiwanese catches (t) including coastal, offshore and DWF catches, and estimates of unreported catches and discards.

Year	Coastal	Coastal unreported	Offshore	Offshore unreported	DWF	DWF unreported	Discards
1950	20,885	2,313	54,297	6,082	n/a	n/a	10,091
1951	25,291	7,293	58,146	16,768	n/a	n/a	11,743
1952	29,696	9,991	61,365	20,645	n/a	n/a	12,185
1953	30,250	11,372	65,194	24,509	n/a	n/a	12,547
1954	30,804	10,276	69,023	23,025	11,672	3,894	12,085
1955	31,358	10,460	72,852	24,302	31,319	10,447	12,164
1956	31,911	10,645	76,681	25,579	42,582	14,205	12,256
1957	32,465	10,830	80,509	26,856	50,364	16,801	12,277
1958	33,019	11,015	84,338	28,134	65,177	21,742	12,578
1959	33,573	11,199	88,167	29,411	79,232	26,430	12,594
1960	31,761	10,595	91,170	30,413	88,763	29,610	14,811
1961	34,525	11,517	112,927	37,670	109,044	36,375	17,981
1962	35,214	11,747	128,176	42,757	120,505	40,198	19,403
1963	40,489	13,506	139,081	46,395	123,024	41,039	20,981
1964	35,597	11,875	156,419	52,178	129,641	43,246	22,057
1965	33,688	11,238	156,566	52,228	141,784	47,297	23,757
1966	28,615	9,545	167,718	55,948	170,469	56,865	28,230
1967	29,158	9,727	182,628	60,921	190,468	63,537	30,319
1968	27,985	9,335	204,064	68,072	242,674	80,952	39,559
1969	29,254	9,759	218,211	72,791	256,394	85,528	41,646
1970	30,338	10,120	232,541	77,571	274,857	91,687	45,363
1971	30,515	10,179	247,429	82,538	291,983	97,400	49,168
1972	27,383	9,134	238,833	79,670	344,309	114,855	62,451
1973	26,130	8,716	260,298	86,831	360,695	120,321	62,519
1974	25,565	8,528	238,499	79,559	314,568	104,934	51,703
1975	29,540	9,854	293,259	97,826	323,170	107,803	55,819
1976	32,732	10,919	314,452	104,895	322,634	107,625	58,122
1977	33,079	11,035	324,379	108,207	343,927	114,728	60,116
1978	32,024	10,683	355,094	118,453	329,542	109,929	58,025
1979	36,380	12,136	364,708	121,660	340,642	113,632	60,494
1980	35,645	11,891	370,906	123,727	350,744	117,002	59,177
1981	37,615	12,548	346,203	115,487	321,833	107,358	56,717
1982	39,445	13,158	345,471	115,243	316,514	105,583	57,166
1983	45,257	15,097	320,495	106,911	320,621	106,953	59,447
1984	49,650	14,840	334,131	99,868	369,453	110,425	61,066
1985	52,817	17,175	316,417	102,890	413,608	134,494	62,358
1986	55,087	20,169	306,179	112,101	463,361	169,650	69,506
1987	52,255	16,425	300,649	94,500	574,942	180,716	73,149
1988	47,439	17,205	308,114	111,743	697,246	252,868	80,051
1989	47,594	13,784	333,799	96,676	736,582	213,331	65,891
1990	46,162	14,669	292,670	93,005	768,945	244,357	62,047
1991	39,031	14,170	267,224	97,011	715,513	259,755	56,332
1992	43,201	10,892	280,792	70,797	738,388	186,173	50,352
1993	40,540	10,573	258,880	67,520	833,041	217,269	59,005
1994	43,496	14,822	242,553	82,655	680,082	231,753	53,388
1995	41,033	15,238	256,560	95,165	712,034	264,423	65,588
1996	40,576	13,202	256,933	83,599	669,567	217,860	64,938
1997	43,609	12,306	247,854	69,944	746,183	210,573	59,152
1998	39,911	14,689	209,721	77,188	841,794	309,825	67,427
1999	39,911	11,527	205,645	59,394	853,599	246,535	57,921
2000	44,016	14,701	169,520	56,620	879,804	293,857	64,585
2001	51,869	21,669	159,989	66,839	792,751	331,188	65,149
2002	49,669	23,090	185,939	86,441	806,549	374,956	67,028
2003	63,739	26,983	193,482	81,908	875,200	370,506	61,342
2004	56,290	26,822	197,722	94,213	725,849	345,863	61,952
2005	52,956	29,166	201,700	111,087	762,390	419,989	52,969
2006	54,381	32,809	154,873	93,436	758,058	457,343	50,032
2007	54,280	26,206	135,440	65,389	984,431	476,622	46,619

Appendix Table A2: Total reconstructed catch (t) for Taiwan within its EEZ, 1950-2007. Others category includes 92 taxa plus miscellaneous marine fishes grouping.

Year	*Katsuwonus pelamis*	Elasmobranchii	Shrimps and prawns	*Scomber japonicus*	*Thunnus albacares*	*Trichiurus lepturus*	*Todarodes pacificus*	*Saurida tumbil*	Others
1950	0	7,793	2,105	3,340	5,567	1,113	0	1,113	62,736
1951	0	10,416	2,436	5,208	6,510	1,302	0	1,302	77,286
1952	0	12,071	3,180	6,706	6,706	2,280	0	2,012	88,117
1953	0	13,144	3,216	6,918	6,918	2,352	0	2,075	95,421
1954	0	11,700	2,178	5,611	6,327	2,388	0	2,746	102,320
1955	0	11,447	3,095	7,563	6,132	3,679	0	8,994	98,201
1956	0	12,696	3,088	9,164	5,250	2,196	3,628	8,973	99,974
1957	0	12,680	2,765	6,983	4,870	2,848	827	9,004	110,829
1958	596	12,524	2,685	6,645	4,856	4,430	1,022	6,390	117,518
1959	481	10,908	3,167	7,058	4,652	3,529	2,566	8,502	121,652
1960	384	10,740	2,960	6,450	4,454	4,377	1,920	10,827	121,975
1961	1,143	11,026	3,315	5,868	4,649	6,554	3,201	9,222	151,830
1962	2,140	12,449	4,111	5,502	5,273	10,011	6,572	10,240	161,813
1963	1,496	11,081	5,996	8,582	4,803	8,739	7,716	14,093	177,174
1964	1,267	11,697	6,665	12,752	5,069	12,118	7,366	10,772	188,571
1965	839	12,782	9,164	12,125	5,490	12,430	6,787	15,328	178,996
1966	659	14,354	9,982	9,883	5,888	11,567	8,126	17,204	184,566
1967	453	16,930	12,624	6,498	6,575	14,130	5,365	15,642	204,665
1968	526	21,978	13,748	14,266	8,737	12,765	4,430	15,993	217,913
1969	536	22,525	19,928	17,002	10,178	9,956	5,208	15,624	230,056
1970	292	23,229	17,167	21,940	7,123	11,862	6,047	15,661	248,356
1971	577	23,676	18,323	16,118	5,607	12,338	3,780	15,761	275,201
1972	536	21,116	19,034	11,629	3,266	21,570	6,315	13,442	258,758
1973	1,497	20,561	22,678	5,064	14,061	20,067	14,433	13,167	271,445
1974	1,048	24,982	23,286	2,052	5,581	14,292	8,524	11,706	261,290
1975	1,575	38,465	35,359	2,735	10,106	14,876	13,377	14,733	300,222
1976	1,382	37,171	34,538	3,214	10,357	15,324	16,901	16,760	328,348
1977	1,962	35,664	35,432	6,061	14,470	14,754	12,600	17,996	339,301
1978	3,514	32,624	44,258	4,086	18,880	17,380	12,694	13,863	370,604
1979	2,554	29,720	47,963	4,489	21,237	11,838	23,602	18,177	376,904
1980	2,546	36,983	45,550	5,084	18,631	20,109	20,908	15,771	378,404
1981	1,872	30,727	39,428	15,529	15,626	16,344	24,570	10,975	358,096
1982	2,850	34,832	41,449	13,284	14,742	19,904	21,433	12,107	354,451
1983	5,605	30,954	42,896	15,501	13,784	17,098	11,875	10,956	340,893
1984	5,818	31,454	47,243	19,633	13,244	15,283	48,670	9,067	309,820
1985	12,241	39,056	52,032	23,308	13,454	14,144	17,167	7,993	312,356
1986	12,658	32,378	54,105	25,953	12,573	17,810	11,134	9,230	320,257
1987	13,909	30,018	44,525	20,472	16,236	11,582	12,576	6,503	310,804
1988	16,988	22,493	32,489	19,220	13,743	17,519	13,021	7,666	344,190
1989	26,106	26,216	29,816	18,246	10,007	23,684	23,350	4,468	332,690
1990	38,661	32,716	17,966	17,916	13,211	10,666	18,313	3,449	296,688
1991	32,881	32,123	14,713	15,392	13,192	9,457	26,799	2,892	272,749
1992	39,795	30,159	13,361	23,137	35,331	9,651	5,985	3,749	248,810
1993	49,823	23,912	8,394	21,226	36,165	8,725	5,279	3,445	225,435
1994	65,505	18,864	9,647	32,767	28,406	11,524	6,514	2,639	213,181
1995	81,935	21,428	14,481	32,530	27,565	9,737	13,361	4,051	209,083
1996	91,178	19,680	14,788	33,567	22,632	7,366	11,894	4,085	195,601
1997	58,985	18,503	13,199	28,238	33,512	5,348	7,424	1,916	212,235
1998	76,961	15,523	8,075	18,270	34,680	4,109	17,916	1,568	171,551
1999	66,962	19,803	7,909	23,998	27,530	4,962	5,961	1,628	163,373
2000	68,207	17,884	5,373	13,573	25,092	3,446	3,239	1,712	151,955
2001	70,155	14,463	6,334	12,839	27,285	4,668	2,492	1,188	167,347
2002	86,254	16,422	6,128	19,855	24,292	4,766	2,395	864	192,380
2003	62,978	23,402	611	28,636	21,259	4,633	256	975	229,432
2004	84,513	21,604	7,308	38,264	14,237	5,490	0	1,230	209,543
2005	69,930	21,173	12,847	43,292	18,771	4,716	0	1,281	228,895
2006	72,955	21,676	6,576	30,974	16,678	5,168	0	1,024	186,121
2007	60,188	16,789	4,655	21,673	12,604	3,706	0	818	164,776

Reconstruction of Fisheries Catches for Tokelau (1950-2009)[1]

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Abstract

Total marine fisheries catches were estimated for Tokelau between 1950 and 2009. As there are no commercial fisheries in Tokelau, our estimate represents subsistence fisheries only. Subsistence catches were estimated using *per capita* consumption rates. These rates were either found in independent fisheries studies or estimated from dietary assessments. The subsistence catches total approximately 24,250 t over the 1950-2009 time period (399 $t \cdot year^{-1}$ in the 2000s), which is almost 4.3 times larger than the FAO reported landings. This report highlights the importance of accurate fisheries catch reporting, as it is required for proper fisheries management and, for small island countries such as Tokelau, it is essential for maintaining food security.

Introduction

Tokelau, a territory of New Zealand, is comprised of three atolls: Fakaofo, Nukunonu, and Atafu. They are located approximately 300 miles north of Western Samoa at 8°-10° S and 171°-173° W (Figure 1). The land area is only 12.2 km^2, with an Exclusive Economic Zone (EEZ) of 319,031 km^2 (www.seaaroundus.org). The atolls are situated with Atafu in the northwest, Nukunonu in the middle, and Fakaofo in the southeast. Although each atoll consists of many small islands and islets, the majority of the population for each atoll is confined to one main island or islet (van Pel, 1958). The atolls are all closed, leaving no deep water passes for ships to enter the lagoons (van Pel, 1958). Atafu is the smallest atoll, both in land area (2.5 km^2) and lagoon size (19 km^2). Nukunonu is the largest with about 5.5 km^2 of land area and 109 km^2 for lagoon coverage. Fakaofo falls in the middle with 3 km^2 of land area, 59 km^2 of lagoon coverage (Ono and Addison, 2009).

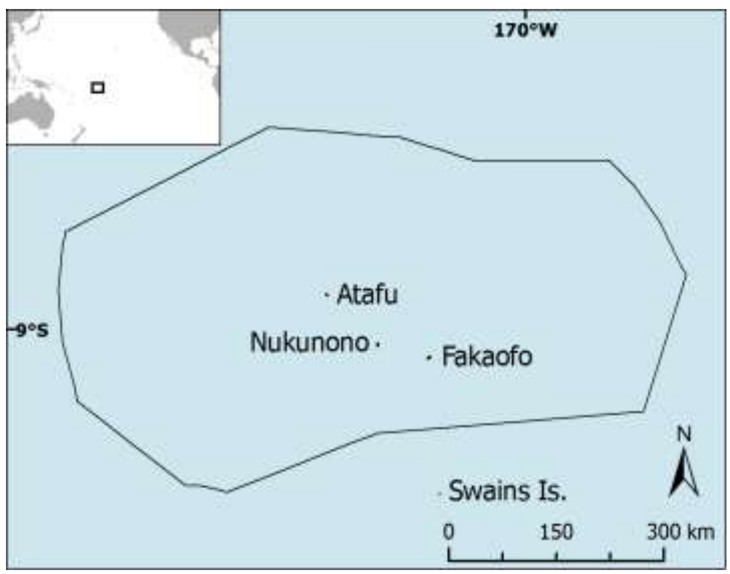

Figure 1. Map of Tokelau showing the three atolls, Atafu, Nukunono, and Fakaofo, and its EEZ, as well as Swains Island, a previous fourth atoll known as Olohega.

The Tokelau chain does, geographically, also consist of a fourth atoll, now known as Swains Island (Clanton, 2008). It is located 100 miles south of Fakaofo (Bertram and Watters, 1984) (Figure 1). The island was originally settled in 1400 by the Tokelauans and was given the name Olohega (Bertram and Watters, 1984). However, the atoll was officially annexed to the United States in 1925, and now forms part of American Samoa (Bertram and Watters, 1984; Clanton, 2008). Although there are many different

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stories of what occurred with the early foreign explorers who came across Olohega, it is consistent that the eventual annexation to the United States occurred because of the Jennings family. In 1856, an Englishman reportedly sold his perceived "claim of ownership" to an American, Eli Hutchinson Jennings Sr. (Bertram and Watters, 1984; Clanton, 2008). Jennings and his wife ran a copra plantation using Tokelauan labour (Clanton, 2008). In 1917, Tokelauan workers submitted a claim to Western Samoa complaining about the working conditions on Olohega (Bertram and Watters, 1984). However, the matter was referred over to the United States as officials in Apia stated they had no authority over the Jennings family (Bertram and Watters, 1984). This led to questions of sovereignty of the island and seeing an opportunity to claim new land, the United States took possession. The island is still inhabited by a small Tokelauan population and many Tokelauans continue to consider it part of Tokelau, both historically and culturally (Bertram and Watters, 1984; Ono and Addison, 2009).

Tokelau was under British colonial rule (starting in 1889) and was incorporated with the Gilbert and Ellice Islands Colony in 1916 (Bertram and Watters, 1984). The current three atolls of Tokelau were brought under New Zealand administration in 1926. However, it was not until the Tokelau Act of 1948 that New Zealand took formal control over the atolls (Adams *et al.*, 1995; Townend, 2007). Although New Zealand has been pushing for Tokelau to become an independent self-governing country, Tokelau has resisted at every step. In 1974, the New Zealand Ministry of Foreign Affairs was said to begin the "process of administrative decolonization", even though it was known that Tokelau had firmly rejected the idea of self-government (Bertram and Watters, 1984). Since then, Tokelau voted in two referenda, first in 2006 and again in 2007, to determine whether or not they wish to become a self-governing nation. In both referenda they fell short of a two-thirds majority vote needed to change their political status (Hoëm, 2009).

Despite the Tokelauans best efforts to resist the new social and economic structure that the New Zealand government was trying to implement, there have been some radical changes to their way of life. Although tradition is still observed on the surface, the same sense of community and cooperation is not there (Hooper, 1985). This disruption is the result of New Zealand's attempts to introduce new programs and social order, which are counter to the Tokelauans expressed feelings (Bertram and Watters, 1984). A major change which had wide-spread effects was the introduction of the New Zealand public service lines in 1976, which were staffed by Tokelauans (Bertram and Watters, 1984; Hooper, 1985). This took a lot of able-bodied men out of the village labour force. Before this happened, the activities of these men were coordinated by the village council. Now that they are being employed by an outside entity there is less cohesiveness between the village and council (Hooper, 1985). Although this change led to less fisher-hours per week, the new influx of cash allowed more modern fishing gear to be purchased. New aluminum dinghies (12-14 feet long with 15 to 25 horsepower outboard engines) have mostly replaced the traditional canoes used (some canoes with outboard motors are in use) (Hooper, 1985). These allow for more efficient fishing as it takes less time to manoeuvre the area and less human effort (Hooper, 1985).

As a fairly isolated community, Tokelau has been and continues to be very dependent on subsistence fishing activities. Almost everyone participates in some type of fishing activity (Chapman *et al.*, 2005). Even though ship transport has increased significantly over the years, there is still heavy reliance on locally caught fish in the diet. On Atafu, the people not only engage in subsistence fishing, but also root-crop cultivation and fruit-tree harvesting (Ono and Addison, 2009). Previously, copra was a major commercial crop exported from the atolls and, at times, brought in decent revenues (Bertram and Watters, 1984), but not anymore (Ono and Addison, 2009). Tokelau is heavily subsidized by the New Zealand government, and beginning in 1976, many Tokelauans went to work in the public service lines with wages being paid by New Zealand (Hooper, 1985; Passfield, 1998). Tokelau does bring in a small amount of profit from the sale of handicrafts such as hats, bags, and wood carvings (Passfield, 1998; Ono and Addison, 2009).

