Reconstructing domestic and foreign fishing catch in a tropical fishery: the case of Kenya (2011-2017)

by

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Abstract

Small-scale fisheries are critical to the coastal communities of many East African countries, but are frequently underrepresented in official government statistics. Here, I update and extend a previous reconstruction of the total marine fisheries catches in Kenya's Exclusive Economic Zone (EEZ) for 1950 to 2010 to the year 2017 to reflect recent transformational change in the governance and intensity of local and regional fisheries. Total domestic catch estimates for 1950 to 2017 are 2.6 times higher than the data reported by Kenya to the Food and Agriculture Organization (FAO). The proportion of unreported domestic catch peaked in 1974 at 82% before declining to just 8% in 2017, a change that has been attributed to improvements in Kenya's catch data collection system. Reconstructed domestic catches peaked in 1985 before decreasing during the 1980s and 1990s, driven by overfishing of inshore fish stocks. A gradual increase in catch since 2000 corresponds with the introduction of gear restrictions and spatial fisheries management measures. Small-scale catches dominated the reconstructed domestic catch, with artisanal, i.e. small-scale commercial, and subsistence, i.e. for home consumption, catches accounting for approximately 67% and 26% of the total, respectively. Industrial catches made up 4% of total domestic catches and recreational just 2%, with both sectors showing a declining trend since the 1980s. Domestic catches were dominated by reef fish species, with the major taxa being Siganidae (9%), Lethrinidae (9%), Scaridae (8%) and Carangidae (5%), highlighting the importance of inshore reef species to domestic fisheries. Offshore waters of Kenya's EEZ are exploited by distant-water fishing fleets. Catches by these fleets were estimated at nearly 400,000 tonnes from 2011 to 2017, suggesting high levels of offshore exploitation. Given Kenya's intention to develop its own domestic offshore fishery in the near future, this scenario has serious implications for the sustainability of the offshore fishery during such an expansion. The increased accuracy of the catch data presented in this study provides valuable insight into the exploitation patterns of Kenya's fisheries and allows for the application of data-limited fisheries assessment approaches. In doing so, this reconstruction facilitates both the effective management of Kenya's marine fisheries and the monitoring of long-term changes in Kenya's marine ecosystems.

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1 Introduction

1.1 The importance of marine fisheries in Kenya

The Southwest Indian Ocean (SWIO) is a region of highly biodiverse and productive ecosystems. Annual fisheries landings in the Western Indian Ocean reached over 5.3 million tonnes in 2017 and contributed approximately 20% of the world's tuna supply (FAO 2019). Over 70% of marine fisheries in the SWIO are considered small-scale, and play a critical role as a source of both protein and income for the 100 million people living along the SWIO coast (Everett et al. 2017; Hicks et al. 2019). In Kenya, one of the fastest growing economies in the SWIO, marine fisheries are equally important. Despite national poverty rates dropping from 46% to 36% between 2006 and 2016 (The World Bank 2019), inequality remains high in the country, with coastal regions experiencing poverty rates of up to 60% (The World Bank 2019). Livelihoods in rural areas of the coast depend heavily on marine fisheries, which provide over 80% of total income to more than two thirds of Kenya's coastal communities (Malleret-King 2000), making them a critical pillar in Kenya's coastal economy.

The last decade has been a period of transformational change in Kenya's marine fisheries as the East African country has been at the nexus of major shifts in both local management approaches and regional fishing pressure. In 2006, Kenya transitioned national fisheries governance from centralised management into a decentralised, community-based framework (Cinner and McClanahan 2015; Kawaka et al. 2017). The move by Kenya towards a co-management framework mirrored a similar transition taking place in small-scale fisheries across the globe, including throughout Asia, South America and the Pacific (d'Armengol et al. 2018). In tandem with major changes to local fisheries management, Kenya's offshore waters are experiencing the consequences of regional shifts in fishing pressure. The presence of Somali piracy along the East African coast, which peaked in 2011, acted as a deterrent to international Distant-Water Fishing (DWF) fleets in the SWIO. Declining piracy in recent years has meant that DWF fleets are rapidly shifting from the Western Pacific ocean back into the Indian Ocean, including into Kenya's EEZ (IOTC 2018). Changes such as these may be having major impacts on the health of Kenya's fisheries. However, deficiencies in Kenya's marine fisheries data severely limit understanding of the exact state of many fish stocks during this period of change.

1.2 Deficiencies in Kenya's marine fisheries data

The low macro-economic significance of Kenya's small-scale fisheries has caused the sector to be systematically overlooked (Tuda 2018), a pattern often reflected in small-scale fisheries across the globe (FAO 2015; Zeller et al. 2015). Kenya's marine fisheries contribute just 0.1% to Kenya's Gross Domestic Product (GDP) (KNBS 2015), and as such have historically received little national attention, investment or development. Limited resources combined with the complex multi-gear, multi-species nature of the fishery has severely hindered the collection of accurate and comprehensive marine fisheries statistics at the disparate and often remote landing sites along the coast (Tuda 2018). The majority of marine fisheries catches are reported by Kenya at highly aggregated taxonomic categories, with only around 10% of catches reported at the species level (SDF&BE 2016). Marine catch data in Kenya has also historically been characterised by high levels of underreporting (Carrara and Coppola 1985; Kaunda-Arara et al. 2003; Le Manach et al. 2015a).

The deficiencies in fisheries data, including detailed biological data, limit its usefulness for traditional, single-species stock assessment methods (Tuda 2018). Fisheries experts are instead turning to alternative catch-based approaches to assess the state of the fisheries in data-limited contexts. Officially reported catch data has been used, for example, to infer the effect of fishing on Kenya's inshore fish assemblages over time (Tuda 2018), and to estimate the Maximum Sustainable Yield of Kenya's shallow-water shrimp fishery (Fulanda et al. 2011). However, reliance on incomplete and underreported marine catch data to conduct these assessments may be resulting in inaccurate, misleading or underestimated inferences about the state of marine fisheries (Rudd and Branch 2016). This in turn could lead to the mismanagement of both marine ecosystems and coastal food security.

In an attempt to examine and address the issue of poor catch data in Kenya's marine fisheries, an in-depth reconstruction of unreported catches was conducted for the years 1950 to 2010 as part of the *Sea Around Us* research initiative (Le Manach et al. 2015a). The initial reconstruction estimated Kenya's total catches over the time period to be almost 985,000 tonnes, 2.8 times higher than the catch officially reported by Kenya to the Food and Agriculture Organization of the United Nations (FAO). A subsequent stock status analysis conducted on the improved catch statistics indicated that the status of marine fisheries stocks in Kenya has been steadily declining since the 1970s (Sea Around Us 2015). The initial catch reconstruction and subsequent catch-based stock status assessment provided valuable insight into the nature and vulnerabilities of Kenyan marine fisheries across the 1950-2010 time period. However, catches were only reconstructed up until the year 2010, just after the introduction of co-management to Kenya's fisheries and prior to the influx of DWF fleets into East African waters.

Thus, the ability to detect any effect that these changes may have had on catch trends and the status of fish stocks in Kenya using currently available fisheries catch data is limited.

1.3 Kenya's domestic and foreign fisheries

1.3.1 Domestic small-scale fisheries

Kenya's domestic fisheries are dominated by the small-scale sector. The sector consists of two major fisheries; the boat-based coastal fleet and shore-based gleaners, which together exploit over 270 different species (Buckley et al. 2019). Coastal fleet fishers utilise simple vessels such as dugout canoes reaching fishing grounds within 3-5 nautical miles from shore, while the shore-based fishers glean invertebrate species from intertidal reef and seagrass flats. Despite its more marginalised status, the gleaner fishery provides critical income to fishers through the collection of invertebrate species with lucrative international markets such as octopus, sea cucumber (bêche-de-mer) and shells (Ochiewo et al. 2010; Kivengea 2014). The export value of gleaner-caught species was over US$1.9 million in 2016 (SDF&BE 2016). The majority of catch by each of these small-scale fisheries is sold at local markets, i.e. artisanal, while the remaining catches are kept for home consumption, i.e. subsistence (Cinner et al. 2009), contributing to local food security.

Increased small-scale fishing pressure eventually resulted in drastic declines in inshore ecosystem and fishery health during the 1990s and 1980s (McClanahan et al. 2002; McClanahan et al. 2008). By 2006, catch rates had declined to just 23% of 1980s rates (Samoilys et al. 2017), leaving coastal livelihoods in jeopardy. The Kenyan government responded to these declines by transitioning fisheries management control into a community-based, co-management system during the 2000s (Cinner and McClanahan 2015), allowing for localised spatial management measures such as gear restrictions and marine reserve areas. By 2017, six national protected areas and 24 locally managed marine areas covered 1.03% of Kenya's EEZ (Obura et al. 2017). Recent studies indicate that these protected areas are having positive effects on the recovery of reef fish biomass and fisheries catch rates (Cinner and McClanahan 2015; McClanahan and Kosgei 2019). However, despite localised indications of recovery, the exact state of Kenya's marine fish stocks remains uncertain due to insufficient national-scale fisheries data.

Historically, small-scale catch data has been collected by Kenya's State Department of Fisheries (SDF) on the principle of 'total enumeration' (Ndegwa and Geehan 2017). However, incomplete coverage due to resource limitations has led to a negative bias in reported catch statistics (KCDP 2013). To address this issue, Kenya began the transition to a sample-based approach in 2013 (Ndegwa and Geehan 2017). Under the new system, the number of landing sites surveyed on a regular basis was reduced from 197 to 22, with sampled catches raised to national estimates (SDF 2016; Ndegwa and Geehan 2017). The overhaul was conducted with the aim of enabling more accurate monitoring of trends in fish catches, and Kenyan fisheries officials believe the sample-based catch estimates to be the first near-accurate reported catch statistics (N Wambiji, Kenya Marine and Fisheries Research Institute, pers. comm).

1.3.2 Domestic industrial fisheries

Although small-scale fisheries dominate Kenya's domestic fisheries, a small industrial sector has also existed on a sporadic basis, consisting of two fisheries. A small fleet of 20 industrial trawlers began operating during the 1970s in the nutrient-rich waters of Ungwana Bay, but tensions with small-scale fishers in the bay resulted in a complete ban on industrial shrimp trawling in 2006 (Munga et al. 2012). In 2011, the fishery was tentatively resumed under the stricter guidance of a newly developed Prawn Fishery Management Plan (Government of Kenya 2010), and has been gradually growing in both fleet size and catch quantities (KMFRI 2018). The second domestic industrial fishery is the offshore longline fishery, which targets swordfish (*Xiphias gladius*), but also catches other large pelagic species including bigeye tuna (*Thunnus obesus*), yellowfin tuna (*Thunnus albacares*) and tiger sharks (*Galeocerdo cuvier*) (Ndegwa et al. 2018). Although catches by domestic longliners reached up to 730 $t \cdot year^{-1}$ during the 1980s, current catches are only approximately 150 $t \cdot year^{-1}$ (Ndegwa et al. 2018). The Kenyan government intends to expand its dwindling domestic offshore fisheries by enhancing domestic capacity for industrial tuna production and trade. By developing fisheries related infrastructure and capabilities, a key priority in the Kenya Vision 2030 (Government of Kenya 2017b), the country hopes to better utilise its "untapped" offshore resources (Government of Kenya 2018) in order to support social and economic development.

1.3.3 Foreign fisheries

The marine resources of Kenya's EEZ are also exploited by foreign fisheries in both inshore and offshore waters. Each year Kenya's domestic coastal fleet is supplemented by a migration of small-scale fishers from the Tanzanian islands of Zanzibar and Pemba, who enter Kenya's waters during the favourable northeast monsoon season. These migrant fishers bring with them higher-capacity vessels and gears, and often outnumber local fishers (WIOMSA 2011). Migrant fishers tend to target high value finfish species such as sharks, Carangidae, Lethrinidae and Siganidae (van Hoof and Steins 2017).

Offshore waters are exploited by an influx of a different kind. Licences to access Kenya's EEZ are provided by the Kenyan government to DWF fleets from countries including Spain, France, the Seychelles and the Republic of Korea (POSEIDON et al. 2014a). The growing foreign industrial fishery exploits the productive offshore fish stocks that have historically remained unexploited by domestic fishers. Similar to small-scale fisheries, catch by these foreign offshore fishing fleets is also thought to be drastically underreported (Aloo et al. 2014; POSEIDON et al. 2014a), risking the sustainable management of Kenya's offshore fish stocks. Furthermore, the offshore pelagic species targeted by these fleets range well beyond the waters of Kenya's EEZ, and are under management responsibility of the Indian Ocean Tuna Commission (IOTC). The transboundary nature of these stocks thus requires regional co-management, assessment and catch-sharing.

