Fisheries Centre

The University of British Columbia

Working Paper Series

Working Paper #2014 - 09

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Year: 2014

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RECONSTRUCTING PAPUA NEW GUINEA'S MARINE FISHERIES CATCH, 1950-2010

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ABSTRACT

We reconstruct marine fisheries catches for Papua New Guinea (PNG) from 1950-2010 to account for catches missing from official statistics. Annual national landings statistics are dominated by tuna catches, which have been relatively well documented since 2000. Nonetheless, PNG's national fisheries statistics are still considered to be incomplete and underreported due to the omission of small-scale sector catches. This reconstruction thus focuses on quantifying PNG's small-scale fisheries by accounting for unreported catches. Reconstructed total non-tuna catch in PNG was 2.4 million t from 1950-2010, suggesting that actual catches were around four times the 590,000 t of non-tuna catches reported by FAO on behalf of PNG for the same time period. Our results suggest that there is high socio-economic reliance on PNG's small-scale inshore fisheries and that steps should be taken to ensure the future sustainability of this crucial food security resource and associated income opportunities.

INTRODUCTION

Marine fisheries are an important but underdeveloped sector in Papua New Guinea (PNG). From 2000 to 2006, official statistics indicate that the fisheries sector contributed an average of 2.3% to national Gross Domestic Product (GDP) (FAO 2010), although this figure may actually under-estimate the sector's true value (Gillett 2009). The marine component of PNG's fishery sector is the largest in terms of added value, making up over 90% of GDP contribution while the freshwater and aquaculture categories make up 9% and less than 1% respectively (Gillett 2009). Fish is an integral part of society, particularly as food, as a trade items in traditional barter systems, and as a commodity for earning cash. The majority of inshore fishing is conducted on a small-scale basis with diverse gears, ranging from gleaning (collecting) of invertebrates to hand-lining, spear fishing, netting, use of traditional and modern poisons, and trolling (FAO 2010). Up until the 1980s, most inshore fishing was done using non-powered boats on a part-time subsistence basis. In the 1970s, foreign vessels started exploiting tuna stocks in PNG's EEZ (Doulman and Wright 1983), and tuna have dominated landings data for the past 20-30 years. Fisheries management in PNG has been predominately focussed on tuna, whereby nationalisation of the sector and sustaining the resource base have been major objectives in recent years (Friedman *et al.* 2008; FAO 2010). Small-scale fisheries management only extends to the inshore commercial sector, such as sea cucumber (holothurians), lobster (*Panulirus* spp.), and barramundi (*Lates calcarifer*) fisheries. In general, whilst data exist for exports of these species, basic catch data, and catch and effort data are generally poor except for some periodic surveys funded by aid projects or conservation agencies, and subsequently, subsistence catches are not reported in national statistics (Kuk and Tioti 2012). This gap in basic knowledge about domestic food security fisheries hampers effective management. At the same time, local nutritional needs, continuing incorporation in the cash economy and associated desires, and global

demand for PNG's marine products will likely to continue to increase pressures on small-scale fisheries. A basic understanding of the true status of marine fisheries catches is therefore crucial.

This report will partly fill the knowledge gap by reconstructing the marine fish catches of PNG from 1950-2010, with special attention to the small-scale sector. Industrial tuna catches will be addressed separately in a complementary publication dealing with Pacific-wide tuna fisheries. The result will be a more comprehensive picture of past and present human reliance on marine capture fisheries in PNG (i.e. excluding aquaculture). This increased understanding of the impact of fishing on PNG's marine fisheries may assist management authorities, economic players in the fisheries sector and resource users in facilitating sustainable fisheries management for the future.

Background

Papua New Guinea is located in the western Pacific Ocean and has an Exclusive Economic Zone (EEZ) of about 3 million km^2 (FAO 2010). It comprises the eastern half of the island of New Guinea, and includes numerous smaller islands, the main ones being New Britain, New Ireland, Bougainville and Manus. The coastal environment of PNG is diverse, with fringing and barrier reefs, deltas, and mangrove swamps (Lambeth *et al.* 2002). There is an estimated 40,000 km^2 of coral reefs that extend to 30m in depth (Doulman and Wright 1983). Most of the larger islands have steep mountainous terrains. In 2011, PNG had a population of 7 million with an annual growth rate of 2.8 % per annum over the last decade and population density for the whole country of 11.2 per hectare. It is estimated that about 850,000 live in rural coastal and island areas (Govan et al 2013). With less than 15% of its population living in urban areas[1], PNG remains one of the most rural countries in the world with a largely subsistence-based population.

PNG's National Fisheries Authority (NFA) categorises marine fisheries as being 'coastal commercial' or 'offshore'. Coastal commercial fisheries are artisanal in nature, whereby local fishers target finfish and invertebrates for the export market or for local sale. Artisanal fishing takes place from shore or close to the coast (Dalzell 1991). Invertebrates are collected by gleaning on reef flats or free-diving in deeper water (Kinch 2002; Friedman *et al.* 2008), while reef fish are caught using handlines, gill nets, hand spears, or traps (Friedman *et al.* 2008). Sea cucumbers have been over-exploited as evident by the moratorium on harvesting and export since 2009 (Kinch *et al.* 2008), and trochus are considered to be at or near their maximum sustainable yield, whereas other inshore resources are still considered to be under-exploited (Friedman *et al.* 2008).

The offshore fishery refers to the industrial tuna fishery, which consists of local (Papua New Guinean) vessels and foreign-owned but locally-based vessels (i.e. registered in PNG). The PNG government also licenses foreign flagged vessels to fish tuna within PNG's EEZ, under conditions specified in access agreements (Kuk and Tioti 2012). The offshore fishery is not covered in this reconstruction. An industrial prawn trawl fishery has operated in the Gulf of Papua since 1969 (Dalzell *et al.* 1996). This fishery was initially conducted by Japanese trawlers until the mid-1980s, when the government phased out foreign vessels and nationalised the Gulf of Papua prawn fishery (Kuk and Tioti 2012).

Subsistence fishing allows coastal and island communities to meet their immediate food needs (Dalzell and Wright 1986; Wright and Hill 1993). Subsistence fishers tend not to fish more than they need to

[1] World Bank Data: http://databank.worldbank.org. Accessed 3 December 2013.

consume, thus catches are limited. Most subsistence catches are from hand-lining, netting or spear fishing using canoes and outboard powered fibreglass dinghies (Wright and Hill 1993). Despite the importance of this sector to coastal and island communities, there is very little information about the nature of fishing that takes place.

Typical inshore fish catches comprise about 130 species of fish (NFA 2007), and are estimated to be about 30% reef fishes, 10% pelagics, and the remaining 60%, a mix of crustaceans, molluscs, invertebrates, and seaweed (MRAG 2005). Until the moratorium in 2009, the sea cucumber fishery was the most valuable inshore commercial fishery, followed by prawns, sashimi grade tuna, lobster, and trochus. Discards are generated mainly by the prawn trawl fishery, as well as tuna longline and purse seine fisheries. Trawl nets are operated only in the prawn fishery; trawling of migrating lobsters was banned in 1984 (Friedman *et al.* 2008).

Historical development

Fishing is a tradition in PNG, where it previously held a central role in ceremonies such as funerals and the coming of age of young men (Bell 1935). Fishing practices in some locations have been regulated by customary marine tenure, whereby use rights dictate individuals' and communities' ability to access marine resources (Cinner *et al.* 2012). In some localities, clan chiefs can prohibit fishing in preparation for a big festival (Bell 1935), or close fishing grounds if they notice a decline in fish catch (Cinner *et al.* 2006). The PNG government makes provisions for customary management by local communities, therefore local use rights have legal recognition (Ruddle 1993). Customary management is also recognised in the *Fisheries Management Act* of 1998 (revised in 2012).