Although fishing is extremely important to Tokelauans, catch amounts are not recorded or monitored. The FAO FishStat database, which provides time series data on marine fisheries landings from 1950 to present, is based predominantly on the national statistical data supplied by its member countries. Therefore, the quality of these data depends on the accuracy of the country's collection methods.

The objective of this study is to provide a complete time series estimate of the total marine fisheries catch of Tokelau from 1950-2009. Although there have been several studies in the past which have estimated Tokelau's fisheries catch for specific years, there has not been a comprehensive review of the trend over time.

MATERIALS AND METHODS

Estimates were only made for subsistence catches, as there are no fishing practices in Tokelau which would qualify as commercial fishing. These estimates were based on reports from several different researchers. These reports consisted of a mixture of catch and consumption data, as well as information about eating and fishing habits, which were used to make assumptions when there were no data available. Available catch data were used, along with human population data, to estimate *per capita* consumption rates. Interpolations between data anchor points were used to estimate the catch rates for the entire study period (1950-2009). A taxonomic breakdown was then applied, which included categories by species and family.

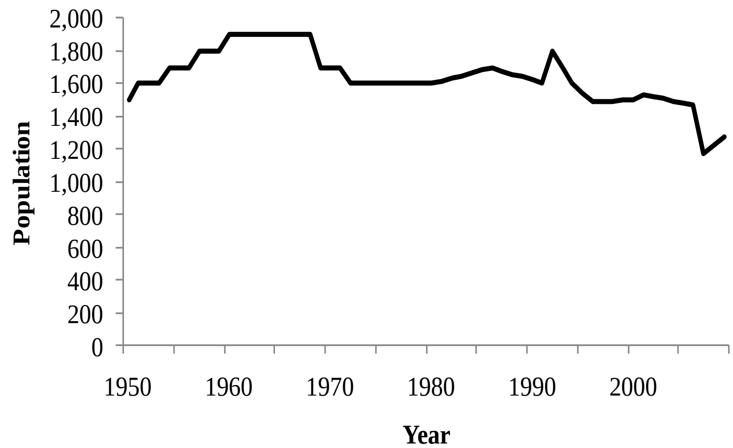

Figure 2. Estimated population of Tokelau, 1950-2009.

Human population data

Our estimates for total catch amounts were computed from *per capita* consumption rates combined with human population data. Population data were obtained from the population statistics historical demography website (www.populstat.info [accessed July 8, 2011]). For most years after 1978, no population data were available. This can be attributed to the fact that in 1975 the New Zealand Ministry of Foreign Affairs assumed control of the islands and shortly after that they reverted from annual population censuses to having one estimate every five years (Bertram and Watters, 1984). Data for the years 1991, 1996, and 2001 were obtained from official Tokelau census data[2] as well as the year 2006 (Anon., 2006). The population for 2007 was obtained from Gillett (2009) as this also provided a critical anchor point for seafood consumption for the same year. Data for 2008 and 2009 were linearly interpolated between the 2007 population and a 2011 estimate from the World Factbook[3]. For the remaining years when no data were available, a linear interpolation between years of known population was performed to give a complete time series of population data from 1950-2009 (Figure 2).

Subsistence fisheries

Several reports indicate the absence of commercial fisheries operating in Tokelau (Dalzell *et al.*, 1996; Passfield, 1998). All fishing activities are therefore deemed to be subsistence. Subsistence fishing in Tokelau includes fishing for personal consumption, as gifts to send overseas, and for trade within the community.

Table 1. *Per capita* consumption rates used to estimate total demand.

Years	Consumption Rate (kg/person/year)	Source
1950	255	Assumption-based[a]
1951-2006	-	Linear interpolation
2007	214	Gillett (2009)
2008	214	Carried forward
2009	214	Carried forward

[a]2007 estimate adjusted for increased domestically sourced fresh fish in 1950.

Gillett (2009) estimated the 2007 total catch for Tokelau to be 375 tonnes. This estimate was obtained by analyzing estimates from several independent studies completed between 1977 and 1998, with adjustments for changes in transportation availability and population (Gillett, 2009). This estimate accounts for increased transport between Tokelau and Apia, Samoa, and thus includes 125 tonnes of export (Gillett, 2009). Using these figures and the current population, Gillett (2009) estimated a consumption rate of 214 kg·person^{-1}·year^{-1}, which was used as the 2007, 2008, and 2009 anchor point (Table 1).

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[2] http://www.spc.int/prism/country/tk/stats/Social/Population/age_sex_.htm [accessed June 8, 2011]
[3] https://www.cia.gov/library/publications/the-world-factbook/geos/tl.html [accessed June 8, 2011]

For the early time period (1950-1980s), the only contact that Tokelau had with the outside world was from a trading ship, which three or four times a year brought basic items such as flour, sugar, rice, kerosene, and tobacco to the atolls (van Pel, 1958). It was therefore assumed that they were not, at that time, receiving the canned meats and fish that were available later in the time period (Passfield, 1998). Given the percentages of total animal protein obtained from canned meats and fish in 1998 (Passfield, 1998), it was assumed that this amount of animal protein was supplied in the early period by fresh seafood. In this computation we assumed that the densities of all protein products were the same. The result of this assumption was a consumption rate in 1950 that was 41 kilograms higher than in 2007, (i.e., 255 $kg \cdot person^{-1} \cdot year^{-1}$) (Table 1). We then linearly interpolated between the 1950 assumed and the 2007 reported consumption rates. Using these consumption rates along with the population data, the total demand for fresh fish was calculated for the 1950-2009 time period.

Exports

In order to calculate total subsistence catch, 'exports' needed to be added to what was being locally eaten by the Tokelauans. Although there are no formal exports, the people of Tokelau do send frozen and dried fish to friends and family in Samoa as gifts (Hooper, 1985; Passfield, 1998; Gillett, 2009). Passfield (1998) calculated exports for Fakaofo, and when extrapolated to all of Tokelau, they were estimated to be 15.4 tonnes per year. It is also known that it was around 1980 when the Tokelauans began sending frozen clams to Western Samoa a few times a year (Hooper, 1985). Therefore, the exports were set to zero from 1950 to 1979, and then linearly interpolated between zero tonnes in 1979 and 15.4 t in 1998. We interpolated again between the 1998 point and Gillett's (2009) point of 125 t for 2007-2009. Adding these values to the dietary demand for each year gives the estimate for annual subsistence catches, 1950-2009.

Catch composition

The Food and Agriculture Organization of the United Nations (FAO) reports the fish catch for Tokelau under two categories: 'tuna-like fishes not elsewhere included' (nei) and 'marine fishes nei'. Also according to the FAO data, up until 1990 there were no tuna-like fish caught (except for one year of non-zero catch data in 1956). However, it is known that tuna-fishing has historically been a very important practice to the Tokelauans (Gillett and Toloa, 1987; Ono and Addison, 2009). In order to show a more complete picture of the catch composition, information was combined from several different sources. Gillett and Toloa (1987) gave us a basic composition by not only recording the species but also the percentage breakdown of the tuna and tuna-like fish. They also recorded the species information for the other pelagic fish, but only provided an overall percentage. Based on the household survey of Passfield (1998) and the observations of van Pel (1958), we broke down the inshore fish category into species and assigned percentages to both those and the species within the other pelagic category. Although marlins (*Makaira* spp.) have been known to be landed by Tokelauan fishers, they have not been included as a distinct taxon within the catch

Table 2. Estimated catch composition for the subsistence fisheries of Tokelau. Prior to 1986, adjustments were made to account for the complete absence of *Katsuwonus pelamis* until 1980. Percentages were linearly interpolated between 1980 and 1986. (See 'catch composition' in text).

Taxa	**Catch (%)**	
	1950-1980	**1986-2009**
Acanthocybium solandri	6.02	5.06
Acanthuridae	3.65	3.65
Elagatis bipinnulata	1.50	1.50
Selar crumenophthalmus	7.30	7.30
other Carangidae	7.30	7.30
Carcharhinidae	1.00	1.00
Chaetodontidae	1.46	1.46
Coryphaena hippurus	1.50	1.50
Cypselurus spp.	18.25	18.25
Grammatorcynus bilineatus	0.13	0.11
Gymnosarda unicolor	1.05	0.88
Istiophorus platypterus	0.50	0.50
Katsuwonus pelamis	0.00	3.52
Labridae	1.46	1.46
Lethrinidae	1.46	1.46
Lutjanidae	2.19	2.19
Misc. invertebrates	3.65	3.65
Misc. marine crustaceans	1.46	1.46
Misc. marine fishes	3.65	3.65
Mugilidae	3.65	3.65
Octopus spp.	1.46	1.46
Panulirus spp.	1.46	1.46
Scaridae	10.95	10.95
Serranidae	2.19	2.19
Sphyraena barracuda	0.50	0.50
Thunnus albacares	7.40	6.215
Thunnus obesus	7.40	6.215
Tridacna spp.	1.46	1.46

composition. Gillett (1985) reports Tokelauan fishers occasionally catch billfish, with sailfish (*Istiophorus platypterus*) being caught most commonly, while marlins are landed far less frequently than they used to be. Table (2) shows the complete breakdown of the subsistence catch for 1986 and onwards. Prior to 1986, the percentages of the various tuna species were adjusted to account for skipjack tuna (*Katsuwonus pelamis*) being absent from the waters of Tokelau from 1950-1980 (Table 2).

Skipjack tuna is subject to large fluctuations in abundance. For example, the Skipjack Survey and Assessment Programme which completed its surveys for Tokelau waters in 1978, spotted 71 schools in just 35 hours (Anon., 1983). By contrast, the United States Bureau of Commercial Fisheries spent approximately 47 hours of a research cruise looking for schools of skipjack in the waters of Tokelau and spotted none (Anon., 1983). A native Tokelauan communicated to the researchers of the Skipjack Survey that in a span of ten years they will probably see one or two extremely abundant years (Anon., 1983). Hooper (1985) described a span of 15-20 years with no skipjack sightings. This covers the period of 1950-1970. In 1971, skipjack tuna reappeared but only for a span of about a week, after which they disappeared again (Hooper, 1985). In 1986, skipjack was recorded as part of the catch during a 12 week study (Gillett and Toloa, 1987). Taking into account all of this information, these fluctuations were adjusted for by assigning zero percent of the tuna catch to skipjack from 1950-1980. We renormalized the percentages for the other tuna species for this time period (Table 2). Skipjack tuna percentages were then linearly interpolated from zero in 1980 to 3.52% in 1986. The values for the other tuna species were also adjusted, as the percentage of skipjack increased.

Baitfish

Fisheries of Tokelau use handline and noose fishing techniques which require the use of baitfish. Baitfish fisheries in other parts of the South Pacific operate in parallel to the tuna pole-and-line fishery, often using the same vessels (Gillett, 2011). The baitfish required to catch a given amount of tuna varies depending on the type of bait species used, fishing method applied, and many other factors. Tokelau appears to be a unique case in all aspects of baitfish use. The method typically used in other countries does not apply for Tokelau due to topographical characteristics which prevent large vessels from entering the lagoon (Anon., 1983). Tokelauans use very traditional methods for tuna fishing which differ from the method that the tuna to baitfish ratio of 32:1 is based on (Gillett, 2011). Reports on Tokelauan use of baitfish suggest a range of species are used including flying fish (*Cypselurus* spp.), double-lined mackerel (*Grammatorcynus bilineatus*), garfish (*Hemiramphus* spp.), shortfin scad (*Decapterus macrosoma*), bigeye scad (*Selar crumenophthalmus*), and squirrelfish (Holocentridae) (Gillett, 1985). This variation in baitfish use may reflect the seasonal availability of certain species. Given these differences in baitfish use, we assume that the traditional methods used by the Tokelauans are more specific and efficient than the typical baitfish catch method for pole-and-line gear. Assuming that Tokelauan fishers use half as much baitfish as used for pole-and-line fishing, we modified Gillett's (2011) tuna to baitfish ratio to an adjusted 64:1. Tokelauans use baitfish to catch more than just tuna, therefore this ratio was applied to the following species which are all landed by the handline and noose methods: yellowfin tuna (*Thunnus albacares*), dogtooth tuna (*Gymnosarda unicolor*), wahoo (*Acanthocybium solandri*), rainbow runner (*Elagatis bipinnulata*), bigeye tuna (*Thunnus obesus*), indo-pacific sailfish (*Istiophorus platypterus*), sharks (Carcharhinidae), and barracuda (*Sphyraena barracuda*) (Gillett, 1985). Skipjack tuna was not included, as they are mainly caught with artificial lures (Gillett, 1985). Traditional methods made use of pearl-shell lures, however these have become rare and difficult to acquire (Hooper, 1985). Gillett (1985) found that Tokelauans are resourceful people and would even make use of a yellow, translucent handle of a screwdriver for a lure. Baitfish estimates for Tokelau were divided evenly between the six previously mentioned taxa of baitfish used. These estimates were not included in the subsistence catch composition and therefore the 3 taxa which are used solely for bait (*Hemiramphus* spp., *Decapterus macrosoma,* and Holocentridae) and not actually consumed in the diet are not listed in Table (2).

RESULTS

The reconstructed total catch for the period 1950-2009 was estimated at 24,255 t. This equates to approximately 4.3 times the total landings reported by the FAO on behalf of Tokelau for the same time period (Figure 3). Average annual catches peaked in the 1960s at approximately 460 t·year^{-1}, with a low of 368 t·year^{-1} in the 1990s. Catches in the recent period (2000s) are estimated to be 399 t·year^{-1}. Exports totalled 1,091 t over the study period, representing 4.5% of the total catch. However, these were not commercial exports, but rather gifts mainly sent to Samoa.

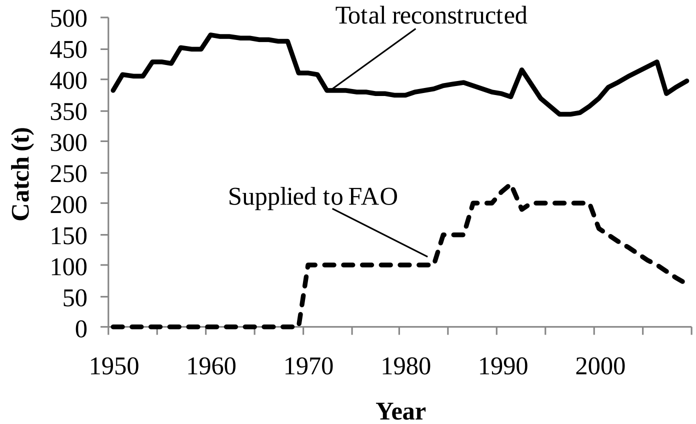

Figure 3. Total reconstructed fisheries catches for Tokelau compared to data supplied to FAO, 1950-2009.

The total reconstructed catch was dominated by flying fish (*Cypselurus* spp.) with an estimated 4,425 t over the time period, representing approximately 18% of the total catch (Figure 4). Families Scaridae and Carangidae, as well as the species *Selar crumenophthalmus* (bigeye scad), *Thunnus albacares* (yellowfin tuna), *Thunnus obesus* (bigeye tuna), and *Acanthocybium solandri* (wahoo) also made up large portions of the catch, with approximately 44 t·year^{-1}, 29 t·year^{-1}, 30 t·year^{-1}, 28 t·year^{-1}, 28 t·year^{-1}, and 23 t·year^{-1}, respectively. The category 'other taxa' includes the remaining 21 taxonomic groups of the subsistence catch (as per Table 2), as well as the other three baitfish taxa, as they represented smaller portions of the total catch. Together, they represent roughly 37% of the total catch. Baitfish alone represented only 0.4% of the total catch, with approximately 90 t being used over the entire time period.

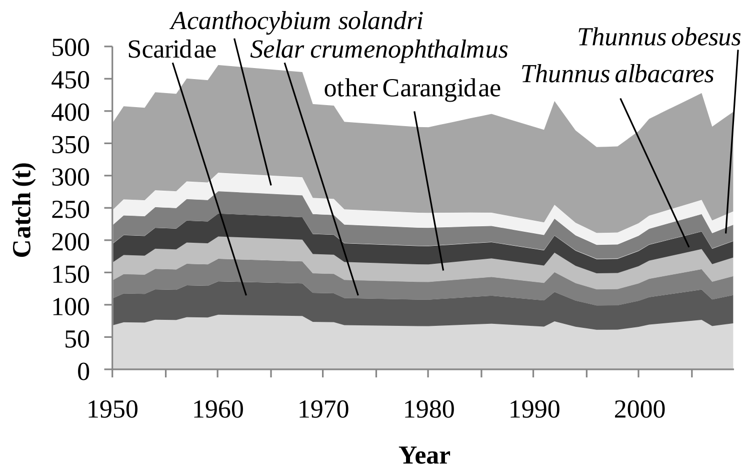

Figure 4. Taxonomic breakdown of total reconstructed catch for Tokelau. The grouping 'other taxa' represents 24 taxa (as listed in Table 2, plus 3 additional baitfish taxa).

Discussion

The total reconstructed catch for Tokelau during the time period 1950-2009 was over four times larger than the total catch reported by the FAO on behalf of Tokelau. The main reason for this difference is that there is no system in place for monitoring fisheries catches in Tokelau (Anon., 1983). According to Bertram and Watters (1984), the reports of the New Zealand Ministry of Foreign Affairs, which took over control of the islands in 1974-1975, show the lack of interest the Ministry had in the territory. Large discrepancies exist between the reported and reconstructed tuna catches. The FAO data suggest that there were zero tuna or tuna-like fish caught from 1950-1989, whereas the total tuna and tuna-like fish estimated from the reconstruction for the years of 1950-1989 represented 68% of the estimated tuna and tuna-like catch for the entire 1950-2009 study period. Also, the data supplied to FAO only represent two categories: 'tuna-like fish nei' and 'marine fish nei'. In contrast, our reconstruction accounts for 31 taxa. Furthermore, while there are no invertebrate species taken into account in the FAO data, our reconstructed estimate suggests that invertebrates represent 9.5% of the total reconstructed catch.

