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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 4 times higher than 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 is predominately focussed on tuna, whereby nationalisation of the sector and sustaining the resource base are major objectives (Friedman, Kronen 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. Whilst data exists for exports of these species, basic data on catch and effort in general are poor, and subsistence catches are left out of 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 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 paid 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 can assist 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, Hanchard 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 whol country of 11.2 per hectare (PNG NSO 2012). 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, Kronen et al. 2008), while reef fish are caught using handlines, gill nets, hand spears, or traps (Friedman, Kronen et al. 2008). Sea cucumbers have been over-exploited as evident by the moratorium on harvesting and export since 2009, 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, Kronen 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, Adams 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 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.

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

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 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, Kronen 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, Basurto 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, Marnane 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, Hanchard et al. 2002; Kinch, Purcell et al. 2008). Local catches were used primarily to meet household and community subsistence and exchange needs; on the other hand, 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, Purcell 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, while 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 has 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

Papua New Guinea 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 the tuna, bêche-de-mer, lobster, prawn, and barramundi fisheries, with another two for live reef fish and aquarium fish still in a 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; Govan, Kinch 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 fisheries personnel, adequate resourcing, enforcement issues, economic development of inshore commercial fisheries, and sustaining the tuna resource base (FAO 2010). Papua New Guinea'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, Purcell 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 greater details. 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, Kumasi 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, Kumasi et al. 2013). Unfortunately, the same level of reporting is not maintained for artisanal fisheries, albeit under an Asian Development Bank project in the mid-2000s landing and market surveys were conducted in the New Ireland, Morobe and Milne Bay Provinces. Relatively reliable national export data exist for inshore commercial fisheries such as sea cucumbers, lobster, and trochus. Here, statistics only cover the quantity that is exported and not what is consumed locally[2], and reporting to FAO is incomplete. Hence, there is a gap in time series 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, Kronen et al. 2008). Finally, there is no accounting for small-scale subsistence fisheries, despite this sector's substantial importance to local well-being.

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

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

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 Papua New Guinea originate from the following sources: i) subsistence fishing; ii) artisanal (inshore commercial) sector; iii) shark fishery iv) discards; v) marine recreation sector; vi) illegal/foreign catches; and vii) under-reported tuna catches.

This reconstruction will focus on non-tuna catches, in this case, the small-scale and marine recreation sectors, commercial shark fishery, and discards from the sea cucumber and industrial prawn trawl fishery. Tuna catches are addressed in a complementary report.

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 and invertebrates that was consumed for food. Subsistence catch was calculated as:

$S = P*C*F$

where
P is PNG 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·person^{-1}·year^{-1}, while for coastal communities it was much higher, i.e. 53 kg·person^{-1}·year^{-1} (Bell *et al.* 2009, based on information from Gibson (2000)). We assumed that PNG's fish consumption level 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

[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.

started to linearly decrease *F* in 1960 to a second anchor point of 64% in 2005 (Bell, Kronen 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, trochus and other shell fisheries. In addition, a giant clam fishery operated in Milne Bay Province from the 1980s to 2000. Bêche-de-mer[4] exports have been documented since 1878, and coastal inhabitants started harvesting trochus after World War II (Friedman, Kronen 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 FAO landing statistics in 1981, while giant clam, trochus and other shells were absent throughout. To address this, we add estimates of unreported barramundi, lobster, reef fish, sea cucumber, giant clam, trochus and other shell catches from 1950-2010.

Reef fish: In 1986, there was only one known artisanal reef fishery in Papua New Guinea, which involved several fishing villages near Port Moresby (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: 133 t[2];
2004: 50 t[2].

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, Kronen et al. 2008), with exception of the commercial lobster fishery which has a fleet licenced 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.

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, Purcell et al. 2008) and 2000-2010 (NFA, unpublished data). Dry export weights were converted to fresh wet weight using a conversion

[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'.

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 beche-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, Story 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: 1030t (Chapau 1993);
1980: 400t (Chapau 1993);
1990: 333t (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 $t \cdot year^{-1}$, 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.

Giant clams: Unreported giant clams (flesh weight) were estimated from adductor muscle exports during the 1980s to 2000 when a domestic artisanal fishery for *Tridacna* spp. operated out of Milne Bay Province. From 1983-1988, a total of 86 t *Tridacna* spp. adductor muscles were exported (Kinch 2002). A ban on exports was imposed in 1988 and subsequently lifted in 1995. Between 1995 and 1999 a further 65 t of adductor muscles, and 16 t of *Tridacna* spp. shells, were exported, before a total ban on exports of wild giant clams was once again imposed in 2000 (Kinch 2002). We converted adductor muscle weight to fresh flesh weight using a conversion factor of 8.82 (Munro 1992). We assume that giant clams that were taken for local consumption are included within the subsistence catch estimate.

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). 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). From 2004 to 2008 export data was reported for 'shark products', which consist primarily of shark meat (93%) and shark fins (7%)[‡] (Kumoru 2002). 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.

IUU catch

Throughout the 1960s to 1980s giant clams in the South Pacific, including PNG, were illegally poached by Taiwanese fishing vessels, the height of the activity lasting from 1967-1981, with peak catches in the mid-1970s (Munro 1992). Poaching declined when stocks became depleted. The Taiwanese are estimated to have poached clams equivalent to 100 to 400 t of adductor muscles annually in the South Pacific (Lucas 1997). We reconstructed illegally poached giant clams by assuming peak harvest from 1974 to 1976, during which the equivalent to 250 t (mid-point of estimated quantity of poached giant clams) of adductor muscles were taken from throughout the South Pacific. We started accounting for Taiwanese poaching in PNG in 1967, assuming a starting catch that was half that of the peak catch, and a 'depleted' ending catch in 1981 that was 10% of the peak catch. Linear interpolation was used to fill in missing data between the anchor points. The portion of giant clams taken from PNG's waters was unknown. During the 1980s, large amounts of giant clams were exported from Fiji and PNG[ϕ], of which PNG's share was about 45%. As this was the only indication we had of the relative size of PNG's giant clam fishery relative to other South Pacific countries, we applied it to derive the portion of giant clams that were illegally poached from PNG by Taiwanese fishing vessels. We then converted adductor muscle weight to fresh flesh weight using a conversion factor of 8.82 (Munro 1992).