Traditionally, fishing was done using paddle or sail-powered canoes. Both men and women participate in various fishing activities, with women and children mainly concentrating on collecting invertebrates and men on catching finfish and diving for commercial invertebrates such as sea cucumbers and molluscs (Chapman 1987; Lambeth *et al.* 2002; Kinch *et al.* 2008). Local catches were used primarily to meet household and community subsistence and exchange needs; whilst village level catches of sea cucumbers and trochus have also supplied PNG's export trade in marine products, which date as far back as the late 1800s for the bêche-de-mer trade (Kinch 2002; Kinch *et al.* 2008).

Mechanisation of boats began in the 1970s when some small-scale fishers began using outboard engines. However, fishing with motorised boats was not economical due to the added cost of fuel, and fish catches essentially remained unchanged (Haines and Chapau 1991). During the 1970s, rural communities also started getting involved in commercial reef fisheries as the government implemented a series of training programmes (NFA 2007). Despite a series of donor funded projects aimed at developing infrastructure and fishing techniques throughout the 1980s, PNG's domestic coastal commercial fisheries have not kept pace with the industrial tuna sector. Fishing for reef fish in some localities have declined due to economic inefficiencies (Gillett 2009); bêche-de-mer exports peaked in 2006 and have since collapsed, and lobster landings have been decreasing since 2000.

Fisheries Management

PNG gained independence in 1975 and is since governed under a system consisting of the national government and semi-autonomous governments in each of its 20 provinces. In 1984, the first *Fisheries Act* signalled official recognition of fishing as an issue of national interest and formal management was commenced by the government (FAO 2010). The National Fisheries Authority (NFA) was established in 1995 under the provision of the *Fisheries Management Act*, and in 2001 was mandated to manage Papua

New Guinea's fisheries resources. Provincial governments maintain a degree of control over fisheries through the ability to write their own fisheries acts, but only if they do not conflict with the *Fisheries Management Act* (Kuk and Tioti 2012).

Fisheries management objectives are centred on promoting long term sustainable development of marine resources, through balancing economic and ecological objectives (FAO 2010). The NFA implements six fisheries management plans, including those for tuna, bêche-de-mer, lobster, prawn, and barramundi fisheries, with another two for live reef fish and aquarium fish which are still in draft form. Specific measures such as licence restrictions, size limits, closed seasons and total allowable catch are stipulated for these commercial fisheries. The NFA is further responsible for collecting fisheries data, conducting commercial fish stock assessments and research, and managing the processing and export of fish products (FAO 2010; Carleton *et al.* 2013). In contrast, there is little management of the subsistence fisheries sector outside of some conservation interventions by non-government organisations, which encompasses most of the fishing that takes place in PNG.

Challenges for fisheries management include a shortage of motivated and trained fisheries personnel, adequate resourcing, enforcement issues, economic development of inshore commercial fisheries, and sustaining the tuna resource base (FAO 2010). PNG's extensive EEZ area and lightly populated coastal zone make surveillance and enforcement especially difficult (Mainardi 2009). In the past, local fishers in village-based fisheries such as the barramundi and sea cucumber fisheries have not complied with fish size and gear restrictions (Mobiha 1995; Kinch *et al.* 2008).). Illegal fishers from Indonesia, operating small boats with trawlers, nets, and hand/long lines are also becoming a greater concern for PNG, as they compete with local fishers for demersal fish and sharks (MRAG 2005). In total, it was estimated in the mid-2000s, that IUU losses represent at least a quarter of the total value of PNG's fishery (MRAG 2005).

Fisheries statistics

Fisheries data collection falls under the responsibility of the NFA, though there are plans to have Provincial Fisheries Officers collect catch and landings data. The need for establishing a comprehensive statistics collection system in PNG for effective fisheries management has been recognised for almost 40 years (Kearney 1976). Data for the tuna industry after 2001 is fairly reliable due to the implementation of effective catch logsheet and observer programmes (Usu *et al.* 2013). An electronic data reporting system is currently being put in place, and fleets have been cooperative in submitting catch data. In addition, observer coverage for PNG and foreign flag tuna vessels has improved to 80% in recent years (Usu *et al.* 2013). Unfortunately, the same level of reporting for artisanal fisheries is not regularly collected, except for aid donor projects, such as the Asian Development Bank project which conducted landing and market surveys in the New Ireland, Morobe and Milne Bay Provinces in the mid-2000s. Relatively reliable catch and export data exist for some inshore commercial fisheries such as sea cucumbers and trochus. Here, statistics on fisheries such as reef finfish, sea cucumber, lobster, and trochus only cover the quantity that is exported and not what is consumed locally[2]. There are also large time series gaps in data, as trochus is not reported while sea cucumbers landings only started to appear in 1981 despite having been exported since the late 1800s (Friedman *et al.* 2008). Finally, there is no accounting for small-scale subsistence fisheries, despite this sector's substantial importance to local well-being.

[2] http://www.fisheries.gov.pg/FisheriesIndustry/InshoreReefFish/tabid/108/Default.aspx.

Reported Landings
Annual reported marine inshore fisheries landings from 1950-2010 were extracted from FishStat (FAO 2012), and represent the reported baseline as used here. Marine landings were categorised into 20 taxonomic groups covering finfish and invertebrates. Landings were not further disaggregated by fishing gear or fishing vessel.

In this reconstruction we subtracted reported industrial tuna landings from total reported marine fisheries statistics as the industrial tuna sector is not considered. Reported Industrial tuna landings from 1970 to 2010 were calculated as the sum of the following species: albacore, bigeye tuna, blue marlin, kawakawa, longtail tuna, skipjack tuna, striped marlin, swordfish, and yellowfin tuna. We included marlins and swordfish because these species tend to be caught as bycatch in the industrial sector[3].

Unreported Catch
Unreported catches in PNG originate from the following sources: i) subsistence fishing; ii) artisanal (inshore commercial) sector; iii) shark fishery iv) discards; v) marine recreation sector; vi) under-reported tuna catches; and vi) foreign industrial tuna catches.

This reconstruction will focus on non-tuna catches, in this case, the small-scale and marine recreation sectors, industrial shark fishery, and discards from the sea cucumber and industrial prawn trawl fishery. As mentioned above, tuna catches are addressed in a complementary, Pacific-wide study.

Small-scale fisheries
Marine catches from the small-scale sector are categorised into subsistence and artisanal subsectors.

Subsistence catch
The primary purpose of subsistence fishing is to provide protein to fulfil nutrition needs, and as a resource in social and commodity exchanges. In PNG, the majority of fishing is done on a part-time basis to supply protein, as fishers also engage in agriculture or have other jobs and customary needs (Dalzell 1991). Thus, we assumed that subsistence catches from 1950-2010 were equivalent to the amount of fish that was consumed for food. Subsistence catch was calculated as:

$$S = P*C*F$$

Where

P is PNG's rural population;
C is marine fish consumption rate; and
F is the percentage of fish consumption from subsistence fishing.

Of the three parameters, *P* had the greatest impact on *S,* as total subsistence catch could vary widely depending on whether the total (national) or only coastal populations were considered. Marine consumption rate *C* at the national level (including both inland, coastal and island populations) was 10.2 $kg \cdot person^{-1} \cdot year^{-1}$, while for coastal communities it was much higher, i.e. 53 $kg \cdot person^{-1} \cdot year^{-1}$ (Bell *et al.* 2009, based on information from Gibson (2000)). We assumed that PNG's fish consumption level

[3] Anon. (1993) By-catch and discards in Western Pacific tuna fisheries: A review of SPC data holdings and literature. South Pacific Commission, Noumea, New Caledonia.

remained constant throughout the period 1950-2010. We set the percentage of fish that comes from subsistence fishing (as opposed to being bought at a market), *F*, at 100% in 1950, under the assumption that all small-scale fishing that took place at that time was for subsistence, though some marine resources would have made their way to district and provincial centres for sale. We then started to linearly decrease *F* in 1960 to a second anchor point of 64% in 2005 (Bell *et al.* 2009), and held this to be constant to 2010.