Since all of Tokelau's catches are subsistence and our estimates are based on consumption rates, annual catch rates are subject to fluctuations which correspond to fluctuations in the population. There is a general trend of population decline from its peak in the 1960s until present. Countering the effect of this decline is the increased transport between Tokelau and Samoa which has led to an increase in informal exports. In 1980, Tokelauans began sending frozen seafood by ship to friends and family as gifts. The decrease in dietary demand, in combination with increasing amounts being sent overseas, has resulted in a relatively constant overall trend in catches.

Fishing is an activity that almost everyone in Tokelau takes part in. Fishing occurs off-shore, on the outer reef, and in the lagoons (van Pel, 1958). Typically, it is the men who fish on the outer reef, with women and children taking part in gathering and fishing in the lagoon and on the reef (Chapman, 1987; Ono and Addison, 2009). Chapman *et al.* (2005) surveyed the atolls to obtain an estimate of the gender distribution for various fishing activities, the percentage of time using different fishing techniques, and the percentage of people on the island who take part in fishing. Of the 75% of households interviewed, 99% take part in fishing activities. An average of 12% of the fishing effort was performed by women, with most of this effort focused on reef gleaning and diving for clams. Women also participated, albeit to a lesser extent, in gillnetting and reef fishing (Chapman *et al.*, 2005). Passfield (1998) found that each household spent approximately 14 person hours per week fishing.

Although the Tokelauans have incorporated newer, modern fishing gear into their practices, there are some areas where tradition still dominates. The handmade wooden canoes are still required for handling yellowfin, skipjack, marlin, or large sharks, as well as for a traditional Tokelauan method of noosing *pāla* (*Acanthocybium solandri*) (Hooper, 1985). Many traditional fishing methods such as *lama hahave* (fishing with a scoop net and torch) and *takiulu* (luring fish into a prepared noose) are still used. Tokelauans also still use the *inati* system to distribute large catches (particularly of skipjack tuna) or catches of sacred 'fish' (turtles, marlin, and sailfish), so that everyone receives an equal share (Hooper, 1985; Ono and Addison, 2009). Use of spears and spear-guns are not a favoured form of fishing, as it is believed that they result in fish being afraid whenever people enter the water (Hooper, 1985). However, spear-guns have become more widely used in recent years (Ono and Addison, 2009). The main methods of fishing are trolling, reef gleaning, reef fishing, mid-water fishing, gillnetting, diving, bottom fishing, and bait fishing (Chapman *et al.*, 2005). Today, as well as in the past, trolling for *Katsuwonus pelamis* (skipjack tuna) and *Thunnus albacares* (yellowfin tuna) is the most important type of fishing to the Tokelauan people (Ono and Addison, 2009).

There are no commercial fisheries in Tokelau. Although it is known that a portion of the catch is used for internal island trade or shipped to friends and family as gifts, these activities are not a commercial cash enterprise. The act of selling fish is viewed as offensive by the Tokelauan people (Hooper, 1985). Traditional systems make it almost impossible to sell fish, regardless of what the individual's views are. The people of Tokelau operate under the *inati* system, which essentially requires fishers to share large catches with the entire community. This takes away the motivation and possibility of catching fish to be sold for personal financial gain (Passfield, 1998). Even if Tokelau abandoned these traditional systems, they do not have the resources to maintain a commercial fleet of their own. There are no ports for larger commercial vessels to dock and land large quantities of catch. The *MV Tokelau*, which transports goods and people to and from Tokelau, must anchor offshore and have its passengers and cargo transported to land by a low aluminum barge with an outboard motor (Townend, 2009). The atolls are closed and only have about 15 natural depressions and a few blasted channels which small vessels can pass through into the lagoon (Gillett and Toloa, 1987). Therefore, given the topography of the atolls, it would not be easy to maintain a commercial fleet for Tokelau. In 1980, the United Nations Development Programme (UNDP) attempted to develop the Tokelauan fishing industry by giving each atoll a 29-foot catamaran which would be used to start a small artisanal fishery or to simply help increase their current subsistence efforts (Hooper, 1985). However, use of the catamarans required a large amount of village cooperation and this was difficult to organize with a large proportion of the population working in the public service sector (Hooper, 1985). The catamarans also have high operating costs (e.g., fuel and maintenance) which would require fish to be sold to recoup costs, which is something the Tokelauans frown upon (Hooper, 1985). Thus, the catamarans ended up being used for shipping people and goods across the lagoon (Hooper, 1985). Another reason that commercial fishing would not be profitable in Tokelau is that fishing beyond the subsistence level would possibly put too much pressure on the already limited fish stocks which would likely be detrimental to resource levels (van Pel, 1958; Passfield, 1998).

Overall it appears that there is little threat of overfishing in Tokelau. This can be attributed to the Tokelauans methods and views toward fishing. The Tokelauans are very aware of what is available in their waters and thus know what they can and cannot take. As well, appropriate measures would be taken if any declines were in fact observed (Hooper, 1985). The Tokelauans rely heavily on the fish, and know if overfished they will not have anything to eat for the next week, month, or year. Giant clams on the other hand, may be in jeopardy. According to an early report by van Pel (1958), *Tridacna gigas* were relatively abundant in the early period, whereas later on there is no mention of them. However, later reports mention two other clam species: *Tridacna squamosa* and *Tridacna maxima* (Passfield, 1998). According to Hooper (1985), giant clams were regarded as an emergency resource that were only harvested when severe weather conditions prevented the catch of other fish. However, around 1980, the Tokelauans made use of the commercial freezers given to them by the UNDP and would load them up with frozen giant clams to be sent to friends and family in Western Samoa as gifts (Hooper, 1985). This occurred only a few times a year based on the shipping schedule (Hooper, 1985). Although this may have put pressure on stocks, it seems that the Tokelauans only had to change their technique and dive a little deeper if they wished to continue harvesting (Hooper, 1985). In a more recent study, there is mention of frequent harvesting of *T. squamosa* and *T. maxima*. However, it also stated that on Atafu there have been strict limitations put in place on the harvesting of these clams (Ono and Addison, 2009). Therefore, it seems that concern over these stocks has resulted in measures being put in place to prevent overharvesting.

Although there have not been many studies conducted on the fishing activities of Tokelau, it can be seen from the data that has been collected that even something as simple as a household survey once every five years could provide important information (Zeller *et al.*, 2006; Gillett, 2009). Although creel surveys (i.e., interviews with fishers and surveillance of their catch) are too costly for small countries to complete every year, a survey completed once every five years would provide important data which could be interpolated between collection years (Zeller *et al.*, 2007). If data were collected on the eating habits of Tokelauans, how much they export and import, how much of their seafood consumption is fresh, what types of fish they are catching, or what kind of gear they are using, this could be used to derive more comprehensive estimates of their annual catches (Zeller *et al.*, 2007). Regional (e.g., SPC) and international agencies (e.g., FAO) should consider facilitating and establishing such data collection and utilization approaches, and the required technical and financial resources. For a small island country such as Tokelau, where people rely on the ocean for their sustenance, monitoring of fisheries removals is fundamental to maintaining national food security.

Acknowledgments

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Appendix Table A1: FAO landings vs. total reconstructed catch (in tonnes) for Tokelau, 1950-2009.

Year	FAO landings	Reconstructed catch
1950	0.25	384.0
1951	0.25	408.5
1952	0.25	407.3
1953	0.25	406.1
1954	0.25	430.3
1955	0.25	429.1
1956	0.50	427.8
1957	0.25	451.7
1958	0.25	450.4
1959	0.25	449.1
1960	0.25	472.7
1961	0.25	471.3
1962	0.25	470.0
1963	0.25	468.6
1964	0.25	467.2
1965	0.25	465.8
1966	0.25	464.5
1967	0.25	463.1
1968	0.25	461.7
1969	0.25	411.9
1970	100.00	410.7
1971	100.00	409.4
1972	100.00	384.2
1973	100.00	383.0
1974	100.00	381.9
1975	100.00	380.7
1976	100.00	379.6
1977	100.00	378.4
1978	100.00	377.3
1979	100.00	376.1
1980	100.00	375.8
1981	100.00	379.3
1982	100.00	382.7
1983	100.00	386.2
1984	150.00	389.8
1985	150.00	393.1
1986	150.00	396.5
1987	200.00	391.5
1988	200.00	386.5
1989	200.00	381.6
1990	220.00	376.7
1991	231.00	371.8
1992	191.00	416.5
1993	200.00	393.6
1994	200.00	370.8
1995	200.00	358.0
1996	200.00	345.0
1997	200.00	345.3
1998	200.00	346.0
1999	200.00	357.8
2000	160.00	369.6
2001	150.00	388.8
2002	140.00	396.9
2003	130.00	405.0
2004	120.00	412.8
2005	110.00	420.9
2006	100.00	429.0
2007	90.00	376.7
2008	80.00	388.3
2009	70.00	399.6

Appendix Table A2: Total reconstructed catch (in tonnes) for Tokelau (1950-2009) by major taxa. Others grouping includes 24 taxa.

Year	*Cypselurus* spp.	Scaridae	*Selar crumenophthalmus*	Other Carangidae	*Thunnus albacares*	*Thunnus obesus*	*Acanthocybium solandri*	Others
1950	70.1	41.9	28.2	27.9	28.3	28.3	23.0	136.3
1951	74.5	44.5	30.0	29.7	30.1	30.1	24.5	145.0
1952	74.3	44.4	29.9	29.6	30.0	30.0	24.4	144.6
1953	74.1	44.3	29.8	29.5	29.9	29.9	24.4	144.2
1954	78.5	46.9	31.6	31.3	31.7	31.7	25.8	152.8
1955	78.3	46.8	31.5	31.2	31.6	31.6	25.7	152.3
1956	78.1	46.7	31.4	31.1	31.5	31.5	25.7	151.9
1957	82.4	49.3	33.1	32.8	33.3	33.3	27.1	160.4
1958	82.2	49.1	33.0	32.8	33.2	33.2	27.0	159.9
1959	81.9	49.0	33.0	32.7	33.1	33.1	26.9	159.4
1960	86.2	51.6	34.7	34.4	34.8	34.8	28.4	167.8
1961	86.0	51.4	34.6	34.3	34.7	34.7	28.3	167.3
1962	85.7	51.3	34.5	34.2	34.6	34.6	28.2	166.8
1963	85.5	51.1	34.4	34.1	34.5	34.5	28.1	166.4
1964	85.2	51.0	34.3	34.0	34.4	34.4	28.0	165.9
1965	85.0	50.8	34.2	33.9	34.3	34.3	28.0	165.4
1966	84.7	50.7	34.1	33.8	34.2	34.2	27.9	164.9
1967	84.5	50.5	34.0	33.7	34.1	34.1	27.8	164.4
1968	84.2	50.4	33.9	33.6	34.0	34.0	27.7	163.9
1969	75.1	44.9	30.2	29.9	30.4	30.4	24.7	146.2
1970	74.9	44.8	30.1	29.9	30.3	30.3	24.6	145.8
1971	74.7	44.7	30.0	29.8	30.2	30.2	24.6	145.4
1972	70.1	41.9	28.2	27.9	28.3	28.3	23.1	136.4
1973	69.9	41.8	28.1	27.9	28.2	28.2	23.0	136.0
1974	69.7	41.7	28.0	27.8	28.1	28.1	22.9	135.6
1975	69.5	41.5	27.9	27.7	28.1	28.1	22.8	135.2
1976	69.2	41.4	27.8	27.6	28.0	28.0	22.8	134.8
1977	69.0	41.3	27.8	27.5	27.9	27.9	22.7	134.3
1978	68.8	41.1	27.7	27.4	27.8	27.8	22.6	133.9
1979	68.6	41.0	27.6	27.3	27.7	27.7	22.6	133.5
1980	68.6	41.0	27.6	27.3	27.7	27.7	22.5	133.4
1981	69.2	41.4	27.8	27.6	27.2	27.2	22.2	136.8
1982	69.8	41.7	28.1	27.8	26.7	26.7	21.7	140.1
1983	70.5	42.1	28.3	28.1	26.2	26.2	21.3	143.5
1984	71.1	42.5	28.6	28.4	25.7	25.7	20.9	147.0
1985	71.7	42.9	28.8	28.6	25.1	25.1	20.4	150.4
1986	72.3	43.3	29.1	28.8	24.6	24.6	20.0	153.9
1987	71.4	42.7	28.7	28.5	24.3	24.3	19.7	151.9
1988	70.5	42.2	28.3	28.1	23.9	23.9	19.5	150.0
1989	69.6	41.6	28.0	27.8	23.6	23.6	19.2	148.1
1990	68.7	41.1	27.6	27.4	23.3	23.3	19.0	146.2
1991	67.8	40.6	27.3	27.0	23.0	23.0	18.7	144.3
1992	76.0	45.5	30.5	30.3	25.8	25.8	21.0	161.6
1993	71.8	42.9	28.9	28.6	24.4	24.4	19.8	152.7
1994	67.7	40.5	27.2	27.0	23.0	23.0	18.7	143.9
1995	65.3	39.1	26.2	26.0	22.2	22.2	18.1	138.9
1996	62.9	37.6	25.3	25.1	21.4	21.4	17.4	133.9
1997	63.0	37.7	25.3	25.1	21.4	21.4	17.4	134.0
1998	63.1	37.8	25.4	25.2	21.4	21.4	17.4	134.3
1999	65.3	39.0	26.2	26.0	22.2	22.2	18.0	138.8
2000	67.4	40.3	27.1	26.9	22.9	22.9	18.6	143.4
2001	70.9	42.4	28.5	28.3	24.1	24.1	19.6	150.9
2002	72.4	43.3	29.1	28.9	24.6	24.6	20.0	154.0
2003	73.9	44.2	29.7	29.5	25.1	25.1	20.4	157.1
2004	75.3	45.1	30.3	30.0	25.6	25.6	20.8	160.2
2005	76.8	45.9	30.9	30.6	26.1	26.1	21.2	163.3
2006	78.3	46.8	31.5	31.2	26.6	26.6	21.6	166.5
2007	68.7	41.1	27.6	27.4	23.3	23.3	19.0	146.2
2008	70.8	42.4	28.5	28.2	24.0	24.0	19.6	150.7
2009	72.9	43.6	29.3	29.1	24.8	24.8	20.2	155.1

RECONSTRUCTING MARINE FISHERIES CATCHES FOR THE KINGDOM OF TONGA: 1950-2007[1]

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ABSTRACT

Total marine fisheries catches were estimated for Tonga from 1950-2007 by reconstructing past catches and accounting for all fisheries sectors, including commercial and non-commercial components. Our catch reconstruction for Tonga estimated the total catch to be over 3.5 times larger than the landings reported to FAO over the study period. For recent period (2000s), this discrepancy has decreased with total catches averaging 5,600 t·year^{-1}, compared to 3,300 t·year^{-1} reported by FAO on behalf of Tonga. The majority of catches that were unaccounted for in the reported landings were from the subsistence sector, which represented 70% of the total reconstructed catch. This illustrates the substantial under-representation of small-scale subsistence fisheries in the official statistics for Tonga. Small-scale fisheries play a key role in the socioeconomic framework and food security of Pacific Island countries such as Tonga and this needs greater recognition and better accounting.

INTRODUCTION

The Kingdom of Tonga is located between 15˚- 23.5˚S and 173˚- 177˚W in the South Pacific Ocean (Figure 1). Tonga consists of approximately 170 islands, of which 37 are inhabited (Zann 1994; Anon., 2010a), and has an Exclusive Economic Zone (EEZ) of approximately 665,000 km² (www.seaaroundus.org). The islands of Tonga are clustered into three groups: Tongatapu, Ha'apai, and Vava'u, which have a combined land area of about 747 km² (Malm, 2009). About 70% of the population of Tonga resides on Tongatapu, which is also the location of the capital city, Nuku'alofa. The islands of Ha'apai and Vava'u are less developed, have smaller populations and rely more on subsistence fishing and farming (Evans *et al.,* 2003).

Prior to the Tongan constitution of 1875, fishing rights to nearshore marine areas were under control of community chiefs and belonged only to coastal people (Kronen *et al.,* 2003). After 1875, there was an abolishment of exclusive fishing rights to particular marine areas and all people had the right to fish or gather marine resources (Kronen *et al.,* 2003). This system is still in place today, with the exception of fish fences, live rock extraction,

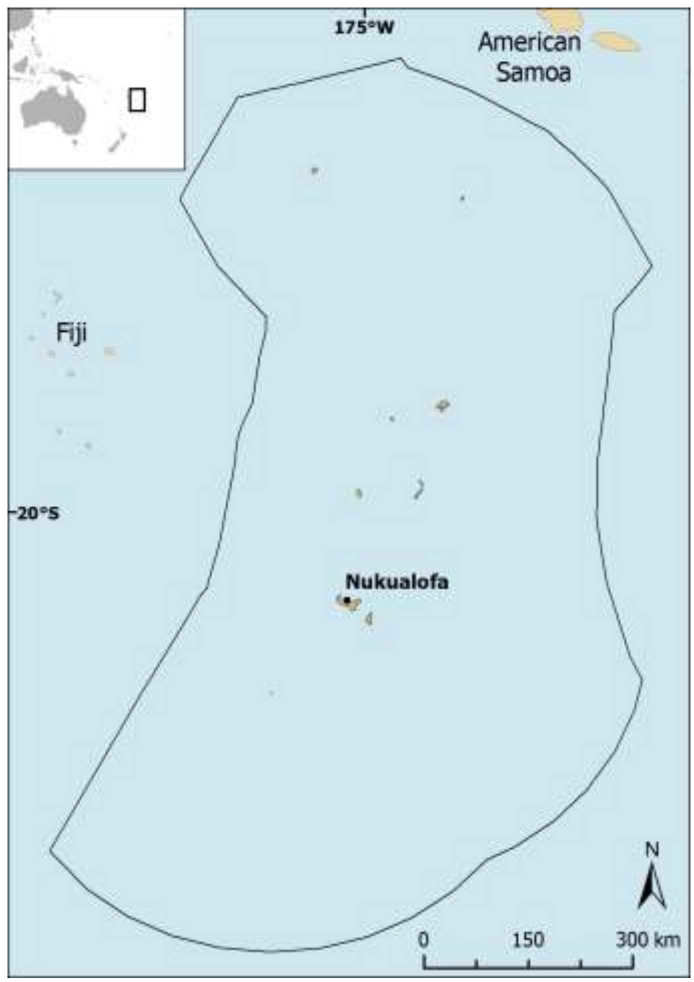

Figure 1. Map of Tonga and its Exclusive Economic Zone.