1.4 Objectives of this study

A comprehensive understanding of current and historical catch trends is critical in facilitating informed management decisions regarding Kenya's marine fisheries. The research presented here aims to improve estimates of total catch by building on the 1950-2010 catch reconstruction by Le Manach et al. (2015a) and updating it to 2017 in order to complement and correct officially reported catch data for Kenya. This research addressed the following four part research question; (i) what is the total estimate of marine resource extraction in Kenya from 2011 to 2017, (ii) what proportion is unreported catch, (iii) what is the percentage contribution by the various fishing sectors, taxonomic groups and gear types, and (iv) what level of foreign fishing, and by which countries, exists in these waters. This research will contribute to improved fisheries management and food security in Kenya by providing an accurate historical baseline that will allow for a range of valuable ecosystem and stock status indicators and assessments to be undertaken.

2 Methods and Materials

2.1 The reconstruction process

A preliminary reconstruction of Kenya's total marine fisheries catch for 1950 to 2010 was conducted by Le Manach et al. (2015a). Here, the original reconstruction was updated to account for new information and continued to 2017, the most recent year for which FAO baseline data was currently available. The reconstruction was conducted using the well-established approach described in Zeller et al. (2016). Only marine wild capture fisheries were addressed in this reconstruction, therefore, freshwater catches, aquaculture production, aquarium trade and catch of marine mammals, turtles or seaweed were not included.

The broad steps of the catch reconstruction process are conceptualised in Fig. 2.1. The specific methods used to reconstruct catches in this study are described below.

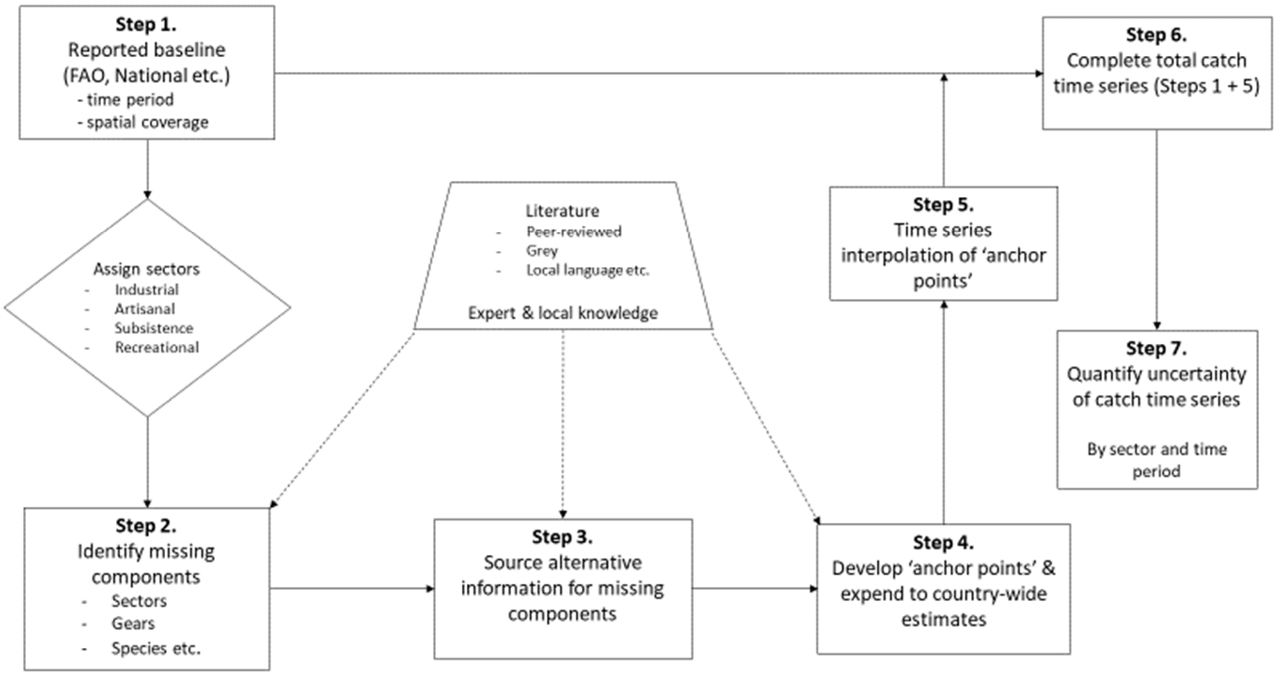

Fig. 2.1 Conceptual representation of the seven broad steps of the catch reconstruction approach, adapted from Zeller et al. (2016).

2.2 Study location

This reconstruction pertains to marine fisheries catch taken within Kenya's EEZ, defined as the area extending 200 nautical miles from shore (UN 1982). Kenya's EEZ covers an area of 162,000 km^2, including an area of approximately 42,000 km^2 that is currently under dispute with Somalia (Fig. 2.2) (Chan 2018). For the purposes of this research, and as per *Sea Around Us* methods, the disputed area was included within Kenya's EEZ.

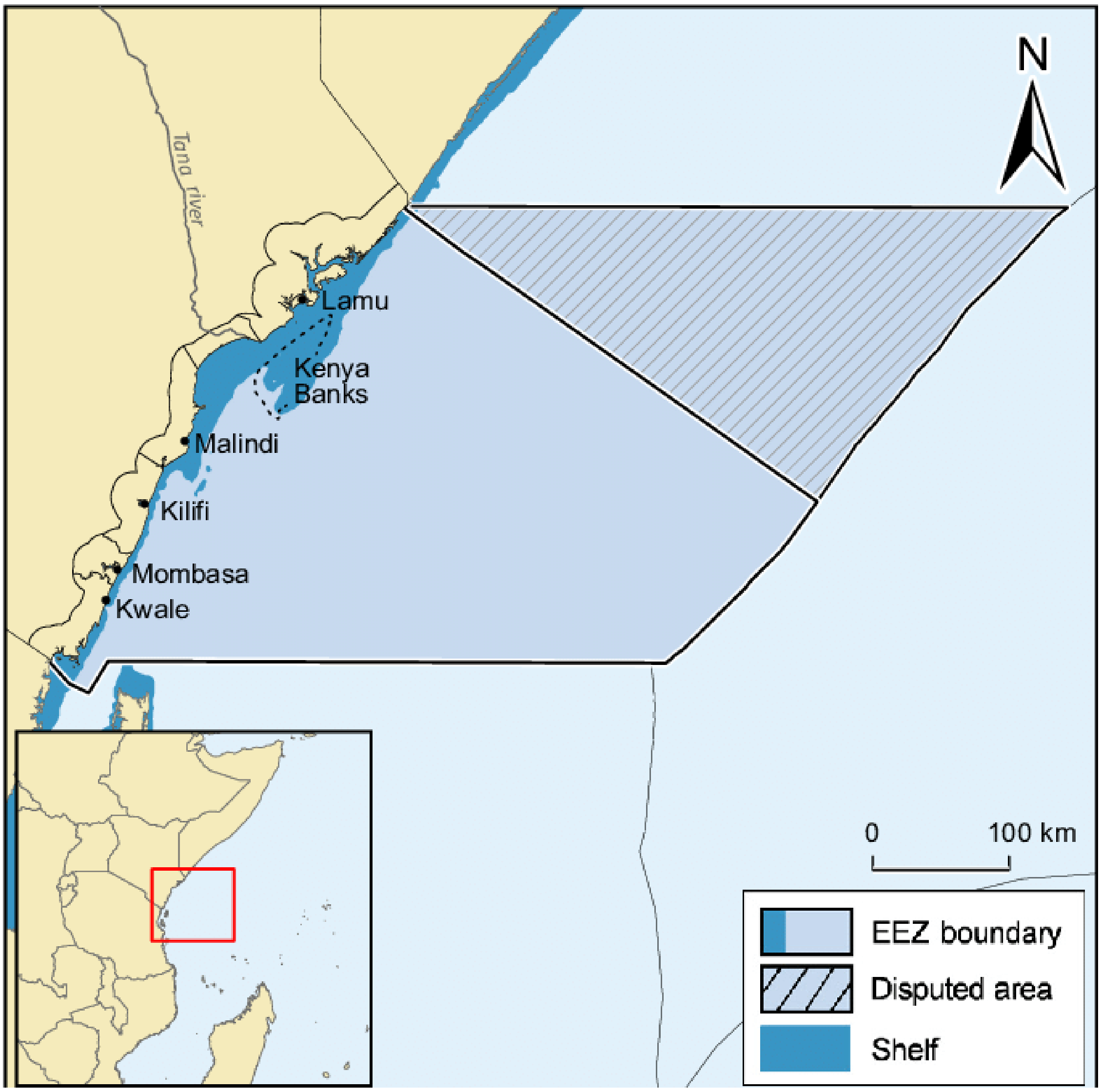

Fig. 2.2 Map of Kenya's Exclusive Economic Zone (EEZ) including shelf waters (to 200 m depth), the disputed area with Somalia, and the location of the major coastal cities. Source: Le Manach et al. (2015a)

2.3 Initial allocation of reported data

Official catch data is reported by national authorities of member countries to the FAO (Garibaldi 2012). FAO provides catch data on behalf of member countries via the 'FishStatJ' database. Officially reported landings data by Kenya for the years 2011-2017 were extracted from the FAO database FishStatJ (FishStatJ 2015) and compared to national reports produced by Kenya's Ministry of Agriculture, Livestock and Fisheries (SDF 2014a; SDF&BE 2016). The national reports differed both in total quantity and in taxonomic breakdown to FishStatJ data, and only provided data up to the year 2016. Due to these discrepancies, and to maintain consistency with the previous 1950-2010 reconstruction, FishStatJ data were employed as the official reported catch baseline for this reconstruction.

FAO catch was first allocated to the four sectors, industrial, artisanal, recreational and subsistence, that were active within Kenya's EEZ during the 2011 to 2017 time period. Comparison of FAO reported data with the dataset published by the Indian Ocean Tuna Commission (IOTC) revealed that no official catch had been reported by Kenya for either the industrial longline fishery or the recreational sector since 2010. All reported catch was thus allocated between the industrial shrimp trawl fishery and the two small-scale fisheries.

Reported catch of shrimp and bycatch species were allocated to the industrial shrimp trawl fishery using information published by the Kenya Marine and Fisheries Research Institute (KMFRI) (KMFRI 2018). All reported catch of 'Brachyura', 'Crassostrea spp.', 'Crustacea' and 'Holothuroidea' were allocated to the small-scale shore-based gleaner fishery, along with 50% of 'Octopodidae' and 6% of 'Palinuridae' (SDF 2016). All remaining catch was then allocated to the small-scale coastal fleet. Each fishery was then studied and reconstructed individually.

2.4 Small-scale sector

2.4.1 Small-scale coastal fleet

Catch by the small-scale coastal fleet between 2011 to 2017 was first reconstructed using catch and effort parameters, as per Le Manach et al. (2015a). This method resulted in estimates lower than the reported data for 2016 and 2017 (see details in Appendix A). As such, an alternative method using an adjustment factor was employed to reconstruct catch by the small-scale coastal fishery.

Reported catch by the small-scale coastal fleet fishery increased dramatically between 2015 and 2017. This peak indicates that despite the sample-based collection system beginning in 2013, data collected under the old 'total enumeration' system were submitted to the FAO until 2015, sample-based data reported in 2017, and 2016 a transitionary year between the two. As such, the difference between reported catch in 2015 and 2017 was used to derive an adjustment factor of 1.56. In order to avoid the artificial amplification of the pre-existing peaks and troughs in the reported catch, the adjustment factor was applied to the average of 2011-2015 reported catch then added to the original reported catch of each year. The average between the adjusted 2015 total and the original reported 2017 catch was calculated to re-estimate 2016 catch.

The taxonomic breakdown of reconstructed total catch for this sector was based on the breakdown of reported catch, and improved using more detailed government fisheries reports (SDF 2014a; SDF&BE 2016).

2.4.2 Shore-based gleaning

Reported catch of four of the taxa targeted by shore-based gleaners declined or disappeared after 2015 (SDF 2016). Although the decline may be attributable to falling catch rates, the timing indicates that it may also be an artefact of the change in catch-data collection system that occurred in the same year. In either case, an adjustment factor would not be an appropriate re-estimation technique for gleaner catch as it would either mask a declining trend in actual total catch or carry back an increased negative bias in the reported catch of 2017. Instead, a parameter-based method was used to re-estimate total catch by shore-based gleaners between 2011 and 2017.

