Tentative Reconstruction of Kenya's Marine Fisheries Catch, 1950–2010*

Frédéric Le Manach,[1,2†] Caroline A. Abunge,[3] Timothy R. McClanahan[4] and Daniel Pauly[5]

[1] *Sea Around Us, Fisheries Centre, University of British Columbia, 2202 Main Mall, Vancouver V6T 1Z4, Canada*
[2] *Institut de Recherche pour le Développement, UMR212 Ecosystèmes Marins Exploités, Avenue Jean Monnet, CS 30171, 34203 Sète cedex, France*
[3] *Wildlife Conservation Society, Kibaki Flats 12, Mombasa, Kenya*
† *Current address: BLOOM Association, 77 rue du Faubourg Saint-Denis, 75010 Paris, France*

fredericlemanach@bloomassociation.org; cabunge@wcs.org; tmcclanahan@wcs.org; d.pauly@fisheries.ubc.ca

Abstract

Total marine fisheries catches were estimated for Kenya for the 1950–2010 time-period using the catch reconstruction approach developed by the *Sea Around Us* and applied to coastal countries worldwide. This included catches (including dead discards) of the industrial, artisanal, recreational, and subsistence fishing sectors. The total reconstructed catch for domestic sectors for the 1950–2010 time-period reached almost 985,000 tonnes. This figure is 2.8 times the official catch reported to the Food and Agriculture Organization of the United Nations (FAO). Major taxa caught were Lethrinidae (emperors; 9.0%), Scaridae (parrotfishes; 8.8%), *Siganus* spp. (rabbitfish; 8.6%), Elasmobranchii (sharks and rays; 5.3%), and Carangidae (jacks; 4.7%). The artisanal sector (i.e., small-scale commercial) was the most prominent, with 64% of the total catch. Unreported landings represented 63% of the total catch, whereas dead discards represented close to 2%.

Introduction

Kenya is located on the east coast of Africa between Somalia and Tanzania. Its Exclusive Economic Zone (EEZ) extends over 110,000 km² (97th in the World and declared in 1986; Figure 1). The coast is lined with coral reefs covering over 600 km² (Spalding *et al.* 2001), except in the central part, where coral growth is prevented by inputs from the Tana River (Ungwana Bay). Mangrove stands are also abundant, especially in the northern half of the coast (UNEP 1998). Despite these rich habitats, marine fisheries are limited due to a narrow shelf, resulting in a small inshore fishing area (Chuenpagdee *et al.* 2006),[1] where essentially all small-scale fisheries occur. Other factors influence small-scale fisheries, such as the northeast and southeast monsoons (from December-March and May-October, respectively), which further restrict fishing activities to inshore waters when the sea is too rough (Obura 2001a). Consequently, marine fisheries have been estimated to represent only 10% of Kenya's total fish catch (FAO 2012); the vast majority of the total fisheries catch comes from the thriving fisheries of Lake Victoria (one of the most important fishing areas on the African continent; FAO 2001; Anon. 2007).

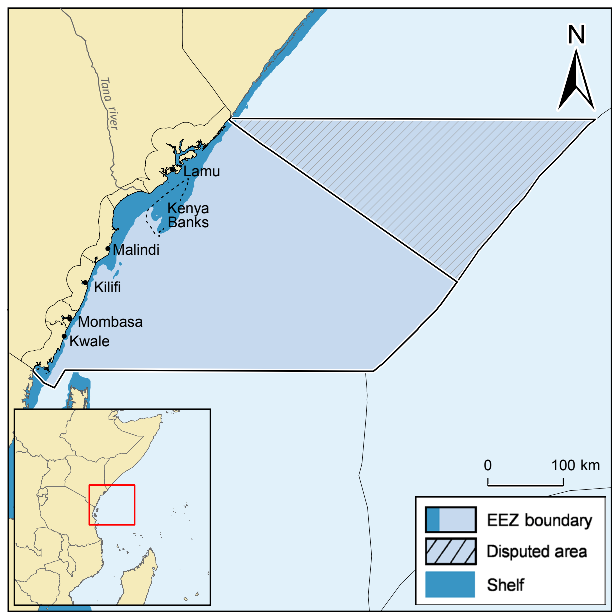

Figure 1. Map showing the extent of the Kenyan Exclusive Economic Zone (EEZ) and shelf water (to 200 m depth), as well as the location of the major coastal cities of Kwale, Mombasa, Kilifi, Malindi and Lamu (the limits of these districts are also shown), as well as the North Kenya Banks (dotted line).

Kenyan marine fisheries have always been critical to food security and livelihoods for coastal communities (Devisse 1989), similarly to many developing countries around the world (see also Zeller *et al.* 2014). For example, Malleret-King (2000) estimated that fisheries provided 80% of the total income to 70% of some coastal communities. Although the number of fishers increased at a rate of 2% per year during the 1980s (McClanahan *et al.* 2008), there is now some evidence that traditional fishing activities are declining, while other sectors are developing (e.g., sport fishing). One possible explanation is that tourism-related activities play an increasing role in coastal development (Mangi *et al.* 2007). Thus, some fishers have found alternative livelihoods: or tourists who wish to do sport fishing or visit marine protected areas for their more diverse fauna and protected habitats (Malleret-King 2000; Obura 2001a; Pitcher and Hollingworth 2007).

* Cite as: Le Manach F, Abunge CA, McClanahan TR and Pauly D (2015) Tentative reconstruction of Kenya's marine fisheries catch, 1950–2010. Pp. 37–51 *In* Le Manach F and Pauly D (eds.) Fisheries catch reconstructions in the Western Indian Ocean, 1950–2010. Fisheries Centre Research Reports 23(2). Fisheries Centre, University of British Columbia [ISSN 1198–6727].

[1] Defined as the area between the shoreline and either 200 m depth or 50 km distance from shore, whichever comes first.

Declining marine fisheries catches may also be related to declines in fish abundance. Reefs that sustain small-scale fisheries have been under severe pressure for decades in Kenya (see e.g., Khamala 1971; Muthiga and McClanahan 1987; Obura 2001b; Tuda *et al.* 2008). Their resources have been heavily exploited, and concerns of over-exploitation have been raised since the 1980s (Weber and Durand 1986; UNEP 1989). This has had impacts on both fish biomass and species composition, as evidenced by a long-term decrease in biomass and an increasing proportion of small, herbivorous species (Kaunda-Arara *et al.* 2003; McClanahan *et al.* 2008). A Beach Management Unit (BMU) system was introduced in 2006 to reverse these trends by involving communities in fisheries management (Oluoch and Obura 2008). Several gears such as spearguns and beach seines have also been forbidden, and the number of locally-managed marine protected areas (no-take zones, seasonal closures, or gear restrictions) has increased in the last decade. This shift in fisheries management has already had positive results in fish biomass and diversity (Kaunda-Arara and Rose 2004; Abunge 2011), and may lead to increased resilience for local marine ecosystems in light of changing global climate.

Official fisheries statistics provided each year since 1950 to the Food and Agriculture Organization of the United Nations (FAO) consist of four distinct taxonomic groups:

- Reef fishes (by far the most important group; e.g., Siganidae, Lethrinidae);
- Large pelagics (e.g., tunas, billfishes, and sharks);
- Shrimps (i.e., 'natantia');
- Other invertebrates (e.g., oysters, squids, octopuses).

Although it has been claimed in official reports that landing data were reliable (Nzungi *et al.* 2008), various researchers have criticized the quality of these data, underlining the poor monitoring of fishing activities along the coast, aggravated by low fishers' compliance (Oduor 1984; de Sousa 1987; Obura 2001a). This was clearly evidenced by a small-scale fisheries' reporting system designed in 1984, which determined that almost twice the officially reported amount was actually caught (Carrara and Coppola 1985). Although these new figures should have been processed and released as early as 1985, the absence of any increase in the official catch time-series documents that this was not done. More recently, McClanahan and Kaunda-Arara (1996) and McClanahan *et al.* (2008) showed that the actual catch per area was as high as 16 $t{\cdot}km^{-2}{\cdot}year^{-1}$ in some areas, starkly contrasting with the number based on official statistic, which oscillated between 2 and 4 $t{\cdot}km^{-2}{\cdot}year^{-1}$ (Kaunda-Arara *et al.* 2003). However, the situation is thought to have improved over the last decade (Obura 2001a; Muthiga *et al.* 2008), notably due to the implementation of frame surveys in 2004 (Republic of Kenya 2004–2012). Unfortunately, the monitoring, control and surveillance capacities are still lacking, as many fishers do not report their catch and official catch data still appear to have an unreported component (UNEP 1998; Mangi *et al.* 2007; Tuda *et al.* 2008; Maina 2012).

In this report, we apply to Kenya the reconstruction methods developed around principles in Pauly (1998), described in Zeller *et al.* (2007) and applied worldwide by the *Sea Around Us* (Zeller and Pauly 2007; Zeller and Harper 2009; Harper and Zeller 2012; Harper *et al.* 2012; Zeller *et al.* 2014). We aim to improve the overall quality of fisheries statistics by thoroughly reviewing the available literature and re-estimating the total extraction of marine fish since 1950.

Materials and methods

Preliminary re-allocation of the catch

The nominal catch provided by the Indian Ocean Tuna Commission (IOTC; www.iotc.org/data/datasets) was used to re-allocate the FAO catch of the large pelagics to various sectors. Given that the FAO dataset clearly includes the catch of the longline fleet (targeting swordfish) from 1980 to 1983, we assumed that the catch of this fleet was included in the FAO data for the entire period. When the IOTC catch for a given taxa was higher than the catch of this taxa reported by FAO, we assumed that it was because it was grouped in a more general taxon (due to low catches). We made the same assumption for the sport fishing fleet, thus we also assumed that at least some recreational (i.e., sport) fishing catches were included in the officially reported data. For both these fleets, the re-allocation of the FAO data was done according to Table 1.