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

* Average ratio of fin weight to round (whole) weight for Blue shark and Silky shark.

‡ 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.

ϕ Marine Invertebrates of the South Pacific: An Examination of the Trade. A Traffic Network report, October 1995 (unpublished report).

recreational fishing in PNG (Friedman, Kronen et al. 2008; FAO 2010), although the NFA's management plan for barramundi[5] does recognise recreational fishing of the species. Recreational fishers target marlins, trevallies, 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[6]. 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 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.

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[7]. 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. 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 ranged between 8 to 20 $kg \cdot person^{-1} \cdot trip^{-1}$. An annual recreational catch rate of 280 $kg \cdot person^{-1} \cdot trip^{-1}$ was then determined on the basis of 2 recreational trips per month for 10 months in a year, assuming an average catch of 14 $kg \cdot person^{-1} \cdot trip^{-1}$.

Discards
The prawn trawl fishery has been operating in Papua New Guinea since 1969 (Dalzell, Adams 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[8]. We started accounting for prawn trawl fishery discards in 1970, whereby prawn discards (Dis_{prawns}) were estimated as:

[5] National Fisheries Authority, Fisheries Management Act 1998, The Barramundi Fishery Management Plan.URL: http://www.fisheries.gov.pg . Accessed 18 December 2013.
[6] Papua New Guinea High Commission in Australia. URL: http://www.pngcanberra.org/tourism/sports_game_fishing.htm. Accessed 3 December 2013.
[7] Signature Staff. URL: http://www.signaturestaff.com.au/job-seekers/jobs-PNG. Accessed 3 December 2013.
[8] 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.

$Dis_{prawns} = Ct_{prawn}i \cdot 0.9 \cdot 0.7$ where Ct_{prawn} 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). 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 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 (Tables 2 & 3). 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, Kronen 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, Adams et al. 1996), while invertebrate catches consisted of bivalves, gastropods, crustaceans, and a small amount of octopus and urchins (Friedman, Kronen 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, Adams et al. 1996; Friedman, Kronen 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%); 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 sharks (*Carcharhinus melantropterus*), whitetip reef sharks (*Triaenodon obesus*) sharks, grey reef sharks (*Carcharhinus amblyrhychos*), tiger sharks (*Galeocerdo cuvieri*, lemon sharks

(*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[9], 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 '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. This estimate was 4 times higher than 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 $t \cdot year^{-1}$ in the 1950s, peaked at 95,000 $t \cdot year^{-1}$ in 1992, and were about 44,000 $t \cdot year^{-1}$ 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 estimated by the fish consumption approach ranged between 717,000 t and 1.5 million t from 1950-2010 (Figure 2). The "rural coastal and island population within 10km" scenario (i.e., 1,195,360 t) returned results that fell in the mid-range, thus were used as the time series data for 'unreported subsistence catch' in this reconstruction.

The subsistence sector accounted for 67% of total reconstructed catches, followed by the artisanal sector at 30% and the industrial fishery at 2%, while the marine recreational sector and fish discards together made up 3% of total reconstructed catches (Figure 3). Unreported catches totalled around 1.8 million t, of which the majority (1.2 million t) came from the subsistence sector (Figure 4). Illegal poaching by Taiwanese vessels resulted in a further 10,220 t of giant clams being taken from PNG's waters from the late 1960s to early 1980s. Almost 75% of reconstructed marine catches from 1950-2010 were accounted for by 11 taxa (Figure 5). Sea cucumbers were the most abundant (404,000 t), followed by Lethrinidae (284,000 t), Gastropods (221,000 t), and Mugilidae (182,000 t). Bivalves made up 4% of total reconstructed catches, while shark species contributed almost 2.5% to the total. 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.

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

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 approximately 3.7 times higher than 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. Molluscs such as giant clams have a long tradition as subsistence food and trade item in PNG (Kinch 2008), but there are few data that quantify their use. The cursory treatment of invertebrates provided in this reconstruction shows that bivalves and gastropods accounted for approximately 13% of total reconstructed catches, of which about one quarter was exploited by artisanal fishers for export and the remainder for subsistence consumption.

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, Purcell 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, Kronen 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 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 7,700 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, Adams 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 34,700 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, Purcell 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, Purcell et al. 2008; Carleton, Hambrey et al. 2013; SciCOFish 2013), and in 2009 a moratorium on bêche-de-mer exports was declared.

Marine recreation catch contributed less than 1% 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 economic 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, Kronen 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 about two-thirds of total unreported catches, highlighting the magnitude of marine resources that is unknowingly being taken from inshore waters. Furthermore, the intrusion of foreign fishing vessels into PNG's EEZ incurs fisheries losses, both ecological and economic. While the non-commercial fisheries are apparently still not overexploited (Friedman, Kronen 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.

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References

Bell, F. (1935). "Fishing in Tanga." The Australian Museum Magazine **5**: 355-359.

Bell, J., M. Kronen, et al. (2009). "Planning the use of fish for food security in the Pacific." Marine Policy **33**: 64-76.

Carleton, C., J. Hambrey, et al. (2013). "Effective management of sea cucumber fisheries and the beche-de-mer trade in Melanesia." SPC Fisheries Newsletter **140**(24-42).