In order to estimate total annual catch by gleaners, a time series of the number of shore-based fishers was sourced from government frame surveys (Fisheries Department 2006; SDF 2012, 2014b, 2016). Catch-per-unit-effort (CPUE) was linearly interpolated between anchor points of 3 $kg \cdot day^{-1}$ in 2010 (Le Manach et al. 2015a) and 3.4 $kg \cdot day^{-1}$ in 2017 (Musembi et al. 2019). The fisher time-series was then multiplied by CPUE rates and an assumed effort of 200 fishing days per year, as per Le Manach et al. (2015a).

The taxonomic breakdown of catches was estimated using a combination of catch reported to the FAO, government fisheries reports (SDF 2014a; SDF&BE 2016) and scientific literature (Mirera 2017). For taxa that declined or disappeared after 2015, the average of catches between 2011 and 2015 were used to adjust the 2016 and 2017 breakdown. Finally, a sixth category was created representing catch of shells, which are known to be collected for the tourism and export market (Marshall 2001; Aloo et al. 2014) but were not included in reported data.

Catch of holothurians, crabs, octopus and shells tend to be sold at local and international markets, and were thus considered artisanal (Kimani 1995; Aloo et al. 2014; Mirera 2017), while catch of cupped oysters and marine crustaceans were considered to be caught for subsistence purposes.

2.5 Large-scale sector

2.5.1 Industrial shrimp trawl fishery

Kenya's previously prohibited domestic industrial shrimp trawl fishery resumed in 2011 under the guidance of a newly developed Prawn Fishery Management Plan (Government of Kenya 2010). Given the tighter regulatory control of the re-emerging fishery, including the periodic deployment of Marine Fisheries Observers (MFO) to collect detailed catch data (KMFRI 2018), it was assumed that all landed catch by industrial trawlers (i.e. targeted shrimp and retained bycatch) was reported. However, catches discarded at sea (discards), which are omitted from FAO statistics (Zeller et al. 2018), were assumed to not be included in officially reported catches. Periodic surveys by MFOs reported the ratio of retained to discarded catch to be 4:1 in 2016 and 2:1 in 2017 (KMFRI 2018), and an average ratio of 3:1 was applied to 2011-2015.

Detailed information on the species-specific breakdown of shrimp catch and bycatch (retained and discarded) provided by KMFRI (2018) were used to estimate the taxonomic breakdown of catch by the industrial shrimp trawl fishery from 2011 to 2017.

2.5.2 Industrial longline fishery

A domestic industrial longline fishery has been active in Kenya's EEZ on a sporadic basis since the 1980s. Both the IOTC and the FAO have previously reported catch by this sector. However, no industrial catch was reported by the IOTC since 2010, despite reports of a domestic longliner operating in Kenya's EEZ during much of the 2011-2017 time period (Ndegwa et al. 2018; Ndoro and Ndegwa 2018). Further comparison of the IOTC database with national reports also indicated that catch by the domestic industrial longliner was not included in the officially reported catch.

An IOTC report based on the on-board catch records of the single registered longliner reported catch as 150.4 tonnes in 2016 (Ndegwa et al. 2018). To reconstruct catch of this fishery, this catch amount was applied to years that the Kenyan flagged longliner vessel was registered in the IOTC database (2011-2012 and 2016-2017). The taxonomic breakdown published in Ndegwa et al. (2018) was then applied to final catch estimates (Table 2.1).

Table 2.1 The taxonomic breakdown applied to catch by the industrial longline fishery between 2011 and 2017, as described by Ndegwa et al. (2018).

Common name	Species	% of catch
Bigeye tuna	*Thunnus obesus*	35.43
Swordfish	*Xiphias gladius*	23.21
Yellowfin tuna	*Thunnus albacares*	14.99
Blacktip shark	*Carcharhinus limbatus*	6.30
Tiger shark	*Galeocerdo cuvier*	6.15
Black marlin	*Istiompax indica*	5.29
Others	Marine pelagic fishes not identified	4.21
Blue shark	*Prionace glauca*	3.10
Hammerhead, bonnethead, or scoophead sharks	Sphyrnidae	1.13
Sailfish	*Istiophorus platypterus*	0.18

2.6 Recreational sector

2.6.1 Sport fishery

Kenya's productive offshore waters have made it a popular destination for sport fishing since the 1970s. To reconstruct catch for this sector, catch records for the recreational sport fishery for 2004 to 2012 were obtained from reports published by the Kenya Association of Sea Anglers (KASA)[1]. These records included total catch (kgs), the number of individuals caught, and the number of individuals tagged and released[2]. To estimate retained recreational sport fishing catch, the quantity of catch that was subsequently tagged and released had to first be removed from the KASA catch totals. Retained catch per taxa was estimated as:

$$C_{retained} = C_{total} / N_{total} \times (N_{total} - N_{tr})$$

Where $C_{retained}$ is retained catch, C_{total} is total reported catch, N_{total} is the total number of individuals caught and N_{tr} is the number of individuals tagged and released.

[1] The African Billfish Foundation is currently processing more recent years of data, and these will be used to correct/improve reconstructed sport fishing catch once published.

[2] The previous catch reconstruction for 1950-2010 had considered all sport fishing catch to be landed and was thus retrospectively corrected to account for the proportion of catch that was in fact tagged and released between 1990 and 2010.

It was then assumed that KASA only managed to record 50% of the total catch that was occurring along Kenya's coastline, based on doubts expressed about the quality of recreational catch data and the need for improvements in catch data collection for the fishery (Pepperell et al. 2017; N Conway, Fish and Safari Kenya, pers. comm.). After this adjustment, total estimated catch for 2012 was then extrapolated based on the trend in international arrivals (KNBS 2015, 2019) to estimate catch for 2013-2017 (**Error! Reference source not found.**).

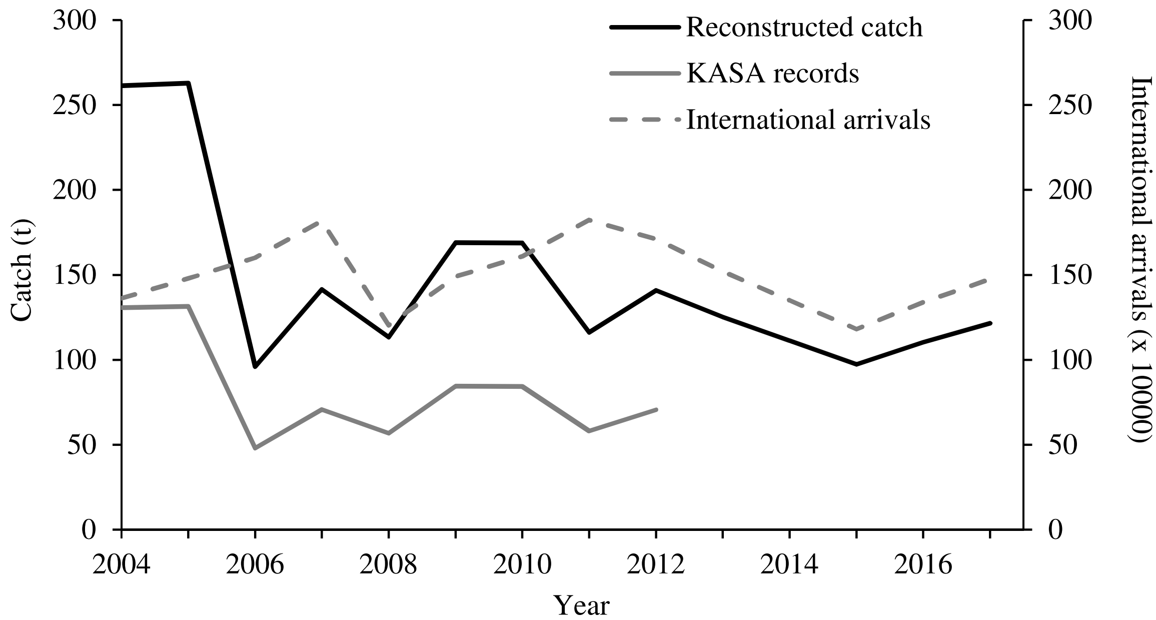

Fig. 2.3 Retained recreational catch reported by the Kenyan Association of Sea Anglers (KASA), annual international arrivals to Kenya, and total reconstructed recreational sport fishing catch for 2004-2017.

The information from KASA records and IOTC reports were used to estimate the taxonomic breakdown of total recreational sport fishing catch. No evidence was found to indicate any other recreational fisheries in Kenya such as coastal reef fishing, and thus none were assumed to exist. This assumption will however require future research.

2.7 Foreign fisheries

2.7.1 Small-scale migrant fishers

Large numbers of fishers from the Tanzanian islands of Zanzibar and Pemba migrate to fish in Kenya's waters each year. To reconstruct total annual catch by these fishers, catch and effort parameters were used. The number of migratory fishers were calculated as 2% of local fishers in Lamu (the furthest northern county in Kenya), and 10% in all other counties (WIOMSA 2011). A migrant fisher CPUE time-series ($kg \cdot fish^{-1} \cdot day^{-1}$) was estimated as 2x the local CPUE in each county, a conservative estimate given that (WIOMSA 2011) reports migrant CPUE as nearly 5x local fishers. The number of fishers and CPUE time-series were then multiplied by an annual effort of 120 fishing days per year (i.e. four months, the average trip length according to Wanyonyi et al. (2016)) to estimate the total catch time-series of migrant fishers.

Of the total reconstructed catch by migrant fishers, 30% was considered taxonomically similar to local coastal fleet, and the remaining 70% consisting of species targeted by migratory fishers (WIOMSA 2011), as detailed in Table 2.2.

Table 2.2 Taxonomic breakdown of reconstructed catch by migrant fishers from Tanzania. Adapted from (WIOMSA 2011).

Common name	Taxon name	% of catch
Jacks and pompanos	Carangidae	15
Sea basses	Serranidae	15
Sharks, rays and skates	Elasmobranchii	15
Snappers	Lutjanidae	15
Octopuses	Octopodidae	5
Spiny lobsters	Palinuridae	5
FAO coastal fleet taxa	Others*	30

* Composed of between 18 and 62 taxonomic categories

2.7.2 Distant-water tuna fleets

The only non-domestic industrial fishery active in Kenya between 2011 and 2017 was the foreign offshore fishing fleet. The fishery consists of DWF fleets which, despite retreating during the peak of Somali piracy in the late 2000s, have begun to return to East African waters (POSEIDON et al. 2014a). Licences to access Kenya's EEZ are provided by the Kenyan government to foreign fishing vessels, which then exploit the productive offshore fish stocks that have historically remained untapped by domestic fishers.

Foreign fleets are required to report catches to Kenya's national fisheries department (Government of Kenya 2016), with IOTC member states also required to report catch to the IOTC. However, no definitive baseline of reported catches by foreign vessels occurring within Kenya's EEZ could be sourced from either.

In order to estimate total annual catches by this fishery, a time-series of foreign fishing vessels was combined with gear-based catch estimates. Official records of the number of licenced foreign purse-seine and longline vessels were available for 2011 to 2014 (Government of Kenya 2017a), and were used as anchor points for these years. The number of licenced foreign vessels in 2014 was then carried forward to 2017 (Appendix B).

The time-series of licenced vessels was then multiplied by annual catch-per-vessel estimates of 6,011 t for purse-seiners and 223 t for longliners (IOTC 2013). Annual estimates were then adjusted to three-month estimates based on reports that foreign fishing typically occurs in Kenya's EEZ from May to July (POSEIDON et al. 2014a).

The taxonomic breakdown applied to the resulting total catch estimates was based on the taxonomic breakdown of industrial catch reported by the IOTC for spatial cells overlapping Kenya's EEZ (01- 04° S, 39-44° E), detailed in Table 2.3.

Table 2.3 Taxonomic breakdown applied to catches by foreign fishing fleets. The breakdown is based on catch reported foreign fleets to the IOTC within the 1° x 1° spatial blocks overlapping Kenya's EEZ.

Common name	Taxon name	% of catch
Skipjack tuna	*Katsuwonus pelamis*	49.184
Yellowfin tuna	*Thunnus albacares*	44.338
Bigeye tuna	*Thunnus obesus*	6.440
Albacore	*Thunnus alalunga*	0.036
Non-target species	Marine pelagic fishes not identified	0.001

2.8 Estimating uncertainty

The final step was to address and present the uncertainty associated with the reconstruction. Due to the nature of reconstructions, i.e. the reliance on secondary information and informed assumptions, traditional approaches to quantifying uncertainty are less applicable. Instead, a method was developed and employed by Zeller et al. (2015) which adapts the approach used by the Intergovernmental Panel on Climate Change to calculate uncertainty in their assessments (Mastrandrea et al. 2010). This method calculates the uncertainty of an anchor point or assumption based on confidence in its validity based on the quality, consistency and consensus of the evidence from which it was sourced.

