Reconstruction of the Domestic and Distant-Water Fisheries Catch of La Réunion (France), 1950–2010*

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Abstract

Total marine fisheries catches were estimated for the island of La Réunion (France) for the 1950–2010 time-period using the catch reconstruction approach developed by the *Sea Around Us*. This included total catches (i.e., with estimates of dead discards) of the industrial, artisanal, and recreational sectors. The reconstructed catch for domestic sectors (i.e., excluding the distant-water fleets registered elsewhere, but belonging to firms in La Réunion) for the 1950–2010 time-period reached over 199,000 t (of which 60.8% were caught in La Réunion's EEZ). This figure is 1.6 times higher than the 127,800 t officially reported to the Food and Agriculture Organization of the United Nations. The major taxa in the catches were *Thunnus albacares* (yellowfin tuna; 15.5%), *Lethrinus mahsena* (sky emperor; 14.4%), *Xiphias gladius* (swordfish; 14.2%), *Prionace glauca* (blue shark; 6.0%), *T. alalunga* (albacore tuna; 5.7%), and Carangidae (jacks and pompanos; 5.2%). The industrial and artisanal sectors were the most prominent, with 60.7% and 31.2% of the total catch, respectively. Unreported landings represented 39.9% of the total catch, including 14.2% of dead discards. Total catch of non-domestic fleets totalled over 300,000 t from 1950 to 2010, including 121,700 t of *Dissostichus eleginoides* (Patagonian toothfish), 31,500 t of *Jasus palensis* (Saint Paul rock lobster), and 32,200 t of other demersal species caught in the French Southern and Antarctic Lands, as well as 117,000 t of large pelagics caught throughout the Western Indian Ocean.

Introduction

La Réunion is a 3 million year old volcanic island of 30 km of diameter, located in the Mascarene Archipelago between the east coast of Madagascar and Mauritius (Figure 1). It is characterized by a very steep slope and two volcanoes at its center: the *Piton des Neiges* (inactive and culminating at 3,070 m), and the *Piton de la Fournaise* (active). The continental shelf is limited mostly to the west coast, where there is a narrow fringing coral reef, which is small in comparison to that of the neighbouring island of Mauritius (David and Mirault 2006). The growth of a fringing reef elsewhere is inhibited by meteorological conditions, as well as volcanic eruptions and regular hurricanes during the warm season (November to May).

Thanks to its location and history, La Réunion has always been at an important social and cultural crossroad. It was discovered by the Arabs in the 10th century, and re-discovered in 1512 by Pedro de Mascarenhas (hence the name of the archipelago to which it belongs). Since the 17th century, the French have been interested in this island and have gradually colonized it. In the 18th century, the *Compagnie Française des Indes Orientales* started to develop the national economy *via* the production and export of spices, coffee and sugar cane. In 1946, La Réunion became a French Overseas Department, and integrated the European Community in 1997. The economy of La Réunion still relies on agriculture, but also increasingly on construction, services and tourism (INSEE 2006). Despite delays in infrastructure development (Fleurant 1989), tourists (mostly from France mainland) currently account for approximately one-third of the resident population, and the trend is going upward. All major cities are located along the coast, concentrating most infrastructure and population in a narrow band, while the interior is subject to lower human exploitation. The coastal band is thus under a high anthropogenic pressure (e.g., runoff, industrial wastes, erosion, urbanization; Faure 1982; Letourneur and Chabanet 1994; Conand 2002).

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Numerous studies since the 1970s have allowed to monitor these changes (Bouchon 1978; Faure 1982; Conand 2002; Anon. 2012), and it is clear that coral reefs of La Réunion — once home to over 200 species of madreporan corals and 320 species of fish (Faure 1982; Chabanet 1994) — have been visibly degraded since the mid-1980s (Conand 2002). It is thought that 30% of local reefs are currently degraded, and 50% are still threatened (Anon. 2012). However, conservation measures are being taken,[1] and the fringing reef on the west coast — by far the largest of the island — is currently almost entirely protected (80%; not its southernmost section) by a 35 km² marine protected area created in 2007.[2]

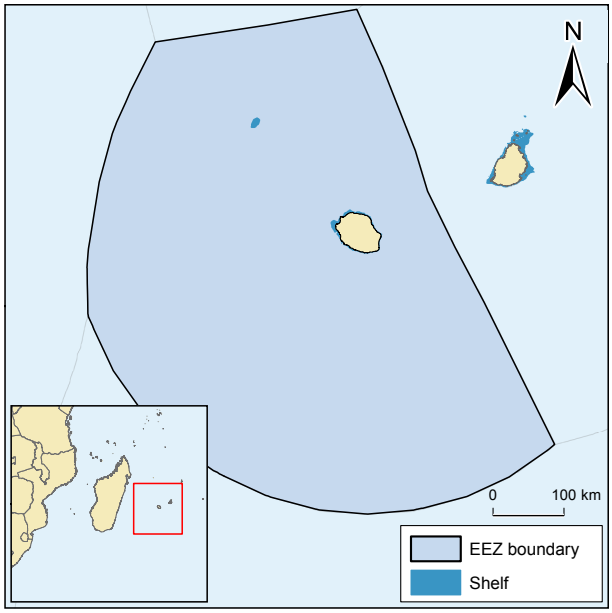

Figure 1. Map showing the location of La Réunion as well as the extent of its EEZ (light blue) and continental shelf (dark blue).

Although surrounded by the ocean, inhabitants from La Réunion have never really relied on it to provide food. This is largely explained by the limited shelf and by the often rough conditions at sea. This also has historical roots, as slaves were not allowed to fish from a boat, in order to limit risks of escape (David and Mirault 2006; Méralli-Ballou 2008). The Exclusive Economic Zone (EEZ) of La Réunion extends well over 300,000 km², and several categories of fishers are now active within and around it. Until the early 1980s, the fisheries contribution to the island's economy was low (limited to inshore fisheries and some distant fisheries), despite motorization of the entire fleet by the mid-1960s (Bertrand 1985). However, it soon became more important, particularly in the 1990s with the expansion of the tuna and billfish (mostly swordfish) fisheries, as well as the development of the *Dissostichus eleginoides* (Patagonian toothfish) and *Jasus palensis* (Saint Paul rock lobster) fisheries in the French Southern and Antarctic Lands (Bertrand 1985; Roos *et al.* 1998; Guyomard *et al.* 2006; Méralli-Ballou 2008; Palomares and Pauly 2011; Pruvost *et al.* 2015). These distant fisheries have gradually become of prime importance to the economy of the island, and largely contribute to the fact that the fishing industry is the second largest exporting sector, just behind sugar cane (Méralli-Ballou 2008).