To address uncertainty in the population parameter, we calculated subsistence catch using four scenarios (Table 1). We then assessed the range of results generated by the four scenarios, and used the scenario which best represented the average as the subsistence catch estimate.

Artisanal catch

Inshore commercial fishing in PNG is carried out in inshore areas using small-scale gears. The artisanal sector includes the established barramundi, lobster, reef fish, sea cucumber, and trochus fisheries. Bêche-de-mer[4] exports have been documented since 1878, and coastal inhabitants started harvesting trochus after World War II (Friedman *et al.* 2008). Gold lip pearl shell was a predominant resource harvested up until the 1950s, and has been replaced by black lip pearl shell in recent years (Kinch 2003). However, sea cucumbers only started appearing in landings statistics in 1981, while trochus was absent throughout. To address this, we add estimates of unreported barramundi, lobster, reef fish, sea cucumber, trochus and other shell catches from 1950-2010.

Reef fish: In 1986, there was only one reported artisanal reef fishery in Papua New Guinea, which involved several fishing villages near Port Moresby, the PNG national capital (Lock 1986). That year, the fishery was estimated to have catches of 577 t, which was in addition to the 592 t of fish and shellfish landed at government run coastal fishery stations (Lock 1986). This suggests that reef fish catches were under-reported by close to 100%. Given the lack of data pertaining to other time periods, we doubled landings of reef fish in all years to account for under-reported catches. We assumed that reef fishes are reported as 'marine fishes nei' in FAO landings data since there is no other specific reef fish taxa category. We started accounting for reef fish in 1970, roughly the time when boat mechanisation began. Anchor points for reef fish landings were:

1986: 592 t (Lock 1986);
2003[2]: 133 t;
2004[2]: 50 t.

We assumed no artisanal reef fish catches prior to 1970 and started to linearly increase from 0 t in 1970 to the 1986 anchor point of 592 t. We then linearly decreased reef fish landings to a second anchor point in 2003, then held the 2004 anchor point constant until 2010.

Barramundi and lobster: Like the reef fish fishery, PNG's barramundi and lobster fisheries are largely village-based industries (Friedman *et al.* 2008), with exception of the commercial lobster fishery which has a fleet licensed to operate in the Gulf Province. Given their similar small-scale characteristics and the lack of data, we raised reported lobster landings by the same amount as that in the reef fish fishery (i.e., 100%) to account for unreported catches.

[4] 'Bêche-de-mer' refers to sea cucumbers that have been processed for sale/export while the actual animal is referred to as 'sea cucumber'.

Sea cucumbers: Unreported sea cucumber catch was estimated on the basis of bêche-de-mer export data, of which there were two time series - 1960-1999 (Kinch *et al.* 2008) and 2000-2010 (NFA, unpublished data). Dry export weights were converted to fresh wet weight using a conversion ratio of 1/12 (Ngaluafe and Lee 2013). This means that on average, only 12% of initial fresh weight remained once sea cucumbers have been processed for export. Due to lack of data before 1960, we applied the 1960 export volume to the 1950 decade. In 2009, the NFA introduced a moratorium of the fishing of sea cucumber and the export of bêche-de-mer, and this moratorium is still in place.

Trochus: Trochus catch was estimated based on trochus shell export data. Trochus shell tonnage was converted to raw trochus weight, as during processing, the raw trochus is first emptied of its meat and then dried before being graded for export. Each tonne of trochus shell was assumed to represent 49% of raw trochus (Tiraa-Passifeld *et al.* 2011). Artisanal trochus export data were available from 2000-2010 (NFA, unpublished data). Three anchor points for trochus export volume for the years 1950-1990 were assigned:

1950-1952: 1030 t (Chapau 1993);
1980: 400 t (Chapau 1993);
1990: 333 t (Dalzell and Wright 1986).
Linear interpolation was then used to fill in missing data from 1990 onwards to 2000.

Other shells: This category includes green snail and pearl oyster shells, which have been exported from PNG since World War II (Yamaguchi 1993). Between 1950-1984, green snail shell exports averaged 60 $t \cdot year^{-1}$ (Yamaguchi 1993), and time series data for green snail shell exports were available from 1970 to 1989 (Yamaguchi 1993). Pearl oyster shells were calculated as being 1/3 the amount of green snail shell exports (Yamaguchi 1993) to derive total shell exports. From 2000 to 2010 exports of shells (green snail and pearl oyster) from artisanal fisheries were available (NFA unpublished data). Missing shell export data from 1990 to 1999 were linearly interpolated from the anchor point in 1989 to that in 2000. Total unreported shell catch was then estimated by converting shell export tonnage to raw shell weight using the same conversion rate as that to trochus shell.

Shark fishery
Exports of shark meat, shark fins, and/or shark products are recorded in national fisheries statistics but catches are not reported to the FAO (Lack and Sant 2012), thus are treated as unreported catch in this reconstruction. The earliest commercial shark fishery in PNG was operated by Taiwanese gillnetters in the Gulf of Papua in the 1980s (Nichols 1993), but ceased by the late 1980s due to decreased catch rates and sanctions over drift net fishing (Kumoru 2003). Shark fishing was then primarily carried out by artisanal fishers (Kumoru 2002) who participated in the dried shark fin trade, and a commercial shark longline fishery developed in the mid-1990s (Kumoru 2003). Shark catches from 1981 to 2010 were estimated by converting exported quantities of shark meat and shark fins to their green/whole (unprocessed) weight.

Commercial shark catch: We started accounting for commercial shark catches in 1981, the earliest year for which shark export data was available (Nichols 1993). We assumed that there was no commercial shark catch after 1986, the last year when export data for the shark gillnet fishery was available, until 1990 when 18 t of shark meat was exported (NFA 2002), likely the result of long-line bycatch. Export data for commercial shark catches were available for the years 1981-1986 (Nichols 1993); 1998-2002 (Kumoru

2003); and 2004-2008 (Lack and Sant 2012). Linear interpolation was used to fill in missing shark export data from 1991 to 1997, and the 2008 value was kept constant to 2010. Shark green weight was calculated using a conversion factor of 1.67 for shark (Kumoru 2003), and 18.9 for shark fin (Hindmarsh 2007).[5] From 2004 to 2008 export data was reported for 'shark products', which consist primarily of shark meat (93%) and shark fins (7%) (Kumoru 2002).[6] In years where both shark meat and shark fin exports were recorded, we accounted for the greater of the green weight of the two to avoid possible double counting of whole sharks.

Artisanal shark catch: Artisanal sharkfin export data was available for years 2000 to 2010 (NFA, unpublished data). We assumed that artisanal shark fishing started in the same year as the commercial gillnet fishery (1981). From 2000 to 2008 artisanal shark fin (dried) exports were on average 1% of commercial frozen shark meat exports. We applied this proportion to commercial frozen shark meat exports to estimate artisanal shark fin exports from 1981 to 1999. We linearly interpolated artisanal shark fin exports between 1986 and 1990 when there was no commercial shark fishery. A dried to green weight conversion factor of 70 (NFA 2007a) was used to estimate artisanal shark catches, which were then added to commercial shark catches to arrive at annual total unreported shark catch (green weight) for PNG.

Marine recreational fishing

Marine recreational fishing as a leisure activity takes place mainly in larger urban areas in PNG, and participants are mostly resident expatriates (FAO 2010). There is no formal management of marine recreational fishing in PNG (Friedman *et al.* 2008; FAO 2010), although the NFA's management plan for barramundi[7] does recognise recreational fishing of the species. Recreational fishers target marlins, trevallies, mackerels and tuna, and sport fishing competitions have been held regularly in PNG since the 1970s. While fishing tour operators encourage 'catch and release' fishing, it is up to client's discretion and the rule does not appear to be strictly enforced[8]. On the other hand, sport fishing tournaments do enforce a strict 'catch and release' policy, and marlins, sailfish and barracudas tend to be released by local recreational fishers.