The underlying data used as anchor points or to inform assumptions were assessed, and an uncertainty score (Table 2.4) attributed to each fishery for the time period studied (Appendix

C). Catch-weighted averages of upper and lower confidence limits were then calculated and applied to catch estimates of each sector.

Table 2.4 Uncertainty scores used to evaluate the quality and reliability of reconstructed catch time series and attribute confidence intervals. IPCC criteria from Figure 1 of Mastrandrea et al. (2010) and adapted by Zeller et al. (2016).

Score		+/- (%)	Corresponding IPCC criteria
4	Very high	10	High agreement & robust evidence
3	High	20	High agreement & medium evidence **or** medium agreement & robust evidence
2	Low	30	High agreement & limited evidence **or** medium agreement & medium evidence **or** low agreement & robust evidence
1	Very low	50	Low agreement & low evidence

3 Results

3.1 Domestic fisheries

The total reported domestic marine fisheries catch from 1950 to 2017 was approximately 440,000 tonnes (Fig. 3.1). The majority of total reported catch was composed of small-scale catch, with the artisanal and subsistence sectors making up approximately 95%.

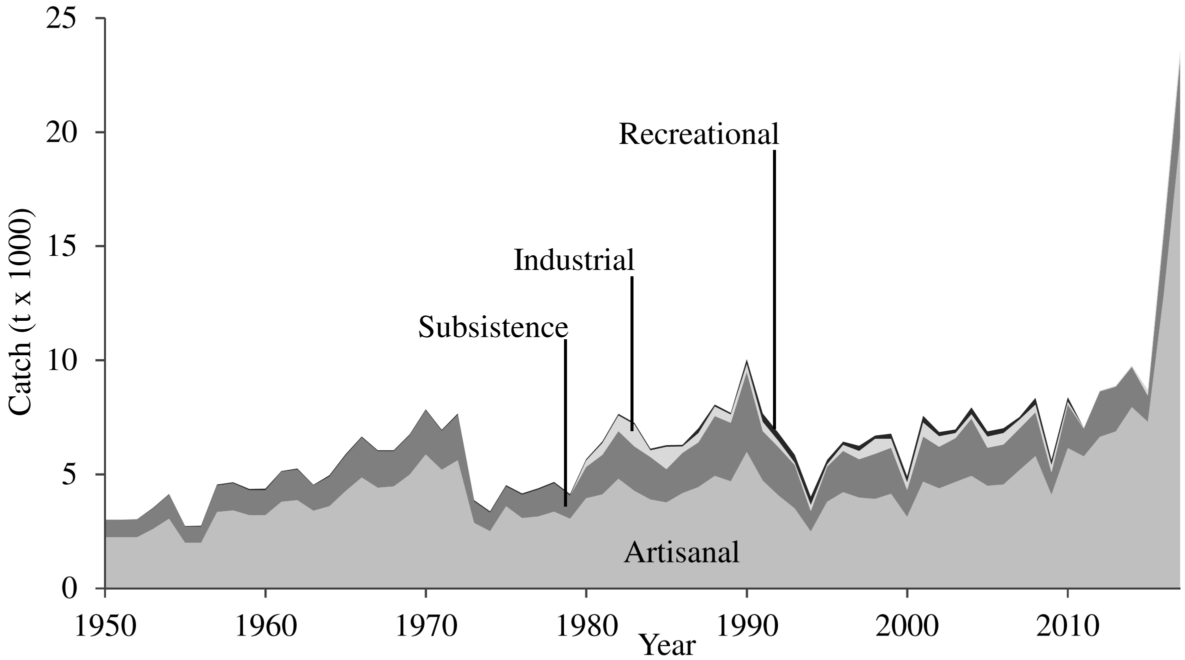

Fig. 3.1 Catch reported by Kenya to the FAO (1950-2017), reallocated to the artisanal, subsistence, industrial and recreational sectors.

Total reconstructed domestic catch in Kenya's EEZ was estimated to be just over one million tonnes between 1950 and 2017, 2.6 times higher than the data reported by Kenya to the FAO for the same time period (Fig. 3.2).

Both reported and reconstructed catches more than double between 2000 and 2017. However, while reconstructed catches increase at a fairly consistent rate of approximately 5% from 2000 to 2017, reported catches increased dramatically over just two years, with annual catch increasing at an average rate of 5.4% between 2000 and 2015 followed by 65.9% between 2015 and 2017.

Overall, the small-scale artisanal sector consistently dominated domestic catches over the 1950 to 2017 time period, accounting for over 67% of total reconstructed catches. The proportion of subsistence catch, however, has gradually declined from approximately 26% during the 2000s to 14% in 2017. Industrial catch peaked at 18% of total reconstructed catch during the 1980s, when both the industrial shrimp trawl fishery and the domestic longline fishery were in full operation. Since then, catches by the industrial sector have declined, making up just 3% of total reconstructed catches in 2017. The proportion of recreational catches has also been declining, and by 2017, the recreational sector accounted for only 0.05% of total reconstructed catch.

Due to the predominance of small-scale inshore reef fisheries, reef taxa dominated total reconstructed catches. The main taxa were Siganidae (9%), Lethrinidae (9%), Scaridae (8%), Carangidae (5%) and Lutjanidae (4%) (Fig. 3.3).

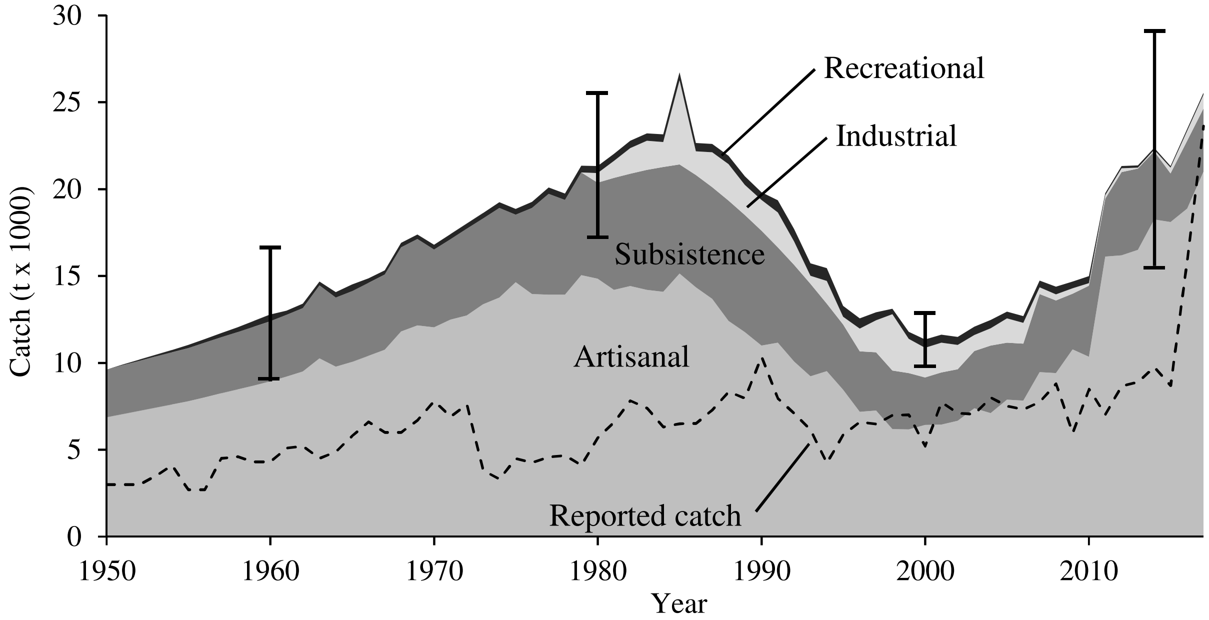

Fig. 3.2 Total reconstructed domestic catch for 1950 to 2017 showing catch by sector. Reported landings are shown as a black dashed line. Uncertainty estimates are displayed for the time periods 1950-1969, 1970-1989, 1990-2009 and 2010-2017.

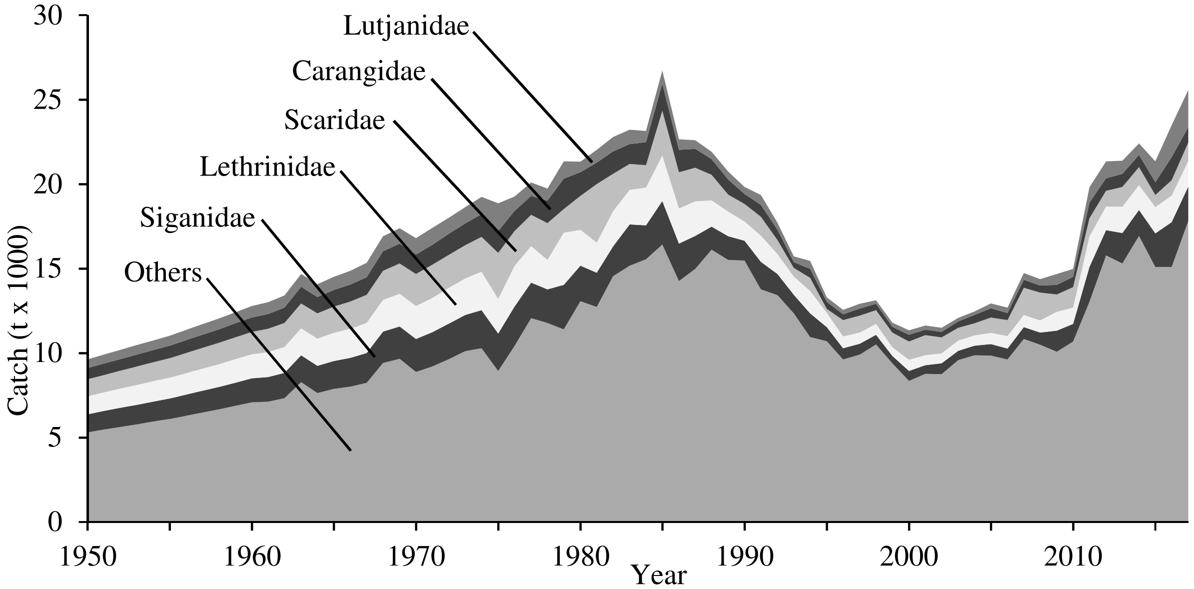

Fig. 3.3 Total reconstructed domestic catch for 1950 to 2017 showing the five main family-level taxa. The remaining 56 taxa are grouped into 'others'.

3.1.1 Coastal fleet

Total reconstructed catch of the small-scale coastal fleet was estimated to be approximately 990,000 tonnes over the entire 1950 to 2017 time period, accounting for 82% of the total domestic catch. Reconstructed catch increased from approximately 8,000 tonnes in 2000 to 25,500 tonnes in 2017 (Fig. 3.4).

Reported small-scale coastal fleet catch nearly tripled over the studied time period, increasing from 8,440 t in 2011 to 23,198 t in 2017. The proportion of catch by the small-scale coastal fleet considered to be unreported decreased dramatically from 60% in 2015 to 0% in 2017.

Reconstructed catch of the small-scale coastal fleet was composed of 80 taxonomic categories. Catch was dominated by the taxa Siganidae (rabbitfishes; 10%), Lethrinidae (emperors; 10%), Scaridae (parrotfishes; 9%), Elasmobranchii (sharks and rays; 6%) and Carangidae (jacks and scads; 5%) (Fig. 3.4). The largest variation was seen in Scaridae, which ranged from 18% (1985) to 2% (1995) of total catch. The proportion of Siganidae and Lethrinidae both decreased slightly over time from approximately 12% in the 1970s to approximately 10% and 8%, respectively, in the 2011-2017 time period.