Chapau, M. (1993). Papua New Guinea: Searching for an effective lagoon and shallow reef marine resources management system. FAO Fisheries Report no. 474 FAO/Japan Expert Consultation on the Development of Community-Based Coastal Fishery Management Systems for Asia and the Pacific, Kobe (Japan), 8-12 June 1992, FAO, Rome (Italy). Fishery Policy and Planning Division.

Chapman, M. (1987). "Women's fishing in Oceania." Human Ecology **15**: 267-288.

Cinner, J., X. Basurto, et al. (2012). "Institutional designs of customary fisheries management arragements in Indonesia, Papua New Guinea, and Mexico." Marine Policy **36**: 278-285.

Cinner, J., M. Marnane, et al. (2006). "Periodic closures as adaptive coral reef management in the Indo-Pacific." Ecology and Society **11**(1).

Cisneros-Montemayor, A. and U. Sumaila (2010). "A global estimate of benefits from ecosystem-based marine recreation: potential impacts and implications for management." Journal of Bioeconomics **12**: 245-268.

Dalzell, P. (1991). "The Value of Nutritional Surveys for Fisheries Workers." SPC Fisheries Newsletter **56**: 27-28.

Dalzell, P., T. Adams, et al. (1996). Coastal Fisheries in the Pacific Islands. Oceanography and Marine Biology: an Annual Review A. Ansell, R. Gibson and M. Barnes, UCL Press. **34, 395-531:** 395-531.

Dalzell, P. and A. Wright (1986). An assessment of the exploitation of coral reef fishery resources in Papua New Guinea. The first asian fisheries forum. J. Maclean, L. Dizon and L. Hosillos. Manila, Philippines, Asian Fisheries Society**:** 477-481.

Doulman, D. and A. Wright (1983). "Recent Developments in Papua New Guinea's Tuna Fishery." Marine Fisheries Review **45**: 47-59.

FAO (2010). Fishery and Aquculture Country Profiles-Country Profile Fact Sheets: Papua New Guinea. Edition 2010. Available at http://www.fao.org/fishery/facp/PNG/en [Accessed: Dec. 2013], Rome, FAO Fisheries and Aquaculture Department [online].

FAO (2012). FishStat Plus, Version2.32. Universal software for fishery statistics time series. Available at www.fao.org/fishery/statistics/software/fishstat/en [Accessed: Oct. 2013], Rome, Food and Agriculture Organization of the United Nations (FAO), Fisheries and Aquaculture Department, Fishery information, Data and Statistics Unit.

Friedman, K., M. Kronen, et al. (2008). "Papua New Guinea country report: Profiles and results from survey work at Andra, Tsoilaunung, Sideia, and Panapompom (June to November 2006)." Secretariat of the Pacific Community, Coastal Fisheries Programme **Noumea, New Caledonia**.

Gibson, J. (2000). The Economic and Nutritional Importance of Household Food Production in PNG. Food Security for Papua New Guinea: Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference, University of Technology, Lae, 26-30 June 2000. ACIAR Proceedings, No.99. R. Bourke, G. Allen and J. Salibury. Canberra, Australian Centre for International Agricultural Research.

Gillett, R. (2009). Fisheries in the economies of the Pacific island countries and territories. Mandaluyong City, Philippines, Asian Development Bank.

Govan, H., J. Kinch, et al. (2013). Strategic Review of Inshore Fisheries Policies and Strategies in Melanesia. Part II: Country Reports. . Port Vila, Vanuatu, Melanesian Spearhead Group.

Haines, A. and M. Chapau (1991). Observations on the traditional mackerel tuna (Euthynnus Affinis) fishery of Timoenai Island, Manus Papua New Guinea. Research report 91-04., Department of Fisheries and Marine Resources, PNG. 10p.

Hindmarsh, S. (2007). "A Review of Fin-weight Ratios for Sharks. A document presented to the Indian Ocean Tuna Commission Working Party on Ecosystems and Bycatch in 2007." IOTC-2007-WPEB-I4.

Kearney, R. (1976). The expansion of fisheries in Papua New Guinea: Prospects and problems. Report to Waigani Seminar, Papua New Guinea, 3-7 May 1976. Noumea, New Caledonia. 21p, South Pacific Commission.

Kinch, J. (2002). "Giant Clams: their status and trade in Milne Bay Province, Papua New Guinea." TRAFFIC Bulletin **19**(2): 1-9.

Kinch, J. (2002). "Overview of the beche-de-mer fishery in Milne Bay Province, Papua New Guinea." SPC Beche-de-mer information Bulletin **17**: 2-16.

Kinch, J. (2003). "Marine Mollusc Use Among the Women of Brooker Island, Louisiade Archipelago, Milne Bay Province, Papua New Guinea." SPC Women in Fisheries Information Bulletin **13**: 5-14.

Kinch, J. (2008). From Prehistoric to Present: Giant Clam (Tridacnidae) Use in Papua New Guinea. Early human Impact on Megamolluscs. A. Antczak and R. Cipriani. Oxford, England, Archaeopress.

Kinch, J., S. Purcell, et al. (2008). Papua New Guinea: a hotspot of sea cucumber fisheries in the Western Central Pacific. Sea cucumbers. A global review of fisheries and trade. *FAO Fisheries and Aquaculture Technical Paper. No. 516.* V. Toral-Granda, A. Lovatelli and M. Vasconcellos, FAO. pp.57-77.

Kuk, R. and J. Tioti (2012). Fisheries Policy and Management in Papua New Guinea. Papua New Guinea, National Research Institute.

Kumoru, L. (2002). National Shark Longline Management Plan. Port Moresby, Papua New Guinea, National Fisheries Authority.

Kumoru, L. (2003). The Shark Longline Fishery in Papua New Guinea, SCTB16 Working Paper BBRG-2. Port Moresby, Papua New Guinea, Papua New Guinea National Fisheries Authority.