According to several authors, official statistics are solely based on declarations of commercial fishers (both artisanal and industrial), and therefore only account for the 'legal portion' of all fisheries (Biais 1987; Roos *et al.* 1998; David and Mirault 2006). However, it is acknowledged that unreported commercial activities, as well as subsistence and recreational fisheries widely occur (Bertrand 1985; Biais and Taquet 1992; Roos *et al.* 1998; David and Mirault 2006), and the lack of enforcement and observers makes this difficult to monitor despite important catches (David and Mirault 2006). Adding to the problem, the accuracy of official fisheries statistics pertaining to the commercial sector has long been criticized, notably by Biais and Tacquet (1992) and Tessier and Poisson (1997). Indeed, artisanal fishers are known to under-report their catches to pay less revenue taxes, while over-reporting the number of trips to benefit more from fuel tax breaks (Roos *et al.* 1998). Also, landing surveys do not cover fishing activities occurring at night, thus missing substantial catches. Lastly, the statistics reported to FAO are confusing with regards to some distant sectors whose ownership is from La Réunion. The rock lobster fishery in Saint Paul and Amsterdam (partly reported by La Réunion in the early time-period; see below) is also reported as 'French Southern Territories' catches; (Pruvost *et al.* in press), similarly to the finfish (mostly Patagonian toothfish) fishery in Kerguelen and Crozet (Palomares and Pauly 2011); and vessels from the tropical purse-seine fishery are reported as 'Mayotte' catches (Doherty *et al.* this volume).[3]

Official fisheries statistics are therefore of poor quality and mis-represent the true extent of fisheries activities by La Réunion's fishers. In this report, we apply to La Réunion the reconstruction methods developed around principles in Pauly (1998), described in Zeller *et al.* (2007) and applied worldwide by the *Sea Around Us* (see, e.g., Zeller and Pauly 2007; Zeller and Harper 2009; Harper and Zeller 2012; Harper *et al.* 2012). We aim to improve the overall quality of fisheries statistics of La Réunion by thoroughly reviewing the available literature, re-allocating the FAO catch to the various fisheries sectors, and re-estimating the missing catches since 1950.

Fishing Sectors and Methods

Pelagic fisheries

A substantial part of the FAO data for La Réunion is composed of large pelagic taxa (FAO 2012): major tunas (*Katsuwonus pelamis* [skipjack tuna], *Thunnus alalunga* [albacore tuna], *T. albacares* [yellowfin tuna], *T. obesus* [bigeye tuna]), other Scombridae (*Acanthocybium solandri* [wahoo], *Euthynnus affinis* [kawakawa], and

[1] The first coral reef conservation measures occurred in 1969, when it was forbidden to use live coral for construction (Faure 1982). In 1976, spearfishing was forbidden, and the lagoon was also protected (David and Mirault 2006).

[2] Critics have been raised about this MPA, as it is in a heavily populated area, highly impacted by coastal activities such as tourism. For example, over 20,000 persons meet along its beach for New Year's Eve, pouring various liquids in the lagoon, walking on the reef, and leaving tonnes of detritus behind. A recent surge in shark attacks also pointed at the MPA as a potential reason for it (Anon. 2012).

[3] Mayotte became a French Department in 2011, and these purse-seine vessels have started to reflag elsewhere, e.g., in Mauritius.

'Scombroidei nei'), billfishes (*Istiophorus platypterus* [Indo-Pacific sailfish], *Tetrapturus angustirostris* [shortbill spearfish], *Xiphias gladius* [swordfish], and 'Istiophoridae nei'), and Elasmobranchii (sharks, rays, skates, etc.). These pelagic species comprise 12 out of the overall 31 taxa reported for La Réunion and compose 52.1% of the total catch reported by FishStat over the 1950–2010 period, and 80.6% over the 1990–2010 period.

The FAO data for these 12 taxa are nearly identical to the data available in the nominal catch database of the Indian Ocean Tuna Commission (www.iotc.org/English/data/databases.php).[4] Therefore, we re-allocated the FAO catch of large pelagics to various gears using the annual IOTC gear breakdown by taxon. Taxon names appearing in both datasets were consistent for the most part with the exception of Indo-Pacific sailfish, which was reported at the family level ('Istiophoridae nei') in FAO data. We used the annual IOTC data to reallocate a portion of the 'Istiophoridae nei' FAO catches to Indo-Pacific sailfish from 1993 to 2010, and used the average 1993–1995 IOTC breakdown to reallocate catches from 1991 to 1992, as there were no IOTC data for Indo-Pacific sailfish during these two years. Also, we used the previous years' breakdown to reallocate the FAO catch of skipjack tuna in 2009–10, and 'Scombroidei nei' (IOTC name was 'Scombridae') in 2003 and 2006–07.

This re-allocation allowed us to treat the different sectors more accurately, as the artisanal fleet (using handlines and troll lines) and the industrial fleet of longliners targeting swordfish were separated. The remaining catches of 'non-IOTC species' were re-allocated to other sectors: (i) the artisanal demersal fishery in coastal waters, (ii) the industrial demersal fishery on distant banks, and (iii) the shrimp trawl fishery in Madagascar (see below).

Longline fleet targeting swordfish

Following up on the success of the Asian fleet that started to target large pelagics in the Indian Ocean in the early 1950s (Allain 1974; Marsac and Stequert 1984; Poisson and Taquet 2001), a domestic fleet of longliners targeting swordfish was created in 1991 (Poisson *et al.* 1994; Poisson and Taquet 2001), and quickly became one of the major fishing sectors in La Réunion (René *et al.* 1998). These vessels are active at night, using drifting longlines of 20–100 km equipped with baited hooks. Each vessel can deploy hundreds to several thousands of hooks per set (Poisson and Taquet 2000; Evano and Bourjea 2012).

Only two fishing boats were active the first year, but thanks to an agreement signed between La Réunion and Mauritius as well as a tax-exemption regime, the number of longliners quickly rose to 31 in 2000 (INSEE 1991, 1996, 2000, 2002; René *et al.* 1998; Poisson *et al.* 1999; Poisson and Taquet 2001).[5] Due to the resulting high fishing pressure, the biomass of some stocks of targeted species was reduced, which resulted in longliners exiting the fishery in 2002–2003 (INSEE 2003, 2005; Evano and Bourjea 2012). However, the number of longliners was soon back to the 2000 level, with 34 vessels active in 2005 (INSEE 2008; Evano and Bourjea 2012). In 2010, around 20% of all registered vessels in La Réunion (i.e., 45) were longliners targeting swordfish (Leblond *et al.* 2011; Evano and Bourjea 2012).

Longliners were first active in La Réunion's EEZ beyond 12 nautical miles (nm) to minimize competition with the artisanal fleet, as well as in Mauritian waters, Tromelin (now jointly managed by France and Mauritius),[6] and around a bank situated 90 nm northwest of La Réunion (INSEE 1997, 1998, 2000). Since then, the fleet has expanded towards the Mozambique Channel and now operates in the entire western Indian Ocean (René *et al.* 1998; Poisson and Taquet 2001; Guyomard *et al.* 2006; Evano and Bourjea 2012), although most catches occur in the waters east of Madagascar and southwest of La Réunion (Poisson and Taquet 2001; Guyomard *et al.* 2006). The fleet has also somewhat changed its target species, targeting more bigeye tuna for the sashimi market (René *et al.* 1998; Poisson and Taquet 2001), as well as other species of tuna (Evano and Bourjea 2012). Since 2010, the largest longliners operate in the Mozambique Channel from Madagascar (i.e., they only go to La Réunion to land their catch), which effectively resulted in an increase in total fishing effort (Chavance *et al.* 2012).