We start accounting for marine recreational catch in 1970. Total recreational catch (*Rec*) is calculated as:

$$Rec = P_i * e * M * R$$

Where

P is PNG population in year I;
e is percentage of expatriates living in PNG;
M is marine recreation sector participation;
R is marine recreational catch rate.

[5] Average ratio of fin weight to round (whole) weight for Blue shark and Silky shark.
[6] Proportional break down of 'shark products' was derived from the average export volume of frozen shark meat to frozen shark fin from the shark longline fishery, 1998-2002.
[7] National Fisheries Authority, Fisheries Management Act 1998, The Barramundi Fishery Management Plan.URL: http://www.fisheries.gov.pg . Accessed 18 December 2013.
[8] Papua New Guinea High Commission in Australia. URL: http://www.pngcanberra.org/tourism/sports_game_fishing.htm. Accessed 3 December 2013.

The time series data on the number of expatriates in PNG was based on one anchor point in 2010, when there were approximately 20,000 expatriates[9]. We divided this by total population to derive an expatriate proportion, which was then applied to population time series data starting in 1970 to calculate the number of expatriates. Thus, we assumed proportionality between PNG population and the level of resident expatriates. However, we realise that there were more expatriates in the earlier periods, especially prior to independence, and that more recently an increase in expatriates has again occurred due to the resource extraction boom (although many of these are fly-in/fly-out and may not partake in much recreational fishing). We then applied a marine recreational angler participation rate for Oceania of 17.7% (Cisneros-Montemayor and Sumaila 2010) to estimate the number of expatriate recreational fishers, assuming that recreational fishing trends among PNG expatriates mirrored those in the Oceania region.

Recreational catch rate was approximated from the second author's (J. Kinch) observations of and participation in recreational fishing in PNG, where a typical catch may range from 8-20 kg·person^{-1}·trip^{-1}. An annual recreational catch rate of 280 kg·person^{-1}·trip^{-1} was then determined on the basis of 2 recreational trips per month for 10 months per year, assuming an average catch of 14 kg·person^{-1}·trip^{-1}.

Discards

The prawn trawl fishery has been operating in Papua New Guinea since 1969 (Dalzell *et al.* 1996) and produces a high level of bycatch and discards. It is estimated that prawns comprise only 10% of a vessel's catch. Of the remaining 90% bycatch, about 20%, consisting of taxa such as Mullidae, Serranidae, Scombridae, Carangidae, and Lutjanidae, is retained for domestic use while 70% is discarded[10]. We started accounting for prawn trawl fishery discards in 1970, whereby prawn discards (Dis_{prawns}) were estimated as:

$$Dis_{prawns} = Ct_{prawn}i \cdot 0.9 \cdot 0.7 \text{ where } Ct_{\text{prawn}} \text{ is prawn catch in year } i.$$

Discards in the bêche-de-mer export trade are due to deterioration and poor processing. Discarded bêche-de-mer are not accounted for in export data, and are estimated to range between 5 to 10% of exports (J. Kinch, NFA, pers. obs.). We take the average, i.e. 7.5% of exported bêche-de-mer to calculate discards in PNG's sea cucumber fisheries.

Sectoral breakdown

We treated all reported landings from 1950-1969 as originating from the small-scale sector. Of these, barramundi, Indo-Pacific swamp crab, sea cucumbers, skipjack tuna, anchovies, and spiny lobsters were allocated to the inshore commercial i.e., (artisanal) sector. All remaining taxa were then split into a subsistence and artisanal component. Two industrial non-tuna fisheries are considered in this reconstruction – the Torres Strait lobster fishery, which began in the late 1960s, and the prawn trawl fishery. We started accounting for the non-tuna industrial sector in 1970, to which we assigned all spiny lobster, prawn, and *Metapenaeus* shrimp landings.

All other non-industrial landings from 1970-2010 were allocated to the small-scale sector. Of these, certain taxa were allocated to the artisanal sector as described for the 1950-1969 period. The breakdown of small-scale sector landings to their artisanal and subsistence components was based on the

[9] Signature Staff. URL: http://www.signaturestaff.com.au/job-seekers/jobs-PNG. Accessed 3 December 2013.
[10] Strategies for Trawl Fisheries Bycatch Management. Papua New Guinea: National Report on Bycatch Management and Reduction of Discards. URL: www.rebyc-cti.org/countries-profiles. Accessed 8 Dec 2013.

proportion of households that fished solely for consumption versus those who fished for both food and income. We assumed that in 1950 the vast majority of coastal households practiced subsistence fishing, and thus allocated 100% of landings to the subsistence subsector. We then linearly decreased this proportion to a second anchor point in 1990. The 1990 population census reported that 60% of coastal rural households fished for subsistence, while 40% fished for both food and income (Gillett 2009). We used these figures as our 1990 anchor point and maintained them through to 2010.

Catch composition

Small-scale sector catches were broken down to finfish and invertebrate components (Table 2a & 2b). A coastal fisheries study found that on average, households across four communities in PNG consumed about 33 $kg \cdot capita^{-1} \cdot year^{-1}$ of fresh fish and 7 $kg \cdot capita^{-1} \cdot year^{-1}$ of invertebrates (Friedman *et al.* 2008). We applied this to the breakdown of small-scale catches, and assigned 82% to finfish and 18% to invertebrate in all years between 1950-2010. Finfish species were dominated by Lethrinidae, Carangidae, and Lutjanidae (Dalzell *et al.* 1996), while invertebrate catches consisted of bivalves, gastropods, crustaceans, and a small amount of octopus and urchins (Friedman *et al.* 2008). Common gastropods included conches (*Strombus luhuanus*, *Lambis lambis*) and whelk (*Terebralia palustris*), while common bivalves included mud clams, Venus clams, Tridacnidae, and *Anadara* spp. (Dalzell *et al.* 1996; Friedman *et al.* 2008).

The composition of bycatch from the prawn trawl fishery was used to break down discards from the prawn trawl fishery[8]. The major taxa that were discarded were: Clupeidae (31%); Leiognathidae (23%); Engraulididae (15%); Lutjanidae (11%); Mullidae (6%); Sciaenidae (5%); Theraponidae (5%) and Arridae (5%).

The composition of shark longline catches was predominantly silky shark (74%), blue shark (12%), and other reef and oceanic sharks (14%) (Lack and Sant 2012). Artisanal shark catches commonly consist of blacktip reef shark (*Carcharhinus melantropterus*), whitetip reef shark (*Triaenodon obesus*), grey reef shark (*Carcharhinus amblyrhychos*), tiger shark (*Galeocerdo cuvieri*), lemon shark (*Negaprion acutidens*), and hammerhead sharks (*Sphyrna* spp.)(NFA 2007a). Lacking further information, we assumed that lemon and hammerhead sharks were caught least frequently, while reef sharks and tiger sharks were more common in catches, on the basis of their status on the IUCN Red List of Threatened Species (www.iucnredlist.org). We used the rationale that 'Vulnerable' and 'Endangered' species were less abundant in the wild while those rated as being 'Near Threatened' were relatively more abundant. Lemon sharks are assessed as 'Vulnerable'; hammerhead sharks range from 'Vulnerable' to 'Endangered'; and reef sharks and tiger sharks are 'Near Threatened'. Artisanal shark catches from 1981 to 2010 were broken down as reef sharks (60%); tiger sharks (20%); lemon sharks (10%); and hammerhead sharks (10%).

To estimate marine recreational catch composition, we first listed all fish species that appeared on PNG Game Fishing Association's national records[11], and categorised them into 8 major groups: barracuda, cobia, Carangidae, dolphin fish, marlins, Scombridae, sharks, and tunas. We then qualitatively assessed whether each species occurred with high, medium, or low frequency in a typical catch, based on the number of species as well as number of records in different weight classes held for individual species within each major group. Out of the 8 major groups, barracuda, Scombridae, marlins, Carangidae and tunas were assessed as 'high', while cobia and dolphin fish were assessed as 'medium' and sharks as

[11] Game Fishing Association of Papua New Guinea URL http://www.gfa.com.pg/. Accessed 8 Dec 2013.