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aquaculture, and marine protected areas (Kronen *et al.,* 2003).

Tongan fisheries include both commercial and non-commercial sectors. The small-scale fisheries target reef-lagoon, pelagic and deep-slope species. While the majority of small-scale fishery catches are from reef areas, Tonga's deep-slope fishery has been considered one of most successful in the Pacific Island region (Dalzell *et al*., 1996). Traditionally, Tongans fished only inside the reef (Bell *et al*., 1994); however, in the early 1980s a deep-water fishery began, initially using small boats, but eventually expanding to include larger vessels (Mead, 1979; 1981). A large-scale commercial fishery for offshore pelagics started in the 1980s with one vessel, but grew to 25 vessels by the 2000s (Likiliki *et al*., 2005). A commercial lobster fishery began in the late 1960s and a sea cucumber (bêche-de-mer) fishery was established in the 1990s. Neither of these invertebrate fisheries expanded substantially. The open ocean fisheries were conducted mainly by men, while reef collecting activities (reef gleaning) involved mostly women and children (Malm, 2009).

Expansion of Tonga's commercial fisheries has been relatively unstable due to large fluctuations in stocks. For example, mullet stocks (Mugilidae) in Tongatapu have faced several major collapses, beginning in the 1960s when monofilament nets were introduced (SPC, 1988). Deepwater snapper (Lutjanidae) stocks on offshore slopes and seamounts have also been substantially depleted (Zann, 1994). The lobster fishery has gone through various boom and bust cycles since it began in the 1960s (Bell *et al*., 1994) and the bêche-de-mer fishery, which began in 1990, was deemed overfished by 1996 and has been under a ten-year moratorium since 1998 (Bell *et al*., 1994).

The commercial fisheries sector of Tonga makes up around 3% of the country's GDP (Gillet, 2009); however, subsistence farming and fishing are practiced by the majority of people (Zann, 1994). Though there has been a shift in recent years towards agriculture and imported foods in Tongatapu, fishing remains an important source of protein in the diet for many on the outer islands of Ha'apai and Vava'u.

Methods for subsistence fishing vary depending on the equipment that is readily available, and many fishers employ a combination of techniques. The most popular gear is the handline, followed by spear fishing and gillnetting (Kronen and Bender, 2007). Women and children use spears, traps, and may also participate in some types of group fishing. Men typically fish with spears, hooks, nets, and traps.

The objective of this study is to provide a comprehensive estimate of Tonga's total marine fisheries catches by accounting for commercial (industrial and artisanal) and non-commercial (subsistence) fisheries sectors. The Food and Agriculture Organization of the United Nations (FAO) reports marine fisheries landings, as supplied by each member country, in the form of time-series data, extending from 1950 to present, and can be found in the FAO FishStat database (www.fao.org/fishery/statistics/en). These data are based on national statistical data from each country, and can be subject to omissions depending on the method of statistical collection and the quality of data transfer. As such, much of the FAO landings data include only the commercial fisheries sector. Given the importance of fishing for subsistence in the coastal communities of a country such as Tonga, and its common under-representation in catch statistics (e.g., Zeller *et al*., 2006a), we will estimate this unreported fisheries component to improve our understanding of Tonga's use of marine fisheries resources using a catch reconstruction approach (Zeller *et al*., 2007). This study looked at all subsectors within Tonga's fisheries, including large-scale (i.e., offshore fishing), artisanal (i.e., reef, deep-slope, and near-shore fishing), and subsistence fishing in order to estimate total marine fisheries catches by Tonga from 1950-2010.

METHODS

Tongan fisheries focus on targeting reef and lagoon, deep-slope and pelagic species. There are both commercial and non-commercial components to the reef and lagoon fisheries, whereas the deep-slope and pelagic fisheries are predominantly commercial. Estimates of Tonga's commercial landings were obtained from FAO, whereas subsistence catch data and taxonomic information on small-scale fisheries were derived from household surveys, independent studies and from gray literature sources. Subsistence fisheries estimates were only available for some years; therefore, subsistence catch data were combined with human population data to derive *per capita* subsistence catch rates, which were then expanded to cover the entire study period. Our efforts at reconstructing Tonga's fisheries catches focused mainly on estimating catches for the small-scale sector and improving the taxonomic resolution of all sectors.

Human Population data

Human population data for 1950 were obtained from populstat (www.populstat.info/), for 1956, 1966, 1976, 1986 and 1996 from the Statistic Department of Tonga (Fifita, 1996), and for 2006 from the Secretariat of the Pacific Community (Anon., 2010b). Linear interpolations were used to estimate the population between years of known data. Data from 1976 onwards provided a population breakdown for the main island (Tongatapu) and the outer islands (Ha'apai, Vava'u, and others). Prior to 1976 we extrapolated the ratio back to 1950 and applied it to the total population to derive the Tongatapu and outer Island populations for the earlier time period (Figure 2).

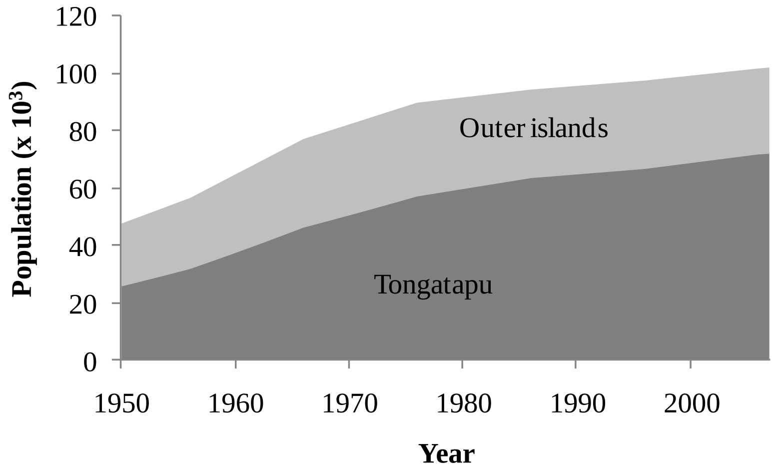

Figure 2. Tonga's population for the main island (Tongatapu) and outer islands combined (Ha'apai, Vava'u and others), 1950-2007. There has been a migration to the main island, Tongatapu, from the outer islands in the recent period. In the mid-2000s approximately 70% of the population resided on Tongatapu, whereas in the 1950s just over 50% resided on the main island.

Subsistence fisheries

Most inhabitants of the outer island groups of Ha'apai and Vava'u participate in fisheries on some level. On the main island group, Tongatapu, there has been a shift in dietary preferences from fish as a major source of protein to mutton flaps, chicken pieces, and corned beef, which have become cheap alternatives (Finau *et al.,* 1994; Gillett, 2009). Our estimates for subsistence fishing reflect a decrease on islands with increased urbanisation (e.g., Tongatapu) due to wider availability of other food alternatives. This is supported by Kronen *et al.* (2003), who found a decrease in fresh fish consumption with increased urbanization.

Reliable estimates for subsistence fisheries catches in the early time period were not readily available. Kent (1980) estimated that local fisheries production in 1977 (i.e., 1,100 t) supplied less than half of the populations seafood demand. Assuming the remaining demand was met through subsistence catch, we derived an estimated subsistence amount of 1,300 t for 1977 by assuming that artisanal catches supplied approximately 45% of the overall demand. An estimate by Dalzell *et al.* (1994), for the mid 1990s was 933 t. Both of these seemed low when considering that more recent estimates were more than double. The estimation techniques in these earlier accounts were not adequately described, and they seemed unrealistically low when converted to *per capita* subsistence catch rates (i.e., 10-14 $kg{\cdot}person^{-1}{\cdot}year^{-1}$). Furthermore, the FAO country profile for Tonga (www.fao.org/fishery/countrysector/FI-CP_TO/en [accessed June 2010]) suggests that these earlier subsistence estimates were in fact low. Therefore, we used Gillet and Lightfoot's (2002) estimate for 1997 of 2,863 t as the best estimate of subsistence catches. This 1997 subsistence estimate was converted to *per capita* subsistence catch rates for the main island and the outer islands using the proportion of subsistence catches from the main and outer islands (40% and 60% respectively) as presented by Lovell and Palaki (2002). The resulting per capita rates were: 17 $kg{\cdot}person^{-1}{\cdot}year^{-1}$ for the main island and 56 $kg{\cdot}person^{-1}{\cdot}year^{-1}$ for the outer islands for 1997. Halapua (1981 in Bell *et al.*, 1994) estimated that in the Ha'apai island group (i.e., outer islands), subsistence reef-lagoon fisheries constitute 70% of the total annual catch. We applied this breakdown to the 1997 catch for the outer islands using our estimated subsistence catch as 70% of the total catches to derive our artisanal catch amount (i.e., 56 $kg{\cdot}person^{-1}{\cdot}year^{-1}$ accounted for 70% of total catch rate for outer islands being approximately 80 $kg{\cdot}person^{-1}{\cdot}year^{-1}$). We assumed that in 1950 catches on the outer Islands were all subsistence and used our 1997 *per capita* rate for total catches of 80 $kg{\cdot}person^{-1}{\cdot}year^{-1}$ (i.e. domestic supply) as the 1950 subsistence catch rate. A linear interpolation was used to derive a time series from 1950 to 1997, and this trend was carried forward from 1997 to 2007.

We further assumed that the *per capita* subsistence catch rate for the main island (Tongatapu) in 1950 was the same as the outer islands in the late 1990s (56 kg·person^{-1}·year^{-1}), as commercial fisheries and food imports were less developed in the early time period and the entire population would have relied more heavily but not exclusively on subsistence catches.

In the later time period, as commercial fisheries developed, mainly around Tongatapu, reliance on subsistence fisheries diminished as the population derived more of their animal protein supply from commercial fisheries and from alternative non-seafood sources including imported food items. To derive a complete time series, we carried the 1950 rate (56 kg·person^{-1}·year^{-1}) forward unaltered to 1970, when the reef and lagoon fishery of Tongatapu started to show signs of overexploitation. From the 1970 anchor point of 56 kg·person^{-1}·year^{-1} to the 1997 estimate of 17 kg·person^{-1}·year^{-1} we interpolated linearly. From 1997 onward, the rate was decreased by 1% year^{-1}, which is the same decrease observed in the subsistence rate for the outer islands.

Table 1. Comparison of tuna catches presented in FAO Fishstat and in Likilili *et al.* (2005) for the Tongan Longline fishery, which included albacore, bigeye, black marlin, skipjack, swordfish, tuna-like, and yellowfin catches.

Year	FAO	Likiliki *et al.* (2005)
1997	690	214
1998	870	193
1999	1129	327
2000	1269	931
2001	1836	1988
2002	1804	1647
2003	1126	1308
2004	517	373

When combined with commercial catches for the domestic market (i.e., artisanal catch), these subsistence catch estimates resulted in an average *per capita* fish consumption rate of 80 kg·person^{-1}·year^{-1} in 1950, decreasing to 38 kg·person^{-1}·year^{-1} by 2007.

Commercial fisheries data

Offshore pelagics: Catches for tuna presented in the FAO data were comparable to estimates presented in Likiliki *et al.* (2005) for the tuna longline fishery. For some years, the FAO provide more comprehensive estimates (Table 1). We therefore assumed that the FAO data for offshore pelagics (tuna and billfishes) best represented total catches for the industrial pelagics fishery. We assumed that catches of pelagic species for the domestic market by the small-scale sector, were not included in the landings presented by the FAO and were therefore estimated as a component of the artisanal catch (see *taxonomic breakdown* section).

Deep slope fishery: The deep slope fishery began in the 1980s and mainly targets snapper (Lutjanidae) and grouper (Serranidae). This fishery was developed to alleviate pressure on the reef and lagoon fish stocks, which by the 1980s were already under pressure from overexploitation (Ministry of Fisheries, 2007). Initially, these catches would have supplied the domestic market; however, once their value as an export commodity was established, most of the catch went to foreign markets (Ministry of Fisheries, 2007). Catches for the deep slope fishery were obtained from Bell *et al.* (1994) for the period 1986-1992, from the Ministry of Fisheries (2007) for the period 1992-2005, and from FAO Fishstat for 2006 and 2007. Estimates for the 1980-1987 period were derived by linear interpolation from assumed zero catches in 1980 to the first available anchor point in 1987. We assumed that these estimates included catches for both domestic and foreign (export) markets, although the majority would have been for export, and thus were not included in our calculations of total domestic supply (see *Subsistence* section).

Artisanal fishery: A report by Bell *et al.* (1994) presented estimates for the artisanal fishery of Tongatapu for 1987 and 1993. The 1993 estimate was based on catches from the two major landing sites, expanded to account for all of Tongatapu. These estimates were made over a 10-month period (March-December), so catches were also expanded (using the monthly average over the 10-months) to represent catches for January and February. The 1987 and 1993 artisanal catch estimates were 823 t and 386 t, respectively. These included mullet (Mugilidae) catches, which were subsequently removed from the artisanal catch estimate and treated separately. We estimated artisanal catches for 1950 using our Tongatapu subsistence catch estimate for 1950 and the assumption that in 1950 subsistence catches made up 70% of the total catch, while artisanal catches made up the remaining 30%. This assumption was based on our estimated subsistence-artisanal breakdown for the outer islands in the 1990s. On the outer islands, we assumed that in 1950 there was no artisanal sector and that all catches were subsistence. For the later time period, we estimated artisanal catches using our subsistence estimate and the assumption that, in the 1990s on the

Table 2. Species composition of the reef fisheries catches in Tonga applied to both artisanal and subsistence catches. Source: Ministry of Fisheries Database, Inshore Fisheries Statistics (Bell *et al*., 1994).

Family	Species	Tongan Name	Catch (%)
Acanthuridae	*Acanthurus* spp.	Pone	8.71
Acanthuridae	*Acanthurus lineatus*	Ponetuhi	0.50
Acanthuridae	*A. triostegus*	Manini	0.25
Acanthuridae	*Naso* spp.	Ume lei	0.54
Acanthuridae	*N. unicornis*	Ume	8.90
Balistidae	*Pseudobalistes fuscus*	Humu	1.53
Belonidae	*Tylosurus crocodilis*	Haku	0.10
Carangidae	*Caranx* spp.	Lupo	0.33
Diodontidae	*Diodon* spp.	Sokisoki	0.32
Ephippidae	*Platax pinnatus*	Sifisifi	0.07
Fistulariidae	*Fistularia* spp.	Totao	0.09
Gerreidae	*Gerres* spp.	Matu	2.01
Haemulidae	*Plectorhinchus* spp.	Fotu'a	0.97
Holocentridae	*Ostichthys* spp.	Ta'a	2.40
Holocentridae	*Sargocentron* spp.	Telekihi	0.19
Holocentridae	*Myripristis* spp.	Malau	0.70
Kyphosidae	*Kyphosus cinerascens*	Nue	0.50
Labridae	*Cheilinus undulatus*	Tangafa	0.13
Leiognathidae	*Leiognathus* spp.	Sipesipa	0.05
Labridae	*Thalassoma* spp.	Meai	0.87
Labridae	*Cheilinus* spp.	Lalafi	0.67
Lethrinidae	*Lethrinus atkinsoni*	Hoputu	1.78
Lethrinidae	*Lethrinus harak*	Tanutanu	11.53
Lethrinidae	*Lethrinus nebulosus*	Koango, Liki	2.58
Lethrinidae	*Lethrinus* spp.	Manga	1.33
Lutjanidae	*Lutjanus bohar*	Fangamea	0.07
Lutjanidae	*Lutjanus kasmira*	Fate	1.21
Lethrinidae	*Gymnocranius* spp.	Mu	1.23
Monocanthidae	*Aluterus* spp.	Papae	0.05
Mullidae	*Mulloidichthys* spp.	Vete	1.40
Mullidae	*Parupeneus* spp.	Tukuleia	3.82
Muraenidae	*Gymnothorax* spp.	Toke	0.14
Pomacentridae	*Abudefduf septemfasciatus*	Tukuku moana	0.68
Priacanthidae	*Priacanthus* spp.	Mataheheva	0.40
Scaridae	*Leptoscarus vaigiensis*	Ufu	7.67
Scaridae	*Scarus* spp.	Olomea, Pose	18.31
Scaridae	*Bolbometopon muricatum*	Menenga	0.22
Serranidae	*Epinephelus* spp.	Ngatala	5.84
Siganidae	*Siganus argenteus*	Ma'ava	6.11
Siganidae	*S. chrysospilos*	Pongongo	0.63
Siganidae	*S. spinus*	O	4.31
Sphyraenidae	*Sphyraena barracuda*	Ono	0.15
Sphyraenidae	*Sphyraena* spp.	Hapatu	0.45
Terapontidae	*Therapon jarbua*	Kavakava	0.27

outer islands, artisanal catches represented 30% of the total catch. Artisanal catches for 1950, 1987 and 1993 for both main and outer islands were then converted to *per capita* artisanal catch rates and linear interpolations were done to derive a complete time series from 1950-1993. From 1993-2007 we, conservatively, held the artisanal catch rate constant.