Although INSEE (1998, 1999) reporeted that catches of this sector were likely underestimated, it seems that the current version of reported data includes everything but discards of target species (undersized and depredated individuals) and bycatch species (Bach *et al.* 2008, 2013). Most of the bycatch consists of unwanted sharks (mostly *Prionace glauca* [blue shark]; Poisson and Taquet 2001; Poisson 2010; Sabarros *et al.* 2013), pelagic stingrays, epipelagic billfishes, dolphinfish, wahoo, oilfish, as well as various species of fish referred to as 'snoek' (Bach *et al.* 2013; Sabarros *et al.* 2013). The economic interest on sharks has changed over time: at the beginning of the pelagic longline fishery in the 1990s, most *Carcharhinus longimanus* (oceanic whitetip shark) and mako shark were regularly kept onboard, whereas blue sharks where only kept from time to time (Poisson 2010). Currently, blue sharks are always discarded, while oceanic whitetip sharks and *Isurus* sp. (mako sharks) may be commercialized in some instances (Sabarros *et al.* 2013). 'Snoek' and other minor species of fish are mostly discarded, similarly to rays (Chavance *et al.* 2012). Discards may also consist of target species (swordfish) and other bycatch of economic importance (e.g., tuna and other billfishes) made unmarketable due to the depredation by sharks (all year round) and toothed whales (seasonal). Depredated catches are estimated to make up 10–15% of the landings of target species (e.g. swordfish, tuna and other billfishes; Poisson and Taquet 2001; Romanov *et al.* 2013). However, they are

[4] The IOTC data is thought to be the source of FAO data for pelagic catches, however, this is often not the case (see, e.g., Kenya; Le Manach et al. this volume). There are a couple of discrepancies, though: in 1970 (higher IOTC data) and 2009–2010 (higher FAO data).

[5] The *Compagnie des Long Liners* operated some of these tax-exempted vessels, and exported most of the catch to Europe (Poisson and Tacquet 2001). Noteworthy, most of the tax-exempted longliners are currently abandoned at port. The size of the largest vessels have decreased from 24m to 20 m and can no longer take on observers (Bach *et al.* 2010). Consequently, the French Research Institute for Development (IRD) has initiated a self-reporting program in 2011 to collect bycatch and depredation data (Bach *et al.* 2013).

[6] It was forbidden to fish within the 30 nm zone until 1995 (René *et al.* 1998).

sometimes kept for self-consumption (Sabarros *et al.* 2013), but not declared. This undeclared portion is difficult to estimate, and to distinguish from discards. Here, we considered that the non-reported component of the catch exclusively consisted of discards. To estimate them, we assumed that 15%, 25%, 95%, and 50% of the landings of major tunas, swordfish, sharks, and other species, respectively, were unreported (Bach *et al.* 2011; P. Bach, pers. obs.).[7] Due to the lack of data, we considered that these proportions remained constant from 1991 to 2010. The only exception was for sharks, where we assumed the total mortality rate linearly decreased from 80% during the 1991–2006 period (e.g., when finning was prevalent) to 30% by 2010 when finning was no longer occurring and the use of 'circle hooks' reduced mortality (estimate of mortality based on Diaz and Serafy 2005; Campana *et al.* 2009; Butcher *et al.* 2014).

The final step of the reconstruction of this sector was to split the total catch (landings and discards) among the various EEZs within which the fleet is active. We used the IOTC data spatialized by 1°x1° cells (www.iotc.org/sites/default/files/documents/2014/05/IOTC-2014-DATASETS-CELongline.zip).[8] This allowed us to estimate the proportion of the total catch in the EEZs of La Réunion, Madagascar, Mauritius, and the Îles Éparses, as well as the High Seas from 2009 to 2012. Based on the history of the fishery (see above), we set the 1991 proportions at 80% in La Réunion and 10% in Madagascar, and interpolated to the 2009 value. We allocated 5% to Mauritius in 1991 and linearly interpolated to a 2008 value corresponding to the 2009–2012 level. For the High Seas and the Îles Éparses, we distributed the remaining percentages proportionately to their 2009–2012 contribution. For all areas, we used the 2009–10 IOTC proportions 'as is'.

Artisanal fleet

This sector represents the majority of the commercial fishing effort within La Réunion's EEZ. In 2008, over 70% of the artisanal vessels' activity occurred between 3 and 12 nm (5.5 to 22.2 km), which represented almost half of the registered fishers (Leblond *et al.* 2007). The fleet of artisanal fishers is largely composed of small boats (generally smaller than 12 m), trips are short (at most four days; generally less than 24 h), and landings are usually rapidly sold on local markets or to restaurants (Leblond *et al.* 2007). However, due to a large and rising seafood demand, these landings are not sufficient, and substantial quantities of fish must be imported to satisfy the local market demand (Biais and Taquet 1992).

Three types of boats are used by artisanal fishers:

- Traditional wooden boats, of which the range of action is limited to 5 nm (trips of less than 12 h);
- Fibreglass boats (locally known as '*vedettes*'), which can go further offshore (up to 20 nm) and are mostly used for trips longer than 12 h;
- Mini-longliners smaller than 10 m, which are also active within 20 nm from the coast.

A wide array of gears is used, including longline, handline, trap, beach seine, troll line, electric reel, and gillnet. This results in a large variety of species targeted by artisanal fishers (INSEE 2006), including large pelagics (e.g., Istiophoridae, Scombridae, Xiphiidae), small pelagics (e.g., Carangidae) and demersal species (e.g., Serranidae, Lethrinidae).[9]

Historically, the artisanal fleet focused very little on the pelagic resources. However, the first anchored fishing aggregating device (a-FAD) was tried out in 1987 under the supervision of the French Research Institute for the Exploration of the Sea's (IFREMER), and starting in 1988, many other a-FADs (managed by the regional fisheries committee [CRPMEM]) were put in place around the island to increase the artisanal fleets' efficiency and to limit the fishing pressure on reefs (Biais and Taquet 1992; Leblond *et al.* 2007, 2010, 2011). After a production peak in 1994–95 and the consequent price collapse (Roos *et al.* 1998), the fishery became less viable, and several a-FADs were abandoned. The management (funding and maintenance) of the a-FAD network was handed over to the CRPMEM, and the total number of a-FADs reached 30 by the late 1990s (Rey-Valette *et al.* 2000). Nowadays, there are 34 active a-FADs around the island,[10] and it is estimated that almost 50% of the time spent fishing by artisanal fishers is around a-FADs (Tessier *et al.* 2000). Over 90 *barques* (6 m and 20 kW) and 75 *vedettes* (6–12m; 50–200 kW) are active around La Réunion's a-FADs, mostly using handlines (Guyomard *et al.* 2012). Since the appearance of the fleet of mini-longliners in the mid-2000s, conflicts with the other fleets in the artisanal sector have emerged (Chavance *et al.* 2012).