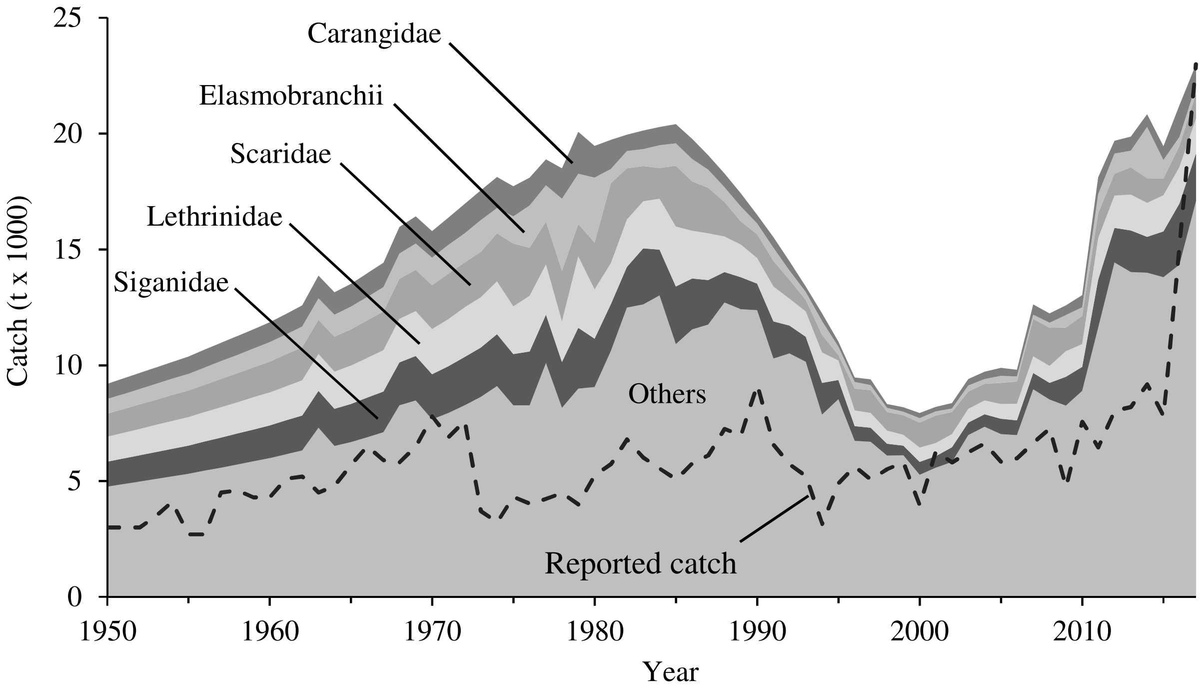

Fig. 3.4 Reported and reconstructed catch by the small-scale coastal fleet for 1950 to 2017 showing the five dominant taxonomic categories. The remaining 75 taxa are grouped into ‘others’. Reported catch is shown as a black dashed lineShore-based gleaners

Total reconstructed catch by shore-based gleaners between 1950 and 2017 equalled approximately 65,000 tonnes, approximately 4.3 times higher than reported catch (Fig. 3.5). Reconstructed catch by gleaners followed a steadily increasing trend over the entire time period. Reported gleaner catch, however, decreased sharply after 2015, with unreported catch rising from 59% to 88% between 2015 and 2017.

Catch by gleaners consisted predominantly of Mollusca (shells; 25%), Brachyura (crabs; 24%), mixed crustaceans (mixed crabs and lobsters; 17%) and Holothuroidea (sea cucumbers; 14%). The remaining catch consisted of Crassostrea (cupped oysters; 5%), Octopodidae (octopus; 4% and Palinuridae (tropical spiny lobsters; <1%).

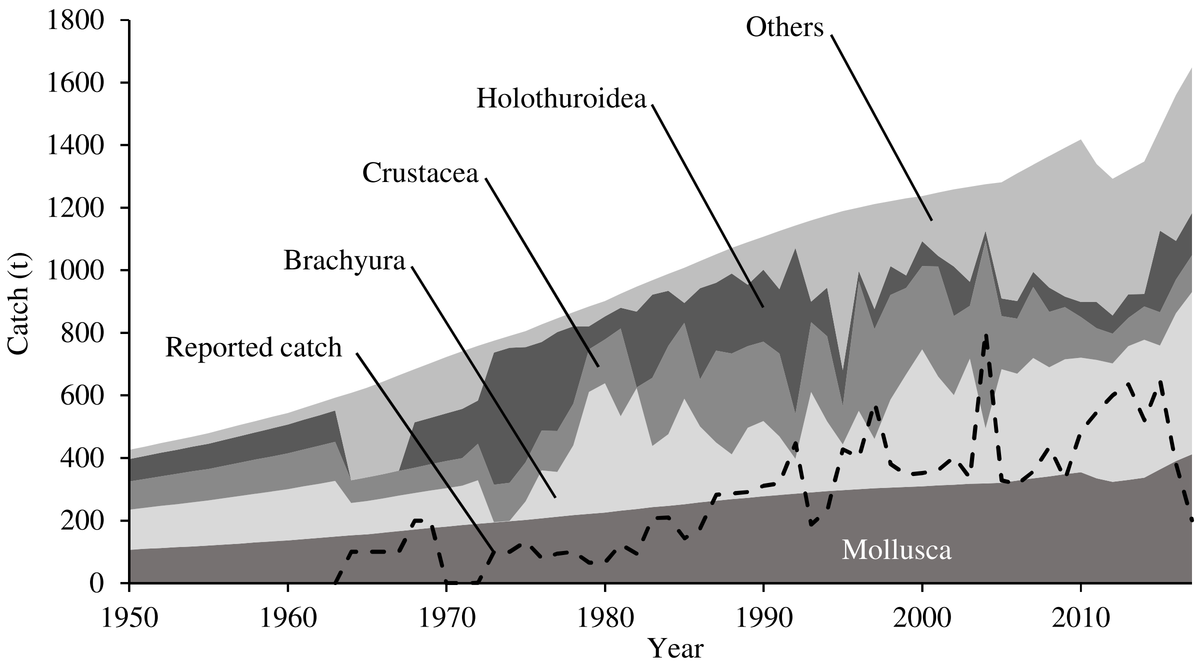

Fig. 3.5 Reported and reconstructed catch of the shore-based gleaner fishery for 1950 to 2017, showing the four dominant taxonomic categories. The remaining two taxa are grouped into 'others'. Reported catch is shown as a black dashed line.<u>Industrial shrimp trawling</u>

The industrial shrimp trawl fishery had the third highest catch of Kenya's domestic fisheries. Total reconstructed catch by the industrial shrimp trawl fishery between 1950 and 2017 was just over 42,000 tonnes, and was approximately 4.3 times higher than catch reported to the FAO (Fig. 3.6).

The majority of industrial shrimp trawl catch was taken between the 1980s and the mid-2000s. Unreported catch was highest during this period (approximately 80%) given that catch reported by the FAO over this period did not include retained or discarded bycatch. However, with the reintroduction of the fishery in 2011, unreported catch dropped to an average of 34%, consisting only of discarded bycatch.

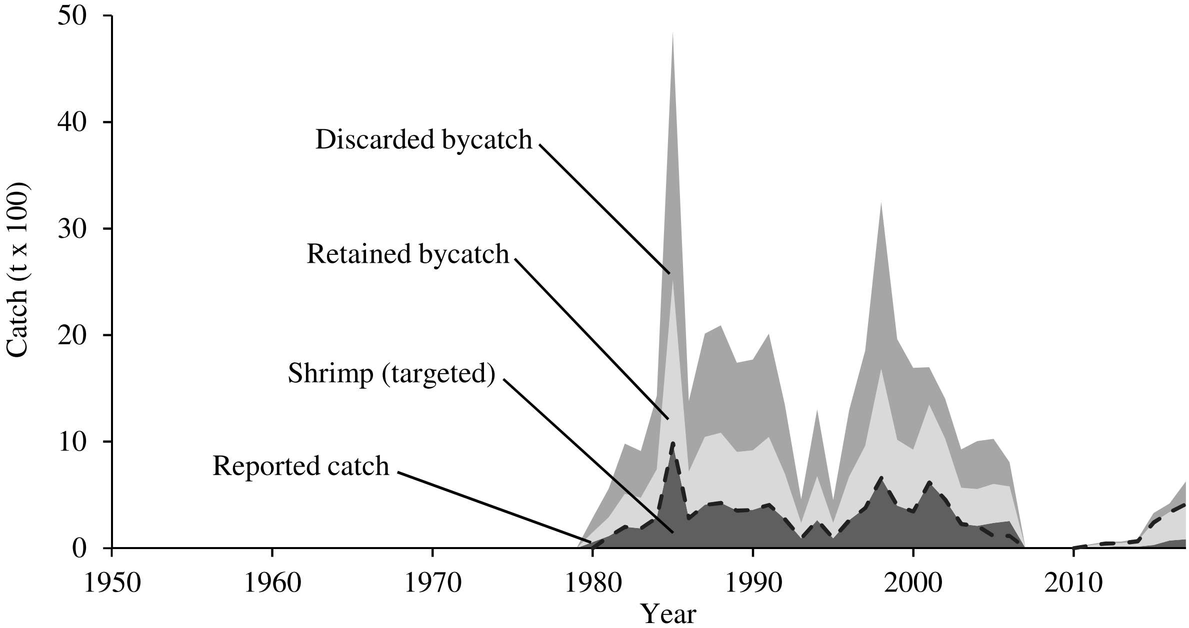

Fig. 3.6 Reported and reconstructed catch by the industrial shrimp trawl fishery from 1950 to 2017, showing the proportion of shrimp (targeted), retained bycatch and discarded bycatch. Reported catch is shown as a black dashed line.

Targeted shrimp catch contributed 21% (approximately 9,000 tonnes) of total catch by the industrial shrimp trawl fishery from 1950 to 2017 and consisted of 10 shrimp and prawn species. Retained bycatch was significantly more diverse with 49 taxa and made up 34% (approximately 14,000 tonnes) of total catch over the time period. Discarded bycatch contributed 45% (nearly 19,000 tonnes) of total catch over the time period and consisted of 45 taxa. The proportion of discarded bycatch remained consistent from 1980 to 1999 at 48% of total catch but decreased to an average of 27% between 2011 and 2017.

3.1.4 Industrial longlining

Total reconstructed catch by Kenya's industrial longliner fishery between 1950 and 2017 equalled approximately 4,500 tonnes (Fig. 3.7).

All catch by the industrial longline fishery was reported until 2010, after which no catch was reported. Total catch during 2011-12 and 2016-17 equalled approximately 600 tonnes.

Industrial longliner catch predominantly consisted of *Xiphias gladius* (swordfish; 30%), *Thunnus obesus* (bigeye tuna; 25%) and *Thunnus albacares* (yellowfin tuna; 23%), followed by *Prionace glauca* (blue shark; 11%) and *Thunnus alalunga* (albacore; 4%). The remaining 7% was composed of 20 other taxa.

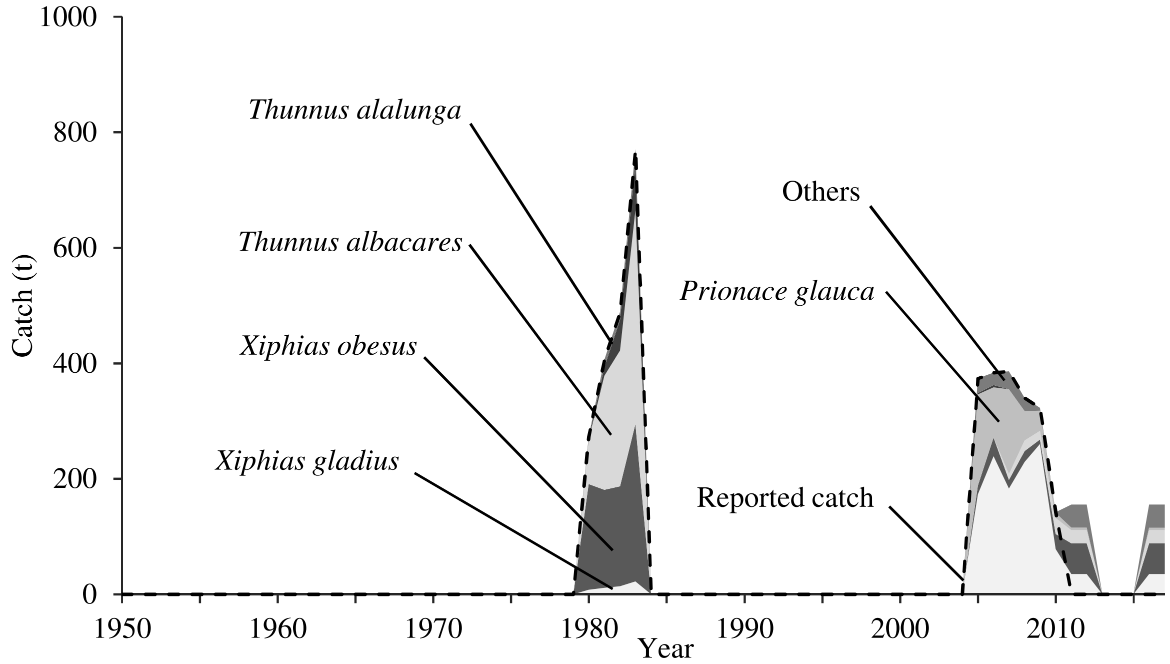

Fig. 3.7 Reported and reconstructed catch by the industrial longline fishery from 1950 to 2017, showing the five major taxa. 'Others' includes an additional 20 taxa. Reported catch is shown as a black dashed line.