'low'. 'High' groups were assigned a total catch proportion of 29% each, 'medium' groups 7%, and 'low' group 3%. Barracudas, sailfish, and marlins were omitted from the species composition break-down because they are normally released by recreational fishers.

RESULTS

PNG's reconstructed domestic catch, excluding tuna, totalled 2.4 million t from 1950-2010 (Figure 3a). This estimate was 4 times the total non-tuna marine landings of 590,000 t that were reported to the FAO for PNG for the same period. Reconstructed catches averaged 22,000 t·year^{-1}, peaked at 95,000 t·year^{-1} in 1992, and were about 44,000 t·year^{-1} in the late 2000s. Reconstructed tuna catches in PNG's EEZ are not addressed here, and will be reconstructed separately as part of Pacific-wide accounting of large-scale tuna fisheries. Subsistence catches made up 66% of total reconstructed catches, followed by the artisanal sector at 29% and the industrial fishery at 2%, while the marine recreational sector and fish discards together made up 3% of total reconstructed catches. Unreported catches totalled around 1.8 million t, of which the majority (1.2 million t) came from the subsistence sector (Figure 3b). Estimated unreported subsistence catches from 1950-2010 ranged between 717,000 t·year^{-1} and 1.5 million t·year^{-1} (Figure 2). The "rural coastal and island population within 10 km" scenario (i.e., 1,190,000 t) returned results that fell in the mid-range and was thus applied in this reconstruction.

The ten major taxa accounted for 72% of reconstructed marine catches from 1950-2010 (Figure 4). Sea cucumbers were the most abundant (325,000 t), followed by Lethrinidae (284,000 t), Mugilidae (182,000 t), and Carangidae (161,000 t). Shark species made up almost 2.5% of total reconstructed catches. Sea cucumber catches increased from the early 1990s, peaking in 2006 and then declined until a moratorium was implemented in 2009. Low value fish such as Leiognathidae and Engraulididae were present in discards, but made up less than 0.5% of total reconstructed catches.

DISCUSSION

This historical reconstruction is an initial attempt at providing a more comprehensive estimate of PNG's total marine fisheries catches. We estimated that from 1950 to 2010, PNG's non-tuna marine fisheries catches were 4 times the officially reported statistics for the same period. Marine fisheries statistics for some resources are known to be under-reported in PNG, and the presence of a large subsistence sector, as well as limited monitoring and enforcement capacity, have been barriers to effective fisheries monitoring and management in the past (Kuk and Tioti 2012).

We intentionally focussed on the subsistence and coastal commercial fisheries, as these are the sectors that are chronically under-represented in official statistics, yet are of crucial domestic food security and income earning opportunities for many coastal and island communities. The magnitude of marine resources taken from PNG's EEZ would be even greater if industrial tuna catches were to be considered in this reconstruction – national fisheries statistics report only catches taken by the domestic (local or locally registered companies) fleet, while the catches of foreign tuna vessels, which are on average equivalent or higher than that of domestic catches, are assumed to be reported by their flag-country.

Subsistence catches from 1950-2010 were estimated based on the amount of fish and invertebrates consumed by the country's population. This estimate leans towards being conservative as it does not include small amounts of sea cucumbers and sharks that are consumed in some parts of PNG (Nichols 1993; Kinch *et al.* 2008). Fish consumption rates were obtained from published socio-economic survey

results, of which coastal consumption and country-wide consumption rates were available for PNG (see Bell *et al.* (2009)) As the population parameter had a large effect on the resultant quantity of fish consumed (and hence total subsistence catch), we estimated subsistence catch using four population scenarios, of which the one that returned results that fell in the mid-range was applied in this reconstruction.

Although management plans are in place for several coastal commercial fisheries (e.g. lobster, bêche-de-mer, barramundi), there is still a large gap in catch data collection and monitoring, as current statistics on inshore commercial fisheries generally account only for the quantity of exports and not actual catches.

PNG's inshore commercial and subsistence sector catches were estimated to total 5,700 t and 30,000 t respectively in 2007 (Gillett 2009). In the time period 2005-2010, annual reconstructed inshore commercial catches averaged 7,100 t while reconstructed subsistence catches averaged 30,450 t. Although different methods were used in both studies, the similarity in magnitude observed in the latter time frame of this reconstruction represents a validation of our approach. On the other hand, Dalzell *et al.* (1996) estimated that inshore commercial catches amounted to 4,966 t in the late 1980s and early 1990s, which is significantly less than the average of 34,200 t estimated for the period 1987-1992 in this reconstruction. The large difference may be attributed to the inclusion of unreported sea cucumber catches. Between 1985 and 1986, bêche-de-mer exports increased by 600% from 20 t to 1200 t (Kinch *et al.* 2008), whereas no sea cucumber landings were reported in 1985 and in 1986 only 340 t of sea cucumbers were reported. The spike in artisanal sector catches in the late 1980s and early 1990s can be attributed to increased bêche-de-mer exports following the easing of trade barriers within China in the late 1980s (Kinch 2002). The subsequent drop is typical of the boom and bust cycle observed in sea cucumber fisheries across the Pacific (Kinch *et al.* 2008; Carleton *et al.* 2013; SciCOFish 2013), and in 2009 a moratorium on bêche-de-mer exports was declared.

Marine recreation catch contributed less than 0.5% to total reconstructed catch. This is not unexpected, as fishing in PNG is treated as primarily as subsistence or artisanal, and not as a leisure activity by locals, though many villagers do partake in fishing as a casual pastime. However, with rising per capita incomes, where purchasing power has increased by 48% between 2000 and 2010[1], the number of local participants in leisure fishing may start to grow.

Despite the high level of discards as a proportion of total prawn catches, discards as a proportion of total reconstructed catch was low. Prawn bycatch may be a source of under-reported catches in the fishery, but we did not account for it in this reconstruction. Rather, as there was documentation on the portion of bycatch that is retained, we assumed that this amount was landed and recorded. Landings of 'marine fishes nei' fluctuated widely and were responsible for the observed drop in reconstructed catches between 1977-1986 and the spike in 2000 and 2001. The trends may be an artefact of changes to the reporting system or institutional structure – for example, prior to the implementation of logbooks in 1997, it was assumed that fish catches (tuna) were landed outside of PNG, thus a substantial amount was not reported or taxed (Mainardi 2009). Due to insufficient information we are unable to speculate further.

Given the cultural and nowadays greater ecomonic significance of fishing, as well as customary access and use rights institutional arrangements in PNG, improving fisheries management will require working closely with communities. This approach is all the more necessary as it is community-level fishing that

demands most attention, from basic data collection to resource and socio-economic assessments (Kuk and Tioti 2012). Fish is crucial for food security in PNG, and it is anticipated that a 64% increase in current (2010) fish supply is required to satisfy nutrition needs by 2030 (Bell *et al.* 2009). Thus, fishing pressure can be expected to grow on PNG's inshore fisheries, and the greater effort by government is required to ensure sustainability in the subsistence and artisanal sectors. This reconstruction estimates that unreported subsistence catches alone make up almost 66% of total of all unreported catches, highlighting the magnitude of marine resources that is unknowingly being taken from inshore waters. While the non-commercial fisheries are apparently still not overexploited (Friedman *et al.* 2008), given the large gap in knowledge on small-scale fisheries catches there is no knowing when some tipping point may be reached.

Acknowledgements

This is a contribution of the *Sea Around Us* Project, a scientific collaboration between the University of British Columbia and The Pew Charitable Trusts.

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Table 1. Scenario parameters used to estimate subsistence catches.