The implementation of this network of a-FADs resulted in higher catches of pelagic species, more registered professional fishers, as well as in an increased duration of the trips (Biais and Taquet 1990; INSEE 1991; Rey 1998; Rey-Valette *et al.* 2000). The development of the pelagic fishery benefited the nearshore resource by reduced the fishing effort targeting shallow-water demersal species (INSEE 1991, 1996; Rey 1998; Rey-Valette *et al.* 2000).

[7] Data compiled by Bach and Sabarros (unpub. data) originating from the regional observer program (Bach *et al.* 2008) and the self-reporting data collection program (Bach *et al.* 2013) for 2011, 2012, and 2013 show different numbers. Here, we relied on historical knowledge based on empirical evidence rather than the self-reported data (longer 'times-series').

[8] Data by 5°x5° cells are also available but less precise, so we disregarded them for the purpose of this spatial allocation.

[9] As an aside, there is a small but extremely valuable fishery controlled by a few families for *bichiques*, which are larvaes of *Sicyopterus* spp. and *Gobius* spp. (gobies). There is also a fishery for bait (mostly *Selar crumenophtalmus*, but also *Decapterus macarellus* and small tunas; Roos *et al.* 1998).

[10] Mostly active in the western part of the island (Tessier and Poisson 1997). In particular, it seems that the quality of the FADs has degraded since 2009, since maintenance subsidies were considered illegal by the European Union after 2007 (Guyomard *et al.* 2012). The new reform of the EU common fisheries policy has re-introduced these subsidies in 2014.

These reef resources are now mostly targeted when the sea is too rough to venture offshore (Biais and Taquet 1992; Conand and Tessier 1996).

We considered two distinct groups of reported catch data for this sector: i) catch of species recorded in both IOTC and FAO database (the 'IOTC species'), but not allocated to the longline fleet targeting swordfish (see above), and ii) catch of species reported only in FAO database (the 'non-IOTC species', i.e., reef species).

IOTC species

The FAO data follow a similar pattern and are very close to those provided by Biais (1991), Biais and Taquet (1992), and DMSOI/SIH since 1980 (FAO data slightly higher in the 1970s, and slightly lower in the 1990s-early 2000s; $r^2 = 0.89$). Here, we kept the FAO data for reasons of consistency, but applied two corrections:

- From 1950 to 1966, the total FAO catch data were replaced with the data from Tessier and Poisson (1997), to which the FAO species breakdown was applied (the catch in excess, when any, was re-allocated to the generic 'groundfishes' grouping and allocated to the distant-bank fishery; see below);
- Catches data in 1970 steeply dropped, and as we found no evidence to support such a large decline in catch, we assumed that this was an issue of underreporting and disregarded the 1970 FAO data. We estimated the 1970 catch as the average of 1969 and 1971 catches.

Several authors have also reported that 'informal fishers' (i.e., non-registered commercial fishers; labeled as 'artisanal' for the purpose of the *Sea Around Us* database) and recreational fishers using the same gears and targeting the same species frequently used the a-FAD network (Biais and Taquet 1992). Non-professional and tourism boats were estimated to represent 57% and 16%, respectively, of the total fleet in the late 1990s (CRPMEM 2006; Bouchard 2009). Although these non-registered artisanal and recreational fishers are allowed to fish on a-FADs during weekends (Roos *et al.* 1998), it seems that this regulation is not really enforced (Tessier and Poisson 1997; Rey 1998), and that their total catch is of the same magnitude of the registered fishers (Guyomard *et al.* 2012). Thus, they form an entirely cryptic component of the artisanal sector, for which no data are reported (Biais and Taquet 1992; Tessier and Poisson 1997; Chavance *et al.* 2012).

These fishers are also known to target deep-water demersal species (mostly snappers; between 200 and 600 m) with electric reels, and sell most of their catches. Large commercial stocks of such species were identified at the end of the 1990s, and numerous fishers (mostly non-registered) started employing electric reels to exploit them (around 100 tonnes were caught in 2006 by the only registered professional fisher). However, as deep demersal stocks are fragile, their biomass rapidly decreased. A study conducted in 2011 confirmed their overexploited status in the western and northern part of La Réunion (Fleury *et al.* 2012a).[11]

We assumed that non-registered artisanal and recreational fishers occupied half of the total fishing effort (e.g.. number of total boat fishing days) as that of registered artisanal fishers, and half of the annual CPUE of registered fishers (D. Guyomard, pers. obs.). We reconstructed these two missing sectors by multiplying the FAO catch of the registered artisanal fishers by 0.5 (to account for reduced fishing effort) and another 0.5 (to account for reduced CPUE), maintaining the same taxonomic breakdown. For the 2007–2010 period, though, we considered that the effort of both non-registered and recreational fishers doubled compared to the previous period, since the end of fuel subsidies resulted in an important exit from the registered fleet towards the informal one. Finally, we also considered that the unreported catch of the registered artisanal fishers was representing 10% of their reported catch (D. Guyomard, pers. obs.).

Non-IOTC species[12]

For this sector, we used demersal and small pelagic total catch data extracted from previous studies (Biais and Taquet 1992), which we believe are the one that were transmitted to FAO.[13]

The taxonomic breakdown provided in several studies was used to disaggregate these totals from 1950 to 1969 (Biais 1991; Biais and Taquet 1992; Tessier and Poisson 1997; DMSOI/SIH, unpub. data). From 1970 to 1998, crabs and Clupeidae were excluded from this breakdown, as they were already included in FAO data. Two adjustments were also made to correct unexplained drops in FAO catches:

- From 1950 to 1953, the average catch and breakdown of the next five years was carried backward;
- For 1965, an interpolation was done between 1964 and 1966.

For the 1999–2010 period, the total catch of demersal species that was extracted from the various studies cited above were proportionately re-allocated from the remaining FAO data. For small pelagics (Carangidae and Clupeoids), we kept the FAO data for consistency, since trends and values of the two datasets were very similar.

We used the same set of assumptions used for the IOTC species (see above) to estimate the unreported catch of non-registered and recreational fishers. For the registered fleet, we assumed 25% of the declared catch was unreported (D. Guyomard, pers. obs.).

[11] Stocks are smaller along the eastern and southern coasts, but their catch rates are higher.

[12] The 'natatian decapods' category was dealt with separately, as it corresponds to rock lobsters targeted in Saint Paul and Amsterdam, as well as shrimp targeted in Madagascar (see below).

[13] We disregarded a seemingly official third dataset (available at: http://41.206.61.142:8080/statbase_3), because we could not determine its origin. We also made an adjustment in 1977, because the remaining FAO data (total minus the catch already re-allocated to the longliners targeting swordfish, and the artisanal fishers targeting IOTC species) was 65 t lower than the data extracted from these various studies. Therefore, were reallocated 65/2 t from both demersal and small pelagic reported components to 'unreported landing'.