3.1.5 <u>Recreational sport fishery</u>

Total reconstructed catch by the sport fishery between 1950 and 2017 was just over 23,000 tonnes, representing 2% of total domestic catch. Annual catches increased steadily from approximately 32 tonnes in 1951 to peak during the early 1990s at just over 700 tonnes (Fig. 3.8). A substantial decrease in catch occurred in 1997, and again between 2010 and 2011. Catch between 2011 and 2017 remained relatively steady at approximately 120 tonnes per year.

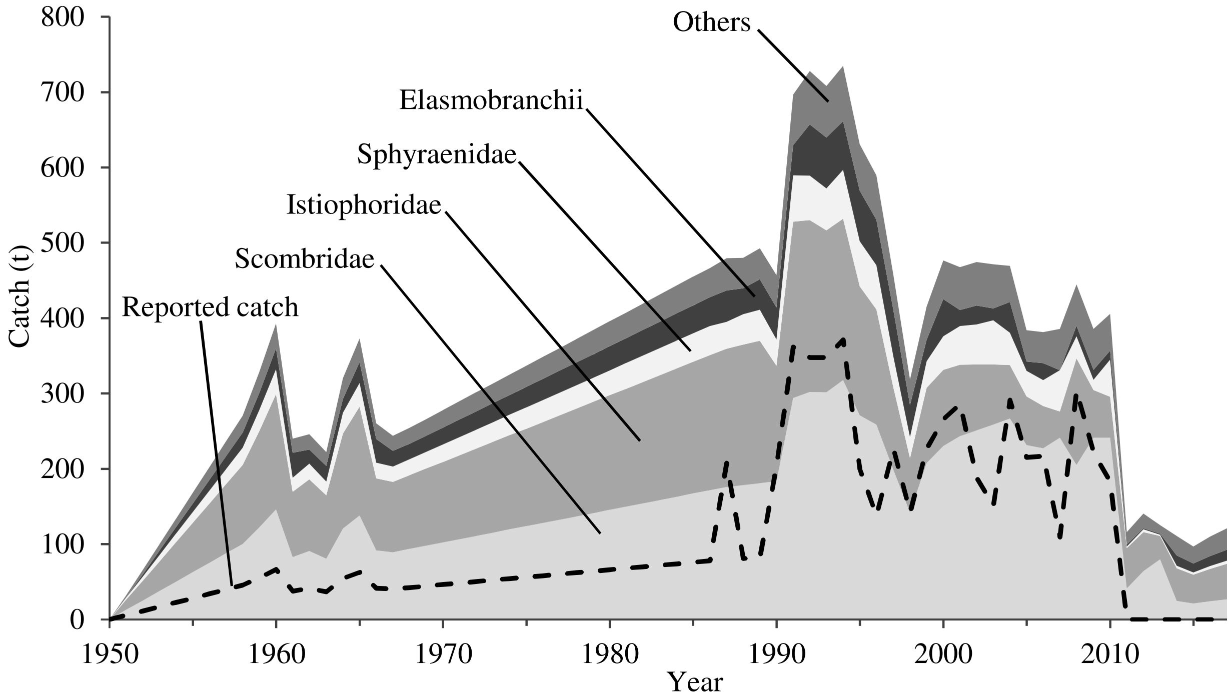

Fig. 3.8 Total reconstructed catch by the recreational sport fishing fleet for 1950 to 2017 showing the five most dominant taxonomic categories. The remaining 12 taxa are grouped into 'Others'. Reported catch is displayed as a black dashed line.

Total reconstructed catch by the sport fishery was 3.3 times higher than catch reported to the FAO. The proportion of total catch that was unreported remained at approximately 80% until 1987, after which it tended to fluctuate between 40% and 70%. In 2010, reporting of recreational sport fishing catch disappeared entirely.

The major taxa making up recreational catch were Scombridae (42%), Istiophoridae (32%), Sphyraenidae (8%), Elasmobranchii (8%) and Coryphaenidae (1%).

3.2 Foreign fisheries

3.2.1 Migrant fishers

Migrant fishers caught just over 70,000 tonnes between 1950 and 2017 (Fig. 3.9). Catch began at approximately 600 tonnes in 1950 and increased to 17,000 tonnes in 1985 before dropping steeply to 500 tonnes in 2000, the lowest catch of the entire time period. After the year 2000 catches began to gradually increase again, reaching nearly 1,000 tonnes by 2017. The trend of migrant fisher catch follows a similar pattern to that of the small-scale coastal fleet due to the assumptions applied to the reconstruction of each fishery.

Catch by the migrant fishery was dominated by Carangidae, Elasmobranchii, Lutjanidae and Serranidae, each making up 15% of total catch. The remaining 40% of catch was composed of 65 taxonomic categories.

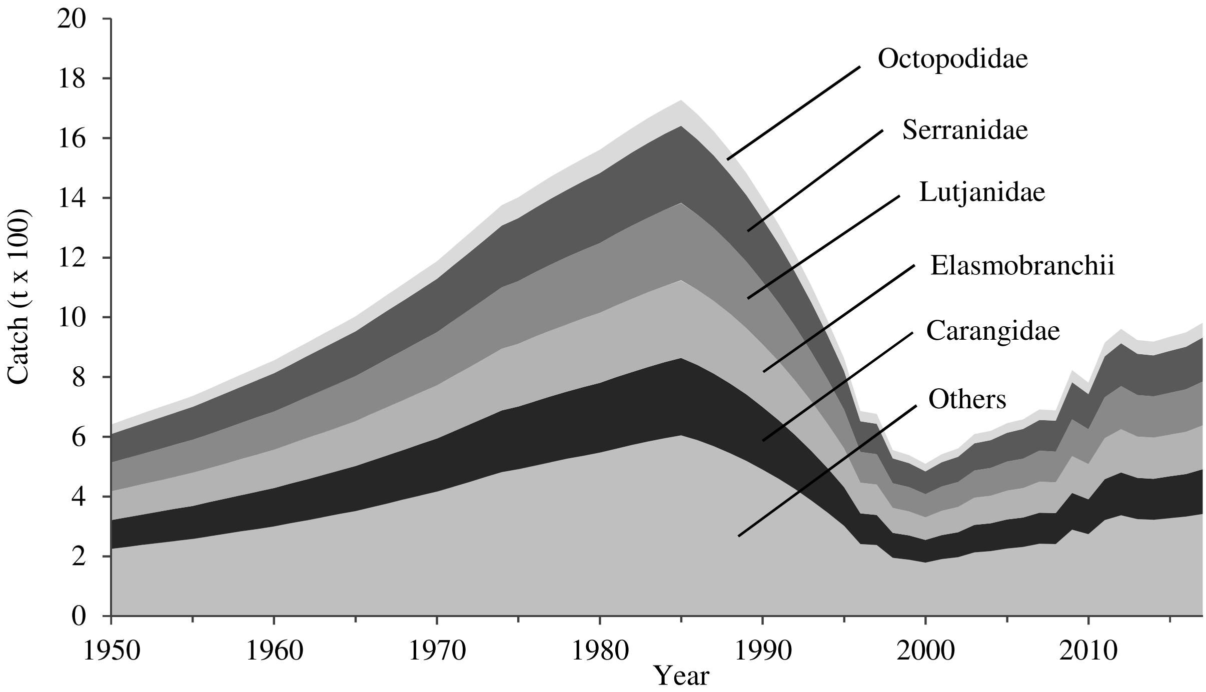

Fig. 3.9 Total reconstructed catch by the small-scale migrant fishery from 1950 to 2017 showing the five major taxa. 'Others' includes an additional 63 taxa.

3.2.2 Foreign tuna fleets

Foreign tuna fleets are estimated to have caught nearly 400,000 tonnes within Kenya's EEZ between 2011 and 2017 (Fig. 3.10), 2.5 times more than the catch estimated to be taken by domestic fisheries over this time period. Catch from 2011 to 2017 showed a slight increasing trend from 55,000 tonnes in 2011 to 56,000 tonnes in 2017. However, no reconstruction of catch by foreign tuna fishing fleets has been conducted for years prior to 2011. Thus, longer term trends in the amount of catch taken by foreign fishing fleets from Kenya's waters are not known.

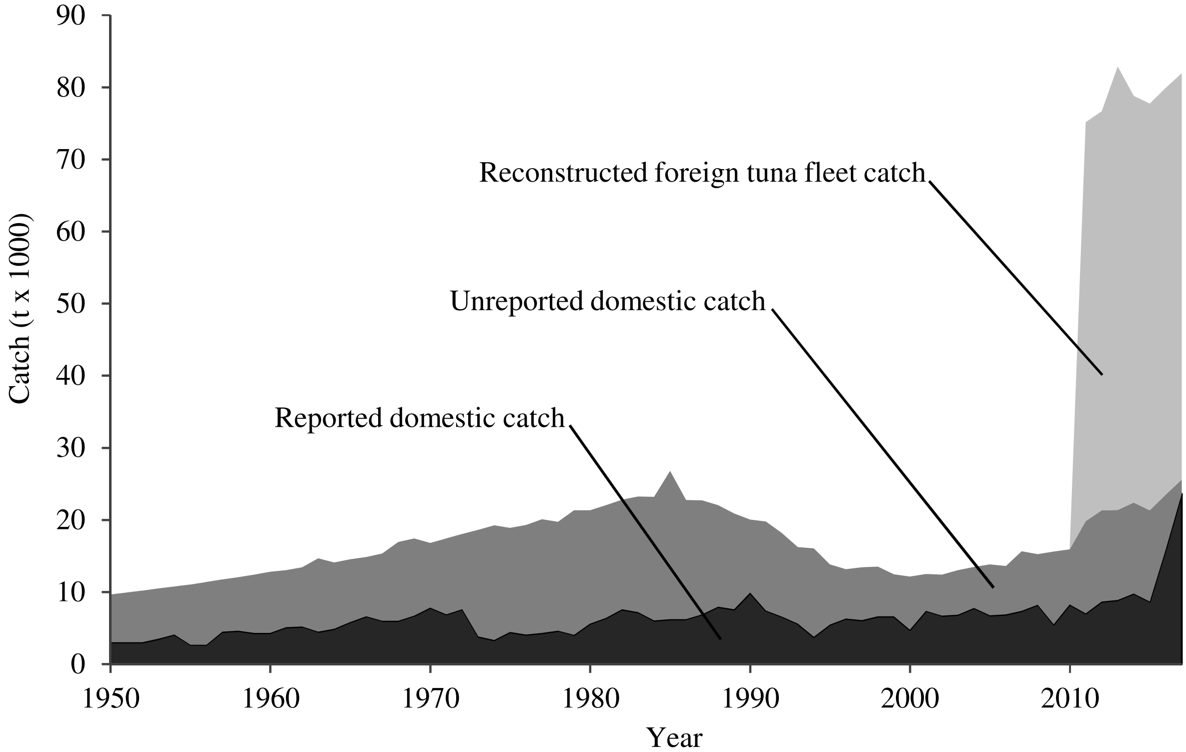

Fig. 3.10 Reconstructed reported and unreported domestic catch (1950-2017) and catch by foreign tuna fleets (2011-2017) in Kenya's EEZ.

Katsuwonus pelamis (skipjack tuna) and *Thunnus albacares* (yellowfin tuna) dominated catch by foreign tuna fleets, making up 48% and 44% of total estimated catch, respectively (Fig. 3.11). The remaining catch consisted of *Thunnus obesus* (bigeye tuna; 8%), *Thunnus alalunga* (albacore; 0.03%), Scombridae (tuna-like species; <1%), and mixed pelagic species (<1%).