The remaining catch of 'IOTC species' was re-allocated to the small-scale coastal fleets. However, we point out that except for 'Elasmobranchii', IOTC and FAO data series exhibit considerable and unexplained discrepancies when compared to each other. However, for consistency reasons and due to the rather unrealistic IOTC series (e.g., mostly flat for *K. pelamis*; plateauing and then steeply dropping for *Scomberomorus commerson*), we only used the FAO data here. The 'non-IOTC species' catch reported to FAO was also automatically allocated to the either the reef-gleaning sector ('Brachyura', '*Crassostrea* spp.', 'Crustacea', 'Holothuroidea', and 50% of 'Octopodidae') or the small-scale coastal fleet (remaining taxa).

As a result, the FAO catch was reallocated to several sectors, which were then studied and reconstructed separately (Figure 2).

Table 1. Correspondence between IOTC taxa and their FAO names, from which their catch was reallocated.

Fleet	Original IOTC taxon	Reallocated FAO taxon	Period
Longline (targeting swordfish)	*Acanthocybium solandri*	Perciformes	All years these species were reported
	Alopias	Elasmobranchii	
	Carcharhinidae		
	Carcharhinus falciformis		
	C. longimanus		
	C. obscurus		
	Istiompax indica	*Makaira indica*	1980–83
		Istiophoridae	2005 onward
	Istiophoridae		All years these species were reported
	Istiophorus platypterus	*Istiophorus platypterus*	1981–83
		Istiophoridae	2005 onward
	Isurus oxyrinchus	Elasmobranchii	All years these species were reported
	I. paucus		
	Kajikia audax	Istiophoridae	
	Katsuwonus pelamis	*Katsuwonus pelamis*	
	Lamna nasus	Elasmobranchii	
	Makaira nigricans	Istiophoridae	
	Marine fishes not identified[a]	Perciformes	
	Prionace glauca	Osteichthyes[b]	
	Pseudocarcharias kamoharai	Elasmobranchii	
	Scombridae	Scombroidei	
	Selachimorpha	Elasmobranchii	
	Sphyrna lewini		
	S. zygaena		
	Sphyrnidae		
	Tetrapturus angustirostris	Istiophoridae	
	Thunnus alalunga	*Thunnus alalunga*	1980–83
		Perciformes	2005 onward
	T. albacares	*Thunnus albacares*	1980–83
		Perciformes	2007 onward
	T. obesus	*Thunnus obesus*	1980–83
		Perciformes	2005 onward
	Xiphias gladius	*Xiphias gladius*	1980–83
		Perciformes	2005–08, 2010
		Osteichthyes	2009
Sport fishing	*Acanthocybium solandri*	Perciformes	All years these species were reported
	Auxis thazard thazard		
	Carcharhinidae	Elasmobranchii	
	Carcharhinus longimanus		
	Euthynnus affinis	Perciformes	
	Istiompax indica		1987, 1990–93, 1995, 2008
		Osteichthyes	1994
		Istiophoridae	2006–07, 2009
	Istiophoridae	Perciformes	1995
		Istiophoridae	2000 onward
	Istiophorus platypterus	Perciformes	1987, 1989–1993, 1995, 2008
		Osteichthyes	1994
		Istiophoridae	1996–2006, 2009–10
	Isurus oxyrinchus	Elasmobranchii	All years these species were reported
	Kajikia audax	Perciformes	1987, 1989–1993, 1995
		Osteichthyes	1994
		Istiophoridae	1996 onward
	Katsuwonus pelamis	*Katsuwonus pelamis*	All years these species were reported
	Makaira nigricans	Perciformes	1987, 1990–93
		Osteichthyes	1994
		Istiophoridae	1998 onward
	Marine fishes not identified[a]	Perciformes	All years these species were reported
	Prionace glauca	Elasmobranchii	
	Scombridae	Perciformes	
	Selachimorpha	Elasmobranchii	
	Sphyrna zygaena		
	Sphyrnidae		
	Thunnus albacares	Perciformes	
	T. obesus		
	Xiphias gladius		

[a] Given that the IOTC focuses on large pelagics, we changed this taxon to 'pelagic fishes' in our database.
[b] For some reasons, the catch of that species were very high compared to the other species of sharks. Given that the catch of *Prionace glauca* was even higher than the total catch of sharks reported to FAO, we decided to reallocate it from the higher taxon 'Osteichthyes'.

Domestic fisheries

Small-scale, coastal fisheries

Small-scale fisheries represent the bulk of total Kenyan marine fisheries and essentially involve men.[2] Many species of fish are targeted, be they demersal reef species or small pelagic species roaming inshore waters, as well as commercially-important invertebrates such as shrimp, octopus, and lobster (Okechi and Polovina 1994; McClanahan and Mangi 2004; Anon. 2007; Maina and Samoilys 2011; Samoilys *et al.* 2011a,b). A dozen gears are used on a regular basis to target these different species, ranging from spearguns to beach seine and ring nets, and from traps to boat-operated driftnets (Samoilys *et al.* 2011a).[3] The major fishing grounds are found around Lamu, the mouth of the Tana River, Ungwana Bay/Malindi, as well as the Mombasa area and the North Kenya Banks (see Figure 1; Oduor 1984; Fondo 2004; Maina 2012; Munga *et al.* 2012). Spearguns, which were introduced in the 1970s (McClanahan *et al.* 1997), are now commonly used by the poorest fishers because they are cheap (McClanahan *et al.* 2005), similarly to other less efficient gears (Ochiewo 2002). On the other hand, beach seines (now also illegal) are mostly used because their efficiency is higher than that of any other gears (however, their catch is split into more shares as it requires more men). Beach seines capture a high diversity and size range, overlapping with other gears and, by impacting on the recruitment of a wide range of species, impair the functioning of the ecosystems that are exploited (McClanahan and Mangi 2004; McClanahan *et al.* 2005; Mangi and Roberts 2006). Due to these different uses, numerous conflicts between gear users have been reported over access to the resource (McClanahan *et al.* 2005; Mangi *et al.* 2007; Munga *et al.* 2010; Fulanda *et al.* 2011).

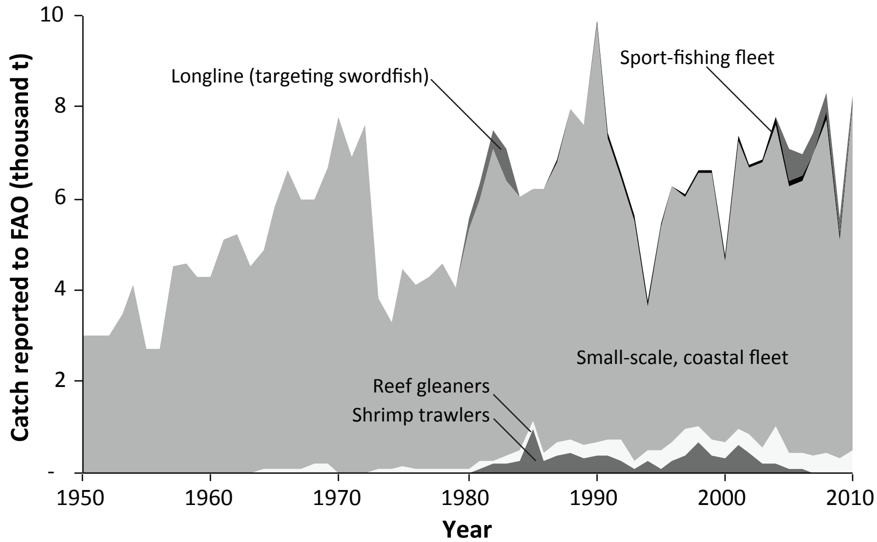

Figure 2. Catch reported to the FAO and reallocated to various fisheries sectors.

The pelagic component[4] of the small-scale fleet (motorized boats) seems to be increasingly important due to the decline of reef fish, although this fleet is mostly active during the north-east monsoon (when non-motorized boats cannot leave the inshore area; Maina 2012). During this season, fishers that are usually active further offshore are also known to retarget to valuable invertebrate species such as lobsters, holothurians and shells (Marshall *et al.* 1999; Maina and Samoilys 2011).

To re-estimate the total small-scale coastal fisheries, we first estimated the number of fishers from 1950 to 2010. To our knowledge, no reliable time-series of the number of fishers and fishing effort exist for this entire period, although figures have been published by the Government since the early 2000s (Republic of Kenya 2004). Officially, the Government reports that there were approximately 13,000 fishers in 2010 (Republic of Kenya 2012), but Tuda *et al.* (2008) and Maina (2012) suggested that these numbers were underestimated, and provided a higher figure of 15,000 fishers for as early as the 1990s. To remain conservative, we disregarded these non-official figures, and calculated the ratio of the geometric mean of the number of fishers provided by the Government for the years 2004 to 2010 (Republic of Kenya 2004–2012; the 2010 figure being the average of 2008 and 2012) over the total population in 2007. We then considered this fishers:total population ratio to be constant from 1950 to 2010 and applied it to the total population time-series (Figure 3).[5] We further disaggregated this fishers' time-series into five regions (roughly following the 'official districts'; see Figure 1), based on the percentage of the population living in the 15 km-band of each of them.[6]

There also exist some indications that fishers are now active fewer days per year, with an average of 220 fishing days per year (McClanahan and Mangi 2001; Caroline A. Abunge and Timothy R. McClanahan, pers. obs.).[7] We therefore assumed that fishers have been active 220 days per year since 1995, but that they used to fish 275 days per year prior to 1975 (i.e., prior to our assumed initial decline in CPUE; see Table 2).

[2] However, women and children are largely involved in collecting and marketing this fish, and in reef gleaning (see section below).

[3] Note that dynamite and poison are thought to be rarely used, except near the Tanzanian border (McClanahan *et al.* 2005).

[4] Besides medium to large pelagics such as tuna and billfishes, these offshore fishers also target sharks. They are valued as a cheap source of meat (traded up to 100 km inland) and for their dried fins exported to Asia. According to Marshall (1997), Kenya exported at least 140 t of shark fins between 1986 and 1990. Most of these exports (75%) were actually re-exports, as about 10 to 20 t (and 50 t during summer) were imported from Somalia every month. However, anecdotal evidence suggests that the domestic fishery is increasingly widespread, threatening shark populations (Spooner 2012).