Sport fishing by tourists

The tourist population is currently a third of that of the residents and given the nature of the island, an overwhelming part of these tourists stay on the coast during their trip. From the plethora of internet fora describing and praising La Réunion's sport fishing activities, there is no doubt that this sector is important in terms of its economic contribution, as well as in terms of its catch. However, skippers working for sport fishing centers are required to own a professional license; therefore, catches of this sector are thought to be included in the artisanal sector, although usually sold to restaurants and fishmongers (where tourists can therefore enjoy a small piece of their trophies). Here, we conservatively assumed that the sport (i.e., recreational) catch by tourists was included in the reported artisanal statistics (since professional licenses are required to operate sport fishing boats), and as such, we did not reconstruct any catches.

Distant banks fishery

The *Société Franco-Mauricienne de Pêche et d'Industrie* (SFMPI; Armement des Mascareignes from 1965 onward) carried out an exploratory demersal fishery in 1961 on distant banks north of Mauritius Biais and Taquet (1992). Several gears were tried out, but only handlines operated from dories yielded economically-viable catches (Lebeau and Cueff 1975; Biais and Taquet 1992; Roos *et al.* 1998), which consisted of 80–90% of *Lethrinus mahsena* alone (sky emperor), as well as *L. variegatus* (slender emperor) and other demersal species (Roos *et al.* 1998). Biais (1987) reported that gutted weight increased from 370 t in 1967 to 640 t in 1972 for the Saya de Malha bank alone. These values (for a single bank) are about half of the remaining FAO data to be allocated (minus 'natatian decapods nei', which are dealt with separately; see below), and show a similar trend. Lebeau and Cueff (1975) reported gutted weight oscillating between 600 t and 900 t per year between 1975 and 1985, and then a decrease to 400–500 t. Again, these values are in the same range as the remaining FAO data. More recently, another fleet of a smaller scale has been active around the distant banks, increasing from two vessels in 1990 to six/seven vessels by the mid-1990s (Biais 1987). These vessels also targeted groupers and snappers with bottom longlines, around the Mauritian banks and along the coast of Madagascar, thanks to access agreements negotiated by the European Commission (Roos *et al.* 1998), and troll for large pelagics when moving between fishing areas. This sector was nearly phased out by the early 2000s (European Economic Community 1989a,b; European Community 1996–2007; Roos *et al.* 1998), which is also consistent with the remaining unallocated FAO catch. Since 2010, two boats (BABOUK and BIGOUDEN) have regularly fished on these distant banks.

Based on this information, we considered that the remaining FAO catch to be allocated (except 'natatian decapods nei'; see below) were representing the distant bank sector. Four adjustments were made:

- The 'zero catch' in 1977 was replaced by interpolated values between 1976 and 1978;
- The 'marine fishes nei' catches (excluding the part reallocated from the artisanal fleet) were multiplied by 1.2 to account for the conversion factor from gutted weight to live weight (FAO 2000);
- The 'marine fishes nei' taxon was split between sky emperor (70%), slender emperor (10%), and other demersal species (20%);
- The final catch was allocated to Mauritius (80%) and Madagascar (20%) waters.

Shrimp fishery in Madagascar

In the late 1960s, the only vessel operating on distant banks also started to target shrimp in the northwest of Madagascar (94 and 48.6 tonnes in 1969 and 1971, respectively), and this second fishery soon became important with the construction of 8 trawlers (Anon. 2011a, b). However, this activity collapsed in 1974 due to the political instability in Madagascar (213.5 and 422.8 in 1971 and 1972, respectively; Bertrand 1985; Roos *et al.* 1998; Méralli-Ballou 2008).

FAO data include significant 'Natatian decapods nei' (i.e., shrimp and lobsters) catches from 1950 to 1974. However, catches prior to the mid-1960s, as well as catches of up to 1,000 tonnes per year in the second half of the 1960s indicated that this taxon also included catches from elsewhere, probably rock lobsters from Saint Paul and Amsterdam. Therefore, we allocated the entirety of the FAO catch to the shrimp sector in Madagascar from 1971 to 1974 (year of the collapse), and linearly interpolated from 0 in 1966 (the sector started around 1967–68) to the 1971 FAO catch (i.e., 300 t). We also applied the weighted discard rate of tropical shrimp fisheries published by Kelleher (2005; amounts similar to those published by Bertrand 1985), i.e., 67.8%, in order to estimate the discards of the sector.

The remaining 'Natatian decapods nei' catches from 1950–1971 were reallocated to the rock lobster fishery in Saint Paul and Amsterdam (see below). Small catches of this taxon after 1974 were allocated to the artisanal fleet.

With that last sector (i.e., shrimp fishery in Madagascar), the total FAO catch was entirely re-allocated to the sectors mentioned above (Figure 2). The following sectors thus entirely constitute add-ons to the data reported to FAO.

Shorefishing and spearfishing by residents

La Réunion only has slightly over 1,000 hectares of coral reef, exclusively along the southern coast (80% of this reef is protected since 2007 *via* the Réserve Naturelle Marine; www.reservemarinereunion.fr). The recreational reef fishing and gleaning sectors have therefore always been limited. However, reef gleaners are active on these reefs and target most edible fish (over 200 species of commercial interest; Deschamps 2005), but also invertebrates such as crabs, clams and octopuses, locally called '*zourites*' (David and Mirault 2006). Fleury *et al.* (2012b) described the recent activity of this sector in the MPA, which can provide us with a general idea of fishing practices and impact on shore resources. Four fishing techniques are authorized within the protected area (Fleury *et al.* 2012b):

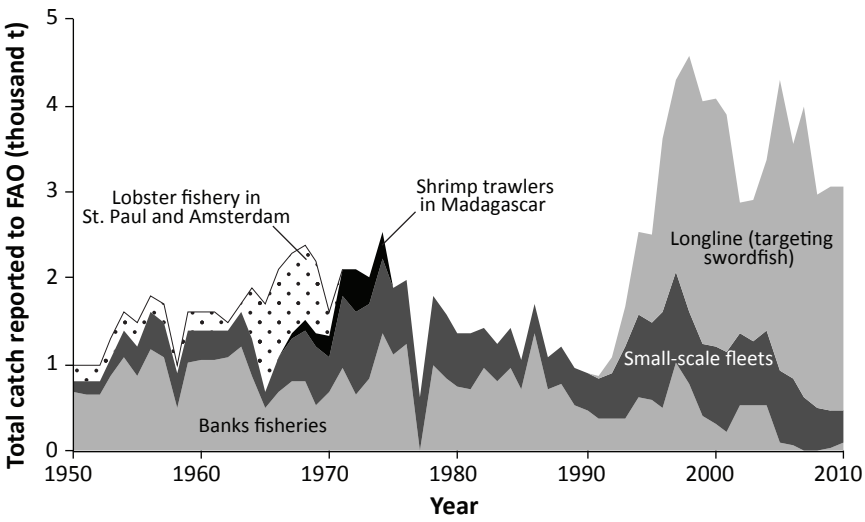

Figure 2. Breakdown of the data reported to FAO by fisheries sectors.

- Beach-seines to catch *Mulloidichthys flavolineatus* (yellowstripe goatfish);[14]
- Sticks to catch octopuses ('*zourites*');
- Handlines (from the shore) and spearguns (external slope) to catch various reef species.