Mullet: Traditionally, mullet were the most sought after species by the domestic market (Bell *et al*., 1994). Zann *et al*. (1994) estimated that in the 1960s, mullet represented 40% of all domestically marketed species. However, heavy exploitation of mullet stocks in the 1950s and 1960s lead to a substantial decline in mullet landings, which likely began in the 1970s (Zann *et al*., 1984) and continued to decline dramatically, with a near collapse in the 1990s (Bell *et al*., 1994).

FAO data do not present mullet catches as a separate category, but they may be accounted for as 'miscellaneous marine fishes'. Independent reports were obtained, which described the state of the mullet fishery and presented catches for some years (Bell *et al*., 1994; Kimura and Fa'anunu, 1995). Bell *et al*. (1994) present mullet landings for Tongatapu of 140 t in 1987 and 3.2 t in 1993. We estimated that from 1950-1970, mullet represented 40% of artisanal catches for Tongatapu, which translates into a 1950 catch of almost 250 t and a 1970 catch amount of 364 t. A linear interpolation was done to estimate catches for the time period, 1970 to 1987 and 1987 to 1993. From 1994 onward we carried forward the 1993 catch of 3.2 t unaltered.

Taxonomic breakdown for artisanal and subsistence fisheries

Taxonomic composition for the reef, deep-slope, and coastal pelagic fisheries are presented in Dalzell *et al*. (1996) but only to the family level. Mead (1980) provided a similar breakdown for deep-slope and pelagic fisheries, which included both family and species details, but only for 1979. Bell *et al*. (1994) provided taxonomic information to the species level for the reef fishery for 1987 and 1993, for the deep-slope fishery (1986-1992), for the mullet fishery and for pelagic species. We used the species composition in Bell *et al*. (1994) as it provided the most comprehensive taxonomic breakdown by sector and species. Mullet catches were composed of *Mugil cephalus* (70%), *Valamugil seheli* (15%) and *Liza* spp. (15%). The species breakdown for the deep-slope fishery was *Etelis coruscans* (25.44%), *Pristipomoides filamentosus* (22.35%), *Epinethelus septemfasciatus* (13.98%), *Etelis carbunculus* (6.07%), *Lethrinus chrysostomus* (5.74%), *Pristipomoides flavipinnis* (3.90 %), *Epinephelus morrhua* (3.71%) and others (18.81%). The remainder of the artisanal catch was broken into reef-lagoon species (70%), sharks and rays (0.15%), other oceanic pelagics (20.1%), small pelagics (8.25%), and 'miscellaneous marine fishes' (2.5%). To each of these categories, we applied the species breakdown presented in Bell *et al.* (1994). Reef fishery catches were assigned to 49 taxa from 25 families (Table 2). Catches of oceanic pelagics were composed of barracudas (*Sphyraena* spp.; 32%), marlin (*Makaira nigricans*, *M. indica* and *Tetrapturus audax*; 40%) and dolphinfish (*Coryphaena hippurus*; 28%). Small pelagics consisted of 11 taxa from 5 families (Table 3). Tuna catches by the artisanal fishery were mainly skipjack (*Katsuwonus pelamis*; 76%), with smaller amounts of yellowfin tuna (*Thunnus albacares*; 20%) and little tuna (*Euthynnus affinis*; 3%). The taxonomic breakdown for sharks was derived from species presented in Bell *et al.* (1994). We assumed: grey reef shark (*Carcharhinus amblyrhynchos*; 20%), silvertip shark (*C. albimarginatus*; 20%), black-tip reef shark (*C. melanopterus*; 20%), great white shark (*Carcharodon carcharias*; 5%), hammerhead (*Sphyrna lewini*; 20%), mako shark (*Isurus oxyrinchus*; 5%) and tiger shark (*Galeocerdo cuvieri*; 10%). No species breakdown was available for ray catches. Thus 1/3 of the shark and ray allocation was assigned to rays

Table 3. Species composition of artisanal catches of small pelagics. Source: Bell *et al.* (1994)

Species	Family	Catch (%)
Stolephorus devisi	Engraulidae	20.0
Atherinomorus lacunosus	Athererininae	20.0
Spratelloides delicatulus	Clupeidae	13.0
Selar crumenopthalmus	Carangidae	11.0
Atule mate	Carangidae	11.0
Hypoatherina ovalaua	Atherinidae	9.2
Sardinella sirm	Clupeidae	7.0
Herklotsichthys punctatus	Clupeidae	6.0
Spratelloides gracilis	Clupeidae	2.0
Scomberoides spp.	Carangidae	0.4
Gazza minuta	Leiognathidae	0.4

Reef gleaning, which targets mainly invertebrates, is known to be a significant contributor to subsistence fishing and is conducted mainly by women (Chapman, 1987; Malm, 2009). While invertebrate fisheries are likely of equal importance as finfish in the subsistence sector (Adams and Dalzell, 1994), quantitative information on the magnitude of invertebrate extractions for subsistence purposes was not readily available (Bell *et al.,* 1994). Therefore, we derived the breakdown of invertebrate to finfish catches for the subsistence fisheries using an estimate given by Malm (2009) for the amount of invertebrates caught by women on the outer islands of Tonga in 1975 (11 kg whole weight·household^{-1}·week^{-1}), since almost all invertebrate fishing was conducted by women. We took 30% of the 11 kg·household^{-1}·week^{-1} to estimate the meat portion of the invertebrate catch (60-70% shell weight [Kunatuba and Uwate, 1993 in Malm, 2009]) and assuming a household size of approximately 5 persons. We expanded the repored catch rate to cover 52 weeks (whole year). The resulting *per capita* invertebrate catch rate was 34 kg·person^{-1}·year^{-1}. We then compared the *per capita* catch rate for invertebrates to the total *per capita* subsistence catch rate for the outer islands in 1975 (67 kg·person^{-1}·year^{-1}) and used the resulting ratio to estimate the finfish component (50%) of the artisanal catch. We then applied this breakdown (50% invertebrates and 50% finfish) to subsistence catches throughout the study period. We used the artisanal sector, reef-species breakdown for the finfish component of the subsistence catch and estimated a breakdown for the invertebrate catch of 80% molluscs and 20% crustaceans.

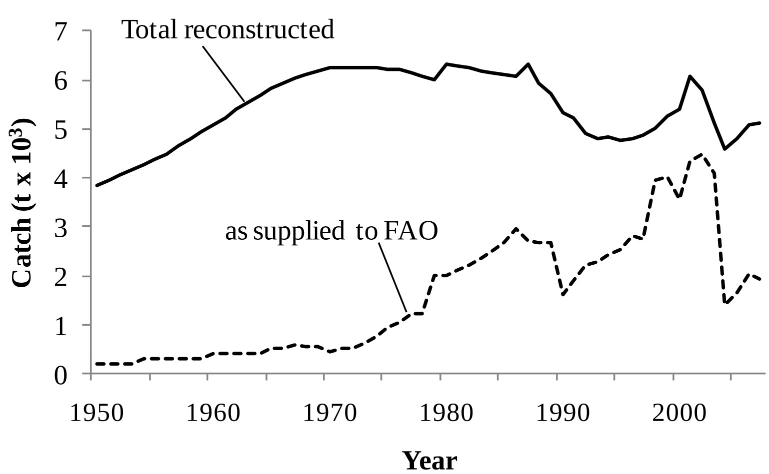

Figure 3. Total reconstructed catch for Tonga 1950-2007 compared to total landings as supplied to the FAO.

RESULTS

Total reconstructed catch

Our estimate of total marine fisheries catches for Tonga, 1950-2007, which included total commercial catches and subsistence catch estimates, was over 323,000 t (Figure 3). This estimate of total marine fisheries catches for Tonga is over 3.5 times larger than the 94,753 t that were reported by the FAO on behalf of Tonga, with major discrepancies prior to the mid-late 1980s. For the more recent years, total reconstructed catches were on average 2 times larger than reported landings. The reconstruction also suggests that total catches peaked in the 1970s and 1980s and has declined since. This pattern is in contrast to the reported data which suggest catches increased until the early 2000 (Figure 3).

Our data suggest that the subsistence sector catches 3 times the amount of fish that the commercial sector lands, and accounts for 70% of total marine fisheries extractions (Figure 4). The time series of subsistence catches shows an increasing trend until the early 1970s, followed by a decrease throughout the remainder of the study period (Figure 4).

Catches for the artisanal sector (mullet and deep slope catches excluded) were estimated to be 54,309 t over the 1950-2007 time period (Figure 4). Of this total, 54% were from the main island of Tongatapu, while the remaining 46% were from the outer islands.

Mullet catches totalled approximately 250 t in 1950, increased to a peak of approximately 360 t·year^{-1} in the late 1960s and then steadily decreased, with a dramatic decline in the late 1980s (Figure 4). We estimated that catches of mullet in the recent period (2000s) were about 3 t·year^{-1}.

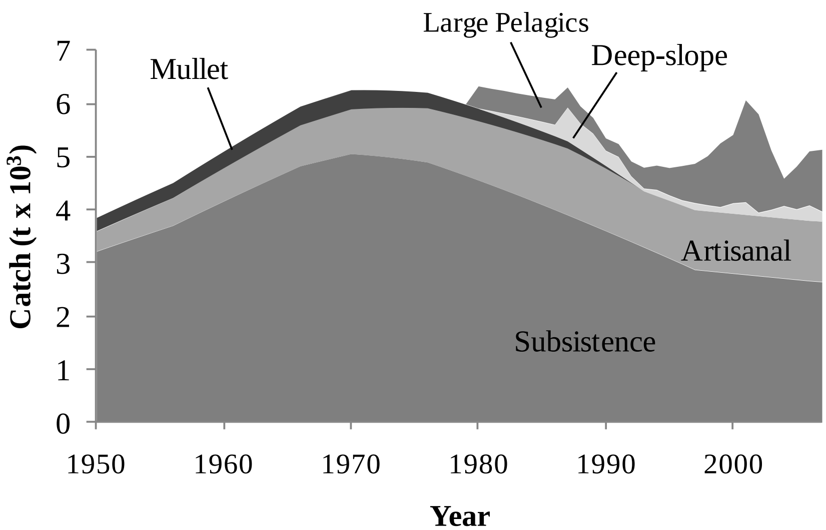

Figure 4. Total marine fisheries catches for Tonga, 1950-2007. Catches include mullet and deep-slope and large pelagic fisheries in addition to estimates of artisanal and subsistence sectors.

The deep slope fishery caught an estimated 5,176 t, mainly of snapper and grouper, between 1980 and 2007 (Figure 4). The deep-slope fishery represented approximately 5% of all commercial sector catches.

Large tuna and billfish catches totalled 19,496 t from 1967-2007. Prior to 1967, catches of tuna and billfish were not reported by the FAO as a separate category.

DISCUSSION

Our total reconstructed catch estimate for Tongan marine fisheries for the period 1950-2010, was 3.5 times larger than the data reported to FAO on behalf of Tonga suggest. For more recent periods, this discrepancy declined to two times, i.e., 2,300 t·year^{-1}. Subsistence catches accounted for the largest unreported component of our reconstruction, representing 84% (3,200 t·year^{-1}) and 48% (2,600 t·year^{-1}) of the total catch for Tonga in 1950 and 2007, respectively, which is in line with the regional estimate for the South Pacific Islands of 80% (Zann and Vuki, 2000). Artisanal catches were estimated using independent data and were approximately 16% (623 t·year^{-1}) and 24% (1,317 t·year^{-1}) of the total catch for 1950 and 2007, respectively. Artisanal catch estimates likely did not include the portion of the catch that was sold directly to restaurants, hotels or at the roadside, as catch estimates from Bell *et al.* (1994) were based on surveys from fish market sales. Our estimate of artisanal catches may, therefore, have been on the low side. The remaining catch was from the large-scale pelagic fishery, which was zero in 1950 and 28% of the total catch in 2007.

Artisanal fisheries (i.e., small-scale commercial) are the main supplier of seafood to the domestic commercial market in Tonga. In 1950, we assumed that the outer islands had no commercially marketed seafood, and all seafood was sourced through subsistence fishing. However, our estimates of artisanal catches on the outer islands for the recent period were substantial, compared to catches on the main island of Tongatapu. This is likely due to the more recent transition on the outer islands towards a cash-based economy. More fish are likely sold, whereas previously, catches on the outer islands were mainly subsistence. Our results suggested that overall, the main island of Tongatapu landed 54% of the artisanal catch, while the outer islands landed the remaining 46%. Mead (1987) provided a similar estimate, with over half of the commercial catch being landed in Tongatapu.

The average *per capita* fish consumption rate was 80 kg·person^{-1}·year^{-1} in 1950, decreasing to 38 kg·person^{-1}·year^{-1} by 2007 when the commercial production for the domestic market (i.e., artisanal catch) was combined with the subsistence catch estimate. This is well within the range presented by Gillet and Lightfoot (2002) of between 14-102 kg·person^{-1}·year^{-1} and for the recent period, close to the range given by Anon. (1993) of 20-50 kg·person^{-1}·year^{-1}. Lower consumption rates were presented in the literature (e.g., 23 kg·person^{-1}·year^{-1} derived from Kimura and Fa'anunu [1995]); however, these were likely based solely on commercial production.

On the main island, there has been a shift in diet preference away from seafood toward cheaper, imported animal protein alternatives such as mutton flaps and corned beef (Finau *et al.*, 1994). The reason for this shift may have been partly driven by a decline in reef-lagoon stocks due to overexploitation around Tongatapu, in addition to the increasing cost of local seafood. The proportionately smaller artisanal catches on the main island as compared to the outer islands may be the result of this decline in availability and accessibility of marine products on Tongatapu.

The large-scale commercial fisheries sector of Tonga expanded substantially in the 1980s, when profitable commercial tuna longline operations began (Bell *et al.*, 1994). Most of the tuna catch is exported, making this fishery the highest contributor to fisheries-based revenue for Tonga. The domestic commercial tuna fishery expanded in the 1980s from one vessel to 33 by 2003 (Likiliki *et al.*, 2005). According to Bell *et al.* (1994), tuna stocks in Tonga did not seem depleted at that time, and could support an expansion, if this fishery were given sufficient resources. Annual tuna catches consist of 70% albacore (*Thunnus alalunga*), 20% yellowfin (*Thunnus albacares*) and 10% big eye (*Thunnus obesus*; Likiliki *et al.*, 2005). Severe declines in 2003 and 2004 catches due to the effects of El Nino resulted in all foreign vessels leaving Tonga in 2005 (Likiliki *et al.*, 2005; Gillett 2009).

Mullet is an important food fish in the Tongan diet (Kimura and Fa'anunu, 1995). Mullet catches began to decline in the 1970s, followed by dramatic declines in the 1980s and early 1990s due to the use of fish fences (Bell *et al.,* 1994; Kimura and Fa'anunu, 1995). Both of these sources agree that *Mugil cephalus,* which made up 70-75% of the mullet catch in the 1980s, was on the verge of local extinction by the 1990s.

This study illustrated the importance of the small-scale fisheries sector to Tonga, and the magnitude of under-representation of subsistence catches. Most Tongans, fish more to meet their daily food needs than for commercial purposes (Kronen, 2004); however, this sector is often overlooked in fisheries management. The subsistence sector accounts for a substantial portion of total marine fisheries removals and draws mainly from nearshore, reef resources. Gillet (2009) estimated that the contribution by the subsistence sector to Tonga's GDP to be roughly 3%, while the commercial sector contributes roughly 6%. Reef fisheries provide a crucial source of animal protein to the Tongan people, particularly the inhabitants of the outer islands where subsistence fisheries dominate. Thus, reef resources and subsistence fisheries are crucial to national food security. Our estimate of domestic seafood supply, based on artisanal and subsistence catches, ranged from 80 kg·person^{-1}·year^{-1} in 1950 to 38 kg·person^{-1}·year^{-1}, in 2007, which is within the range of 14-102 kg·person^{-1}·year^{-1} given in Gillet and Lightfoot (2002), but less than the 102 kg·person^{-1}·year^{-1} presented by Finau *et al.* (1994). Our estimate of domestic seafood supply was on average higher than some previous estimates (Kent, 1980; Anon., 1993; Kunatuba and Uwate, 1983 in Kimura and Fa'anunu, 1995); however, their lower consumption estimates were likely based only on commercial production. There is agreement, however, that the majority (60-70%) of domestic production is from reef and lagoon resources (Bell *et al.*, 1994; Zann and Vuki, 2000).

The health of the Tongan people relies heavily on the health of the reef ecosystem. Although parts of Tonga have switched to a cashed-based economy which relies less on subsistence fishing, alternative economic systems such as bartering still exist on the outer islands and should be considered in resource management decisions and policy development, particularly in terms of food security. For countries such as Tonga, who remain closely tied to the sea for their basic needs, proper accounting of marine fisheries extractions is paramount to their socio-economic stability.

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Appendix Table A1. FAO landings vs. total reconstructed catch (in tonnes) for Tonga, 1950-2007, in metric tonnes.

Year	FAO landings	Total reconstructed catch
1950	200	3,830
1951	200	3,944
1952	200	4,056
1953	200	4,167
1954	300	4,278
1955	300	4,387
1956	300	4,495
1957	300	4,647
1958	300	4,798
1959	300	4,947
1960	400	5,094
1961	400	5,240
1962	400	5,385
1963	400	5,528
1964	400	5,670
1965	500	5,811
1966	500	5,950
1967	581	6,110
1968	548	6,156
1969	555	6,240
1970	444	6,306
1971	533	6,297
1972	532	6,294
1973	626	6,282
1974	753	6,273
1975	928	6,259
1976	1,038	6,233
1977	1,216	6,160
1978	1,210	6,065
1979	2,000	5,988
1980	1,994	6,328
1981	2,093	6,247
1982	2,229	6,267
1983	2,365	6,218
1984	2,502	6,133
1985	2,690	6,070
1986	2,952	6,008
1987	2,724	5,608
1988	2,692	5,425
1989	2,664	5,245
1990	1,616	5,031
1991	1,915	4,890
1992	2,217	4,767
1993	2,282	4,645
1994	2,435	4,648
1995	2,530	4,596
1996	2,826	4,598
1997	2,763	4,570
1998	3,937	4,724
1999	4,029	4,930
2000	3,545	5,054
2001	4,332	5,499
2002	4,493	5,518
2003	4,107	4,815
2004	1,414	4,307
2005	1,632	4,468
2006	2,041	4,597
2007	1,927	4,599

Appendix Table A2. Total reconstructed catch (in tonnes) for Tonga by major taxa, 1950-2007. Others grouping includes 81 taxa.

