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,

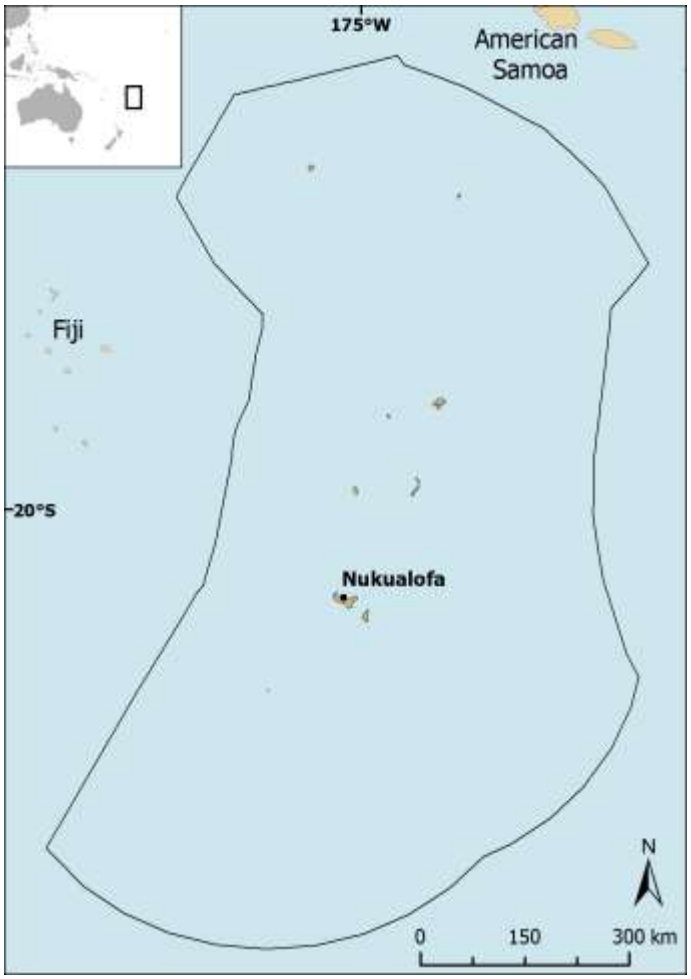

Figure 1. Map of Tonga and its Exclusive Economic Zone.

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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).

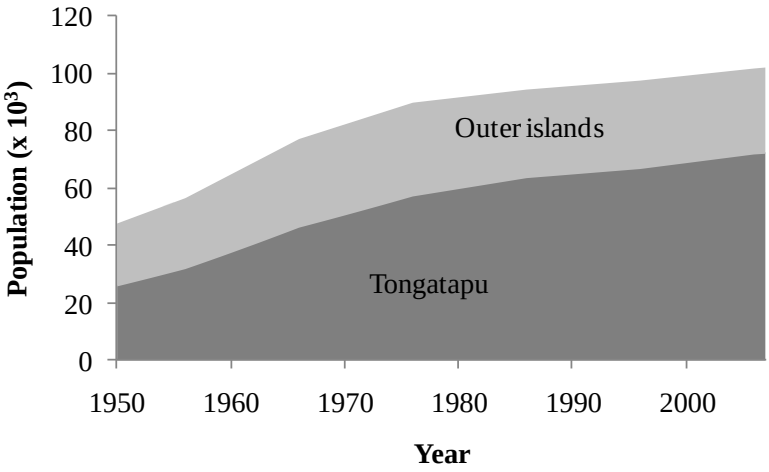

Figure 2. Tonga's population for the main island (Tongatapu) and outer islands combined (Ha'apai, Vava'u and others), 1950-2007. There has been a migration to the main island, Tongatapu, from the outer islands in the recent period. In the mid-2000s approximately 70% of the population resided on Tongatapu, 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·person^{-1}·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·person^{-1}·year^{-1} for the main island and 56 kg·person^{-1}·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·person^{-1}·year^{-1} accounted for 70% of total catch rate for outer islands being approximately 80 kg·person^{-1}·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·person^{-1}·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.

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

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.

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	Atherininae	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.

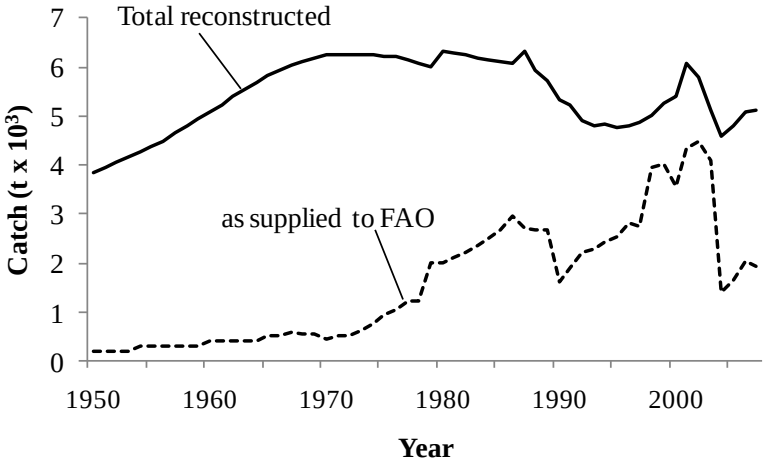

Figure 3. Total reconstructed catch for Tonga 1950-2007 compared to total landings as supplied to the FAO.

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}.

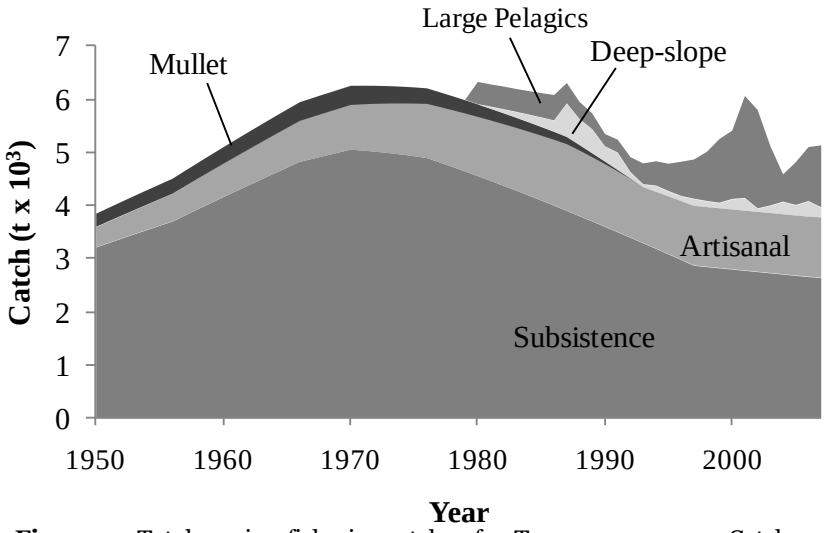

Figure 4. Total marine fisheries catches for Tonga, 1950-2007. Catches include mullet and deep-slope and large pelagic fisheries in addition to estimates of artisanal and subsistence sectors.

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