Lack, M. and G. Sant (2012). "An overview of shark utilisation in the Coral Triangle region." TRAFFIC & WWF.

Lambeth, L., B. Hanchard, et al. (2002). An overview of the involvement of women in fisheries activities in Oceania. Global Symposium on Women in Fisheries: Sixth Asian Fisheries Forum, 29

November 2001, Kaohsiung, Taiwan. Issue 1663 of ICLARM contribution. N. Chao, P. Choo, K. Maticset al, WorldFish. 209 p.

Lock, J. (1986). Study of the Port Moresby Artisanal Reef Fishery. Port Moresby, Department of Primary Industry Fisheries Division.

Lucas, J. (1997). Giant clams: mariculture for sustainable exploitation. Conservation and the Use of Wildlife Resources. M. Bolton. Great Britain, Chapman & Hall.

Mainardi, S. (2009). "A surplus production model with latent truncation and species targeting, with an application to Papua New Guinean fisheries." Fisheries Research **95**: 296-308.

Mobiha, A. (1995). The Management of the Coastal Barramundi Fishery in the Wester Province of Papua New Guinea. Noumea, New Caledonia, Joint FFA/SPC Workshop on the Management of South Pacific Inshore Fisheries.

MRAG (2005). Review of Impacts of Illegal, Unreported and Unregulated Fishing on Developing Countries. London, UK.

Munro, J. (1992). Giant Clams. FFA Report 92/75. Solomon Islands, Pacific Islands Forum Fisheries Agency.

NFA (2007). "A review of fisheries and marine resources in Morobe Bay Province, Papua New Guinea." National Fisheries Authority and Coastal Fisheries Management and Development Project.

NFA (2007a). "A review of fisheries and marine resources in Milne Bay Province, Papua New Guinea." National Fisheries Authority and Coastal Fisheries Management and Development Project.

Ngaluafe, P. and J. Lee (2013). "Change in weight of sea cucumbers during processing: Ten common commercial species in Tonga." SPC Beche-de-mer information Bulletin **33**: 3-8.

Nichols, P. (1993). Chapter 9 Sharks. Nearshore Marine Resources of the South Pacific: Information for Fisheries. A. Wright and L. Hill. Honiara (Solomon Islands), Suva (Fiji), Forum Fisheries Agency (FFA) Institute of Pacific Studies**:** 304-308.

Ruddle, K. (1993). "External Forces and Change in Traditional Community-Based Fishery Management Systems in the Asia-Pacific Region." Maritime Anthropological Studies **6**: 1-37.

SciCOFish (2013). "Status report: Reef and nearshore fisheries and aquaculture 2013." Society for Pacific Communities: 45p.

Tiraa-Passifeld, T., R. Story, et al. (2011). "The 2011 harvest of trochus in Aitutake, Cook Islands." SPC Fisheries Newsletter **136**: 17-20.

Usu, T., B. Kumasi, et al. (2013). Annual Report to the Comission Part 1: Information on Fisheries, Research and Statistics 2012. Western and Central Pacific Fisheries Commission, WCPFC-SC9-AR/CCM-18.

Wright, A. and L. Hill (1993). Nearshore marine resources of the South Pacific, IPS, Suva; FFA, Honiara; ICOD, Canada.

Yamaguchi, M. (1993). Chapter 15 Green Snail. Nearshore Marine Resources of the South Pacific. A. Wright and L. Hill. Suva, Fiji, Forum Fisheries Agency & Institute of Pacific Studies.

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 2. 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 3. 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

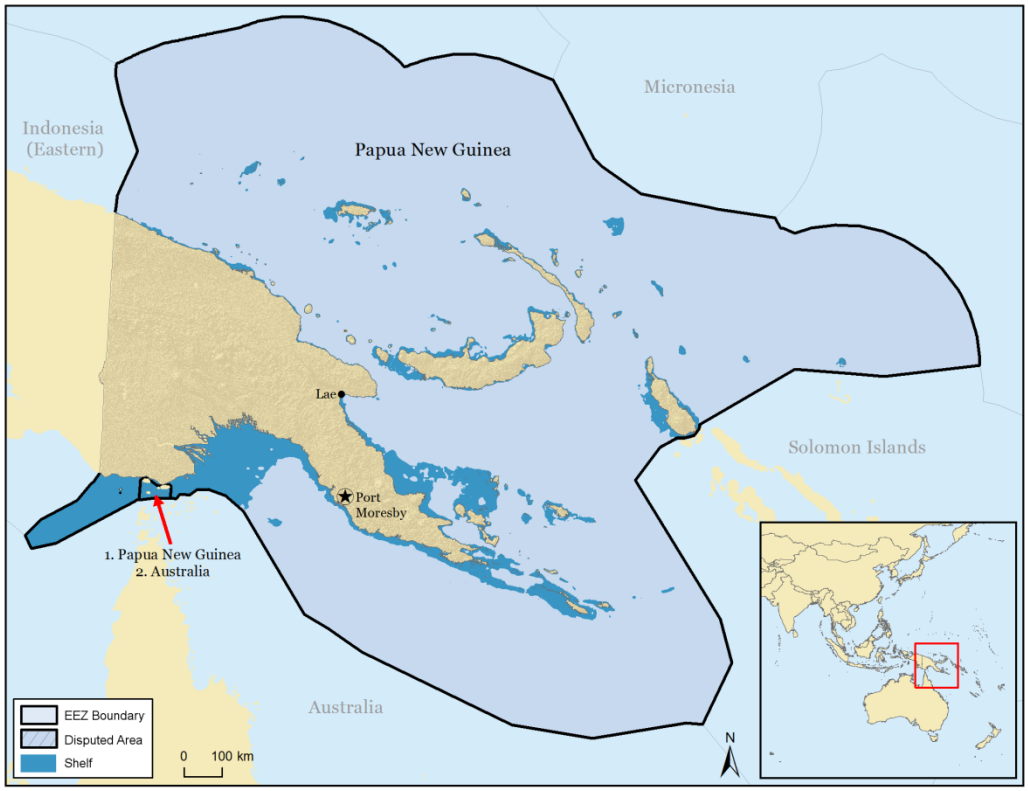

Figure 1. Exclusive Economic Zone (EEZ) and shelf waters to 200 m depth for Papua New Guinea.