Year	Misc. molluscs	*Scarus* spp.	Misc. crustaceans	*Lethrinus harak*	*Naso unicornis*	*Acanthurus* spp.	*Leptoscarus vaigiensis*	*Thunnus alalunga*	Others
1950	1,283	342	321	215	166	162	143	-	1,199
1951	1,317	352	329	222	171	168	147	-	1,239
1952	1,351	363	337	229	176	173	152	-	1,278
1953	1,384	373	345	235	181	178	156	-	1,317
1954	1,417	384	353	242	187	183	161	-	1,356
1955	1,450	394	361	248	192	188	165	-	1,394
1956	1,482	405	369	255	197	192	169	-	1,431
1957	1,530	419	381	264	204	199	175	-	1,483
1958	1,577	433	392	273	210	206	181	-	1,534
1959	1,623	447	404	281	217	213	187	-	1,584
1960	1,670	461	415	290	224	219	193	-	1,633
1961	1,715	474	426	299	230	226	199	-	1,682
1962	1,761	488	437	307	237	232	204	-	1,730
1963	1,806	501	448	316	244	238	210	-	1,778
1964	1,851	515	459	324	250	245	215	-	1,825
1965	1,895	528	470	332	256	251	221	-	1,871
1966	1,939	541	481	341	263	257	226	-	1,917
1967	1,964	549	487	345	267	261	230	-	1,980
1968	1,988	556	493	350	270	265	233	-	2,005
1969	2,011	564	498	355	274	268	236	-	2,031
1970	2,035	571	504	360	278	272	239	-	2,055
1971	2,029	574	502	361	279	273	240	-	2,058
1972	2,022	576	500	362	280	274	241	-	2,060
1973	2,013	577	498	363	281	275	242	-	2,060
1974	2,002	578	495	364	281	275	242	-	2,059
1975	1,991	579	492	365	282	276	243	-	2,058
1976	1,994	580	488	365	282	276	243	-	2,054
1977	2,003	575	480	362	280	274	241	-	2,035
1978	1,975	571	472	359	277	271	239		2,014
1979	1,946	566	463	356	275	269	237	-	1,993
1980	1,917	560	454	353	272	267	235	0	2,392
1981	1,887	555	446	350	270	264	232	0	2,405
1982	1,856	550	437	346	267	261	230	106	2,320
1983	1,825	544	427	342	264	259	228	143	2,298
1984	1,793	538	418	339	261	256	225	135	2,329
1985	1,760	531	409	335	258	253	222	174	2,317
1986	1,727	525	399	331	255	250	220	206	2,317
1987	1,694	518	389	326	252	246	217	252	2,566
1988	1,660	506	379	319	246	241	212	242	2,302
1989	1,625	493	369	311	240	235	206	195	2,218
1990	1,591	480	359	302	233	228	201	152	1,959
1991	1,556	466	349	293	226	222	195	171	1,984
1992	1,520	451	339	284	219	215	189	199	1,735
1993	1,432	436	329	274	212	207	182	231	1,677
1994	1,376	428	318	270	208	204	179	343	1,690
1995	1,319	421	308	265	205	200	176	379	1,693
1996	1,261	413	297	260	201	197	173	431	1,774
1997	1,203	406	286	256	197	193	170	493	1,811
1998	1,179	404	284	254	196	192	169	616	1,927
1999	1,154	402	282	253	195	191	168	801	2,027
2000	1,130	400	279	252	194	190	167	862	2,118
2001	1,129	398	277	250	193	189	167	1,268	2,483
2002	1,136	396	275	249	192	188	166	1,189	2,381
2003	1,138	394	272	248	191	187	165	611	2,340
2004	1,139	392	270	247	190	186	164	182	2,264
2005	1,120	390	268	245	189	185	163	283	2,362
2006	1,111	388	265	244	188	184	162	414	2,536
2007	1,104	386	263	243	188	184	162	390	2,604

RECONSTRUCTION OF MARINE FISHERIES CATCHES FOR TUVALU (1950-2009)[1]

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ABSTRACT

Tuvalu's total marine fisheries catches within its EEZ were reconstructed for the years 1950 to 2009. This reconstruction accounts for officially un- and underreported catches of artisanal and subsistence fishery sectors as well as the baitfish used in the pole-and-line tuna fishery. FAO data were used in combination with data from fish markets, regional reports and consumption data. Total reconstructed catches were estimated to be 69,631 t over the six decades, which is approximately 5 times larger than the amount reported by the FAO on behalf of Tuvalu (12,241 t). Total catches increased from 813 t·year^{-1} in 1950 to 1,607 t·year^{-1} by 2009. The majority of total catches were from the subsistence sector (87%). This investigation reveals the need for an improvement in the accounting of marine fishes catches by all fisheries sectors. Due to the heavy rates of fish consumption in Tuvalu, reliable estimation of catches and resulting resource management decisions will play a role in Tuvalu's future food security.

INTRODUCTION

Tuvalu is an archipelago in the South Pacific consisting of nine atolls; Nanumea, Niutao, Nui, Vaitupu, Nukufetau, Nukulaelae, Niulakita and Funafuti. Tuvalu is located at 8° 31' S, 179° 13' E, approximately halfway between Australia and Hawaii in the south central Pacific (Figure 1). The country's total land area of 26 km² is tiny in comparison to its nearly 752,000 km² Exclusive Economic Zone (EEZ) (www.seaaroundus.org). Tuvalu is critically vulnerable to sea level rise due to its low-lying topography, with most of the country less than 3m above sea level (Connell, 2003; Sauni and Fay-Sauni, 2005; Rayfuse, 2011; Stephen, 2011). The continental shelf off Tuvalu is minimal; there are patch and fringing barrier reefs immediately surrounded by 1,000 m depths. The inner lagoons provide the only significant shallow water areas (Sauni and Fay-Sauni, 2005).

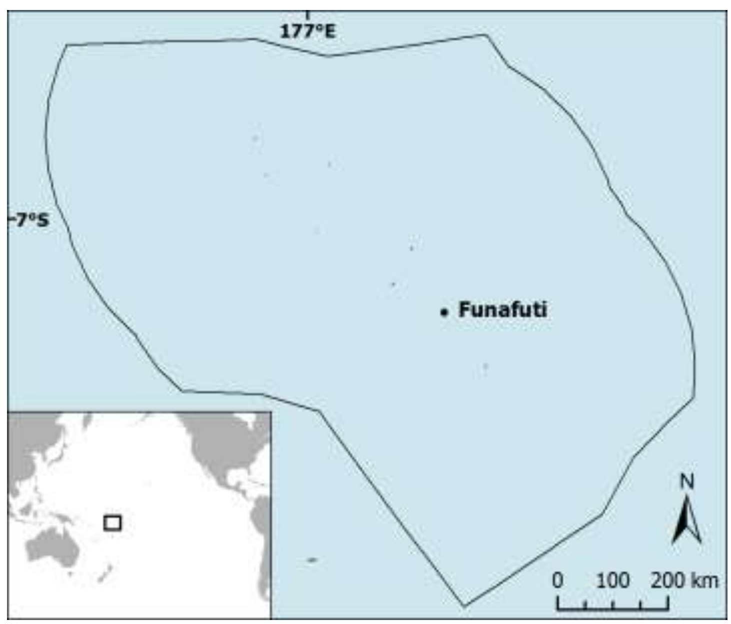

Figure 1: Map of Tuvalu and its Exclusive Economic Zone.

Formerly a British colony known as the Ellice Islands, Tuvalu gained its independence in October 1978. The country has been politically stable and its economy has grown from an initial Tuvalu Trust Fund investment of $ 27 million Australian Dollars (AU$) in 1987 to AU$ 66 million in 2002 (Gemenne and Shen, 2009). As of 2002, the Gross Domestic Product (GDP) of Tuvalu was AU$ 26.9 million, of which 8.2% was from the artisanal fishing industry (Gillett, 2009). The Tuvaluan economy is considered traditional and predominantly non-cash (Sauni and Fay-Sauni, 2005). Marine products, wages and

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remittances sent by family members working overseas - many on foreign fishing vessels - are considered to be the most important sources of income (Sauni and Fay-Sauni, 2005). In the past ten years, annual revenue from foreign fishing fleets has varied, providing between 5.5% and 36.7% of total government revenue and grants (Gillett, 2009). In 1999, Tuvalu received USD$ 5.9 million in foreign fishing access fees. This amount comprised 42.6% of its GDP (Gillett and Lightfoot, 2002). The revenue from foreign tuna fishing is approximately 14.6% of the total value of the fish caught (Gillett, 2009). With Tuvalu receiving such a comparatively small percentage of the value of its fish, the government continues in their attempt to develop commercial fisheries in its vast EEZ, and stimulate economic growth. However, the development of larger-scale commercial fisheries in Tuvalu is hindered by high costs, difficulty raising funds and a lack of infrastructure required for fleet maintenance and operations, processing, internal distribution and export (Gillett, 2002).

The largest component of Tuvalu's fishing activities is subsistence, i.e., for direct consumption. More than 80% of domestic coastal catch in Tuvalu is produced by subsistence fishing (Gillett, 2010). Dalzell (1996) estimated that subsistence and artisanal fisheries make up 87% and 13%, respectively, of Tuvaluan coastal fisheries production. A recent Household Income and Expenditure Survey revealed that fishing contributes to 8% of personal income, after wages and remittances sent from overseas (Anon., 2006). Data on the artisanal sector is incomplete due to the high occurrence of informal bartering (Lambeth, 2000; Poulasi, 2008; WCPFC, 2009, 2010). Fishermen or their wives sell their catch either from home, the roadside using handcarts and ice chests or in small markets (Lambeth, 2000; Gay, 2010). As a result, catch data for the subsistence and artisanal fisheries are largely unknown. As more Tuvaluans try to make the change to working for an income, the artisanal sector is assumed to grow (Sokimi and Chapman, 2005).

The heavy dependence on fish for animal protein is evident through the unique Tuvaluan word '*miti*' which describes a craving specifically for fish. In 2004 and 2005, the urban *per capita* fish consumption in Tuvalu was 68.8 $kg \cdot person^{-1} \cdot year^{-1}$ with 97% of that amount being fresh fish. For rural areas, the *per capita* consumption was 147.4 $kg \cdot person^{-1} \cdot year^{-1}$ (99% being fresh fish) (Gillett, 2009). Tuvalu's seafood consumption rate is among the highest in the world (Gillett and Lightfoot, 2002; Gillett *et al.*, 2001). The island communities of Tuvalu are distinguished not only for their fishing ability, but also their rich knowledge of their environment (Gay, 2010). The close relationship between Tuvaluans and the ocean is readily apparent through their dependence on fish for food security. The island of Niutao, one of the main islands of Tuvalu, has one of the highest population to reef area densities in the region, with 246 people per km^2 of reef (Adams *et al.*, 1996). At the same time, on the atoll of Funafuti, there was a lower population to reef area density of 165 people per km^2 of reef (Adams *et al.*, 1996). However, Funafuti is now home to approximately 5,000 people, 47% of the country's population (Sauni *et al.*, 2008). Even though the urban island has set up management measures such as the 33 km^2 Funafuti conservation area, it is highly urbanized and as such faces problems such as sewage treatment and waste disposal. There is heavy fishing pressure from subsistence needs on this island with many people fishing after work and on the weekends (Sauni *et al.*, 2008). It is estimated that 93% of households on Funafuti eat fresh fish that they catch and 70% of households eat fresh invertebrates that they catch (Sauni *et al.*, 2008). Fish catch rates have increased when compared to estimates from previous years (Sauni and Fay-Sauni, 2005). Thus there is concern for the sustainability of inshore resources in light of the increased fishing pressure and population growth on Funafuti (Adams *et al.*, 1996; Gillett, 2002; Sauni and Fay-Sauni, 2005; Aylesworth and Campbell, 2009).

Fishing in Tuvalu uses a range of techniques including pole-and-line, trolling and reef gleaning, which are used to collect finfish, bivalves, crustaceans and other invertebrates in nearshore and offshore Tuvaluan waters. The fishing roles on Tuvalu, like many other Pacific Islands are divided by gender, with women mainly reef gleaning at low tide, and processing, and men fishing both inshore and offshore. The introduction of outboard engines on canoes in the 1960s and 1970s has made fishing much easier, and consequently, women have felt less of a need for their auxiliary fishing activities (Lambeth, 2000). However, when men are unable to fish because of the weather, women's collecting activities are vital (Chapman, 1987). While fishing techniques vary among the different islands, the main gears used are gillnetting, handlining, castnetting, pole-and-line and spearfishing. Handlines are used to catch demersal fish on the reef (Sauni and Fay-Sauni, 2005). On the outer reefs, spears, handlines, scoop nets and deep bottom methods such as deep-bottom droplining are used (Chapman and Cusack, 1990; Sauni *et al.*, 2008). As of 1991, there were an estimated 200 motorized and 500 non-motorized vessels, most less than 10 m (Gillett, 2003). On the most populated island of Funafuti, there are 10 to 20 commercial vessels (4-5

m) engaged in trolling for mainly skipjack and yellowfin tuna (Gillett, 2003) and some line fishing for reef species (Gillett, 2002).

Fisheries in Tuvalu are dominated taxonomically by skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*), which in 1978 made up half of the total fish catch (Gillett *et al*., 2001). A more recent estimate suggests skipjack and yellowfin represent approximately 75% of total fish landings (Gillett, 2002). Other pelagic fish such as flying fish (*Cypselurus* spp.) also represent a substantial part of the catch. Flying fish, usually caught at night with the use of scoop nets and lights (Gillett, 2002), are commonly used as baitfish in the tuna pole-and-line fishery (Aylesworth and Campbell, 2009). Fish inhabiting the lagoon and reef habitats such as red snapper (*Lutjanus gibbus*) are also caught but make up a lesser portion of the catch. Bycatch is generally consumed, bartered or given away as a part of the fishery.

In the early 1980s, the government established the National Fishing Corporation of Tuvalu (NAFICOT) tasked with the goal of developing industrial fisheries (Sokimi and Chapman, 2005; Gillett, 2011a). One of the roles of NAFICOT was to manage national fishing vessels. In 1982, Japan donated a pole-and-line vessel, in 1989, Japan donated 7 additional vessels (6 launches and 1 extension vessel), and in 2004, Korea donated two longliners. Community fishing centers (CFC) were developed in the 1990s with foreign aid to provide an income opportunity for fishers and also to redistribute the excess supply of fish to the urban population center of Funafuti through NAFICOT. The CFCs provide salting, drying and at times cold storage facilities. However, ice is not usually present in many of the CFCs or on local fishing vessels because of a lack of transportation infrastructure and water availability (Aylesworth and Campbell, 2009). Presently, most CFCs have fallen into disrepair and rely heavily on government subsidies. In 2009, NAFICOT went bankrupt when the government decided to cease financial support (Gay, 2010). This same year, a joint venture was established between Tuvalu and Taiwan; the first purse seiner flying the Tuvaluan flag, the FV *Taumoana* began fishing in August of that year in Tuvalu, FSM and Kiribati, landing a total of 4,877 t of tuna, most likely skipjack and yellowfin (WCPFC, 2010).

The purpose of this study is to reconstruct total marine fisheries catches by Tuvalu within its EEZ between 1950 and 2010 by accounting for all fishing sectors, as a baseline for the assessment of food security and resource availability. During the completion of this study, it was necessary to make assumptions in order to fill large gaps in data availability because the official reported data includes neither taxonomic specificity nor quantitative detail, especially for the pre-1980 time period.

MATERIALS AND METHODS

The Tuvalu Fisheries Department collects offshore commercial catch data for the national fleet. In addition, the department actively collects monthly reports from various fish markets reporting sales and purchasing information. In 2010, Tuvalu started a national catch database for their inshore fisheries (T. Poulasi, pers. comm., Tuvalu Fisheries Department). Unfortunately, data from 2010 was not yet available at the time of this study. Catch data other than for the national fleet for all years prior to 2010 were not collected by the national Fisheries Department (T. Poulasi, pers. comm., Tuvalu Fisheries Department). The artisanal data collected from fish market reports are limited, as they encompass only the small amount of catch sold within the markets (WCPFC, 2009), whereas much catch is sold informally. Data on subsistence fishery catches have not been collected at all. The national data are considered insufficient for the evaluation and monitoring of fishing activities (Chapman, 2004). However, recent attempts

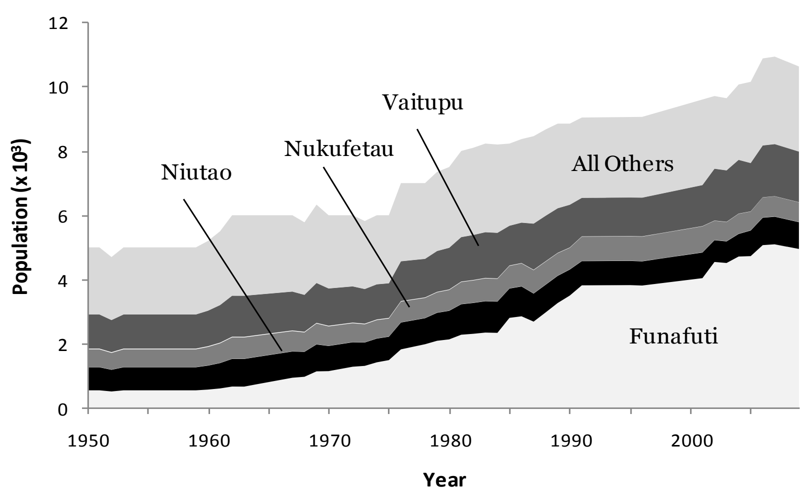

Figure 2. Human population of Tuvalu by major islands, 1950-2009.

have been made to improve data collection. To provide the best picture of Tuvaluan fisheries, data from FAO FishStat, regional reports and independent assessments were accessed and used to develop data anchor points for the estimation of total catches. Interpolations between anchor points were used to derive a complete time series, using a catch reconstruction approach developed by Zeller *et al.* (2006; 2007).