[5] This resulted in an annual growth rate higher than the one published by McClanahan *et al.* (2008), i.e., +2% per year, but our estimate resulted in a more conservative number of fishers in the earlier period.

[6] These figures are based on the World Resource Institute's high-resolution GIS files (http://www.wri.org/publication/content/9291), from which we extracted the population living in the 15-km coastal band (assuming homogeneous distribution of the population within each polygon).

[7] Note that this number is an average for the entire coastline. Some sources tend to indicate that there are more fishing days in the south, e.g., 300 fishing days (Crona *et al.* 2010).

Table 2. Summary of the methods used to reconstruct the catch of the small-scale coastal fisheries in the five regions defined in Figure 1, 1950 to 2010.

Region	Period	CPUE (kg·fisher⁻¹·day⁻¹)	Note	References
Mombasa	1950	16.4	Anchor point; assumed 20% higher than anchor point in 1985	Grottanelli (1955)[a]
	1951–1974	16.4	Assumed similar to 1950	-
	1975–1984	16.2→13.9	Linear interpolation until 1985	-
	1985	13.7	Anchor point	Samoilys *et al.* (2011b,c)
	1986–1994	12.8→5.8	Linear interpolation until 1995	-
	1995–2010	4.9→2.5→3.2	Anchor points	WCS data
Lamu	1950–1985	16.4→13.7	Similar to Mombasa	-
	1986–2000	13.5→10.0	1975–1985 trend carried forward[b]	-
	2001–2010	10.1→11.3	Increase of 1.2% per year[c]	-
Kilifi/Kwale	1950–2000	16.4→2.5	Similar to Mombasa	-
	2001–2010	2.6→2.9	Increase of 1.2% per year[c]	-
Malindi	1950–2010	16.4→7.1	Average between Lamu and Kilifi/Kwale (central position)	-

[a] This author does not provide any specifics, but based on his observations, it can be assumed that catches were abundant. Since there were already signs of over-exploitation of Kenyan reefs in the 1980s (Weber and Durand 1986; UNEP 1989), we assumed that the average CPUE was 20% higher than that reported by Samoilys *et al.* (2011b,c) for the mid-1980s.
[b] We considered that the CPUE decrease in the area of Lamu was slower than in the area of Mombasa, due to a much lower population density, and thus, fishing pressure.
[c] We considered that the trend in CPUE reversed after 2000 as well, similarly to Mombasa area. However, we considered that the recovery rate was half that of Mombasa's, due to lower enforcement of management measures.

We then estimated a CPUE time-series for each of the five regions, based on data collected by the Kenyan branch of the Wildlife Conservation Society (WCS) since 1995, coupled with other anchor points found in the literature (Grottanelli 1955; Samoilys *et al.* 2011b,c), as described in Table 2.

By multiplying these regional CPUE time-series by the number of fishing days and their respective time-series of fishers (Figure 3), we obtained the total 1950–2010 small-scale, coastal fisheries catch (catches in the Tana River estuary were estimated separately; see below).

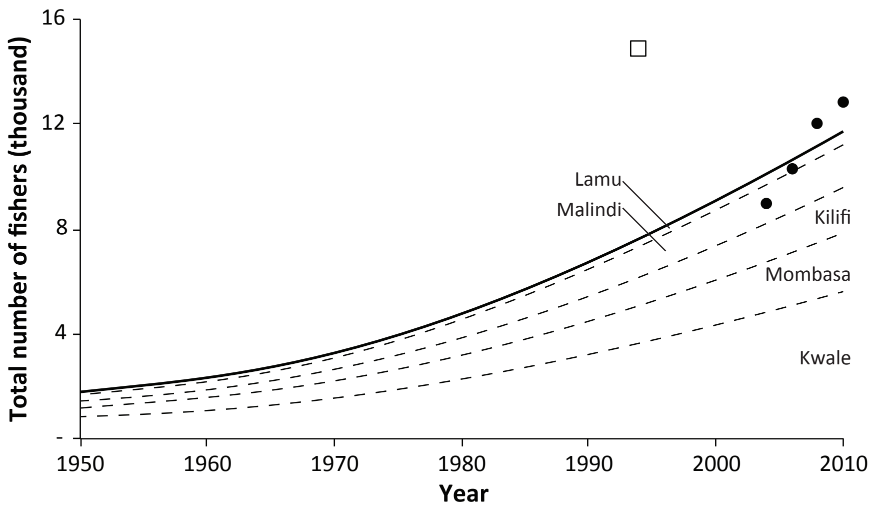

Figure 3. Suggested time-series of the total number of fishers (solid line), given the demography of Kenya. The solid dots represent the estimates of the Government (Republic of Kenya 2004–2012; the 2010 point being the average of 2008 and 2012 data). The white square represents Maina (2012)'s estimate, and is provided here as an illustration only. The dashed lines represent the estimated number of fishers in each region (see Figure 1).

With regards to the taxonomic breakdown, we first adjusted the 1950–1974 data reported to FAO by reallocating part of the meaningless 'Osteichthyes' taxon to the various taxa reported in following years:

- From 1972 to 1974, we applied the 1975–79 average taxonomic breakdown of the small-scale coastal fleet minus 'Elasmobranchii' and '*Panulirus* sp.' (already reported);
- For 1970 and 1971, we applied the updated 1972–76 average taxonomic breakdown of the small-scale coastal fleet minus '*Panulirus* sp.' (already reported);
- From 1950 to 1969, we applied the updated 1970–74 average taxonomic breakdown of the small-scale coastal fleet;
- Finally, we added a new taxon, Scaridae, which seems to represent an important part of the catch according to WCS surveys, but which is absent from FAO data. For this taxon, we simply considered that it was making up 50% of the remaining groundfishes (FAO name is 'demersal perciformes) throughout the time-series.[8]

Once these adjustments were made, we applied the same taxonomic breakdown to the unreported landings estimated above (equals 'total reconstructed' minus 'total reported').

The last step was to allocate the total catch to either the subsistence or artisanal (i.e., commercial) sectors. Based on personal observations and communications with local fishers, we considered that 80% of 'Clupeoids' and 50% of 'Carangidae' and the larger groups of 'groundfishes', 'marine fishes not identified', and 'pelagic fishes' were kept for subsistence purposes, while 90% of all other taxa were sold (commercially-valuable taxa corresponding to the 'artisanal catch'; Maina 2012) and the remaining 10% (e.g., juveniles and low-value species) were kept for subsistence.

Catches in the Tana River estuary were estimated separately, using shrimp and associated fish catches reported by Munga *et al.* (2012):

[8] The rest of the taxonomic breakdown was kept as is for the 1975–2010 period.

- From 1963 to 1979, we considered that the entire shrimp catch reported to FAO was small-scale, as the industrial fishery started in 1980. We then applied the average 1963–1979 catch (i.e., 115 t per year) back to 1950, and then from 1980 to 2000;
- From 2000 to 2006, we used Munga *et al.* (2012)'s small-scale catch data;
- From 2007 to 2010 (no industrial fishery), we took whichever data was the highest for any given year, between Munga *et al.* (2012)'s small-scale catch data and FAO data;
- Munga *et al.* (2012) further estimated that fish were making between 87.6% and 93.5% of the small-scale catch from 2001 to 2008. We therefore applied these percentages from 2001 to 2008, and their average (i.e., 90.9%) from 1950 to 2000 and from 2009 to 2010, to estimate the fish catch by small-scale fishers in the Tana River area.

We considered that the species of shrimp caught by the small-scale fishers were similar to those targeted by the industrial fleet (see below; Mutagyera 1984), i.e., *Penaeus indicus* (70.6%), *Metapenaeus monoceros* (15.6%), *P. monodon* (5.6%), *P. semisulcatus* (5.6%), and *P. japonicus* (2.6%). Similarly, we also used the taxonomic composition of the fish catch reported by Munga *et al.* (2012), which we applied throughout the time-period. We further considered that 80% of Acanthuridae, Cichlidae, Claridae, Clupeidae, and Protopteridae[9] were kept for subsistence purposes (low-value fish), and that 90% of sharks, billfishes, Lethrinidae, Lutjanidae, Mugilidae, cephalopods, Palinuridae, Scaridae, Scombridae, Serranidae, and Siganidae were sold (i.e., artisanal catch; the rest being kept for subsistence). The remaining groups (i.e., Carangidae, and mixed demersals and pelagics) were allocated to the subsistence and artisanal sectors in equal proportions.

<u>Industrial shrimp fisheries</u>

The shrimp fishery is the only sector with a management plan in Kenya (Republic of Kenya 2011; Maina 2012).[10] The single shrimp fishing ground of commercial importance is located in the Ungwana Bay (at the mouth of the Tana River; Mwatha 2002),[11] and is in fact one of the largest in east Africa (Fulanda *et al.* 2011). Due to important discharge of sediments and nutrient-rich freshwater from the river, the Ungwana Bay is also known as the most productive fishing ground along the Kenyan coast (Kitheka 2002; Mwangi 2002). A small fleet fluctuating between four and 20 industrial trawlers was active since the late 1970s (Mwatha 2002), but official statistics were only reported since the mid-1980s (Fulanda *et al.* 2011; Munga *et al.* 2012). Industrial trawling was restricted to waters beyond nine kilometers from shore, whereas small-scale fishers (who not only target shrimp) were allowed to fish within the 9 km zone.[12] However, increasing tensions between the two sectors (e.g., due to gear destruction and resource-sharing (Mwatha 2002; Ochiewo 2002)) forced the government to implement seasonal closures for the industrial fishery in 2001 (Gazette No 7565 of October 31, 2001) and completely ban industrial trawling in 2006.