Scenarios	*P* (number of inhabitants)	*C* (kg·person^{-1}·year^{-1})
A	Total rural population[a]	10
B	Rural coastal population[b]	53
C	% rural population within 5 km of a coast[c]	53
D	% rural population within 10km of a coast[c]	53

[a] World Bank DataBank (http://databank.worldbank.org)
[b] Assumed 13% of PNG's total population lives by the coast, given that 87% lives inland (Gillett 2009)
[c] McGranahan *et al.* (2007)

Table 2a. Composition of small-scale sector finfish catches. Derived from Dalzell *et al.* (1996).

Finfish	Percentage
Lethrinidae	20.7
Mugilidae	13.3
Carangidae	11.7
Lutjanidae	9.6
Scombridae	6.9
Scaridae	6.9
Serranidae	6.4
Acanthuridae	6.4
Mullidae	5.3
Belonidae	5.3
Others	7.0

Table 2b. Composition of small-scale sector invertebrate catches. Derived from Friedman *et al.* (2008).

Invertebrates	Proportion (%)
Bivalves	30.4
Gastropods	54.2
Crustaceans	11.3
Others	5.0

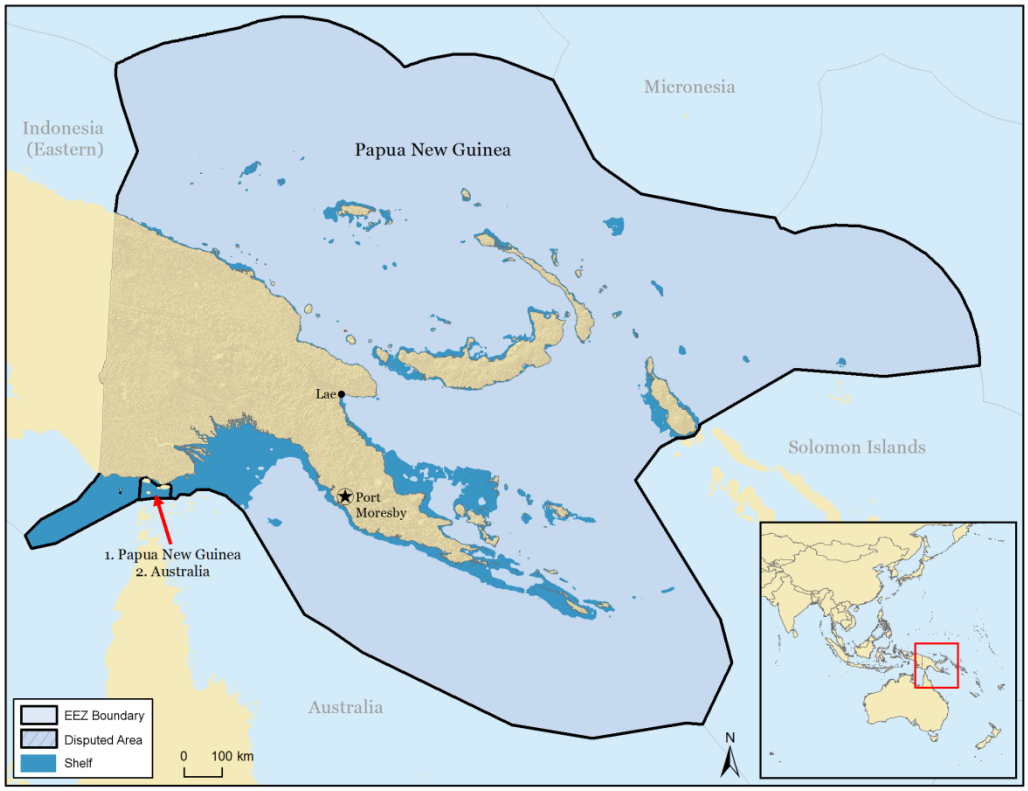

Figure 1. Exclusive Economic Zone (EEZ) and shelf waters to 200 m depth for Papua New Guinea.

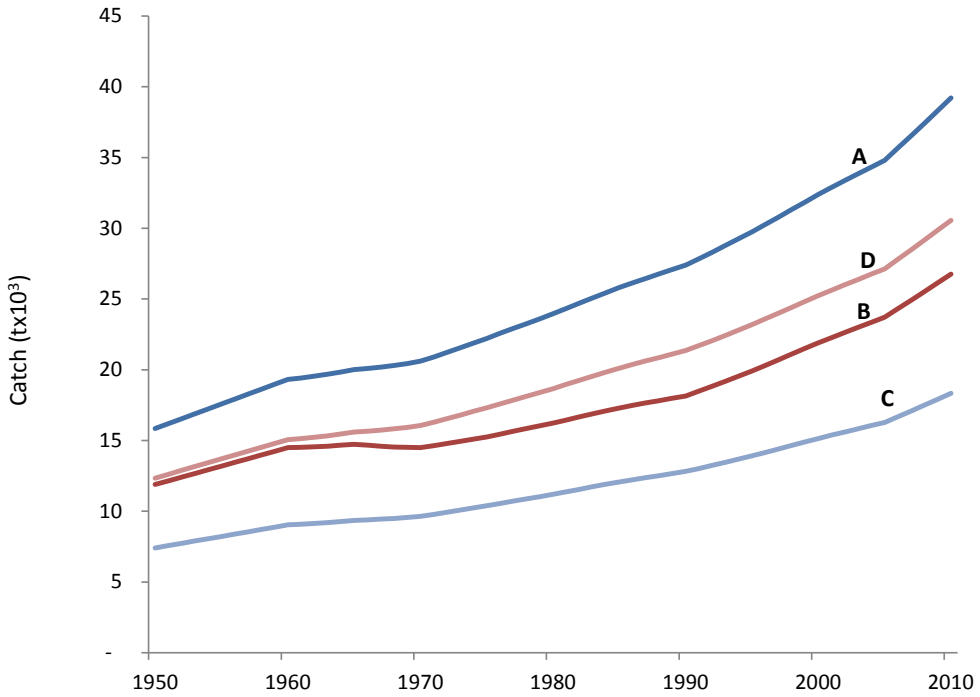

Figure 2. Estimated subsistence catches from 4 scenarios with variation in population and fish consumption rates (see Table 1 for scenario parameters).

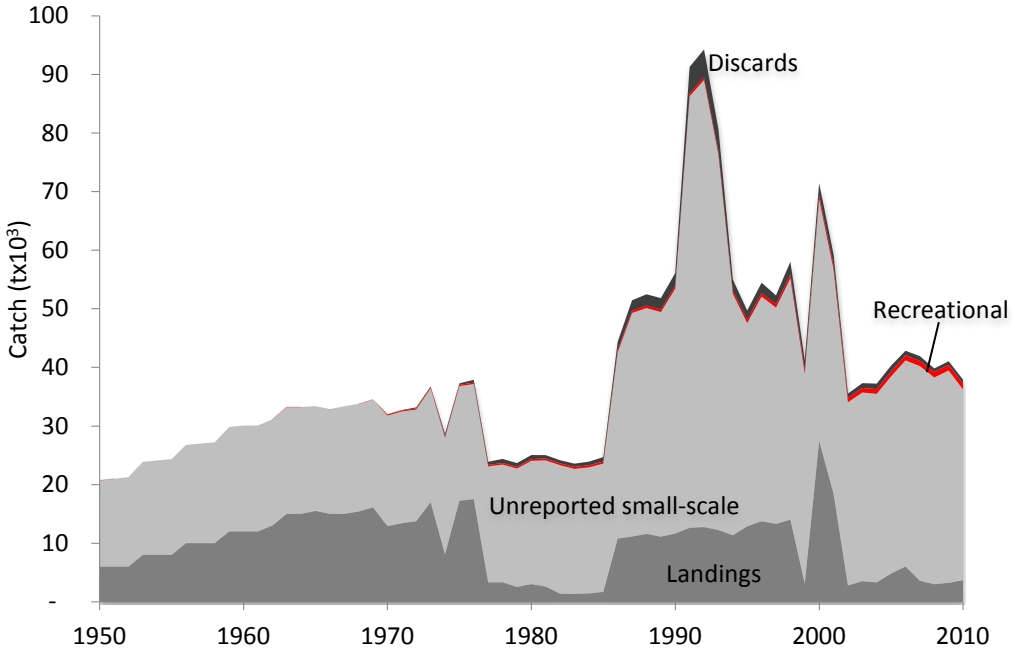

Figure 3a. Papua New Guinea's total catches from 1950-2010, showing unreported catches from small-scale fishing and discards added to the reported landings.