Human Population Data

Population data were obtained in order to convert available *per capita* consumption rates into an estimate of overall demand. National population data were obtained from Populstat (www.populstat.info/ [date accessed: 20 July 2011]) prior to 1997, from the 2008 Biannual Statistical Report (Anon., 2008) for years 2002 to 2007 and from Index Mundi (www.indexmundi.com [date accessed: 20 July 2011]) for 2009. A linear interpolation was used between years of known population data in order to obtain a complete time series. Population data by island were obtained for Funafuti, Niutao, Nukufetau and Vaitupu from Populstat for 1985, 1987 and 1996, a Household Income and Expenditure Survey for 2005 (Anon., 2006) and City Population (www.citypopulation.de [date accessed: 20 July 2011]), for 1979, 1991 and 2002. Over the past 50 years, migration to Funafuti from the other islands has resulted in nearly 50% of the current total population residing on Funafuti, driven mainly by the availability of government jobs (Connell, 2003). The earliest population data found for Funafuti was for 1963 obtained from Populstat. The percentage of the total population which resided in Funafuti in 1963 was applied back in time to 1950. From 1964 to 2005, the population of Funafuti was determined through interpolation of data points. For Niutao, Nukufetau, Vaitupu and all others, the earliest year of data was 1979. Therefore, we calculated the proportion that each of these islands represented and applied these same proportions back to 1950. After 1979, interpolation was done between the island population data. From 2005 to 2010, all island populations were calculated based on 2005 percentages (Figure 2).

Fishing in Tuvalu

The FAO FishStat database was used as the official catch data for Tuvalu (Figure 3). However, FAO data are presented by FAO area and do not delineate the amount taken within EEZ areas. This report aims to reconstruct the catches taken by Tuvaluans within their waters; therefore, it was necessary to disaggregate the catch taken in Tuvalu's EEZ from that taken outside. A significant component of fishing recorded in the FAO data occurred outside of Tuvalu's EEZ. For example, in 1982, Tuvalu fished in a partnership with the Ika Corporation in Fijan waters (SPC, 1994). Tuvalu also fished in Fiji and Solomon Islands in 1987 and 1988 with a peak catch of 1,091 t from the Solomon Islands in 1988 (SPC, 1994; Sauni *et al.*, 2008). In 2009, Tuvalu in a joint venture with the Fong Haur fishing company of Taiwan fished in the Federated States of Micronesia and in Kiribati (WCPFC, 2010). Due to the large proportion of fishing known to occur outside of Tuvalu's EEZ (SPC, 1994; Apinelu, 2004; Sauni *et al.*, 2008; WCPFC, 2010), we assumed 90% of the FAO tuna catch (bigeye (*Thunnus obesus*), skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and tuna-like) was taken outside of Tuvalu's waters (Figure 3). Remaining FAO landings (ie., marine fishes nei) were assumed to have been from small-scale fisheries within Tuvalu's EEZ.

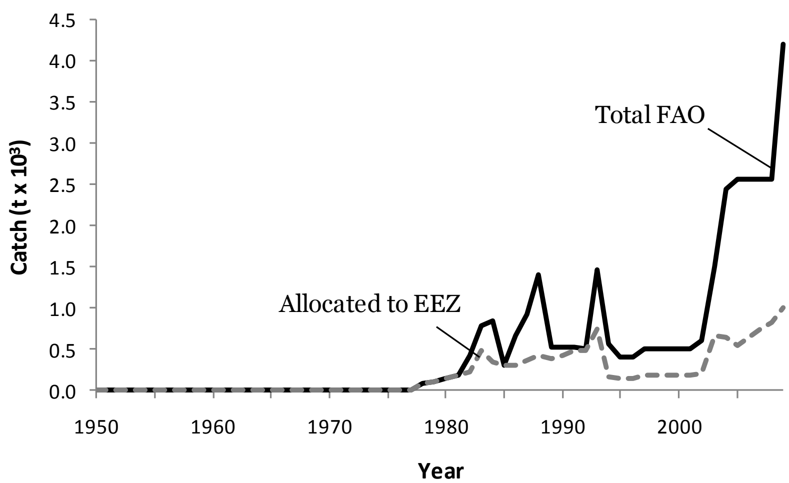

Figure 3. Catches presented by the FAO on behalf of Tuavlu and allocation of FAO data to the Tuvaluan EEZ based on assigning 90% of reported tuna catches to be taken outside EEZ waters, 1950-2009.

Small-scale fisheries

FAO FishStat presents landings of miscellaneous marine fishes from 1950 to 2009. Prior to 1982, FAO landings for Tuvalu are less than 0.5 t·year^{-1} and landings for tuna and tuna-like fishes during this period are zero. Catch amounts or rates from national or independent sources were not readily available for either the artisanal or subsistence sectors; therefore *per capita* consumption rates were used to determine the overall fresh fish demand for Tuvalu (Gillett and Lightfoot, 2002; Sauni *et al.*, 2008; Gillett, 2009). This overall demand was compared to the reported supply to determine the magnitude of underreporting. For 2004, national fresh fish consumption in Tuvalu was calculated using consumption rates for the islands of Funafuti, Nukufetau, Niutao and Vaitupu (Sauni *et al.*, 2008) (Table 1). For the remaining five islands not represented individually, here referred to as 'all others', the average across the four individual islands (i.e., 151.0 kg·person^{-1}·year^{-1}) was used (Sauni *et al.*, 2008). To derive a nation-wide consumption rate, a 2004 weighted average for all islands was calculated (145 kg·person^{-1}·year^{-1}). This rate was used for all of Tuvalu for 2004 and was carried forward, unaltered to 2010 (Gillett and Lightfoot, 2002; Sauni *et al.*, 2008). The 1950 fresh fish consumption rate was assumed to be similar to the rate for the other islands in 2004 (see All others Table 1) with the addition of 5 kg to account for limited imports of protein alternatives available in the later period. The resulting *per capita* consumption rate for 1950 was 155.6 kg·person^{-1}·year^{-1}. A linear interpolation between these two anchor points between the 1950 and the 2004 *per capita* rates was used to complete the time series. The consumption rates were then combined with the human population data to estimate overall demand of fresh fish.

Table 1. Fresh fish consumption rates per island for 2004 (Sauni *et al.*, 2008).

Island	Fresh fish consumption rate (kg/person/year)[a]
Funafuti	135.0
Nukufetau	117.8
Niutao	185.3
Vaitupu	162.5
All Others	150.6

[a]weighted average for all islands 145 kg·person^{-1}·year^{-1}.

To determine the proportion of the total demand supplied by each sector, Dalzell's (1996) breakdown of 13% artisanal and 87% subsistence was used for 1996 to 2009. In 1950, we assumed 100% of the catch to be subsistence and interpolated to 87% subsistence in 1996. The annual artisanal production estimates were then checked to ensure that they exceeded the artisanal landing amounts given in annual reports by the Western and Central Pacific Fisheries Commission (Poulasi, 2008; WCPFC, 2009, 2010). This was necessary as the WCPFC reports reflect only the small fraction of catch landed and received by the CFCs. Fishers normally sell their catch directly to consumers; these transactions are not documented (Poulasi, 2008).

Invertebrates

The people of Tuvalu also consume invertebrates as part of their diet. However, unlike for fresh fish, there is no local commercial fishery for invertebrates (Sauni *et al.*, 2008). Thus, an annual subsistence invertebrate demand was calculated with invertebrate consumption data from the Secretariat of the Pacific Community Coastal Fisheries Program (www.spc.int/coastfish/ [date accessed: 15 July 2011]) (Table 2). Similar to the fresh fish consumption data, invertebrate consumption data were available for Funafuti, Nukufetau, Niutao and Vaitupu. A national average per capita invertebrate consumption rate was calculated to represent the remaining islands. To determine the annual invertebrate demand, the same methodology was used as in determining total demand of fresh fish (see *Small-scale fisheries*). The weighted average consumption rate for invertebrates (3.8 kg·person^{-1}·year^{-1}) was used for 2004 and all years following. For 1950, the national average was used with an adjustment of 2 kg to account for the limited availability of alternate protein sources at that time (i.e., 5.8 kg·person^{-1}·year^{-1}). An interpolation was done between the 1950 (5.8 kg·person^{-1}·year^{-1}) and 2004 (3.8 kg·person^{-1}·year^{-1}) anchor points and the 2004 rate was carried forward unaltered to 2010.

Table 2. Invertebrate consumption rates per island 2004.

Island	Invertebrate consumption rate (kg/person/year)
Funafuti	4.6
Nukufetau	5.6
Niutao	3.6
Vaitupu	0.9
All Others	3.7

Taxonomic breakdown

A substantial portion of both the subsistence and artisanal catch consists of tuna (Gillett *et al.*, 2001). A thorough review of the scientific and grey literature provided numerous estimates of the tuna component of the Tuvaluan catch. Sauni (2008) presents annual tuna landings data for the 1970s of 350 t·year^{-1}. This amount, however, is viewed to be slightly overestimated (Eginton and Mead, 1978). Gillett (2001) reports that 50% of fish sold in Funafuti is tuna. The Pacific Island Fisheries Regional and Country Information report suggested that 75% of all fish landings are ocean species, mainly skipjack and yellowfin tuna (Gillett, 2002). Based on these information sources, an estimate of 300 t was used as an anchor point for 1975. This represents 32.5% of the total demand for 1975. We assumed that tuna consumption was similar in 1950, and allocated 32.5% of the total 1950 catch to tuna. The species composition for the tuna was derived from yearly reports provided by the Tuvaluan government to the Western and Central Pacific Fisheries Commission (Poulasi, 2008; WCPFC, 2009, 2010). The proportion of skipjack to yellowfin tuna represented in the catch were calculated by averaging annual catch data derived from fish market sales for the years 2003 to 2008. To account for other pelagic species, a small portion of the tuna catch (arbitrarily assigned as 10%) was allotted to miscellaneous large pelagic. The remaining 90% were assigned as 54% skipjack and 36% yellowfin tuna (Table 3). Catches were also broken down taxonomically according to fishing sector, either subsistence or artisanal. For the artisanal sector, species compositions given by Dalzell (1996) were used to taxonomically disaggregate all families aside from Scombridae (Appendix A1). The Etelinae subfamily (Family Lutjanidae) was divided into *Etelis* spp. and *Pristipomoides* spp. with each genus receiving half of the Etelinae percentage, to improve taxonomic resolution. Scombridae was excluded, because the tuna component of the artisanal fishery had already been calculated. The invertebrate and fresh fish demands were kept separate for the subsistence sector. The taxonomic breakdown for the subsistence fishery was determined through fish (Appendix Table A2) and invertebrate (Appendix Table A3) catch compositions available in a national report (Sauni *et al.*, 2008). Species catch composition data were available for the islands of Funafuti, Niutao, Nukufetau and Vaitupu for several different habitats such as lagoon, outer reef, sheltered coastal reef and intertidal reef flat. Some species groups that composed a very small percentage of the total catch were grouped and represented at the family level. The invertebrate catch compositions were applied to the invertebrate catch and the fish compositions applied to the fish catch derived from the demand estimates.

Table 3. Taxonomic breakdown of tuna for Tuvalu. Source: (Anon., 1984)

Group	Taxon	Common name	Proportion of catch (%)
Scombridae	*Katsuwonus pelamis*	Skipjack tuna	54
Scombridae	*Thunnus albacares*	Yellowfin tuna	36
Miscellaneous large pelagics	Misc. pelagics	Misc. large pelagics	10

Baitfish

Associated with the pole-and-line fishery for tuna is the use of baitfish, rarely accounted for in fisheries statistics. Baitfish fisheries often operate in parallel to the skipjack pole-and-line fisheries, utilizing the same vessels. Tuvalu's baitfish resources are extremely limited (Gillett, 2011b). In the past, Tuvalu's only pole-and-line fishing vessel, *Te Tautai*, was forced to fish outside of the Tuvaluan EEZ because of the low availability of baitfish (Gentle, 1991).In addition, baitfish resources are more variable around atolls than high islands (Anon., 1984), and atolls like Tuvalu have been less reliable sources of bait. A regional pole-and-line ratio of tuna to baitfish was presented by Gillett (2011b) as 32:1. The dominant species used as baitfish in Tuvalu are *Spratelloides delicatulus, Archamia lineolata, Bregmaceros* spp. and *Atherinomorous lacunoaa* (Anon., 1984). The amount of baitfish used was calculated by taking the estimated tuna catch and applying the 32:1 tuna to baitfish ratio provided by Gillett (2011b) for the region and the taxonomic composition derived from the Tuna Programme (Anon., 1984) was applied (Table 4).

Table 4. Taxonomic breakdown of baitfish for Tuvalu. Source: (Anon., 1984)

Group	Taxon	Common name	Proportion of catch (%)
Clupeidae	*Spratelloides delicatulus*	Delicate round herring	92
Atherinidae	*Atherinomorus lacunosus*	Hardyhead silverside	2
Misc. marine fishes	Misc. marine fishes	Misc. marine fishes	6

Bêche-de-mer

As sea cucumber are not a part of the Tuvaluan diet, they have traditionally received little interest by fisheries managers (Belhadjali, 1997). However, a small bêche-de-mer export industry has developed in

Tuvalu and has become the island's main fishery export item since the late 1970s (Gay, 2010). The industry began after the Fisheries Department became the recipient of UN Development Program funding in 1978. The first export occurred in 1979, 1.8 t of bêche-de-mer sold to Fiji (Belhadjali, 1997). With widely varying production amounts, export continued from 1980 to 1983 (Belhadjali, 1997). Remaining stagnant for a decade, export restarted from 1993 through 1995 supplying Singapore and Fiji. In 2007, harvest in Nukufetau, Nukulaelae and Funafuti began once again with exports to Hong Kong. Only the islands of Funafuti and Nukufetau have suitable habitats for the most profitable sea cucumbers, therefore the sustainability of the bêche-de-mer fishery is of concern (Gay, 2010). The Fisheries Department does not require data on bêche-de-mer catch or exports to be submitted (Gay, 2010). Export weights, nevertheless, were found for all years prior to 2007. Gillett (2009) provided a bêche-de-mer export value of AU$5000 for 2007. From 2007 to 2009, that same export value was used. The monetary value was converted to USD using 2007 exchange rates and the export amount was calculated using the average dollar value per dried kilogram from the years 1993 to 1995 (Belhadjali, 1997). In the processing of sea cucumbers, 90% of their body weight is lost (Dalzell *et al.*, 1996). Thus, all dried weights were converted back to live weights with a conversion factor of ten to represent the bêche-de-mer catch as a component of the total reconstructed catch.

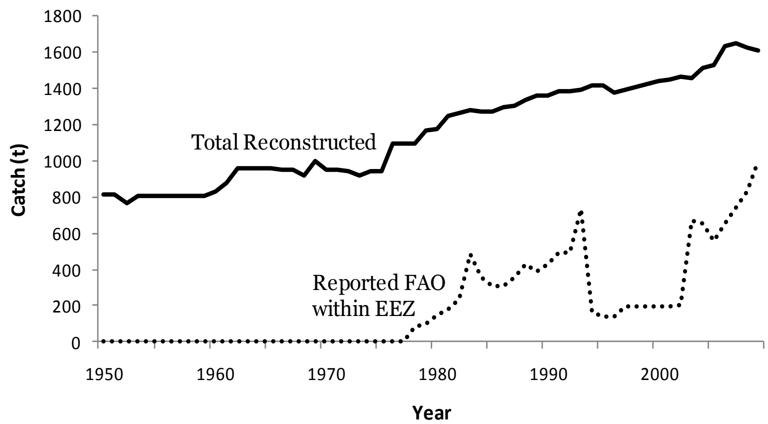

Figure 4. Total reconstructed catch from 1950-2009 for Tuvalu compared to the subset of FAO data assigned to Tuvalu EEZ.

Table 5. Bêche-de-mer catch from 1950-2009.