The main targeted species were *Penaeus indicus* (70.6%), *Metapenaeus monoceros* (15.6%), *P. monodon* (5.6%), *P. semisulcatus* (5.6%), and *P. japonicus* (2.6%; Mutagyera 1984).

To reconstruct the full time-series of industrial shrimp catches, we used the following methodology:

- From 1981 to 2000, we subtracted the average 1963–1979 small-scale catch (i.e., 115 t; see section above) from the reported FAO data, in order to estimate the industrial component. The missing 1980 data were replaced by the average between the assumed zero in 1979 (considered to be the last year before industrial trawling for shrimp started) and the 1981 value;
- From 2001 to 2006, we took whichever data were the highest for any given year, between Munga *et al.* (2012)'s industrial data and FAO data.

Fish accounted for between 25.6% to 56.7% of the trawlers' total catch from 2001 to 2006 (Munga *et al.* 2012), and were as high as 70–80% of the total catch before the 2000s (Ochiewo 2002). Therefore, we considered that shrimp were only contributing 20% of the reconstructed total industrial trawler catch from 1980 to 2000, and then used the data provided by Munga *et al.* (2012) from 2001 to 2006. We also applied the taxonomic composition provided by Munga *et al.* (2012) from 1980 to 2006.

Furthermore, Mwatha (2002) suggested that only adults of commercially-important bycatch species were retained. We assumed 25% of the following species were juveniles and thus discarded: Carangidae, Istiophoridae, Lethrinidae, Lutjanidae, octopodiformes, Palinuridae, Scaridae, Scombridae, Serranidae, and Siganidae. We also assumed that 80% of the 'mixed demersals' were discarded. We applied these ratios from 1980 to 2006, the only exception being Claridae[13] (i.e., catfishes), for which we considered that 100% were discarded until 1999, and then only 80% from 2000 to 2006 (Mwatha 2002). The sum of these assumed discard rates applied to the taxonomic breakdown described above amounted to 79.8% of the bycatch being discarded from 1980 to 1999 and 75.1% from 2000 to 2006, in the same range as discards of 67% reported by Kelleher (2005) and the 1:7 shrimp:discard ratio reported by Mwatha (2002).

[9] This taxon was probably misidentified as it refers to lungfishes, which are strictly limnic.

[10] There have also been unsuccessful attempts of deep-water shrimp/lobsters fisheries in the Ungwana Bay, but this was not economically feasible (Mutagyera 1984).

[11] However, note that some Kenyan trawlers are known to have been fishing shrimp illegally in Somali waters (Anon. 2005a).

[12] This segregation between these two sectors is due to technology: industrial freezers are equipped with funnel-shaped otter trawls and are 25 to 40 m long (storage capacity of 30 to 350 tonnes; engines from 115 to 1,500 horsepower), while small-scale fishers use dug-out canoes and plank wood canoes, thus limiting their activity to a narrow band along the coast.

[13] This taxon is included in the 'miscellaneous marine fishes' category the *Sea Around Us* database, as at the time of writing there was no code for this taxonomic group.

Reef gleaning

Women and children have always been involved in collecting invertebrates such as crabs, holothurians and shells all along the coast at low tide (Grottanelli 1955). Overall, though, the catch of reef-gleaners is thought to be smaller than that of the reef fisheries performed by male fishers (Samoilys *et al.* 2011b).

Shellfish account for the bulk of reef-gleaning catches and are mainly collected for the tourism market (Kimani 1995; Marshall *et al.* 1999), but concerns of over-exploitation have been voiced since the 1970s (Marshall *et al.* 1999). Holothurians are exclusively targeted for the export Chinese market, and, similarly to shells, it appears that both the average size and the density of holothurians have decreased over-time. They are now mostly targeted by scuba divers in deeper waters, similar to Madagascar (Le Manach *et al.* 2012) and Tanzania (Bultel *et al.* this volume). Crabs (mainly *Scylla serrata*) are consumed locally and are mainly caught in the north, where most mangroves are located (Mutagyera 1984; Kimani 1995; UNEP 1998).

We assumed that the number of gleaners was equivalent to 30% of the intermediate number of male fishers (see Figure 3) from 1950 to 1970, and 20% from 2005 onwards (we linearly interpolated the values). This was based on the assumption that reef-gleaning is becoming less important due to the emergence of alternative livelihoods. We then assumed that each gleaner was active 200 days per year and was catching 4 $kg \cdot day^{-1}$ in 1950. This catch rate was linearly interpolated to 3 $kg \cdot day^{-1}$ in 2010, based on the aforementioned signs of over-exploitation.

Due to the lack of information on this sector, we used the FAO data corresponding to these taxa, and allocated to this sector (Figure 2) to estimate a taxonomic breakdown for our reconstructed catch. For years without data, we carried backward the average percentage of each taxon, and re-scaled the total to 100%. Finally, we created another category, i.e., 'shells', which was deemed to represent the species collected for the tourism market.

Longline (targeting swordfish) fleet

As far back as the 1950s, Kenyan waters have been considered to be productive, and Williams (1956) noted the possibility to develop a troll line fishery. As pointed out by de Sousa (1987), FAO data "include the catches from two [domestic] industrial scale tuna longliners which were operated from Mombasa during the early 1980s" (Figure 2). Although IOTC data display the same trend as the FAO data, they are slightly higher. In our database, the difference was thus included as 'unreported landing with respect to data reported by FAO on behalf of Kenya', since we deemed IOTC data to be more accurate.

Since 2005, two industrial longliners targeting swordfish have also been registered in Kenya. In 2010, only one vessel remained (then owned by a Spanish company), before it was highjacked by pirates when it ventured into Somali waters (Anon. 2010; IOTC 2012); this vessel was later transferred to the Atlantic Ocean (Nyongesa Wekesa and Ndegwa 2011). Their catch was estimated by a 'liaison officer' to have declined from 730 and 156 $t \cdot year^{-1}$. The catch of these longliners were also re-allocated from the FAO series (see above; Table 1).

In this report, we did not re-estimate any discards for this sector. This was done separately as part of the *Sea Around Us* work on harmonizing worldwide catches of large pelagics (Le Manach *et al.* in press).

Sport fishing fleet

Kenya has been a tourist destination since at least the 1950s (Williams 1970), but mass tourism started in the 1980s (Weaver 1999; Irandu 2004). This sector is now a pillar of the Kenyan economy (Mangi *et al.* 2007), as there are currently over 1.6 million tourists visiting Kenya every year (Kenya National Bureau of Statistics 2010). Most visitors spend part of their stay visiting places such as the Massai-Mara,Tsavo and Ambosseli National Parks for safaris (Weaver 1999), and about one third also visit coastal areas Williams 1970; Kimani 1995).

Kenyan sport fishing started in the 1950s (Williams 1970) and became much more prominent in the mid-1980s (Marshall 1997), due to increased tourism. According to Marshall (1997), there were about 60 sport fishing boats (5–12m long; 60 to 200 trips each per year) that were registered in the late 1990s, but we can expect this figure to have greatly increased in the 2000s. Indeed, Ndegwa (2010) reported that about 30 centers were registered along the coast in the late 2000s; thus, it is easily imaginable that each center has, on average, more than only two boats. As a matter of fact, Ndegwa (2010) also reports that there are on average nine boats per day at sea at Malindi's resort.

Sport fishing mostly occurs from April to August, the weather being too rough the rest of the year (Abuodha 1999). Boats mainly use hook and line, in contrast with shore-based recreational fishing (mostly trolling, drifting, and spinning).[14] The sport fishing charters generally operate from all major ports and fish the more distant Kenyan Banks, 35–55 km offshore (Ndegwa 2011; Figure 1). However, it seems that, although resorts occur along the entire Kenyan coast, the resorts of Watamu, Malindi (and offshore Kenya banks), Shimoni and Mombasa make up most of the sport fishing activity (Abuodha 1999; Ndegwa 2010). Ndegwa (2010) reports that 22,000 trips were recorded between 1990 and 2008 in the resort of Malindi alone. This author notes, however, a decrease from 1,600 trips per year in the early 1990s to currently 1,200 (Ndegwa 2010).

Some authors previously believed that FAO data included some recreational fisheries data at some point in the past (de Sousa 1987), but this was later questioned by Ndegwa (2010). According to the latter author, the Kenyan

[14] Although a tag and release project was introduced in 1987 (Abuodha 1999), it seems that most fish are still sold on local markets. When skippers judge the fish to be in good-enough physiological condition, though, they may release it after the photo-shoot.

Fisheries Department collected sport fisheries data since 1940, but never computerized them. In 2006, the Indian Ocean Tuna Commission and the Overseas Fishery Cooperation Foundation aimed to collect these data in order to create a historical database and analyze CPUE trends. This database is now available at 41.206.61.142:8080/statbase_3 and has been included in the IOTC catch database. Here, we assumed that these data were now included in the FAO data (Figure 2). These reported catches oscillated between 11 and 182 tonnes and averaged 91 tonnes between 1987 and 2010. However, Ndegwa (2010) reported that recreational catches in Malindi's resort alone consistently ranged around 100 t·year^{-1}, making it therefore likely that only a subset of total recreational catches were ever included in the IOTC dataset.[15] As a matter of fact, Maina (2012) reported catches around 206 t·year^{-1}, with 318 t in 2009. He also noted that much remains to be done to improve the quality of these statistics, reinforcing the feeling that official statistics miss a large part of the recreational sector.

To reconstruct this sector, we produced a set of assumptions based on data provided by Williams (1970) for the 1960s:

- Sailfish were weighting on average 29.5 kg;
- Sailfish were making up 30% of the total catch in weight (the author notes that both sailfish and marlin make up a majority of the catch);
- Malindi's area was accounting for half of the recreational catch in Kenya.

A catch of zero tonnes was set for 1950, and data were linearly interpolated to 1958, the first year for which Williams (1970) presented data.

From 1987 to 2006, we used the data published by the IOTC (Ndegwa 2010), filling the gaps with linear interpolations (1988–89 and 2002–04). For 2007–2010, we used the average of the period 1987–2006; excluding interpolations). Further, we considered that this author only managed to collect half of the actual catch in the area of Malindi (Ndegwa [2010] noted that data still needed to be much improved).