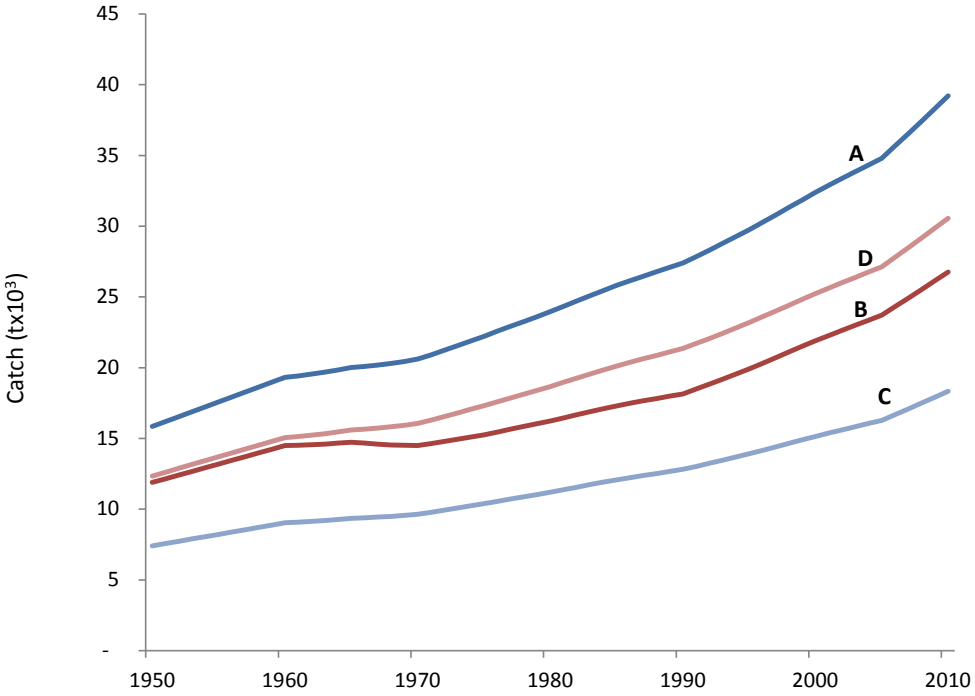

Figure 2. Estimated subsistence catches from 4 scenarios with variation in population and fish consumption rates (see Table 1 for scenario parameters).

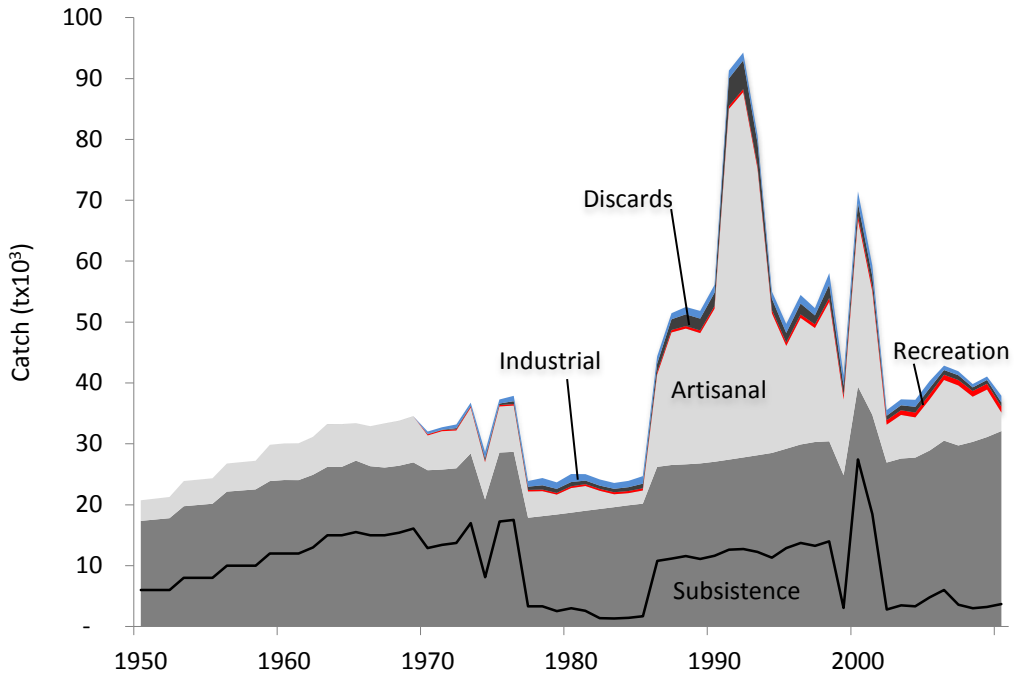

Figure 3. Papua New Guinea's total catches from 1950-2010, showing unreported catches from small-scale fishing and discards added to the reported landings.