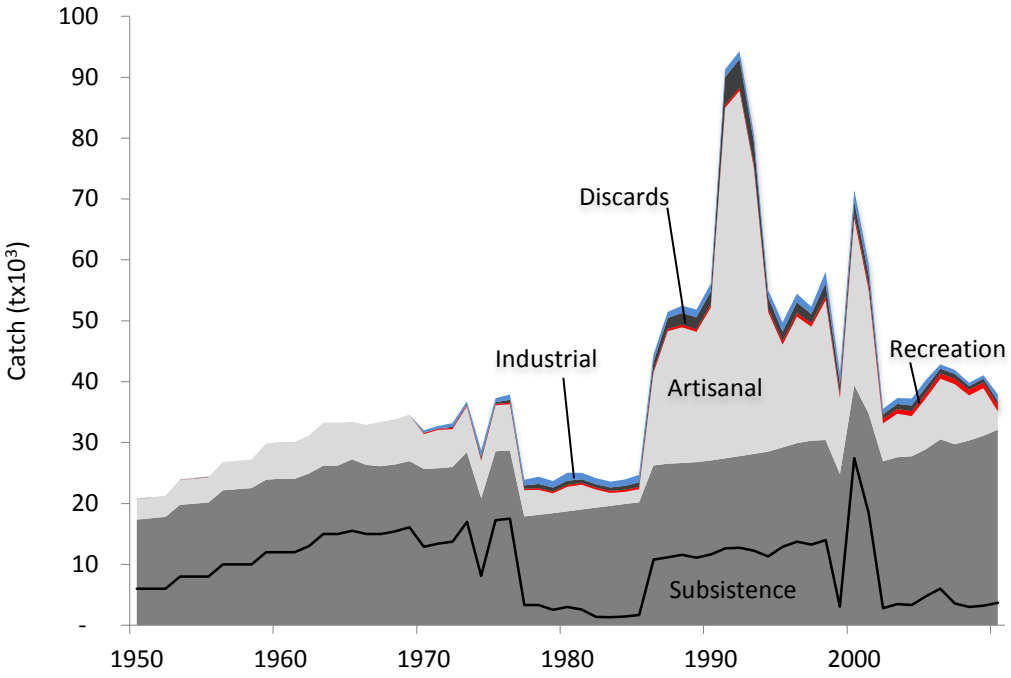

Figure 3b. Reconstructed catches showing contribution of different sectors. The solid line represents FAO reported landings.

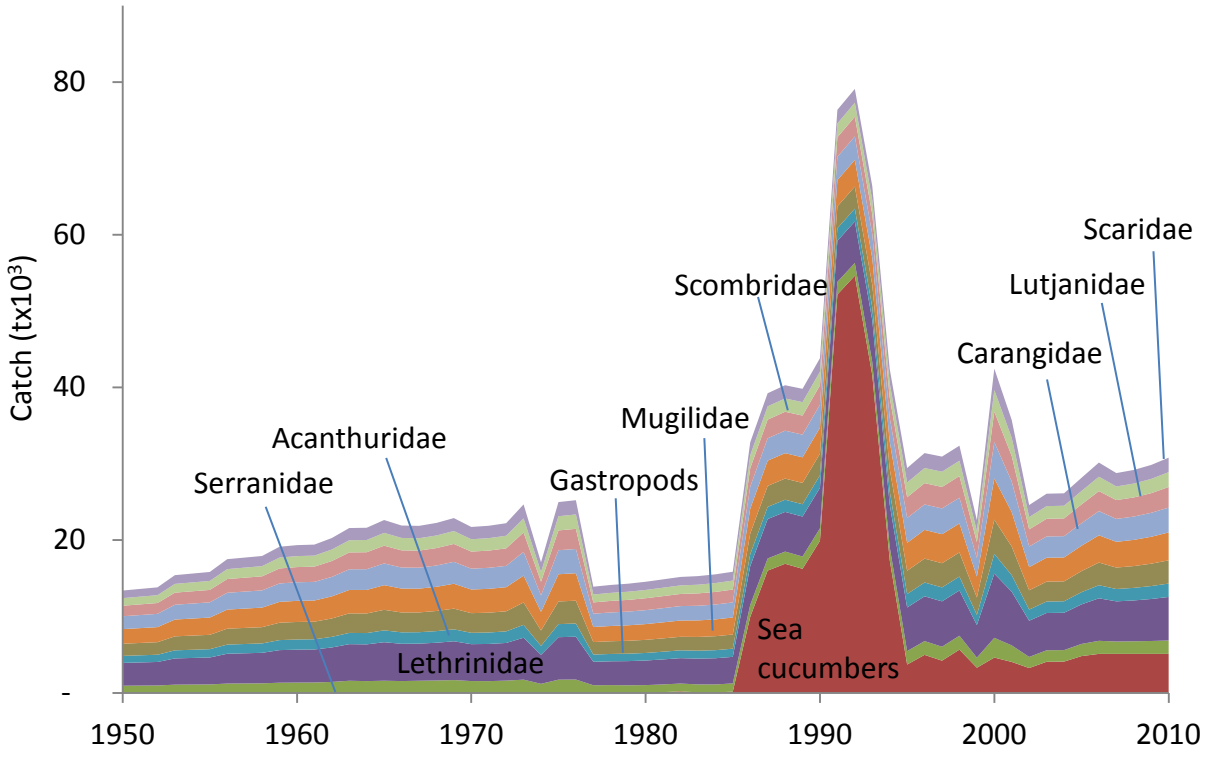

Figure 4. Top 10 taxa in reconstructed catches, 1950-2010.

Appendix 1. Reported landings and reconstructed catches for Papua New Guinea, 1950-2010.

	Reported	Reconstructed catches				
Year	landings	Industrial	Artisanal	Subsistence	Discards	Recreational
1950	6000	0	3103	17347	0	0
1951	6000	0	3153	17567	0	0
1952	6000	0	3203	17788	0	0
1953	8000	0	3859	19755	0	0
1954	8000	0	3882	19958	0	0
1955	8000	0	3904	20160	0	0
1956	10000	0	4340	22149	0	0
1957	10000	0	4381	22333	0	0
1958	10000	0	4422	22517	0	0
1959	12000	0	5680	23883	0	0
1960	12000	0	5746	24054	0	0
1961	12000	0	5807	24037	0	0
1962	13000	0	5998	24910	0	0
1963	15000	0	6827	26210	0	0
1964	15000	0	6852	26205	0	0
1965	15500	0	5993	27236	0	0
1966	15000	0	6426	26323	0	0
1967	15000	0	7124	26105	0	0
1968	15400	0	7281	26401	0	0
1969	16100	0	7507	26948	0	0
1970	15628	100	5963	25663	63	38
1971	30668	100	6532	25772	63	40
1972	27172	300	6454	25980	189	42
1973	45501	200	7635	28428	126	44
1974	49917	670	6296	20860	422	47
1975	34660	397	7748	28562	250	49
1976	50547	767	7535	28689	483	51
1977	27540	841	4264	17860	530	54
1978	52202	1105	4066	18125	696	57
1979	29438	1045	3196	18395	658	59
1980	37110	1091	4200	18692	687	62
1981	34000	921	3817	19009	580	65
1982	4090	824	2774	19301	519	68
1983	1888	886	2033	19597	558	72
1984	4164	992	1913	19907	625	75
1985	10985	1170	2132	20174	737	78
1986	10781	1088	12703	26217	685	82
1987	11132	944	18233	26523	595	85
1988	11578	1150	15545	26633	725	89
1989	11111	1200	17902	26780	756	93
1990	11635	1200	19108	27054	756	97
1991	12620	1200	44777	27403	756	101
1992	12742	1190	46086	27762	750	105
1993	12242	1144	36354	28127	721	109
1994	12724	983	18287	28503	619	114
1995	25591	1299	18161	29191	818	119
1996	24316	1252	22427	29890	789	124
1997	32718	993	20082	30298	626	129
1998	64780	1679	24768	30414	1058	134
1999	42123	1491	13094	24845	939	140
2000	96362	1725	28262	39394	1087	146
2001	111413	1597	21007	34767	1006	152
2002	127660	805	2702	26924	507	158
2003	163344	874	6572	27581	551	164
2004	229101	1061	2285	27740	668	170
2005	240635	1055	8114	28902	665	177
2006	239519	649	9138	30522	409	184
2007	233961	565	9341	29728	356	191
2008	208944	499	6337	30324	314	198
2009	216557	486	7139	31113	306	205
2010	212324	1052	5686	32096	663	212