To scale these results to the entire Kenyan coastline, we considered that Malindi's resort made 50% of the total catch until 1980, and only 25% from 2000 onward (linearly interpolating in between). This was based on the assumption that other resorts gained a larger portion of the total share due to the tourism expansion in the 1980s.

The taxonomic breakdown for this sector was based on Abuodha (1999), although some modifications were made to accommodate the data reported to FAO: *Istiophorus* sp. (30%) and Scombridae (20%); the rest being equally distributed among *Sphyraena* spp., *Scomberomorus commerson*, *Makaira* spp., *Acanthocybium solandri*, Elasmobranchii, and other pelagic species.[16] The unreported landings were calculated by subtracting the data reported to FAO from the data estimated above (Table 3).

Table 3. Correspondence between the reported taxa and the assumed FAO taxa, from which their catch was subtracted to calculate the 'unreported landings'.

Reported taxon	Assumed FAO taxon
Acanthocybium solandri	*Acanthocybium solandri*
Carcharhinidae *Carcharhinus longimanus* *Isurus oxyrinchus* *Prionace glauca* Selachimorpha *Sphyrna zygaena* Sphyrnidae	Elasmobranchii
Auxis thazard *Euthynnus affinis* *Katsuwonus pelamis* Scombridae *Thunnus albacares* *T. obesus*	Scombridae
Istiophoridae *Istiophorus platypterus*	*Istiophorus* spp.
Istiompax indica *Kajikia audax* *Makaira nigricans*	*Makaira* spp.
Pelagic fishes *Xiphias gladius*	Pelagic fishes
Sphyraena spp. *Scomberomorus commerson*	No reported catch; All 'unreported landing'

Foreign fisheries

Distant-water tuna fleets

Historically, offshore stocks have remained largely unexploited by local fishers (Anon. 1996), but have long been intensively exploited by distant-water fleets (FAO 2007). Indeed, Kenyan waters are located in the productive Mozambique Channel and are therefore host to highly productive tuna fisheries (Tuda *et al.* 2008).

In recent years, dozens of purse seiners and longliners from the Seychelles, Mayotte, Spain, France and Taiwan have been reported to have fishing licenses in Kenya, with however no conclusive information.[17] For example, FAO reported licenses for 33 purse seiners and 30 longliners (FAO 2007), while National reports stated that 19 and 34 licenses were active in 2008 and 2010 respectively (Sigana 2009; Nyongesa Wekesa and Ndegwa 2011); Signa *et al.* (2008) on the other hand reported a much higher figure of 116 vessels licensed in 2008. Therefore, it seems that many countries have fishing interests in Kenyan waters, but that they may not be legally present (i.e., licensed) every

[15] Pitcher and Hemphill (1989) also collected recreational catch data from 1976 to 1987, showing that several hundred yellowfin tuna (i.e., several tonnes) were caught in the resort of Shimoni alone.

[16] Noteworthy, it seems that shark sightings decreased over the last few decades (Marshall 1997), similarly to most places in the world.

[17] Note that the EU and the Government of Kenya have been negotiating the signature of a Fisheries Partnership Agreement for several years (Anon. 2005a, 2014).

year. Indeed, the lack of monitoring and surveillance capacity is thought to be a major incentive for illegal fishing (up to 160 vessels; i.e., only 20% of tuna vessels are licensed) and underreporting (Anon. 2005a, 2007).

Catches of this sector are not presented here. Rather, they are estimated as part of the global large pelagic catch reconstruction conducted by the *Sea Around Us* (Le Manach *et al.* in press).

Small-scale migrant fishers

Kenyan waters also host migrant fishers from Tanzania. These fishers, coming from the south during the north-east monsoon season, seek calmer waters and often reach the Malindi area, about halfway up the country. These fishers mainly target highly valuable species such as sharks, Carangidae, Lethrinidae and Siganidae (Crona *et al.* 2010), mainly using lines in the north, and shark nets in the south. Because of the species they target and their usually higher CPUEs (i.e., 2.2 times higher than domestic artisanal fishers, on average), there are often tensions between the two groups. Here, we considered that migrant fishers had a CPUE 2.2 times higher than local fishers in the regions south of Lamu (Figure 1), that their number was equivalent to 10% of that of the local fishers, and that they fished 300 days per year (Crona *et al.* 2010).

Results

Domestic fisheries

The total catch by Kenyan fishers is estimated to have been almost 985,000 tonnes from 1950 to 2010, which is 2.8 times the amount reported to FAO (Figure 4). It increased from 9,600 tonnes in 1950 to a peak of nearly 27,000 tonnes in 1985. It then decreased to 12,100 tonnes in 2000 and increased again to 15,900 tonnes in 2010.

Overall, artisanal, subsistence, industrial, and recreational catches made up 64%, 27%, 5%, and 4%, respectively (Figure 4).

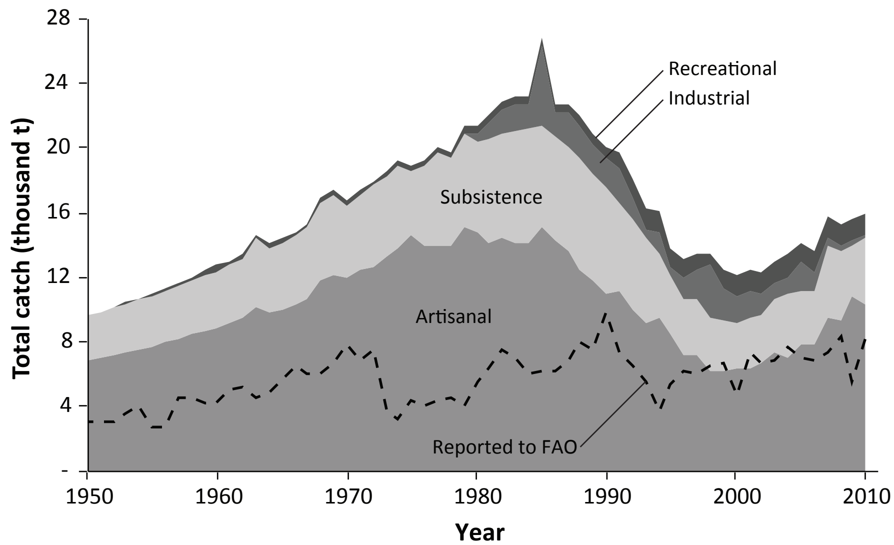

Figure 4. Total reconstructed catch (from 1950 to 2010), showing the artisanal, subsistence, industrial, and recreational sectors, as well as the data reported to FAO (dashed line; see Appendix Table A1 for details).

We estimated that the small-scale coastal fisheries (including those in the Tana River estuary) caught in excess of 845,000 t between 1950 and 2010 (86% of the total). Catches increased from around 9,200 t in 1950 to a peak of 20,500 t in 1985. Catches then decreased to 7,900 t in 2000 to increase again to around 13,000 t by the late 2000s. Lethrinidae, Scaridae, *Siganus* spp., elasmobranchii, and Carangidae were the main taxa, with 10%, 10%, 10%, 6%, and 5% of the catch, respectively, the rest being composed of other taxa of fish and various invertebrates.

More marginalized than reef fishers, reef-gleaners come as the second most important group of fishers in terms of total catch. Over 55,000 tonnes of invertebrates were caught over the 1950–2010 period (6% of the total catch). The overall catch increased from 400 tonnes in 1950 to 1,400 tonnes in 2010, out of which 25% were shells, 23% were marine crabs (mostly *Scylla serrata*), 19% other crustaceans, 15% holothurians, 12% octopuses, and 5% oysters.[18]

Recreational catches by tourists steadily increased — although fluctuating — from 34 t in 1951 to around 1,300 t by 2010. A substantial decrease occurred in 1997–98 (to around 700 t), which was caused by the collapse of coastal tourism following political riots (Obura 2001a). Overall, tourists caught 38,000 t in Kenyan waters, which still only represents around 4% of the total catch. Sailfish represented 28% of the catch and tuna 19%. The rest of the catch was composed of various species of large pelagics.

Finally, the industrial shrimp sector caught 41,000 t of targeted shrimp and associated bycatch (of which almost 18,500 t were discarded) between 1980 and 2006. Total catches (including discards) have increased from 280 t to a peak at 5,000 t in 1985. After a steep decrease, another peak occurred in 1998 at 3,300 t, before the catch decreased to around 800 t when the industry ceased in 2006.

[18] Although the meat of the shells is consumed locally, we considered that this fishery exclusively targeted the tourist market, and was thus artisanal. Furthermore, we considered that cupped oysters and marine crustaceans were caught for subsistence purposes, and that the other categories were sold on local markets (i.e., artisanal catch).

Overall, Lethrinidae, Scaridae, *Siganus* spp., Elasmobranchii, and Carangidae were the most caught taxa, with 9%, 9%, 9%, 5%, and 5% of the total catch, respectively (Figure 5).

Foreign fisheries

Migrant fishers caught almost 100,000 t between 1950 and 2010, with catches increasing from 900 t in 1950 to 2,600 t in 1985, then dropping to 700 t in 2000 and then increasing again to 1,200 t in 2010 (i.e., similar pattern as the domestic small-scale coastal fisheries, due to the series of assumptions used here).