These techniques (especially handlines) are also used elsewhere along the coast. There is very little information regarding historical catches of this recreational sector, but Bertrand (1985) reported that this sector was substantial, although not included in reported data (authorities only report commercial activities). Here, we applied a simple Fermi solution as a first approximation of this sector (von Baeyer 1993; Pauly 2010). Population data were extracted from Sandron (2007) and INSEE (2014), and we conservatively assumed that 1% of the population was catching 20 kg of fish per person and per year. Due to the rather low total resulting from this set of assumptions, we did not apply any taxonomic breakdown.

French Southern and Antarctic Lands

Rock lobster and patagonian toothfish fisheries

Saint Paul rock lobsters have been exploited around the French islands of Saint Paul and Amsterdam since the late 18th century (Angot 1951), in waters up to 700 meters deep (www.sapmer.com/Fishing_technique_St_Paul_Rock_Lobster.html). Most catches are exported to Japan and this sector has represented a major sector of La Réunion's fishing industry in terms of value throughout its existence (INSEE 1988, 1991, 1993). However, its importance has decreased since the expansion of the Patagonian toothfish and tropical tuna fisheries in the late 1980s.

Reconstructions for these two sectors were published separately (Palomares and Pauly 2011; Pruvost *et al.* 2015). These catches represented 121,700 t of Patagonian toothfish, 31,500 t of Saint Paul rock lobster, and 32,200 t of other demersal species.

Mozambique Channel tuna fishery

During the 2000s, some French purse-seiners (including from La Réunion) were flagged in Mayotte (IOTC 2012; Doherty *et al.* 2015).[15] These vessels were active in both Mayotte's EEZ as well as neighboring EEZs in the area, and their catches have been wrongly attributed to Mayotte in the FAO landings data (i.e., vessels were owned by firms outside Mayotte and landed in ports outside of Mayotte).

Catches from purse seiners owned by companies based in La Réunion (i.e., 117,000 t of large pelagics) were reassigned in the *Sea Around Us* database as catches from La Réunion and spatialized in Le Manach *et al.* (in press).

[14] This technique may result in some discards of bycatch. However, given the overall low catches and lack of information, no discards were estimated.

[15] Tuna seiners registered in Mayotte because it offered them certain tax advantages over being registered in the European Union. Notably, these included the ability to benefit from certain tax exemptions while avoid being constrained by limitations to engine power or tonnage (Busson 2011). Vessels rarely stopped in Mayotte other than for technical purposes or repairs, though, as being registered in Mayotte only required one stopover in Mayotte port per year (Busson 2011).

Results and Discussion

Sectors reported to FAO by La Réunion

Overall, the total reconstructed catch of La Réunion's domestic sectors totalled over 199,000 t over the 1950–2010 period. These catches show a bimodal trend, increasing from just over 1,500 t per year in the early 1950s, to almost 4,300 t per year in the early 1970s. Catches then decreased to around 1,400 t per year in 1990. The second peak occurred in the late 1990s at 8,000 t per year due to the expansion of the longline fleet, after which it declined again to reach around 5,000 t per year in the late 2000s (Figure 3).

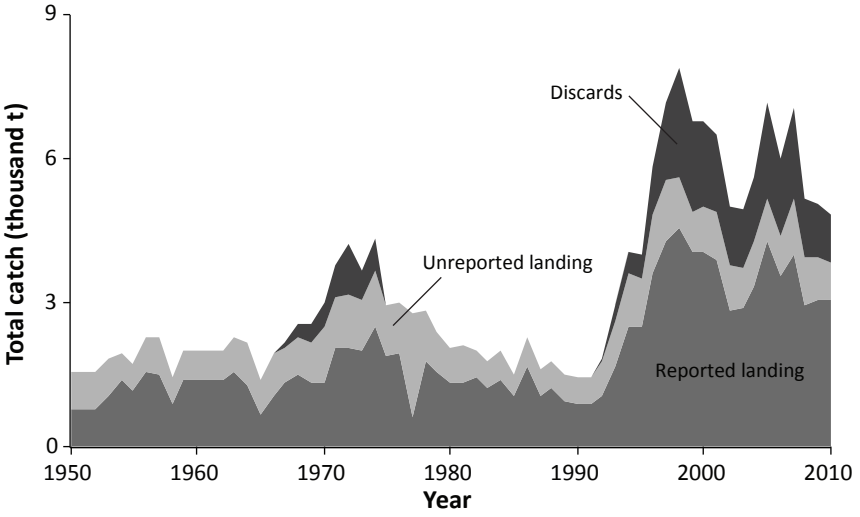

Figure 3. Total reconstructed catch disaggregated by catch type (reported vs. unreported landings, and discarded catches), from 1950 to 2010. See Appendix Table A1 for details.

The current decrease in total catch is consistent with the reported perception by many fishers that there are now less fish under the a-FADs scattered around the islands (Guyomard *et al.* 2012). Also, the longline fleet has experienced a normal initial decrease in catches, which substantially contributed to that decline. Finally, it also appears that the number of fishers has been decreasing, which also may be contributing to reduced catch.

Of the total catches over the 1950–2010 period, 39.9% were unreported (either landed, 25.7%; or discarded, 14.2%), whereas 60.1% were reported to FAO (Figure 3). The amount of unreported catches was estimated to have remained rather constant over time (Figure 3). It is thought that a redesign of the data collection scheme of IFREMER, the *Système d'Information Halieutique* in 2007 will result in improved quality of the domestic catch data in future years. However, our report suggests that three sectors remain entirely unreported in official data source: (i) the non-registered artisanal fishers targeting large pelagics, (ii) the recreational sector by locals targeting demersal species or reef gleaning/fishing from the shore, and (iii) the registered artisanal fishers active at night. Non-registered artisanal fisheries contribute substantial catches and have led to increasing tensions with registered fishers. Unreported catches by night-fishers are likely less important in terms of the magnitude of catch but probably equally important for their of impact on some species. It must be noted that the distinction between the registered and non-registered sector should be seen as a first attempt, as many fishers move from one sector to the other, depending on available subsidies and bureaucratic constraints. Therefore, further studies are necessary to better quantify them and include them in domestic policies.

The majority of this total catch was taken in the EEZ of La Réunion (60.8%). Mauritius and Madagascar were the following most fished EEZs, with 20.7% and 16.4%, respectively, whereas the remaining was caught in the Îles Éparses and in the High Seas (Figure 4).