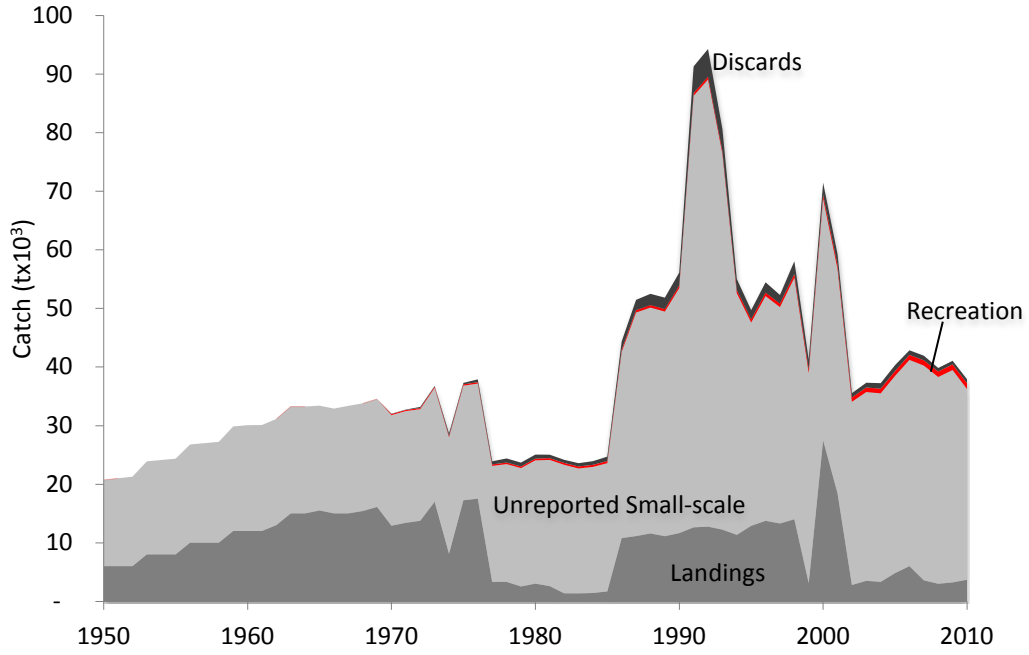

Figure 4. Reconstructed catches showing contribution of different sectors. The solid line represents FAO reported landings.

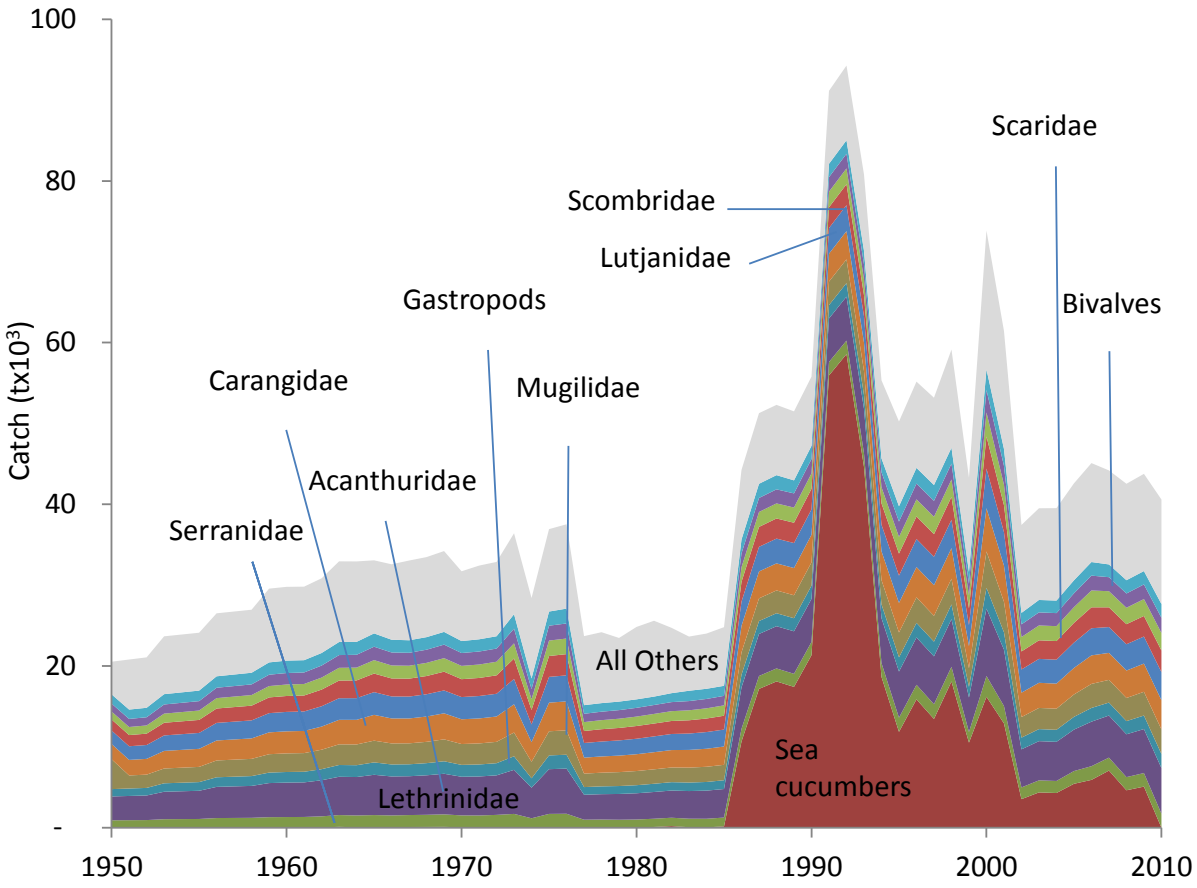

Figure 5. Top 10 taxa in reconstructed catches, 1950-2010.