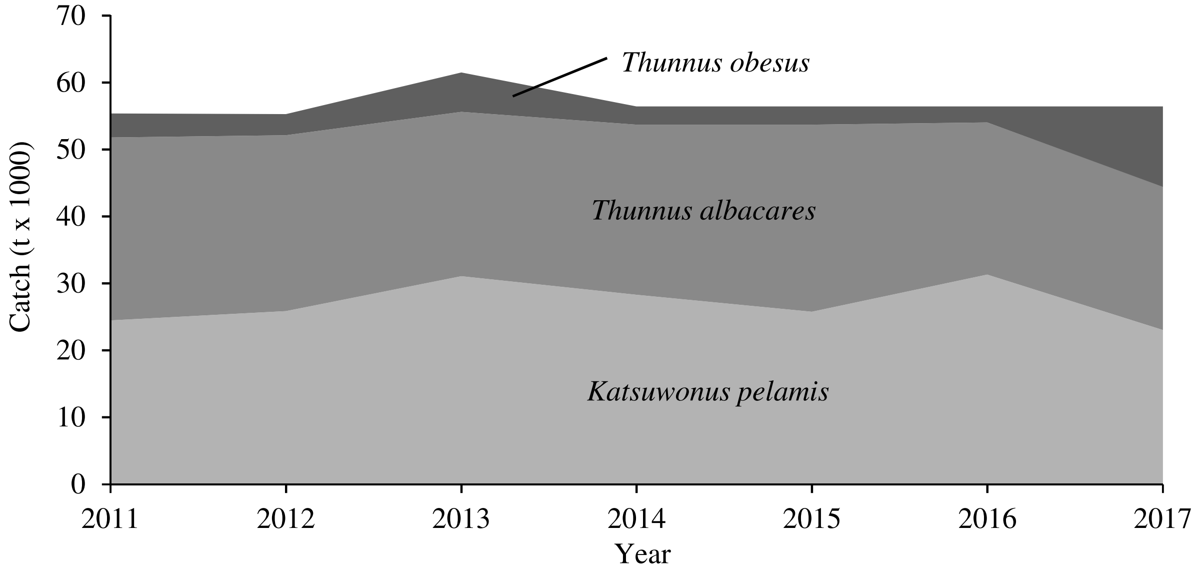

Fig. 3.11 Reconstructed catch taken by foreign tuna fleets within Kenya's EEZ from 2011 to 2017 showing the three dominant taxa.

4 Discussion

4.1 Improved domestic catch reporting

Total reconstructed domestic catches by Kenya between 1950 and 2017 were 2.6 times higher than the landings reported by Kenya to the FAO. Historically, this discrepancy was largely driven by underrepresentation of the small-scale sector, i.e. the coastal fleet and the gleaners, a common pattern throughout developing countries (Kleiber et al. 2015). Targeted attempts by the government to reduce these levels of underreporting since 2010 have made a substantial improvement, with unreported small-scale catch declining to just 6% by 2017. However, attempts to rectify this issue may in fact be overcompensating for it, given that parameter-based estimates of coastal fleet catch resulted in substantially lower catches than sample-based reported catch for the sector (Appendix A). Although the discrepancy may be in part be a result of the conservative approach of catch reconstructions, it also suggests a possible overestimation of total catches stemming from the algorithm used to expand sample-based catches to nation-wide estimates. The expansion step of sample-based systems is a common source of errors (National Research Council 2000). In Mozambique, for example, sampled data were not even extrapolated to nation-wide estimates before being reported (Jacquet et al. 2010). Once exact expansion methods are published by the Kenyan government they can be examined for validity and accuracy and reconstructed catches adjusted accordingly.

Another issue which arises with the catch estimates produced by the new data collection system is the potentially misleading increase that it causes in the reported catch trend. An increase in current catches due to improvements in catch reporting systems without the retroactive correction of past catches is known as 'presentist bias' (Zeller and Pauly 2018). Kenya has now joined just three other countries - Tanzania, Mozambique and Greece - where substantial and traceable presentist bias has been detected (Zeller and Pauly 2018). When retroactive corrections are not applied to official catch data it can have serious consequences for assessments which use trends in catch data to infer the status of fisheries. A study by Rudd and Branch (2016) demonstrated that while consistent under-reporting of catches can still result in recommended catches that are sustainable, it is trends in catch reporting rates that lead to the highest inaccuracy in estimates of fishery status and sustainable catch limits. Thus, future collaborations with the Kenyan government will seek to rectify this issue with the retroactive correction of past catches.

Despite catch by the small-scale coastal fleet nearly tripling under the new data collection system, reported catch by gleaners declined by almost 70% from around 650 tonnes in 2015 to just 200 tonnes in 2017 (Fig. 3.5). Reported catch of the taxa 'Brachyura', '*Crassostrea* spp.', 'Crustacea' and 'Holothuroidea' either declined or disappeared between these years. Although echinoderm and molluscan populations can collapse in very short time-frames (Uthicke et al. 2009), the likelihood of a simultaneous collapse of four different taxonomic groups, each consisting of multiple species, within two years is very low. In addition, government surveys report that gleaner numbers increased over this time, and 2017 catch rates reported by Musembi et al. (2019) were in fact higher than previous years (Marshall 2001). The contribution of gleaners to small-scale fisheries throughout the region is frequently ignored (Unsworth et al. 2019), a pattern that can be embedded in biased sampling methods (Kleiber et al. 2015). The focus of Kenya's sampling system on centralized landing sites, which gleaners frequently bypass (Mirera 2017), is likely driving the omission of gleaner catches in reported statistics. This bias will need to be addressed in the sampling system in future years to ensure that one of Kenya's most valuable fisheries does not continue to go overlooked.

4.2 Catch trends of inshore domestic fishing sectors

Catches by small-scale fisheries increased progressively between 2000 and 2017 (Fig. 3.2), but the driving force behind this increase cannot be determined with confidence until further collaborative corrections can be conducted. It is possible that the ecosystem and fish stock recovery indicated by a number of localised studies (McClanahan and Abunge 2014; Cinner and McClanahan 2015) influenced overall small-scale catches. However, the application of an adjustment factor to the years 2011-2015 means that any effect of stock recovery on total catches between the 2000-2010 and 2011-2017 time periods cannot be ascertained. Once the validity of the new sample-based catch data collection system is confirmed, and historical catches can be retroactively corrected, long-term trends in small-scale catches can be further analysed.

Declines in recreational catches signify the changing nature of the recreational sector, and the need for management in part attributable to fluctuations in tourism during periods of civil unrest in Kenya (Balala 2018). The major driver in recreational catch declines, however, is the emergence of tag and release practices across East Africa (Harris et al. 2013; Pepperell et al. 2017) and the globe (Cooke and Cowx 2004), associated with growing angler conservation awareness. However, the fate of pelagic species after handling and release, and associated mortality, is poorly understood (Graves and Horodysky 2015), and further research is thus needed to better understand post-release mortality rates of large pelagic species in the East African region. The African Billfish Foundation, a charity working along the East African coast, promotes the use of gear-types and handling techniques which minimise physical damage to captured fish (Harris et al. 2013). The translation of regional agendas such as this into local-scale education and management measures is critical to the future sustainability of Kenya's recreational sport fishery.

4.3 Foreign fishing and its implication for domestic industrialisation

Vessels from numerous countries exploit Kenya's productive offshore waters. Foreign tuna-targeting fishing fleets were responsible for the largest portion of reconstructed catch within Kenya's EEZ between 2011 to 2017, with total catches 2.5 times higher than reconstructed domestic catch. Foreign catch reconstructed by this study were based on licencing information for the years 2011-2014. Given that Somali piracy deterred the majority of international vessel traffic in the area during this time (POSEIDON et al. 2014b), it is possible that the number of foreign vessels fishing in Kenya's EEZ prior to the 2011-2014 period was far higher. However, current and historical information regarding the exact number of licenced vessels and associated catch in Kenya's EEZ is extremely limited. This research attempted to provide the best possible estimates in order to establish a baseline to inform future management decisions by the Kenyan government.

Catches by Kenya's own domestic offshore fishery during 2011 to 2017 were less than 0.001% of estimated catch by foreign fleets in Kenya's EEZ, and just 0.004% of total reconstructed domestic catch. The low relative catches of the domestic longline fishery indicates that Kenya's intentions to industrialise and modernise its offshore tuna fleets (Government of Kenya 2017b) are yet to be realised. Kenya's most recent national budget statement suggests that offshore expansion remains on Kenya's agenda, outlining plans to increase support to joint venture and licensing agreements as well as the addition of five deep sea fishing vessels to the domestic fleet (Republic of Kenya 2019). These expansions to offshore fisheries capacity will take place in tandem with improvements to Kenya's limited Monitoring, Control and Surveillance (MCS) capacity, including the establishment of Kenya's first Coast Guard Service, in order to keep a tighter reign over both legal and illegal foreign fishing in its EEZ (Republic of Kenya 2019). An accurate understanding of current offshore exploitation levels is critical to ensuring that an expansion of domestic effort is a replacement rather than an addition to existing fishing effort in offshore waters.

Such an expansion of domestic fishing capacity has the potential to address growing local demand for fish. Local demand for fish is estimated at 500,000 tonnes, but the combined annual total of both inland and marine fisheries production is only around 140,000 tonnes (Republic of Kenya 2019). This gap is filled in part by cheap, low quality fish imports from China (SDF&BE 2016). With the fish stocks of Lake Victoria, Kenya's most important fishery, in serious decline, new avenues of fish production will be critical to ensuring that the gap between local supply and demand does not widen further. Offshore fishing in Kenya's EEZ, estimated as approximately 57,000 tonnes per year, contributes little to meeting local demand. Foreign fishing vessels are legally required to land a minimum of 30% of their catch in Kenya (Government of Kenya 2016), i.e. approximately 17,000 tonnes. However, Kenya currently has no capacity to enforce this regulation making it possible that very little offshore catch is actually being contributed to domestic fish supply. The replacement of foreign fishing effort with a sustainable expansion of its domestic offshore fishery would accord Kenya greater control over its offshore resources, thus securing an ongoing supply of domestically sourced fish that would contribute to the long-term food security of the country.

4.4 Conclusion

Despite employing a conservative approach, the nature of catch reconstructions and their reliance on secondary sources and assumptions mean final reconstructions can often be associated with high levels of uncertainty. The main driver of uncertainty in the domestic reconstruction is the uncertainty associated with the sample-based catch data collection system and its expansion methods. Future investigation into and refinement of these methods will improve the certainty surrounding coastal fleet catch estimates. The second major driver of uncertainty in the domestic catch reconstruction was the limited information regarding catch rates and catch effort of the gleaner fishery. The lack of published information regarding this marginalised but highly valuable fishery suggests that the bias toward boat-based fisheries present in Kenya's sampling methods also extends to scientific research. This bias should be addressed in future fisheries research agendas in order to improve the understanding of this fishery and the impact it may be having on invertebrate fish stocks. Sources of uncertainty in the reconstructed catch for Kenya thus serve to highlight the aspects of Kenya's marine fisheries requiring greater investigation, research and refinement.

The catch data presented by this reconstruction demonstrates that Kenya is on track to improving the data quality of its inshore fisheries. However, improvements are still needed to Kenya's small-scale catch data sampling system to remove bias and ensure the capture of all fisheries in official statistics. These improvements will allow for more accurate catch-based stock and ecosystem assessment methods, such as Catch-based Maximum Sustainable Yield (CMSY), to be conducted, and thus allow for better detection of the effects that localised management such as such as protected areas may be having on the overall health and state of Kenya's marine fisheries. If Kenya is now able to replace extensive foreign offshore fishing with its own sustainable, domestic fishery, then marine fisheries have the potential to become a major contributor to both coastal and national food security and economic development.

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Appendix A: Reconstruction of small-scale coastal fleet catch using a parameter-based approach (2011-2017)

Parameter-based estimates of small-scale coastal fleet catches between 2011 and 2017 were obtained using time-series of the number of fishers, catch-per-unit-effort (CPUE) and annual effort (days fished per year).

The number of fishers involved in the coastal fleet fishery from 2011-2017 was sourced from the biennial government frame surveys. Although the number of boat-based fishers was not explicitly provided, it was calculated by removing the number of "foot fishers" from total fishers in each county. Boat-fisher population was then interpolated between survey years (Fig. 5.1). No frame survey was conducted in 2018 (G Maina, The Nature Conservancy, pers. comm.), so the 2016 fisher counts were multiplied by the average annual growth rate between 2004 (the first survey) and 2016 (the last) in 2016 to calculate the 2017 fisher counts.