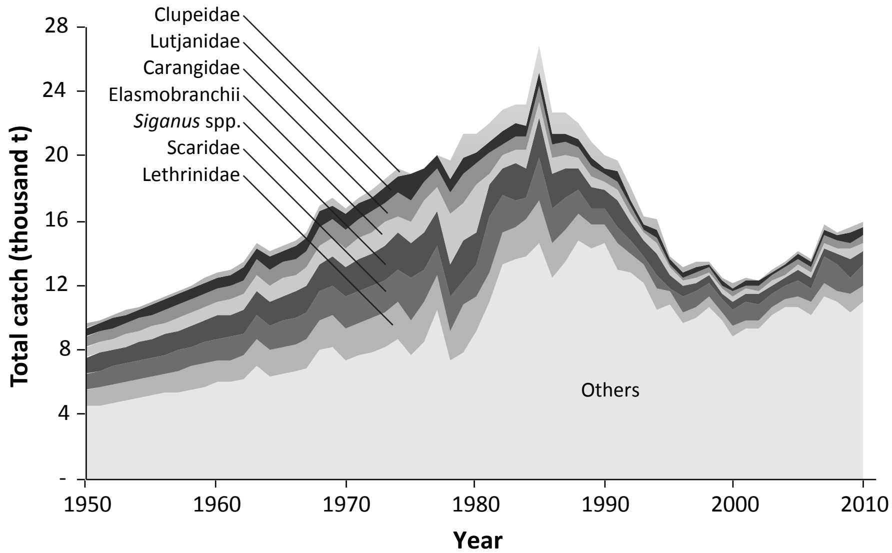

Figure 5. Total reconstructed catch (from 1950 to 2010), showing the main taxa (see Appendix Table A2 for details). 'Others' includes an additional 58 taxa.

Discussion

In this reconstruction, we showed that, similarly to most maritime countries around the world, official fisheries statistics in Kenya only account for a portion of small-scale fisheries, especially in the early time-period (see also Zeller *et al.* 2014). However, these small-scale fisheries generally constitute the pillar of coastal livelihoods (Barnes-Mauthe *et al.* 2013), and represent the bulk of fisheries activities. We also show that subsistence activities (e.g., reef gleaning), recreational fisheries, and industrial discards, are largely missing from official catch statistics, although they have an important social, economic, and ecological impact.[19] Noteworthy, the quality of the official catch statistics has improved over time, as the reported catch was representing only 32% of reconstructed total catches in the 1950s but increased to 50% in the 2000s. However, this relatively good news should not over-shadow the fact that the annual catch per fisher has steeply declined between the 1950s and the 2000s, although this decline may have been stopped due to improved management measures and an expansion of the fleet to more offshore waters.

Our results for the small-scale coastal fisheries are highly dependent on the reconstructed fishers' time-series (Figure 3). This area should be investigated further (e.g., with a sensitivity analysis), as there seems to be some Malthusian overfishing (Pauly 1990, 1994; McClanahan *et al.* 2008) in Kenya, with many people turning to fishing in order to feed their families (Mangi *et al.* 2007). Therefore, our time-series of the number of fishers shall be viewed as preliminary, and more robust estimates of the number of fishers would be welcome.

We hope that these revised statistics will be taken into account by official bodies, as is the case in Mozambique (Doherty *et al.* this volume). Effective fisheries regulations and management must be based on comprehensive and unbiased catch statistics, accounting for all sectors including non-commercial activities.

Aknowledgements

This is a contribution from the *Sea Around Us*, which is supported by The Pew Charitable Trusts and Paul G. Allen Family Foundation.

References

Abunge CA (2011) Managing finite marine resources the Kenyan way. Swara 3: 46–47.

Abuodha P (1999) Status and trends in recreational marine fisheries in Kenya. pp. 46–50 *In* Pitcher TJ (ed.). Fisheries Centre Research Reports 7 (2). University of British Columbia, Vancouver (Canada).

Anon. (1996) Towards integrated management and sustainable development of Kenya's coast — Findings and recommendations for an action strategy in the Nyali-Bamburi-Shanzu area. Prepared by Coast Development Authority, Kenya Marine and Fisheries Research Institute, Kenya Wildlife Service, Fisheries Department, Mombasa Municipal Council, and Kenya Association of Hotelkeepers and Caterers. ix + 77 p.

Anon. (2005a) Review of impacts of Illegal, Unreported and Unregulated fishing on developing countries. Marine Resources Assessment Group Ltd (MRAG), London (UK). 176 p.

Anon. (2005b) Kenya and EU open fisheries negotiations Agritrade — News and Analysis, Technical Centre for Agricultural and Rural Cooperation ACP-EU (CTA), Wageningen (The Netherlands). 1 p.

Anon. (2007) Kenya — State of the coast report 2007 — Towards an integrated management of Kenya's coastal and marine resources. National Environment Management Authority (NEMA), Nairobi (Kanya). vi + 101 p.

[19] Pitcher and Hollingworth (2007) reported that "a U.S. big-game fisher going on holiday in Kenya may spend more money fishing for one day (say $1,000) than many local people, including the boat crew or resort staff, might earn in 5 years".

Anon. (2010) Somali pirates hijack Kenyan longliner Fish Information Services, edition of March 10.

Anon. (2014) An interview with Peter Sol Rogers, Head of Trade Policy and Business Development at Wanainchi Marine Products, (K) Ltd. Agritrade, edition of March 9, 2014.

Barnes-Mauthe M, Oleson KLL and Zafindrasilivonona B (2013) The total economic value of small-scale fisheries with a characterization of post-landing trends: An application in Madagascar with global relevance. Fisheries Research 147(0): 175–185.

Bultel E, Doherty B, Herman A, Le Manach F and Zeller D (this volume) An update of the reconstructed marine fisheries catches of Tanzania with taxonomic breakdown.

Carrara G and Coppola SR (1985) Results of the first year implementation of the Kenyan catch assessment survey. Regional project for the development and management of fisheries in the southwest Indian Ocean. RAF/79/065/WP/18/85/E, Food and Agriculture Organization of the United Nations (FAO), Rome. 85 p. Available at: http://www.fao.org/docrep/field/279541.htm.

Chuenpagdee R, Liguori L, Palomares MD and Pauly D (2006) Bottom-up, global estimates of small-scale marine fisheries catches. Fisheries Centre Research Reports 14(8), Fisheries Centre, University of British Columbia, Vancouver. 112 p.

Cinner JE, Huchery C, Darling ES, Humphries AT, Graham NAJ, Hicks CC, Marshall N and McClanahan TR (2013) Evaluating social and ecological vulnerability of coral reef fisheries to climate change. PLOS ONE 8(9): e74321.

Crona B, Wanyonyi I, Ochiewo J, Ndegwa S and Rosendo S (2010) Fishers' migration along the Kenyan coast Implications for management of coastal fisheries. Policy brief, Western Indian Ocean Marine Science Association (WIOMSA), Zanzibar (Tanzania). 10 p.

de Sousa T (1987) Summary of fisheries and resources information for Kenya. pp. 21–43 *In* Sanders MJ, Sparre P and Venema SC (eds.), Proceedings of the workshop on the assessment of the fishery resources in the southwest Indian Ocean, September 14–25 1987, Albion (Mauritius) SWIOP Document OISO RAF/79/065/WP/41/88/E. Food and Agriculture Organization of the United Nations (FAO), and United Nations Development Programme (UNDP), Rome (Italy).

Devisse J (1989) Les Africains, la mer et les historiens. Cahiers d'études africaines 29(115–116): 397–418.

Doherty B, McBride MM, Brito AJ, Le Manach F, Sousa L, Chauca I and Zeller D (this volume) Marine fisheries in Mozambique: catches updated to 2010 and taxonomic disaggregation.

FAO (2001) Fishery country profile — Kenya. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy). Available at: http://www.fao.org/fi/oldsite/FCP/fr/KEN/profile.htm.

FAO (2007) Fishery country profile — Kenya. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy). 23 p.

FAO (2012) FishStatJ, a tool for fishery statistics analysis. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy).

Fondo EN (2004) Assessment of the Kenyan marine fisheries from selected fishing areas. The United Nations University Fisheries Training Programme, Reykjavik (Iceland). 55 p.

Fulanda B, Ohtomi J, Mueni E and Kimani EN (2011) Fishery trends, resource-use and management system in the Ungwana Bay fishery Kenya. Ocean and Coastal Management 54: 401–414.

Grottanelli VL (1955) Pescatori dell'Oceano Indiano — Saggio etnologico preliminare sui bagiuni, bantu costieri dell'oltregiuba. Cremonese, Rome (Italy). xxii + 409 p.

Harper S and Zeller D, editors (2012) Fisheries catch reconstructions: islands, part II. Fisheries Centre Research Reports 19 (4). University of British Columbia, Vancouver (Canada). 143 p.

Harper S, Zylich K, Boonzaier L, Le Manach F, Pauly D and Zeller D, editors (2012) Fisheries catch reconstructions: islands, part III. Fisheries Centre Research Reports 20 (5). University of British Columbia, Vancouver (Canada). 134 p.

IOTC (2012) Nominal catch database. Available at: http://www.iotc.org/English/data/databases.php [Accessed: March 12, 2013].

Irandu EM (2004) The role of tourism in the conservation of cultural heritage in Kenya. Asia Pacific Journal of Tourism Research 9(2): 133–150.

Kaunda-Arara B and Rose GA (2004) Effects of marine reef National Parks on fishery CPUE in coastal Kenya. Biological Conservation 118: 1–13.

Kaunda-Arara B, Rose GA, Muchiri MS and Kaka R (2003) Long-term trends in coral reef fish yields and exploitation rates of commercial species from coastal Kenya. Western Indian Ocean Journal of Marine Science 2(2): 105–116.

Kelleher K (2005) Discards in the world's marine fisheries: an update. Fisheries Technical Paper 470, Food and Agriculture Organization of the United Nations (FAO), Rome (Italy). 152 p.

Kenya National Bureau of Statistics (2010) Tourism indicators, 2001–2010. Government of Kenya, Nairobi (Kenya). Available at: http://www.knbs.or.ke/tourism_summary.php [Accessed: April 8, 2013].

Khamala CPM (1971) Ecology of *Echinometra mathaei* (Echinoidea: Echinodermata) at Diani Beach, Kenya. Marine Biology 11(2): 167–172.

Kimani EN (1995) Coral reef resources of East Africa: Kenya, Tanzania and the Seychelles. Naga, the ICLARM Quarterly 18(4): 4–7.