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

Year	Reported*	Industrial	Artisanal	Subsistence	Discards	Recreational
1950	6,001	0	3,373	17,347	1	0
1951	6,001	0	3,423	17,567	1	0
1952	6,001	0	3,473	17,788	1	0
1953	8,000	0	4,129	19,755	1	0
1954	8,000	0	4,151	19,958	1	0
1955	8,000	0	4,174	20,160	1	0
1956	10,000	0	4,610	22,149	1	0
1957	10,000	0	4,651	22,333	1	0
1958	10,000	0	4,692	22,517	1	0
1959	12,000	0	5,950	23,883	1	0
1960	12,000	0	6,004	24,054	1	0
1961	12,000	0	6,044	24,037	2	0
1962	13,000	0	6,213	24,910	3	0
1963	15,000	0	7,021	26,210	8	0
1964	15,000	0	7,025	26,205	4	0
1965	15,500	0	6,145	27,236	3	0
1966	15,000	0	6,557	26,323	3	0
1967	15,000	0	7,234	26,105	7	0
1968	15,400	0	7,370	26,401	7	0
1969	16,100	0	7,575	26,948	8	0
1970	12,900	400	5,709	25,663	67	176
1971	13,394	400	6,298	25,772	65	185
1972	13,741	600	6,209	25,980	195	195
1973	16,984	500	7,491	28,428	129	206
1974	8,107	1,010	6,135	20,860	423	217
1975	17,241	662	7,572	28,562	251	228
1976	17,513	873	7,592	28,689	484	240
1977	3,311	930	4,316	17,860	533	252
1978	3,317	1,190	4,100	18,125	700	264
1979	2,529	1,070	3,269	18,395	659	277
1980	3,014	1,323	4,044	18,692	689	290
1981	2,587	1,842	4,064	19,009	587	304
1982	1,365	1,799	2,984	19,301	533	319
1983	1,347	1,093	2,119	19,597	563	334
1984	1,419	1,205	1,993	19,907	628	350
1985	1,684	1,426	2,161	20,174	749	365
1986	10,780	1,257	15,166	26,217	1,406	382
1987	11,131	999	21,770	26,523	1,759	398
1988	11,577	1,210	22,292	26,633	1,923	415
1989	11,110	1,270	21,403	26,780	1,938	432
1990	11,634	1,310	25,126	27,054	2,187	451
1991	12,619	1,481	57,584	27,403	4,538	470
1992	12,741	1,643	60,005	27,762	4,705	489
1993	12,233	1,762	46,992	28,127	3,735	510
1994	11,338	1,841	22,929	28,503	1,877	531
1995	12,877	2,265	16,891	29,191	1,553	554
1996	13,736	2,361	20,790	29,890	1,772	577
1997	13,280	2,327	18,723	30,298	1,459	602
1998	14,001	3,218	22,919	30,414	2,178	627
1999	3,083	3,894	12,430	24,845	1,591	653
2000	27,448	4,834	27,366	39,394	2,090	680
2001	18,447	4,339	20,251	34,767	1,805	708
2002	2,788	3,131	6,217	26,924	731	736
2003	3,497	3,481	7,165	27,581	821	765
2004	3,315	3,755	6,603	27,740	935	795
2005	4,809	3,774	8,405	28,902	1,001	826
2006	5,998	3,323	9,963	30,522	775	857
2007	3,578	3,253	9,853	29,728	794	890
2008	2,991	3,605	7,418	30,324	603	923
2009	3,224	3,615	7,801	31,113	621	957
2010	3,685	4,167	3,028	32,096	663	991

* Not including industrial tuna landings

Appendix 2. Papua New Guinea reconstructed catches by major taxa, 1950-2010. 'Others' includes up to 36 additional taxon groups.