Year	Catch (t)
1979	18.00
1980	8.05
1981	0.90
1982	1.99
1983-1992	0.00
1993	8.71
1994	36.78
1995	32.28
1996-2006	0.00
2007	3.24
2008	3.24
2009	3.24

RESULTS

Total landings presented by the FAO on behalf of Tuvalu for the 1950-2009 time period were 32,255 t, with essentially 0.25 t·year^{-1} reported until 1977, then fluctuating around 600 t·year^{-1} until the early 2000s when landings increased to 4,198 t by 2009. In contrast, reconstructed data for Tuvaluan marine fishes catch taken within the EEZ were over 67,000 t since 1950, increasing from around 800 t·year^{-1} in 1950 to about 1,600 t·year^{-1} by 2009 (Figure 4). The artisanal sector accounted for just under 6,000 t of fish over the 1950-2009 period, whereas the subsistence sector accounted for over 61,000 t (Figure 5). The most commonly caught families in the subsistence sector were Lethrinidae and Serranidae. The most common species, however, were the blue sea chub (*Kyphosus cinerascens*), the humpback red snapper (*Lutjanus gibbus*) and the bluespot mullet (*Valamugil seheli*). Carangidae, Gempylidae and Lutjanidae were the most common families caught in the artisanal sector. FAO presented catches of tuna and tuna-like

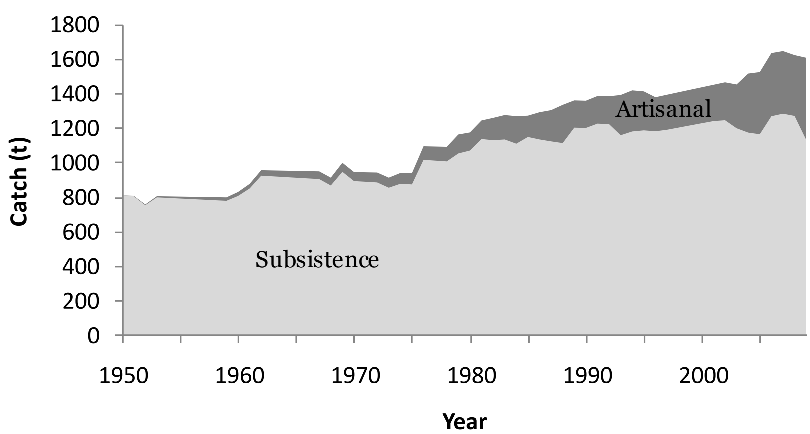

Figure 5. Total reconstructed EEZ catches presented by fishing sector, 1950-2009.

fishes from 1982 onward with a total of 2,223 t. Our reconstruction suggested that 12,438 t of tuna was caught between 1982 and 2009. From 1950 to 1981, 9,347 t of tuna were estimated as part of the reconstruction. A total of 680 t of baitfish were caught for use in the pole-and-line tuna fishery, 92% of which were delicate round herring (*Spratelloides delicatulus*). There were no invertebrates reported in the FAO data. From 1950-2009, a total of 2,070 t of invertebrates were estimated to have been caught. In 1950, the invertebrate catch was 27 t·year^{-1} and by 2009 43 t·year^{-1} of invertebrates were estimated to have been caught. Sea cucumber catch estimates based on bêche-de-mer exports peaked in 1994 at 36.78 t·year^{-1} (Table 5).

Discussion

The FAO FishStat data reported a total of 32,225 t of fish caught by Tuvalu between 1950 and 2009. Of this amount, 12,241 t were determined to have been caught within the Tuvaluan EEZ. In contrast, our total reconstructed catch for 1950 to 2000 was calculated to be 69,623 t. This amount is approximately 5 times more than the official landings presented on Tuvalu's behalf (within their EEZ). The artisanal and subsistence fishery sector catches were assumed to both have been greatly underrepresented by the FAO data. Invertebrates were also not included, even though they comprise an important part of the diet of Tuvaluans. Fisheries catches were underreported particularly during the early years, and official data presented for all years lacked taxonomic detail. In this report, fisheries catches were reconstructed by including all fisheries sectors, such as subsistence, baitfish and invertebrate fisheries. The subsistence fishery sector is important because of its magnitude (Dalzell *et al.*, 1996; Gillett, 2010), but more so because of its implications for food security. For Tuvaluans, fish provides an important source of protein; on Funafuti, households eat fish at least once a week, on the less urbanized islands like Nukufetau households have been reported to eat fish daily (Sauni and Fay-Sauni, 2005). Because of the expense of canned fish and imported meats and the limited opportunities for cash income, it is important for the people of Tuvalu to be able to continue to depend on their fishery resources (Sauni and Fay-Sauni, 2005). In conclusion, although Tuvalu is one of the smallest countries in the world, maintaining reliable data or estimates on its fisheries catches is imperative. The recording of Tuvalu's small-scale fisheries catch amounts with taxonomic detail will enable Tuvalu to more effectively manage its resources.

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APPENDIX A

Appendix Table A1. Taxonomic breakdown of artisanal catch for Tuvalu derived from Dalzell *et al*. (1996).

Family	Common names	Local names	Catch (%)
Lutjanidae	Snappers	Tagau, Taiva, Savane, Palu sega	25.02
Lethrinidae	Emperors or Scavengers	Filoa, Muu, Tanutanu, Gutula, Noto, Saabutu	0.59
Serranidae	Groupers	Gatala, Fapuku, Eve, Sumu	7.13
Carangidae	Jacks and Pompanos	Teu, Tafauli, Ulua, Aseu, Fua ika (Fua ulua), Sokelau	27.85
Gempylidae	Snake Mackerels	Palu	21.54
Sphyraenidae	Barracudas		3.26
Other teleosts	Other bony fish		0.33
Sharks	Sharks		9.98
Istiophoridae	Billfishes		1.87
Belonidae	Needlefishes		1.49
Coryphaenidae	Dolphinfishes		0.93

Appendix Table A2. Taxonomic breakdown of subsistence catch for Tuvalu derived from Sauni *et al*. (2008).

Family	Scientific name	Common name	Local name	Catch (%)
Acanthuridae	*Naso unicornis*	Bluespine unicornfish	Ume	1.72
	Acanthurus guttatus	Whitespotted surgeonfish	Maono	1.73
	Acanthurus lineatus	Lined surgeonfish	Ponelolo	1.01
	Acanthurus triostegus	Convict surgeonfish	Manini	4.45
	Acanthurus xanthopterus	Yellow surgeonfish	Kapalagi	1.17
	Naso lituratus	Orangespine unicornfish	Manini lakau	3.64
	Other Acanthuridae	Surgeonfishes, Tangs, Unicornfishes		1.13
Balistidae	Balistidae	Triggerfishes	Umu	0.04
Caesionidae	*Caesio* spp.	Fusiliers	Ulia	0.41
Carangidae	*Trachinotus baillonii*	Small spotted dart	Sokelau	0.03
	Alectis ciliaris	African pompano	Lalaufou	0.10
	Carangoides ferdau	Blue trevally	Kata	0.28
	Caranx lugubris	Black jack	Tafauli	2.51
	Caranx melampygus	Bluefin trevally	Aseu	0.54
	Caranx sexfasciatus	Bigeye trevally	Teu	0.47
	Elagatis bipinnulata	Rainbow runner	Kamai	0.16
	Scomberoides lysan	Doublespotted queenfish	Ata	0.02
	Selar crumenophthalmus	Bigeye scad	Atule	0.81
	Other Carangidae	Jacks and Pompanos	Aseu	0.54
Chanidae	*Chanos chanos*	Milkfish	Paneava	0.01
Cirrhitidae	*Cirrhitus pinnulatus*	Stocky hawkfish	Patuki	1.68
Exocoetidae	Exocoetidae	Flyingfishes	Isave	2.84
Gempylidae	*Ruvettus pretiosus*	Oilfish	Palu	0.45
Gerreidae	*Gerres* spp.	Mojarras	Matu	3.02
Holocentridae	*Myripristis violacea*	Lattice soldierfish	Malau	3.91
	Sargocentron spiniferum	Sabre squirrelfish	Ta malau	0.47
Kyphosidae	*Kyphosus cinerascens*	Blue sea chub	Nanue	7.69
Labridae	*Thalassoma trilobatum*	Christmas wrasse	Uloulo	0.06
Lethrinidae	*Monotaxis grandoculis*	Humpnose big-eye bream	Muu	0.87
	Lethrinus erythracanthus	Orange-spotted emperor	Saabutu	0.36
	Lethrinus xanthochilus	Yellowlip emperor	Gutula	0.28
	Other Lethrinidae	Emperors or Scavengers	Filoa, Noto / Tanutanu	9.83
Lutjanidae	*Lutjanus kasmira*	Common bluestripe snapper	Savane	1.23

Appendix Table A2. Taxonomic breakdown of subsistence catch for Tuvalu derived from Sauni *et al.* (2008).

Family	Scientific name	Common name	Local name	Catch (%)
	Aphareus rutilans	Rusty jobfish	Palu sega	0.65
	Lutjanus gibbus	Humpback red snapper	Taea	9.77
	Other Lutjanidae	Snappers	-	4.72
Mugilidae	*Valamugil seheli*	Bluespot mullet	Kanase	9.03
	Other Mugilidae	Mullets	Kafakafa, Kanase	5.05
Mullidae	*Mulloidichthys flavolineatus*	Yellowstripe goatfish	Kaivete	0.64
Muraenidae	Muraenidae	Moray eels	-	0.01
Pomacentridae	*Abudefduf septemfasciatus*	Banded sergeant	Mutumutu	0.67
Priacanthidae	Priacanthidae	Bigeye or Catalufas	Matapa	0.04
Scaridae	*Scarus ghobban*	Blue-barred parrotfish	Ulafi	2.03
	Scarus spp.	Parrotfish	Laea	0.71
Serranidae	Serranidae	Groupers and Fairy basslets	Gatala	10.51
	Epinephelus hexagonatus	Starspotted grouper	Eve	0.08
	Epinephelus merra	Honeycomb grouper	Gatala liki	0.15
	Epinephelus polyphekadion	Camouflage grouper	Fapuku	0.47
	Plectropomus laevis	Blacksaddled coralgrouper	Tonu gatala	0.22
	Variola albimarginata	White-edged lyretail	Pula	0.27
Siganidae	*Siganus vermiculatus*	Vermiculated spinefooth	Maiava	1.03
Sphyranidae	*Sphyraena forsteri*	Bigeye barracuda	Pauea	0.24
Miscellaneous	Misc.marine fishes	Misc. marine fishes	-	0.27

Appendix Table A3. Taxonomic breakdown of subsistence invertebrate catch for Tuvalu derived from Sauni *et al.* (2008).

Family	Scientific name	Common name	Local name	Catch (%)
Arcidae	*Anadara* spp.	Ark clams	Koki	0.06
Neritidae	*Nerita polita*	Polished nerite	Sibo	0.07
Octopodinae	*Octopus* spp.	Octopus	Octopus	0.85
Psammobiidae	*Asaphis violascens*	Pacific asaphis	Kasi	5.06
Strombidae	*Lambis truncata*	Giant spider conch	Kalea	2.82
	Strombus luhuanus	Strawberry conch	Panea	53.81
Tridacnidae	*Tridacna maxima*	Elongated giant clam	Fasua	6.37
	Tridacna squamosa	Fluted giant clam	Fasua	2.03
Turbinidae	*Turbo setosus*	Rough turban	Alili	0.84
Miscellaneous Molluscs	Misc. molluscs	Molluscs	-	14.9
Menippidae	*Eriphia sebana*	Smooth redeyed crab	Matamea	0.32
Palinuridae	*Panulirus penicillatus*	Pronghorn spiny lobster	Lobster	12.00
Scyllaridae	*Parribacus antarcticus*	Sculptured mitten lobster	Tuatuaula	0.33
Miscellaneous	Misc. invertebrates	Invertebrates	-	0.54

APPENDIX B

Appendix B1. FAO landings (t) by Tuvalu in FAO area 71, adjusted reported landings within EEZ and total reconstructed catch, 1950-2009.

Year	FAO landings	Reported landing within EEZ[a]	Total reconstructed
1950	0.25	0.25	813.29
1951	0.25	0.25	811.70
1952	0.25	0.25	761.96
1953	0.25	0.25	809.48
1954	0.25	0.25	808.37
1955	0.25	0.25	807.26
1956	0.25	0.25	806.15
1957	0.25	0.25	805.04
1958	0.25	0.25	803.92
1959	0.25	0.25	802.81
1960	0.25	0.25	833.77
1961	0.25	0.25	880.65
1962	0.25	0.25	959.38
1963	0.25	0.25	958.04
1964	0.25	0.25	956.71
1965	0.25	0.25	955.38
1966	0.25	0.25	954.04
1967	0.25	0.25	952.71
1968	0.25	0.25	916.49
1969	0.25	0.25	1002.29
1970	0.25	0.25	948.71
1971	0.25	0.25	947.38
1972	0.25	0.25	946.04
1973	0.25	0.25	916.37
1974	0.25	0.25	943.38
1975	0.25	0.25	942.20
1976	0.25	0.25	1097.49
1977	0.25	0.25	1095.94
1978	80.00	80.00	1094.38
1979	100.00	100.00	1165.47
1980	150.00	150.00	1177.27
1981	180.00	180.00	1246.29
1982	429.00	234.60	1261.14
1983	784.00	480.70	1277.54
1984	840.00	354.00	1271.06
1985	313.00	309.40	1273.88
1986	660.00	309.00	1293.69
1987	933.00	359.70	1305.72
1988	1409.00	427.10	1336.20
1989	519.00	384.90	1361.98
1990	518.00	429.80	1360.01
1991	526.00	492.70	1387.20
1992	499.00	490.90	1385.80
1993	1460.00	737.30	1393.12
1994	561.00	164.10	1419.79
1995	399.00	140.70	1413.89
1996	400.00	139.00	1380.20
1997	500.00	194.00	1394.60
1998	500.00	194.00	1408.98
1999	500.00	194.00	1423.34
2000	500.00	194.00	1437.64
2001	500.00	194.00	1451.89
2002	600.00	204.00	1466.13
2003	1500.00	672.00	1453.79
2004	2450.00	650.00	1516.54
2005	2560.00	553.00	1525.24
2006	2560.00	652.00	1634.67
2007	2560.00	742.00	1646.32
2008	2560.00	832.00	1623.11
2009	4198.00	995.80	1607.82

[a] FAO data were adjusted by assuming only 10% of FAO reported large pelagic catches originated from within Tuvalu's EEZ.

Appendix B2. Total reconstructed catch (t) by major taxa in Tuvalu, 1950-2009. Others grouping includes 78 taxa.

Year	*Katsuwonus pelamis*	*Thunnus albacares*	other Serranidae	other Lethrinidae	*Lutjanus gibbus*	*Valamugil seheli*	Others
1950	136.84	91.23	55.15	51.58	51.26	47.36	379.86
1951	136.66	91.10	55.03	51.38	51.05	47.16	379.33
1952	128.30	85.53	51.61	48.11	47.79	44.15	356.46
1953	136.32	90.88	54.79	50.98	50.64	46.78	379.09
1954	136.16	90.77	54.68	50.78	50.43	46.59	378.97
1955	135.99	90.66	54.56	50.58	50.22	46.40	378.84
1956	135.82	90.55	54.44	50.38	50.02	46.21	378.72
1957	135.66	90.44	54.33	50.19	49.81	46.02	378.59
1958	135.49	90.33	54.21	49.99	49.61	45.83	378.47
1959	135.33	90.22	54.09	49.79	49.41	45.64	378.34
1960	140.57	93.71	56.14	51.58	51.17	47.27	393.34
1961	148.49	99.00	59.25	54.34	53.90	49.79	415.89
1962	161.79	107.86	64.49	59.04	58.55	54.09	453.54
1963	161.59	107.73	64.36	58.81	58.31	53.87	453.38
1964	161.39	107.60	64.22	58.58	58.07	53.64	453.22
1965	161.19	107.46	64.08	58.34	57.83	53.42	453.05
1966	160.99	107.33	63.94	58.11	57.58	53.20	452.89
1967	160.79	107.20	63.80	57.88	57.34	52.97	452.73
1968	154.71	103.14	61.33	55.53	55.01	50.82	435.97
1969	169.22	112.81	67.02	60.57	59.99	55.42	477.27
1970	160.20	106.80	63.39	57.18	56.62	52.31	452.22
1971	160.00	106.66	63.25	56.95	56.38	52.08	452.05
1972	159.80	106.53	63.11	56.72	56.14	51.86	451.88
1973	154.81	103.21	61.09	54.79	54.22	50.09	438.16
1974	159.40	106.27	62.84	56.26	55.66	51.42	451.53
1975	162.00	108.00	62.17	55.55	54.95	50.77	448.77
1976	185.50	123.67	72.99	65.10	64.38	59.48	526.38
1977	185.27	123.51	72.83	64.83	64.11	59.22	526.17
1978	185.03	123.36	72.67	64.56	63.83	58.97	525.96
1979	194.04	129.36	76.14	67.51	66.73	61.65	570.04
1980	197.75	131.83	77.52	68.60	67.80	62.63	571.13
1981	210.67	140.45	82.51	72.87	72.01	66.52	601.27
1982	213.03	142.02	83.36	73.48	72.59	67.06	609.61
1983	216.18	144.12	84.51	74.35	73.43	67.84	617.12
1984	215.12	143.41	84.02	73.77	72.84	67.29	614.61
1985	215.63	143.75	84.14	73.73	72.79	67.24	616.60
1986	219.02	146.01	85.38	74.67	73.70	68.08	626.83
1987	221.09	147.40	86.11	75.15	74.16	68.51	633.30
1988	226.29	150.86	88.05	76.69	75.67	69.90	648.74
1989	230.70	153.80	89.68	77.95	76.90	71.04	661.92
1990	230.40	153.60	89.48	77.62	76.55	70.72	661.63
1991	235.05	156.70	91.20	78.95	77.85	71.92	675.54
1992	234.85	156.57	91.03	78.65	77.54	71.63	675.54
1993	234.65	156.44	90.87	78.35	77.22	71.34	684.24
1994	234.46	156.30	90.71	78.05	76.91	71.05	712.31
1995	234.26	156.17	90.55	77.75	76.60	70.76	707.80
1996	234.06	156.04	90.38	77.45	76.28	70.47	675.51
1997	236.54	157.70	91.34	78.27	77.09	71.22	682.44
1998	239.03	159.35	92.30	79.09	77.90	71.97	689.34
1999	241.50	161.00	93.26	79.91	78.71	72.71	696.25
2000	243.97	162.65	94.21	80.73	79.51	73.45	703.11
2001	246.43	164.29	95.16	81.54	80.32	74.20	709.95
2002	248.89	165.93	96.11	82.36	81.12	74.94	716.79
2003	246.84	164.56	95.32	81.68	80.45	74.32	710.63
2004	257.42	171.62	99.41	85.18	83.90	77.51	741.51
2005	258.89	172.59	99.97	85.66	84.37	77.95	745.81
2006	277.46	184.97	107.14	91.81	90.43	83.54	799.32
2007	278.89	185.92	107.69	92.28	90.89	83.97	806.67
2008	274.95	183.30	106.17	90.98	89.61	82.78	795.32
2009	276.53	180.67	104.65	89.67	88.32	81.59	786.37