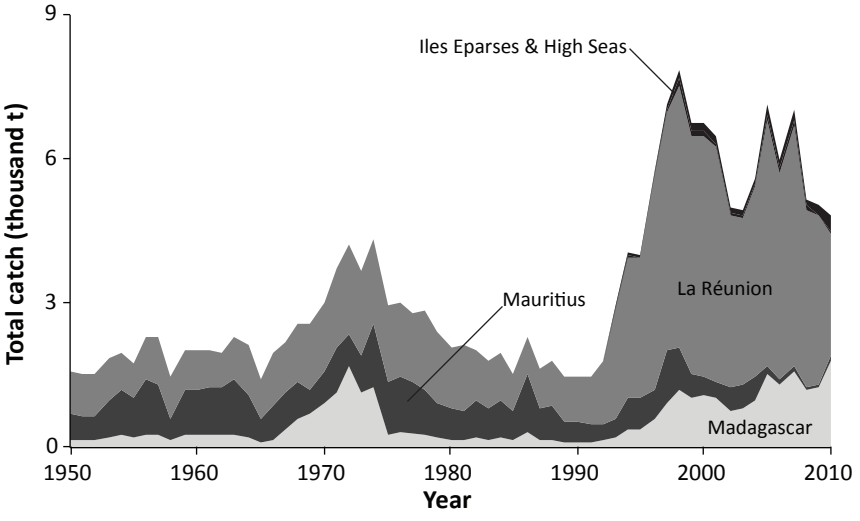

Figure 4. Total reconstructed catch disaggregated by fishing zone (EEZs of neighboring countries or High Seas), from 1950 to 2010.

The most prominent sector is by far the industrial one, with almost 60.7% of the total catch from 1950 to 2010. The artisanal sector comes second with 31.2%, whereas the recreational sector makes up the remaining 8.1%. The share of the industrial sector steadily decreased through the 1950s to early 1990s, after which it bounced back and reached its highest level ever (over 76% in 2010), mostly thanks to the development of the longline fleet (Figure 5). On the other hand, the artisanal sector has been decreasing for the last 15 years, due to the fact that it targets overfished reef species, and increasingly targeted (and already fully exploited) large pelagics. This decrease is also the result of the

decreasing number of registered artisanal fishers (which is partially counter-balanced by their re-entry into the non-registered sector).

The most important taxa with regards to the taxonomic composition of the total catch (i.e., including discards) were yellowfin tuna (15.5%), sky emperor (14.4%), swordfish (14.2%), blue shark (6.0%), albacore tuna (5.7%), and jacks and pompanos (5.2%; Figure 6). Since the inception of the pelagic longline fleet, however, large pelagics occupy the majority of the catch. On the other hand, sky emperor, which represented the bulk of the catch in the earlier time period, are now virtually absent from La Réunion's catch, since the banks fishery has mostly been phased out (Figure 6).

Conclusion

La Réunion is a great example of how fisheries have expanded over-time, in oder to target new species in ever farther and deeper waters. During the first half of the 20th century, local fishing companies started to explore offshore banks between Mauritius and Madagascar, but also some fishing grounds in the Southern Ocean. Later, during the second half of the 20th century, they also started to expand towards the eastern coast of Africa to target large pelagics such as tuna and swordfish.

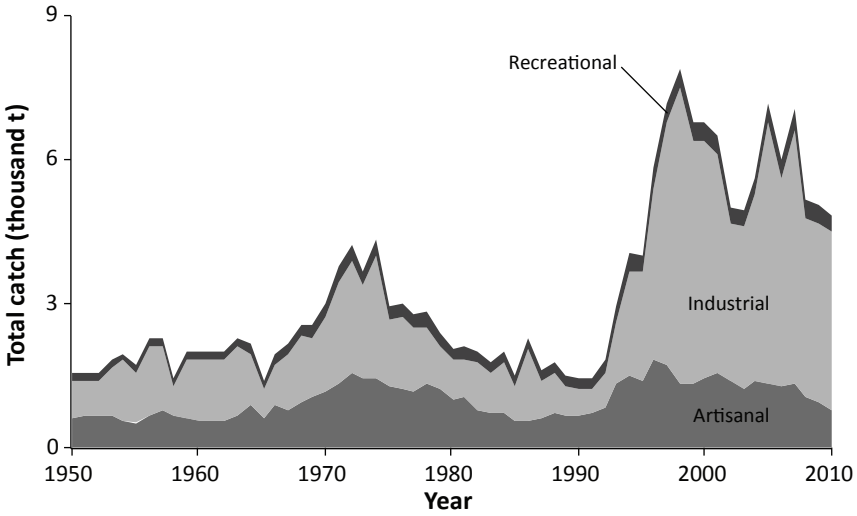

Figure 5. Total reconstructed catch disaggregated by sector, 1950–2010. See Appendix Table A1 for details.

Paradoxically, the coastal artisanal fleet lagged behind in terms of diversification, as it is only in the 1990s that La Réunion's fishers truly started to explore waters closer to home, with the implementation of a network of a-AFDs (at least partly due to decreasing coastal resources), and in more recent years, with the development of deep-sea fisheries. Historically, local fishers were indeed satisfied with abundant inshore reef resources, but the increasing competition with recreational fishers may have been one of the main drivers for this late development.

Although we acknowledge that the reconstruction presented here is sometimes based on strong assumptions (notably with regards to these unreported catches), we feel confident regarding the reallocation of the reported catch to the different sectors, which helps clarify the situation. The sectorial allocation of the data now allows us to easily follow the successive steps in the development of La Réunion's fisheries briefly summarized in the previous paragraph. One can now easily identify the industrial fleets expanding from banks in Mauritius and Madagascar to the French Southern and Antarctic Lands and tropical waters throughout the Western Indian Ocean on the one side; and on the other side, the artisanal fleets diversifying their fisheries slightly later, by expanding further offshore notably *via* the implementation of the network of a-FADs.

These developments resulted in a shift in the composition of the landed catch, from mostly demersal and reef species, to mostly large pelagics.

Positively, this reconstruction also shows that the mortality of sensitive species, notably sharks, is decreasing. This is the result of a shift in gear (from regular 'J hooks' to 'circle hooks'), the end of 'finning' practices after 2006, and the phasing out of coastal fisheries targeting sharks (the marketing of coastal species is now banned).

We hope that this reconstruction will trigger further research, notably to fill the gaps in the data-collection system. It shows that the extent of unreported catches is still important with around 40% of the total catch from 2000 to 2010, notably due to the fleets of non-registered artisanal fishers, and recreational fishers.

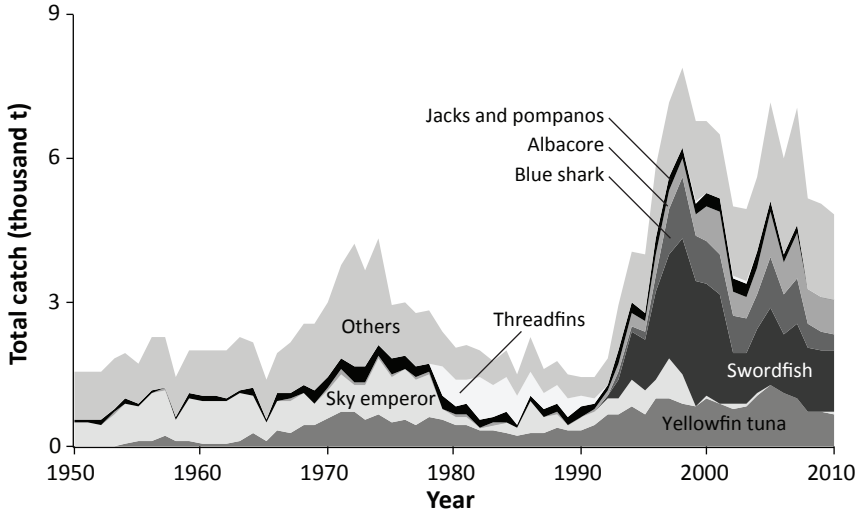

Figure 6. Total reconstructed catch disaggregated by species and higher taxa (top-seven taxa shown; the rest being aggregated as 'others'), from 1950 to 2010. See Appendix Table A2 for details.