Kitheka JU (2002) Freshwater and sediment discharge in Ungwana Bay: the role of the Tana and Sabaki rivers. pp. 2–16 *In* Current status of trawl fishery of Malindi-Ungwana Bay — Final report. Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa (Kenya).

Le Manach F, Chavance P, Cisneros-Montemayor AM, Lindop A, Padilla A, Schiller L, Zeller D and Pauly D (in press) Global catches of large pelagic fishes, with emphasis on the high seas. *In* Pauly D and Zeller D (eds.), Global atlas of marine fisheries: ecosystem impacts and analysis. Island Press, Washington, DC (USA).

Le Manach F, Gough C, Harris A, Humber F, Harper S and Zeller D (2012) Unreported fishing, hungry people and political turmoil: the recipe for a food security crisis in Madagascar? Marine Policy 36: 218–225.

Maina GW (2012) A baseline report for the Kenyan small and medium marine pelagic fishery. Ministry of fisheries development, South West Indian Ocean Fisheries Project (SWIOFP) and EAF-Nansen Project. 74 p.

Maina GW and Samoilys MA (2011) Lamu lobsters — a dwindling resource. Swara 3: 34–35.

Malleret-King D (2000) A food security approach to Marine Protected Area impacts on surrounding fishing communities: the case of Kisite Marine National Park in Kenya. PhD thesis, University of Warwick, Department of Biological Sciences, UK. xi + 307 p.

Mangi SC and Roberts CM (2006) Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. Marine Pollution Bulletin 52(12): 1646–1660.

Mangi SC, Roberts CM and Rodwell LD (2007) Reef fisheries management in Kenya: Preliminary approach using the driver–pressure–state–impacts–response (DPSIR) scheme of indicators. Ocean and Coastal Management 50: 463–480.

Marshall NT (1997) Trade in sharks and shark products in Kenyan waters. pp. 31–38 *In* Marshall NT and Barnett R (eds.), The trade in sharks and shark products in the western Indian and southern Indian and south east Atlantic Oceans. TRAFFIC International, Nairobi (Kenya).

Marshall NT, Milledge SAH and Afonso PS, editors (1999) Stormy seas for marine invertebrates — Trade in sea cucumbers, seashells and lobsters in Kenya, Tanzania and Mozambique. Trade Review. TRAFFIC East/Southern Africa. 53 p.

McClanahan TR, Glaesel H, Rubens J and Kiambo R (1997) The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. Environmental Conservation 24(2): 105–120.

McClanahan TR, Hicks CC and Darling ES (2008) Malthusian overfishing and efforts to overcome it on Kenyan coral reefs. Ecological Applications 18(6): 1516–1529.

McClanahan TR and Kaunda-Arara B (1996) Fishery recovery in a coral-reef marine park and its effect on the adjacent fishery. Conservation Biology 10(4): 1187–1199.

McClanahan TR, Maina JM and Davies J (2005) Perceptions of resource users and managers towards fisheries management options in Kenyan coral reefs. Fisheries Management and Ecology 12(2): 105–112.

McClanahan TR and Mangi S (2001) The effect of a closed area and beach seine exclusion on coral reef fish catches. Fisheries Management and Ecology 8(2): 107–121.

McClanahan TR and Mangi SC (2004) Gear-based management of a tropical artisanal fishery based on species selectivity and capture size. Fisheries Management and Ecology 11(1): 51–60.

Munga CN, Mohamed MOS, Obura DO, Vanreusel A and Dahdouh-Guebas F (2010) Resource users' perceptions on continued existence of the Mombasa Marine Park and Reserve, Kenya. Western Indian Ocean Journal of Marine Science 9(2): 213–225.

Munga CN, Ndegwa S, Fulanda B, Manyala J, Kimani EN, Ohtomi J and Vanreusel A (2012) Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban. Fisheries Science 78(2): 209–219.

Mutagyera WB (1984) Distribution of some deep water prawn and lobster species in Kenya's waters. *In* Iversen SA and Myklvoll S (eds.), Proceedings of the NORAD-Kenya seminar to review the marine fish stocks and fisheries in Kenya, Mombasa (Kenya). 18–20 p.

Muthiga N, Costa A, Motta H, Muhando C, Mwaipopo R and Schleyer M (2008) Status of coral reefs in East Africa: Kenya, Tanzania, Mozambique and South Africa. pp. 91–104 In Wilkinson C (ed.), Status of coral reefs of the World: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville (Australia).

Muthiga NA and McClanahan TR (1987) Population changes of a sea urchin (*Echinometra mathaei*) on an exploited fringing reef. African Journal of Ecology 25(1): 1–8.

Mwangi SN (2002) Water quality and productivity of the Malindi-Ungwana Bay fishing grounds. pp. 30–42 *In* Current status of trawl fishery of Malindi-Ungwana Bay — Final report. Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa (Kenya).

Mwatha GK (2002) Assessment of the prawn fishery, bycatch, resource use conflicts and performance of the turtle excluder device. pp. 43–64 *In* Current status of trawl fishery of Malindi-Ungwana Bay — Final report. Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa (Kenya).

Ndegwa S (2010) Kenyan sports fishing Tuna CPUE. IOTC-2010-WPTT-42, Indian Ocean Tuna Commission (IOTC), Victoria (Seychelles). 8 p.

Ndegwa S (2011) Kenyan sports fishing Kawakawa and Frigate Tuna CPUE. IOTC–2011–WPNT01–28, Indian Ocean Tuna Commission (IOTC), Victoria (Seychelles). 10 p.

Nyongesa Wekesa P and Ndegwa S (2011) National report of Kenya. IOTC-2011-SC14-NR13, Indian Ocean Tuna Commission (IOTC), Victoria (Seychelles). 9 p.

Nzungi PM, Kimani EN and Okemwa G (2008) Fisheries data management in Kenya. pp. 42–43 *In* Report of the first working party on fisheries data and statistics, Mombasa (Kenya), April 24–27 2007. FAO Fisheries Report 852. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy).

Obura DO (2001a) Kenya. Marine Pollution Bulletin 42(12): 1264–1278.

Obura DO (2001b) Participatory monitoring of shallow tropical marine fisheries by artisanal fishers in Diani, Kenya. Bulletin of Marine Science 69(2): 777–791.

Ochiewo J (2002) Assessment of socio-economic impacts of prawn trawling on the artisanal fisheries of Malindi and Ungwana Bay. pp. 71–81 *In* Current status of trawl fishery of Malindi-Ungwana Bay — Final report. Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa (Kenya).

Oduor BW (1984) Status of fish catches and landings in Kenya. *In* Iversen SA and Myklvoll S (eds.), Proceedings of the NORAD-Kenya seminar to review the marine fish stocks and fisheries in Kenya, March 13–15, 1984, Mombasa (Kenya). 64–72 p.

Okechi JK and Polovina JJ (1994) The spiny lobster fishery of Kenya. pp. 103–107 *In* Phillips BF, Cobb JS and Kittaka J (eds.), Spiny lobster management. Fishing news books, Oxford (UK).

Oluoch SJ and Obura DO (2008) Assessment of fisherfolk organizations and beach management units (BMU) in the management of fishery resources in Diani-Chale, southern Kenya. pp. 335–343 *In* Obura DO, Tamelander J and Linden O (eds.), Ten years after bleaching — facing the consequences of climate change in the Indian Ocean — CORDIO Status Report 2008. CORDIO and SIDA/Sarec, Mombasa.

Pauly D (1990) On Malthusian overfishing. Naga, the ICLARM Quarterly 13(1): 3–4.

Pauly D (1994) From growth to Malthusian overfishing: stages of fisheries resources misuse. SPC Traditional Marine Resource Management and Knowledge Information Bulletin 3: 7–14.

Pauly D (1998) Rationale for reconstructing catch time series. EC Fisheries Cooperation Bulletin 11(2): 4–10.

Pitcher TJ and Hemphill SC (1989) Stock assessment of indian ocean yellowfin tuna (*Thunnus albacares*) based on data from a sport fishery. Fishbyte (ICLARM) 7(3): 15–17.

Pitcher TJ and Hollingworth CE (2007) Fishing for fun: where's the catch? pp. 1–16 *In* Pitcher TJ and Hollingworth CE (eds.), Recreational Fisheries. Blackwell Publishing Ltd, Oxford (UK).

Republic of Kenya (2004) Marine waters frame survey 2004 report. Ministry of livestock and fisheries development, Fisheries department, Nairobi (Kenya). 40 p.

Republic of Kenya (2006) Marine waters frame survey 2006 report. Ministry of livestock and fisheries development, Fisheries department, Nairobi (Kenya). 47 p.

Republic of Kenya (2008) Marine waters frame survey 2008 report. Ministry of livestock and fisheries development, Fisheries department, Nairobi (Kenya). 55 p.

Republic of Kenya (2011) Prawn Fishery Management Plan 2010 (L.N. 20 of 2011). The fisheries act (cap. 378), legal notice No. 20, Ministry of livestock and fisheries development, Fisheries department, Nairobi (Kenya). 7 p.

Republic of Kenya (2012) Marine waters frame survey 2012 report. Ministry of livestock and fisheries development, Fisheries department, Nairobi (Kenya). 78 p.

Samoilys MA, Maina GW and Osuka K (2011a) Artisanal fishing gears of the Kenyan coast. CORDIO East Africa and USAID, Mombasa (Kenya). 36 p.

Samoilys MA, Osuka K and Maina GW (2011b) Artisanal fishing in Kenya: what are the effects? Swara 3: 18–25.

Samoilys MA, Osuka K, Maina GW and Obura DO (2011c) Artisanal fishing on the Kenya coast: what are the impacts? *In* 7th WIOMSA Scientific Symposium, October 24–29, 2011, Mombasa (Kenya).

Sigana D (2009) Tuna fishery in Kenya. IOTC-2009-SC-INF09, Indian Ocean Tuna Commission (IOTC), Victoria (Seychelles). 3 p.