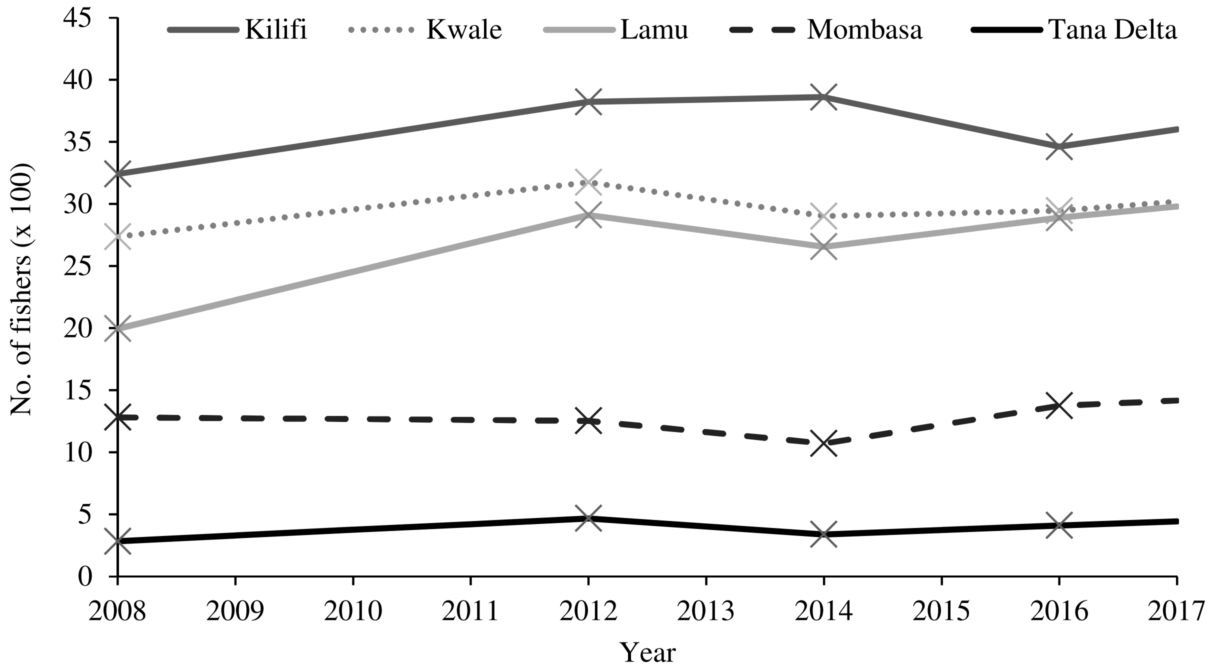

Fig. 5.1 The number of coastal fleet fishers each in each of the five coastal counties in Kenya between 2008 and 2017. Anchor point years, i.e. years where frame surveys were conducted, are represented with an 'X'.

A CPUE (kg/fisher/day) time-series for each county using anchor points found in the government reports and scientific literature (Fulanda et al. 2011; McClanahan and Abunge

2014; Okusa et al. 2016; Dzoga et al. 2018; McClanahan and Kosgei 2019), as described in Table 5.1. Limited information was available on the catch rates of Lamu and Tana Delta, and so anchor points for years prior to 2011 were used to facilitate the estimation of 2011 to 2017 CPUE.

Table 5.1 The catch-per-unit-effort (CPUE) for each of the five coastal counties in Kenya between 2011 and 2017.

County	Period	CPUE	Note	References
Kilifi	2011-2013	3.0	Anchor point; average of 2011-2013[a]	McClanahan and Kosgei (2019)
	2014-2017	3.4	Anchor point; average of 2014-2017[a]	McClanahan and Kosgei (2019)
Kwale	2011-2013	3.9	Anchor point; average of 2011-2013[a]	McClanahan and Kosgei (2019)
	2014-2017	3.6	Anchor point; average of 2014-2017[a]	McClanahan and Kosgei (2019)
Lamu	2007	10.2	Anchor point; average of 2001-2007	Okusa et al. (2016)
	2008-2017	10.3 → 11.5	Increase of 1.2% per year[b]	-
Mombasa	2011-2013	3.9	Anchor point; average of 2011-2013[a]	McClanahan and Kosgei (2019)
	2014-2017	4.8	Anchor point; average of 2014-2017[a]	McClanahan and Kosgei (2019)
Tana Delta	2005	5.0	Anchor point	Fulanda et al. (2011)
	2006-2016	5.0 → 4.4	Linear interpolation between anchor points	-
	2017	4.4	Anchor point	Dzoga et al. (2018)

[a] This study provided averages only for the two time periods 2011-2013 and 2014-2017 for sites in Kilifi, Kwale and Mombasa.

[b] The trend in CPUE was considered to be increasing, similar to Kilifi, its neighbouring county. However, the rate of recovery was considered to be half that of Kilifi's, due to lower management enforcement in the region.

The number of days that fishers were assumed to be active per years was maintained from the previous reconstruction at 220 days (McClanahan and Mangi 2001; McClanahan 2018), as no new or updated information was available. This estimate may be conservative given that there were indications that fishers on the south coast are active closer to 300 days per year (McClanahan et al. 2010).

By multiplying the CPUE time-series of each county by the number of boat fishers in each year followed by the number of fishing days per year, a regional small-scale coastal fleet catch time-series for each county was obtained. These were then combined into a national total catch time-series for this fishery. Reconstructed total catch for 2011-2017 was combined with catch reconstructed by Le Manach et al. (2015b) for 1950 to 2010 and compared to the reported catch baseline (Fig. 5.1).

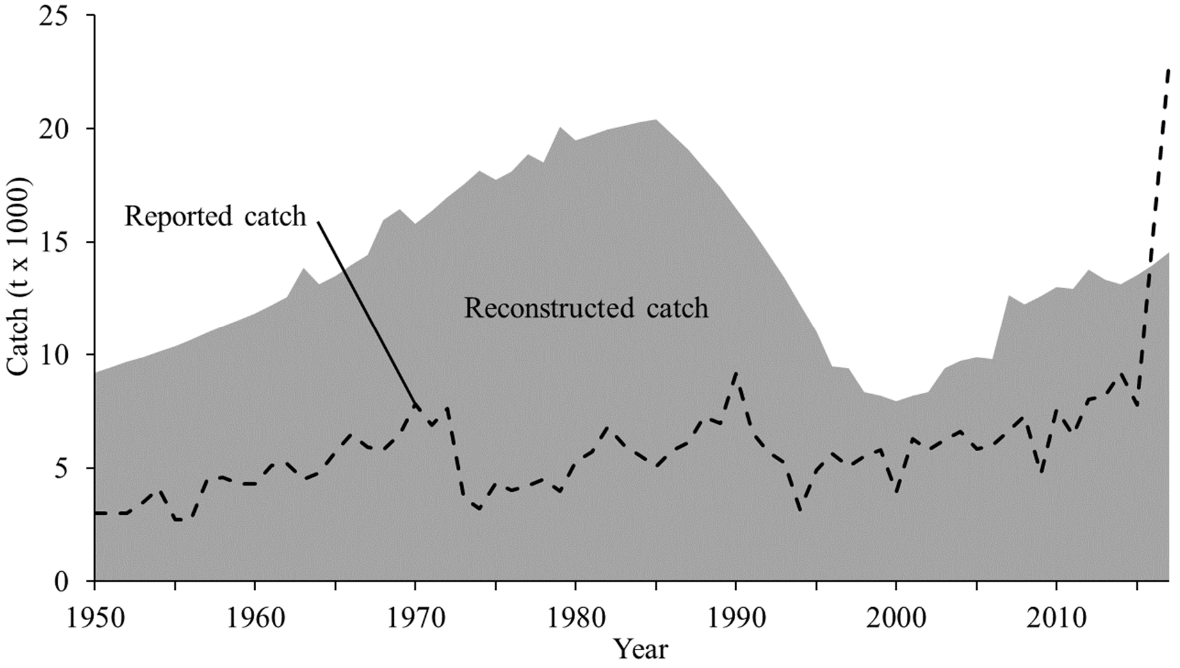

Fig. 5.2 Total reported and parameter-based reconstructed catch by the small-scale coastal fleet from 1950 to 2017. Reconstructed catch for 1950 to 2010 was sourced from Le Manach et al. (2015b). Reported catch is represented by a black dashed line.

Appendix B: Time-series of foreign tuna fleet fishing licences

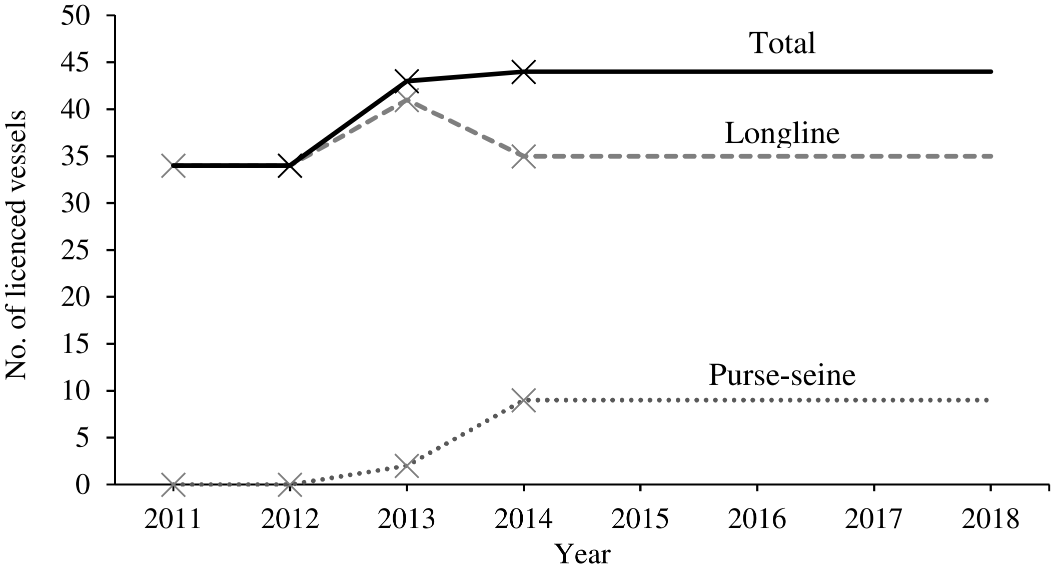

Fig. 5.3 Time-series of the number of purse-seine vessels, longliners and total vessels licenced to fish in Kenya's EEZ between 2011 and 2018 . Crosses represent anchor points (known values).

Appendix C: Uncertainty scores for reconstructed domestic and foreign catches (2011-2017)

Table 5.2 Uncertainty estimates for each major anchor point and assumption used to reconstruct domestic catches between 2011 and 2017 for the five domestic fisheries in Kenya. Uncertainty scores are allocated the categories outlined in **Error! Reference source not found.**, based on the approach by Mastrandrea et al. (2010).

Fishery	Anchor point or assumption	Quality of evidence	Level of consensus	Score	+/- %
Artisanal & subsistence					
Coastal fleet	2017 catch	Medium	Low	2.0	30.0
	2011-2016 catch	Low	Medium	2.0	30.0
Gleaners	Fisher population time-series	High	Medium	2.0	30.0
	CPUE time-series	Medium	Low	1.0	50.0
	Days fished per year	Low	Low	1.0	50.0
Sector average (catch weighted)				1.9	30.9
Industrial					
Shrimp trawling	Discard ratio	High	Medium	3.0	20.0
Longlining	2016 catch	High	High	4.0	10.0
	2011-2012 & 2017 catches	Low	Medium	1.0	50.0
Sector average (catch weighted)				2.9	22.8
Recreational					
Sport fishery	Club catches	Medium	High	3.0	20.0
	International arrivals	High	High	4.0	10.0
Sector average (catch weighted)				3.5	15.0
Total average (catch weighted)				**2.0**	**30.7**

Table 5.3 Uncertainty estimates for each major anchor point and assumption used to reconstruct foreign catches for 2011 to 2017 for the two foreign fisheries active in Kenya during the time period. Uncertainty scores are allocated the categories outlined in **Error! Reference source not found.**, based on the approach by Mastrandrea et al. (2010).

Fishery	Anchor point or assumption	Quality of evidence	Level of consensus	Score	+/- %
<u>Artisanal & subsistence</u>					
Tanzanian migrant fishers	Fisher population time-series	Low	Medium	1.0	50.0
	CPUE time-series	High	High	4.0	10.0
	Days fished per year	High	Medium	3.0	20.0
Sector average				2.7	26.7
<u>Industrial</u>					
Foreign tuna fleets	No. licences 2011-14	High	High	4.0	10.0
	No. licences 2015-2017	Low	Low	1.0	50.0
	Gear-based catch estimates	Medium	Medium	2.0	30.0
	No. months spent fishing in Kenya's EEZ	Low	Medium	1.0	50.0
Sector average				2.0	35.0