Although part of these catches do not enter the market, such activities will have to become better monitored in future years, and we recommend that this sector should be accounted for during decision processes related to domestic fisheries management. The official accounting of these unreported catches is of prime importance for the sound management of fisheries.

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Appendix Table A1. Reconstructed catch by sector compared to total catch reported to FAO, 1950–2010.

Year	Reconstructed catch				Reported to FAO
	Artisanal	Industrial	Recreational	Total	
1950	649	772	143	1,564	800
1951	660	750	146	1,556	800
1952	672	728	149	1,548	800
1953	662	1,028	149	1,838	1,100
1954	554	1,,284	135	1,973	1,400
1955	548	1,052	137	1,737	1,200
1956	704	1,426	162	2,292	1,600
1957	821	1,320	183	2,324	1,500
1958	685	600	163	1,448	900
1959	650	1,224	161	2,035	1,400
1960	602	1,254	155	2,011	1,400
1961	585	1,266	155	2,005	1,400
1962	550	1,290	152	1,992	1,400
1963	688	1,436	174	2,298	1,600
1964	884	1,068	207	2,159	1,300
1965	633	592	171	1,396	700
1966	912	840	216	1,968	1,100
1967	810	1,170	203	2,183	1,360
1968	988	1,344	233	2,564	1,520
1969	1,093	1,218	249	2,560	1,380
1970	1,166	1,584	264	3,014	1,341
1971	1,378	2,095	298	3,771	2,101
1972	1,553	2,355	325	4,233	2,101
1973	1,446	1,939	309	3,693	2,001
1974	1,461	2,559	314	4,334	2,533
1975	1,308	1,352	291	2,951	1,905
1976	1,220	1,501	280	3,001	1,981
1977	1,178	1,354	274	2,806	621
1978	1,335	1,207	300	2,842	1,807
1979	1,245	896	286	2,427	1,594
1980	1,044	788	257	2,090	1,374
1981	1,091	763	265	2,118	1,371
1982	802	976	223	2,001	1,442
1983	756	836	218	1,811	1,254
1984	770	1,003	222	1,995	1,419
1985	578	738	196	1,512	1,056
1986	568	1,528	197	2,293	1,705
1987	633	788	208	1,629	1,094
1988	743	851	227	1,821	1,220
1989	713	561	225	1,499	969
1990	704	548	226	1,478	911
1991	733	511	233	1,477	887
1992	870	705	258	1,832	1,103
1993	1,375	1,236	336	2,947	1,679
1994	1,525	2,170	363	4,058	2,531
1995	1,430	2,245	350	4,026	2,500
1996	1,840	3,563	415	5,818	3,607
1997	1,723	5,072	399	7,194	4,288
1998	1,367	6,169	347	7,883	4,579
1999	1,331	5,095	345	6,771	4,043
2000	1,455	4,964	366	6,784	4,082
2001	1,553	4,587	383	6,523	3,889
2002	1,415	3,250	363	5,029	2,870
2003	1,246	3,367	340	4,953	2,902
2004	1,429	3,847	371	5,646	3,371
2005	1,376	5,417	364	7,157	4,281
2006	1,276	4,374	349	5,999	3,546
2007	1,359	5,237	472	7,069	3,988
2008	1,064	3,718	408	5,189	2,981
2009	983	3,707	389	5,079	3,051
2010	803	3,684	351	4,838	3,051

Appendix Table A2. Total reconstructed catch by taxon, 1950–2010.

Year	Yellowfin tuna	Sky emperor	Swordfish	Blue shark	Albacore	Jacks and pompanos	Threadfins	Others
1950	29	484	-	-	2	71	-	977
1951	29	469	-	-	2	89	-	967
1952	29	453	-	-	2	107	-	957
1953	44	670	-	-	3	107	-	1,014
1954	58	857	-	-	4	125	-	929
1955	117	722	-	-	9	53	-	835
1956	132	991	-	-	10	53	-	1,106
1957	270	924	-	-	21	36	-	1,073
1958	146	420	-	-	11	53	-	818
1959	146	857	-	-	11	107	-	914
1960	102	857	-	-	8	89	-	955
1961	102	865	-	-	8	107	-	923
1962	102	882	-	-	8	53	-	946
1963	117	991	-	-	9	71	-	1,110
1964	312	748	-	-	24	160	-	916
1965	132	407	-	-	10	53	-	794
1966	353	588	-	-	27	178	-	822
1967	292	689	-	-	22	125	-	1,056
1968	438	680	-	-	33	160	-	1,252
1969	438	462	-	-	33	231	-	1,395
1970	585	588	-	-	44	239	-	1,558
1971	731	815	-	-	57	257	-	1,911
1972	731	563	-	-	57	330	-	2,552
1973	585	706	-	-	46	367	-	1,990
1974	705	1,140	-	-	56	257	-	2,177
1975	525	947	-	-	41	312	-	1,127
1976	561	1,051	-	-	44	257	-	1,089
1977	472	948	-	-	37	234	-	1,116
1978	651	845	-	-	52	220	-	1,073
1979	577	197	-	-	44	257	615	737
1980	481	165	-	-	37	160	552	695
1981	451	175	-	-	35	239	513	706
1982	352	55	-	-	28	138	898	532
1983	339	144	-	-	26	145	630	527
1984	322	179	-	-	26	191	747	530
1985	266	118	-	-	20	83	569	455
1986	279	688	-	-	22	68	545	690
1987	315	310	-	-	24	127	345	509
1988	387	328	-	-	30	149	382	546
1989	366	90	-	-	28	130	433	452
1990	366	257	-	-	28	218	181	428
1991	473	247	3	-	61	152	103	439
1992	670	323	87	-	82	142	-	529
1993	701	310	398	175	159	254	-	952
1994	848	541	999	146	235	222	-	1,068
1995	664	512	1,043	175	224	196	-	1,211
1996	1,019	412	1,804	350	444	338	-	1,450
1997	1,015	854	2,138	933	402	295	-	1,558
1998	884	648	2,791	1,298	406	229	-	1,628
1999	829	30	2,590	962	456	214	57	1,633
2000	1,003	80	2,345	846	733	260	6	1,511
2001	895	38	2,248	832	892	262	13	1,343
2002	826	65	1,092	775	473	308	8	1,481
2003	843	60	1,061	714	466	286	7	1,516
2004	1,090	61	1,311	744	556	286	7	1,593
2005	1,294	11	1,616	1,056	951	196	8	2,025
2006	1,130	13	1,219	846	633	168	14	1,976
2007	1,006	-	1,545	945	988	129	8	2,447
2008	754	-	1,316	515	685	19	3	1,897
2009	720	16	1,282	408	708	19	3	1,924
2010	683	52	1,285	309	723	19	2	1,764