Signa D, Tuda PM and Samoilys MA (2008) Social, economic and environmental impacts of beach seining in Kenya — an information review and field study. CORDIO and FAO, Mombasa (Kenya). 86 p.

Spalding MD, Ravilious C and Green EP, editors (2001) World atlas of coral reefs. University of California Press, Berkeley, CA (USA). 416 p.

Spooner S (2012) How demand for delicacy drives silent massacre of Kenya's sharks. Daily Nation (Kenya), edition of March 9.

Tuda PM, Nyaga W, Maina GW, Wanyonyi I and Obura DO (2008) Estimating total fishing effort over tidal to annual periods in the Diani-Chale-Gazi reff fishery in Kenya. pp. 321–334 *In* Obura DO, Tamelander J and Linden O (eds.), Ten years after bleaching — facing the consequences of climate change in the Indian Ocean — CORDIO Status Report 2008. CORDIO and SIDA/Sarec, Mombasa.

UNEP (1989) A coast in common: an introduction to the eastern African action plan United Nations Environment Programme, Nairobi (Kenya).

UNEP (1998) Eastern Africa atlas of coastal resources 1: Kenya. United Nations Environment Programme (UNEP), Nairobi (Kenya).

Weaver DB (1999) Magnitude of ecotourism in Costa-Rica and Kenya. Annals of Tourism Research 26(4): 792–816.

Williams F (1956) Preliminary survey of the pelagic fishes of East Africa. Colonial Office Fishery Publications 8: 1–68.

Williams F (1970) The sport fishery for sailfish at Malindi, Kenya, 1958–1968, with some biological notes. Bulletin of Marine Science 20(4): 830–852.

Zeller D, Booth S, Davis GE and Pauly D (2007) Re-estimation of small-scale fishery catches for US flag-associated island areas in the western Pacific: the last 50 years. Fishery Bulletin 105(2): 266–277.

Zeller D and Harper S, editors (2009) Fisheries catch reconstructions: islands, part I. Fisheries Centre Research Reports 17 (5). University of British Columbia, Vancouver (Canada). 108 p.

Zeller D, Harper S, Zylich K and Pauly D (2014) Synthesis of under-reported small-scale fisheries catch in Pacific-island waters. Coral Reefs DOI: 10.1007/s00338–014–1219–1.

Zeller D and Pauly D, editors (2007) Reconstruction of marine fisheries catches for key countries and regions (1950–2005). Fisheries Centre Research Reports 15 (2). University of British Columbia, Vancouver (Canada). 163 p.

Appendix Table A1. Reconstructed catch (t) by sector, compared to the catch reported to FAO, as presented in Figure 4.

Year	Total reconstructed				Reported
	Artisanal	Industrial	Recreational	Subsistence	
1950	6,904	-	-	2,715	3,000
1951	7,089	-	23	2,777	3,000
1952	7,273	-	46	2,838	3,000
1953	7,458	-	68	2,900	3,500
1954	7,643	-	91	2,962	4,100
1955	7,827	-	114	3,024	2,700
1956	8,057	-	137	3,101	2,700
1957	8,287	-	159	3,178	4,500
1958	8,517	-	182	3,255	4,600
1959	8,747	-	222	3,332	4,300
1960	8,976	-	266	3,409	4,300
1961	9,263	-	150	3,505	5,100
1962	9,549	-	165	3,601	5,200
1963	10,304	-	146	4,152	4,500
1964	9,838	-	219	3,910	4,900
1965	10,118	-	251	4,011	5,800
1966	10,468	-	166	4,137	6,600
1967	10,819	-	162	4,263	6,000
1968	11,867	-	168	4,781	6,000
1969	12,221	-	175	4,903	6,700
1970	11,979	-	181	4,530	7,800
1971	12,436	-	187	4,675	6,900
1972	12,867	-	194	4,844	7,600
1973	13,571	-	200	4,741	3,800
1974	13,922	-	206	4,990	3,316
1975	14,488	-	212	4,035	4,459
1976	14,082	-	219	4,834	4,100
1977	14,148	-	225	5,579	4,319
1978	14,367	-	231	4,996	4,596
1979	15,838	-	237	5,116	4,055
1980	15,610	285	244	4,988	5,552
1981	14,397	569	256	6,583	6,316
1982	14,972	994	270	6,319	7,512
1983	15,288	924	284	6,445	7,070
1984	14,655	1,449	299	6,617	6,041
1985	15,185	4,919	314	6,230	6,196
1986	14,547	1,399	331	6,254	6,212
1987	13,888	2,039	348	6,221	6,875
1988	12,793	2,119	365	6,549	7,970
1989	12,272	1,764	382	6,232	7,610
1990	11,423	1,794	400	6,174	9,905
1991	11,505	2,039	663	5,142	7,419
1992	10,473	1,364	706	5,156	6,566
1993	9,699	464	730	4,847	5,617
1994	9,766	1,319	800	3,636	3,772
1995	8,613	459	709	3,585	5,465
1996	7,108	1,314	705	3,555	6,296
1997	7,236	1,879	565	3,365	6,099
1998	6,321	3,294	421	3,225	6,600
1999	6,565	1,989	647	2,843	6,634
2000	6,321	1,714	753	2,844	4,763
2001	6,604	1,708	796	2,847	7,388
2002	7,146	1,412	821	2,476	6,720
2003	7,823	937	847	2,849	6,830
2004	7,496	1,018	872	3,493	7,774
2005	8,233	1,039	757	2,927	7,105
2006	8,161	814	763	2,947	6,955
2007	9,834	-	788	4,120	7,448
2008	9,473	-	788	4,121	8,301
2009	11,105	-	788	2,861	5,564
2010	10,671	-	788	3,764	8,264

Appendix Table A2. Taxonomic breakdown of the reconstructed catch (t), as presented in Figure 5.

Year	Lethrinidae	Scaridae	*Siganus* spp.	Elasmobranchii	Carangidae	Lutjanidae	Clupeidae	Others[a]
1950	1,078	1,000	1,030	629	658	513	210	4,514
1951	1,109	1,029	1,061	650	675	527	216	4,645
1952	1,140	1,058	1,091	672	693	542	222	4,775
1953	1,171	1,088	1,122	694	711	556	227	4,905
1954	1,202	1,117	1,152	715	728	570	233	5,036
1955	1,233	1,146	1,183	737	746	585	239	5,166
1956	1,272	1,183	1,221	763	768	603	246	5,320
1957	1,310	1,219	1,259	789	790	621	254	5,475
1958	1,349	1,256	1,297	815	812	639	261	5,630
1959	1,387	1,292	1,336	843	834	657	268	5,808
1960	1,426	1,329	1,374	872	856	675	276	5,990
1961	1,474	1,374	1,421	887	883	697	285	5,985
1962	1,522	1,420	1,469	917	910	720	294	6,159
1963	1,597	1,475	1,516	944	985	762	312	7,106
1964	1,613	1,509	1,563	982	956	761	310	6,392
1965	1,661	1,554	1,611	1,015	983	783	320	6,589
1966	1,721	1,611	1,670	1,041	1,018	811	331	6,663
1967	1,781	1,668	1,729	1,076	1,052	839	342	6,849
1968	1,872	1,736	1,789	1,113	1,142	890	364	8,017
1969	1,932	1,793	1,848	1,151	1,176	918	376	8,218
1970	1,957	1,892	1,915	1,215	1,144	966	296	7,414
1971	2,030	1,963	1,987	1,262	1,185	1,001	307	7,677
1972	2,131	1,935	2,064	1,294	1,260	954	497	7,890
1973	2,166	1,967	2,098	1,397	1,280	969	505	8,256
1974	2,279	2,070	2,208	1,120	1,344	1,019	531	8,677
1975	2,064	2,712	2,194	1,205	1,293	1,650	5	7,741
1976	2,406	2,066	2,299	1,866	1,192	868	6	8,569
1977	2,170	1,856	2,058	1,590	1,115	790	12	10,508
1978	1,758	2,180	1,954	3,141	1,321	722	1,215	7,452
1979	3,087	1,396	2,573	2,202	1,804	1,016	1,473	7,809
1980	2,134	2,010	2,061	2,840	1,390	627	1,124	9,153
1981	1,778	3,465	1,980	647	1,269	758	1,121	11,039
1982	2,071	2,221	1,711	778	737	860	1,188	13,268
1983	2,042	1,529	2,391	769	843	840	1,203	13,663
1984	2,228	1,336	1,946	1,023	841	667	1,358	13,837
1985	2,686	2,660	2,447	1,006	1,003	775	1,676	14,645
1986	2,081	2,150	2,156	1,004	927	627	1,324	12,502
1987	2,052	1,981	1,879	829	693	512	1,373	13,435
1988	1,563	1,515	1,276	679	671	442	1,081	14,867
1989	1,453	1,010	1,342	704	619	473	1,012	14,315
1990	1,135	1,032	1,114	522	438	410	763	14,667
1991	1,548	1,114	1,563	668	522	590	773	13,041
1992	1,188	825	1,170	498	445	411	866	12,789
1993	1,094	501	1,047	451	243	340	410	12,158
1994	1,338	779	1,319	698	374	464	607	10,496
1995	852	232	788	455	236	261	244	10,786
1996	707	953	602	383	233	264	345	9,687
1997	665	1,002	570	301	312	289	335	9,972
1998	639	821	466	228	291	211	237	10,684
1999	510	859	370	246	256	238	229	9,794
2000	651	1,091	520	290	272	259	231	8,844
2001	580	1,195	460	295	222	237	204	9,310
2002	581	956	608	258	266	262	146	9,342
2003	609	744	503	371	313	195	175	10,128
2004	612	721	490	298	353	220	158	10,630
2005	664	910	620	395	381	294	185	10,763
2006	738	953	600	308	307	313	216	10,217
2007	721	1,611	602	295	437	390	246	11,447
2008	733	1,640	618	331	403	381	214	11,031
2009	1,109	1,021	1,196	646	414	638	304	10,327
2010	982	1,211	949	493	516	477	223	11,083

[a] Includes an additional 58 taxa.