Year	Acanthuridae	Bivalves	Carangidae	Gastropods	Lethrinidae	Lutjanidae	Mugilidae	Scaridae	Scombridae	Sea cucumbers nei	Serranidae	Others
1950	908	1,143	1,664	3,692	2,950	1,361	1,890	983	983	14	908	4,042
1951	922	1,157	1,690	1,617	2,996	1,383	1,920	998	998	14	922	6,189
1952	936	1,171	1,716	1,642	3,042	1,404	1,949	1,014	1,014	14	936	6,237
1953	1,044	1,276	1,915	1,832	3,394	1,566	2,175	1,131	1,131	14	1,044	7,152
1954	1,058	1,290	1,941	1,857	3,440	1,587	2,205	1,146	1,146	14	1,058	7,154
1955	1,072	1,304	1,967	1,882	3,486	1,609	2,234	1,162	1,162	14	1,072	7,156
1956	1,186	1,414	2,175	2,081	3,856	1,779	2,471	1,285	1,285	14	1,186	7,790
1957	1,200	1,428	2,201	2,106	3,902	1,800	2,500	1,300	1,300	14	1,200	7,792
1958	1,214	1,442	2,227	2,131	3,948	1,822	2,530	1,315	1,315	14	1,214	7,793
1959	1,297	1,522	2,378	2,275	4,215	1,945	2,701	1,404	1,404	14	1,297	9,123
1960	1,311	1,536	2,404	2,300	4,261	1,966	2,730	1,420	1,420	14	1,311	9,125
1961	1,315	1,519	2,412	2,308	4,275	1,973	2,739	1,424	1,424	22	1,315	9,093
1962	1,372	1,554	2,517	2,408	4,461	2,058	2,859	1,486	1,486	39	1,372	9,239
1963	1,456	1,614	2,671	2,555	4,734	2,184	3,033	1,577	1,577	115	1,456	9,974
1964	1,462	1,599	2,682	2,566	4,754	2,194	3,046	1,584	1,584	56	1,462	9,949
1965	1,532	1,646	2,810	2,689	4,982	2,299	3,192	1,660	1,660	37	1,532	9,038
1966	1,483	1,577	2,720	2,603	4,822	2,225	3,090	1,607	1,607	39	1,483	9,328
1967	1,477	1,550	2,708	2,592	4,801	2,215	3,076	1,600	1,600	94	1,477	9,860
1968	1,503	1,553	2,756	2,637	4,885	2,254	3,130	1,627	1,627	100	1,503	9,901
1969	1,545	1,574	2,833	2,711	5,022	2,317	3,218	1,673	1,673	111	1,545	9,997
1970	1,470	1,479	2,747	2,579	4,778	2,212	3,062	1,592	1,643	58	1,470	8,629
1971	1,484	1,512	2,775	2,604	4,823	2,233	3,091	1,607	1,661	35	1,484	9,116
1972	1,504	1,520	2,815	2,639	4,889	2,277	3,133	1,629	1,686	89	1,504	9,195
1973	1,676	1,790	3,134	2,941	5,449	2,528	3,492	1,815	1,875	37	1,676	10,004
1974	1,163	1,313	2,196	2,041	3,781	1,791	2,423	1,260	1,323	11	1,163	9,946
1975	1,701	1,748	3,186	2,985	5,531	2,580	3,544	1,843	1,909	13	1,701	10,193
1976	1,718	1,838	3,220	3,014	5,584	2,630	3,578	1,860	1,930	15	1,718	10,430
1977	949	1,066	1,813	1,665	3,085	1,482	1,977	1,028	1,101	47	949	8,539
1978	965	1,060	1,846	1,693	3,136	1,524	2,009	1,045	1,121	53	965	8,771
1979	981	1,054	1,879	1,721	3,188	1,543	2,043	1,062	1,142	12	981	7,870
1980	998	1,049	1,915	1,752	3,246	1,573	2,080	1,081	1,166	22	998	8,958
1981	1,017	1,039	1,954	1,785	3,308	1,590	2,119	1,102	1,190	99	1,017	9,380
1982	1,035	1,106	1,990	1,815	3,363	1,609	2,155	1,120	1,213	206	1,035	8,082
1983	1,052	1,278	2,026	1,846	3,419	1,639	2,191	1,139	1,236	68	1,052	6,699
1984	1,071	1,257	2,065	1,879	3,480	1,675	2,230	1,160	1,261	42	1,071	6,830
1985	1,086	1,242	2,098	1,906	3,531	1,710	2,263	1,176	1,282	175	1,086	7,253
1986	1,574	1,721	2,998	2,763	5,118	2,437	3,280	1,705	1,816	10,671	1,574	8,606
1987	1,598	1,757	3,047	2,805	5,196	2,463	3,330	1,731	1,847	17,173	1,598	8,735
1988	1,606	1,758	3,066	2,819	5,222	2,489	3,346	1,740	1,860	18,099	1,606	8,690
1989	1,617	1,612	3,092	2,838	5,258	2,509	3,369	1,752	1,877	17,424	1,617	8,532
1990	1,639	1,634	3,137	2,877	5,330	2,542	3,415	1,776	1,906	21,340	1,639	8,563
1991	1,656	1,652	3,174	2,906	5,384	2,568	3,450	1,794	1,930	55,948	1,656	9,024
1992	1,674	1,670	3,211	2,937	5,441	2,593	3,486	1,813	1,955	58,580	1,674	9,235

Appendix 2. Papua New Guinea reconstructed catches by major taxa, 1950-2010. 'Others' includes up to 36 additional taxon groups.

Year	Acanthuridae	Bivalves	Carangidae	Gastropods	Lethrinidae	Lutjanidae	Mugilidae	Scaridae	Scombridae	Sea cucumbers nei	Serranidae	Others
1993	1,691	1,688	3,250	2,968	5,498	2,616	3,523	1,832	1,980	44,639	1,691	9,410
1994	1,710	1,706	3,289	3,000	5,558	2,633	3,561	1,852	2,006	18,658	1,710	9,657
1995	1,755	1,895	3,378	3,079	5,704	2,722	3,655	1,900	2,061	11,859	1,755	10,482
1996	1,800	1,941	3,469	3,159	5,852	2,787	3,750	1,950	2,117	15,883	1,800	10,664
1997	1,820	1,961	3,513	3,194	5,917	2,799	3,792	1,971	2,146	13,458	1,820	10,795
1998	1,814	1,956	3,509	3,184	5,898	2,838	3,780	1,965	2,147	18,095	1,814	12,135
1999	1,313	1,468	2,597	2,304	4,268	2,073	2,735	1,422	1,611	10,527	1,313	11,663
2000	2,566	2,546	4,903	4,502	8,341	3,968	5,345	2,779	2,976	16,203	2,566	17,153
2001	2,147	2,097	4,143	3,768	6,981	3,332	4,473	2,326	2,531	12,907	2,147	14,586
2002	1,449	1,418	2,870	2,542	4,710	2,229	3,018	1,569	1,783	3,539	1,449	10,873
2003	1,492	1,537	2,957	2,618	4,849	2,298	3,107	1,616	1,838	4,371	1,492	11,341
2004	1,488	1,552	2,960	2,612	4,838	2,306	3,100	1,612	1,843	4,300	1,488	11,431
2005	1,577	1,613	3,131	2,767	5,126	2,439	3,285	1,708	1,947	5,437	1,577	11,986
2006	1,695	1,681	3,356	2,973	5,509	2,587	3,530	1,835	2,084	5,920	1,695	12,236
2007	1,602	1,578	3,195	2,810	5,206	2,441	3,336	1,735	1,993	7,071	1,602	11,628
2008	1,629	1,643	3,256	2,859	5,297	2,479	3,394	1,765	2,032	4,635	1,629	11,928
2009	1,674	1,649	3,347	2,937	5,441	2,544	3,487	1,813	2,090	5,090	1,674	12,024
2010	1,735	1,699	3,470	3,045	5,641	2,676	3,615	1,880	2,167	4	1,735	12,929