Appendix 2. Papua New Guinea reconstructed catch by major taxa, 1950-2010.

Year	Acanthuridae	Carangidae	Gastropods	Lethrinidae	Lutjanidae	Mugilidae	Scombridae	Scaridae	Sea cucumbers	Serranidae
1950	919	1,664	1,592	2,950	1,361	1,890	983	983	2	908
1951	933	1,690	1,617	2,996	1,383	1,920	998	998	2	922
1952	947	1,716	1,642	3,042	1,404	1,949	1,014	1,014	2	936
1953	1,057	1,915	1,832	3,394	1,566	2,175	1,131	1,131	2	1,044
1954	1,071	1,941	1,857	3,440	1,587	2,205	1,146	1,146	2	1,058
1955	1,086	1,967	1,882	3,486	1,609	2,234	1,162	1,162	2	1,072
1956	1,201	2,175	2,081	3,856	1,779	2,471	1,285	1,285	2	1,186
1957	1,215	2,201	2,106	3,902	1,800	2,500	1,300	1,300	2	1,200
1958	1,229	2,227	2,131	3,948	1,822	2,530	1,315	1,315	2	1,214
1959	1,312	2,378	2,275	4,215	1,945	2,701	1,404	1,404	2	1,297
1960	1,327	2,404	2,300	4,261	1,966	2,730	1,420	1,420	13	1,311
1961	1,331	2,412	2,308	4,275	1,973	2,739	1,424	1,424	20	1,315
1962	1,389	2,517	2,408	4,461	2,058	2,859	1,486	1,486	37	1,372
1963	1,474	2,671	2,555	4,734	2,184	3,033	1,577	1,577	107	1,456
1964	1,480	2,682	2,566	4,754	2,194	3,046	1,584	1,584	53	1,462
1965	1,551	2,810	2,689	4,982	2,299	3,192	1,660	1,660	34	1,532
1966	1,501	2,720	2,603	4,822	2,225	3,090	1,607	1,607	37	1,483
1967	1,495	2,708	2,592	4,801	2,215	3,076	1,600	1,600	88	1,477
1968	1,521	2,756	2,637	4,885	2,254	3,130	1,627	1,627	93	1,503
1969	1,564	2,833	2,711	5,022	2,317	3,218	1,673	1,673	103	1,545
1970	1,486	2,702	2,579	4,778	2,212	3,062	1,598	1,592	54	1,470
1971	1,498	2,728	2,604	4,823	2,233	3,091	1,614	1,607	33	1,484
1972	1,517	2,765	2,639	4,889	2,277	3,133	1,636	1,629	83	1,504
1973	1,689	3,081	2,941	5,449	2,528	3,492	1,823	1,815	34	1,676
1974	1,168	2,141	2,041	3,781	1,791	2,423	1,268	1,260	10	1,163
1975	1,711	3,128	2,985	5,531	2,580	3,544	1,851	1,843	12	1,701
1976	1,726	3,159	3,014	5,584	2,630	3,578	1,869	1,860	14	1,718
1977	946	1,749	1,665	3,085	1,482	1,977	1,037	1,028	44	949
1978	960	1,779	1,693	3,136	1,524	2,009	1,054	1,045	49	965
1979	974	1,808	1,721	3,188	1,543	2,043	1,072	1,062	11	981
1980	990	1,842	1,752	3,246	1,573	2,080	1,092	1,081	20	998
1981	1,008	1,877	1,785	3,308	1,590	2,119	1,113	1,102	56	1,017
1982	1,023	1,909	1,815	3,363	1,609	2,155	1,132	1,120	192	1,035
1983	1,039	1,941	1,846	3,419	1,639	2,191	1,151	1,139	56	1,052
1984	1,056	1,976	1,879	3,480	1,675	2,230	1,172	1,160	39	1,071
1985	1,070	2,005	1,906	3,531	1,710	2,263	1,190	1,176	163	1,086
1986	1,562	2,901	2,763	5,118	2,437	3,280	1,719	1,705	7,457	1,574
1987	1,588	2,946	2,805	5,196	2,463	3,330	1,746	1,731	12,488	1,598
1988	1,598	2,961	2,819	5,222	2,489	3,346	1,755	1,740	10,153	1,606
1989	1,610	2,982	2,838	5,258	2,509	3,369	1,768	1,752	12,722	1,617
1990	1,634	3,023	2,877	5,330	2,542	3,415	1,792	1,776	13,858	1,639
1991	1,652	3,055	2,906	5,384	2,568	3,450	1,811	1,794	39,363	1,656
1992	1,671	3,087	2,937	5,441	2,593	3,486	1,831	1,813	40,743	1,674
1993	1,691	3,120	2,968	5,498	2,616	3,523	1,850	1,832	31,065	1,691

1994	1,711	3,155	3,000	5,558	2,633	3,561	1,871	1,852	12,802	1,710
1995	1,758	3,238	3,079	5,704	2,722	3,655	1,921	1,900	12,460	1,755
1996	1,805	3,323	3,159	5,852	2,787	3,750	1,971	1,950	16,688	1,800
1997	1,827	3,360	3,194	5,917	2,799	3,792	1,993	1,971	14,140	1,820
1998	1,822	3,350	3,184	5,898	2,838	3,780	1,988	1,965	19,012	1,814
1999	1,316	2,431	2,304	4,268	2,073	2,735	1,446	1,422	11,060	1,313
2000	2,586	4,730	4,502	8,341	3,968	5,345	2,804	2,779	17,024	2,566
2001	2,164	3,964	3,768	6,981	3,332	4,473	2,352	2,326	13,561	2,147
2002	1,458	2,684	2,542	4,710	2,229	3,018	1,596	1,569	854	1,449
2003	1,503	2,763	2,618	4,849	2,298	3,107	1,643	1,616	4,592	1,492
2004	1,504	2,758	2,612	4,838	2,306	3,100	1,641	1,612	541	1,488
2005	1,594	2,922	2,767	5,126	2,439	3,285	1,738	1,708	5,712	1,577
2006	1,713	3,139	2,973	5,509	2,587	3,530	1,867	1,835	6,216	1,695
2007	1,618	2,969	2,810	5,206	2,441	3,336	1,767	1,735	7,429	1,602
2008	1,647	3,022	2,859	5,297	2,479	3,394	1,798	1,765	4,667	1,629
2009	1,692	3,105	2,937	5,441	2,544	3,487	1,848	1,813	5,348	1,674
2010	1,754	3,219	3,045	5,641	2,676	3,615	1,916	1,880	3,733	1,735