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Lots of boats and fewer fishes:

a preliminary catch reconstruction for Senegal, 1950-2010

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ABSTRACT

Senegalese marine fisheries resources are relatively abundant, and their exploitation generates high economic returns for local communities. However, these resources are also exploited by large distant-water (or foreign) fleets, which compete with an artisanal effort that has increased to dangerous levels. Meanwhile, the impact of artisanal fisheries is as poorly known as the extent of illegal unreported and unregulated industrial fishing, with the former relying on official surveys, while the occurrence and the extent of the latter was denied. The increasing far-reaching and frequent forays of Senegalese artisanal fishers into the waters of neighbouring countries, the under-estimation of fishing effort and the increasing documented conflicts over fisheries resources suggest that the official statistics, which indicate an increasing domestic catch, may not reflect reality. A thorough literature review and experts and industry consultation were performed to reconstruct Senegalese fisheries data. Official national data were compared to the data supplied to FAO and adjusted from 1950 to 2010, reported and missing sectors were re-assessed, including artisanal catches within and outside Senegalese waters, non-commercial sectors, and industrial catches by the legal, so-called 'domestic' fleet, and by foreign and illegal fleets. The results showed that catches were under-reported by a factor of three; of a total domestic catch of 29.4 million tonnes, only 14.4 million tonnes were reported to the FAO, while foreign extractions were estimated at 15.4 million tonnes including 4.5 million tonnes generated by the illegal fleet. Artisanal catches were responsible for half of total extractions in the last 60 years, compared to around 80%-90% suggested by official data. Additionally, while catches by migrant fishers increased drastically, artisanal catches from the Senegalese Exclusive Economic Zone (EEZ) declined, despite an increasing effort, which implies overcapacity and overfishing. Without seriously addressing the overcapacity problems (both foreign and domestic), there is little prospect to improve the situation for artisanal fishers of Senegal, who will then have to amplify their migrations, resulting in more conflicts, higher cost, but still fewer fish.

INTRODUCTION

Senegal is located at the edge of two of the most productive fishing zones in the world, the Canary Current Large Marine Ecosystem and the Gulf of Guinea Large Marine Ecosystem, between 14°40′N and 17°25′W. This, along with upwelling systems and a relatively wide continental shelf of 23,800 square km, makes

Senegal one of the most productive fisheries in West Africa and consequently in the world (Sutinen *et al.* 1980; Goffinet 1992; Pramod and Pitcher 2006).

Senegal's history was marked by major shifts: it was first occupied by important ethnic groups as part of the Empire of Ghana, after which the *Jolof* Empire, proper to Senegal was established in the 13th century. During this period, the slave trade was so important in the area that around one third of the population was captured and deported to the Americas by competing European powers, mostly the Netherlands, Portugal and Great Britain. This lasted until the area was handed over to France, which, after 1677, used what is now called the Ile de Gorée as a staging point for its slave trade. After almost three centuries of occupation, France granted independence to the 'Mali Federation' comprised of Senegal and the 'French Sudan' (actual Mali). This contract lasted only a few months, and both Mali and Senegal proclaimed their independence, with Senegal choosing its first president in September 1960. This historical path, and the interest of the colonial power in natural resource exploitation, made Senegal one of the few countries for which scientific data on primary resources were available. For example basic data on Senegalese fisheries were available through the 'Institut Français (now 'Fondamental') de l'Afrique Noire' (IFAN) for the 1950s (e. g., Doumenge 1962; Pelissier 1966), in sharp contrast to, e.g., never-colonized Liberia. Moreover, strong ethnic diversity of coastal communities and fishers' migrations from different parts of West Africa over centuries, which also lead to increasing coastal ethnic diversity, contributed to Senegal's long fishing tradition (Goffinet 1992). Senegal, in 1979, was also the first African country to sign a fishing agreement with the European Union (EU), which aimed to establish a domestic industrial fleet and develop its artisanal fleet. Today, a considerable segment of the Senegalese artisanal fleet is capable of long-distance operations.

Fisheries gained a key role in Senegal in rebalancing the economy after the decline of groundnut and phosphate exports since the 1970s (Pramod and Pitcher 2006). The sector now uses approximately 20,000 pirogues and 100 large-scale industrial fishing vessels, employs over 600,000 people (about 1/5th of the working population of Senegal) and provides over 75% of animal protein intake of the local population (Horemans and Kebe 2006). With 36 kg•year-1, Senegal has the second highest per capita fish consumption in Africa (York and Gossard 2004).

The motorization of the small-scale artisanal sub-sector, the uncontrolled issuance of fishing licenses, expanding market and fishing subsidies at first contributed to raising fish catches and trade (Lenselink 2002). ; however, these factors now combine to intensify the decline of Senegalese fisheries (Dahou *et al.* 2001). Over-expansion in fisheries capacity resulted in the over-exploitation of many fish stocks in Senegal and drove some high-value species, such as groupers to commercial extinction (Pramod and Pitcher 2006; Thiao *et al.* 2012). Indeed, all demersal stocks have declined drastically, while the small-pelagic species, which now contribute to the bulk of the fish consumption of the local population, are overexploited (CRODT 2001).

Official data in Senegal refer to two main sub-sectors, one being the small-scale artisanal fisheries, relying overwhelmingly on *pirogues*, i.e., large wooden canoes (Fontana and Weber 1982). The other sub-sector is industrial and consists of large-scale vessels, i.e., domestic and foreign trawlers targeting demersal fish and especially shrimp (in both shallow and deeper waters), and vessels targeting large pelagic fishes such as tuna and small-pelagic fishes such as sardinella(Samba 1994).

The official statistics submitted by Senegal to FAO suggest a mean annual catch of about 400,000 t·year^{-1} for the period from 1997 to 2009, which is lower than the estimated 'maximum sustainable yield' (MSY) between 450,000 and 600,000 t·year^{-1} (CRODT 2001). Assuming the latter estimate is correct would imply that either (*i*) fishing effort is not high enough to extract MSY, or (*ii*) fishing effort is excessive, and MSY can be reached by *reducing* fishing effort. The second hypothesis is by far the most likely because of

the prevailing overcapacity and the excessive effort that results from it. Nevertheless, the lack of reliable catch statistics for segments of the industrial sub-sector such as foreign fishing, the discarding of by-catch, and the non-consideration of sub-sectors such as recreational and subsistence fishing, all together have led to a situation where overall removals from the Senegalese EEZ are unknown. Hence, issues related to the sustainable exploitation of Senegalese marine resources cannot be addressed straightforwardly (Lenselink 2002; FAO 2004; ICCAT 2004; Pramod and Pitcher 2006).

Reliable fisheries catch statistics are the key to effective fisheries management. However in West Africa they are particularly untrustworthy (Goffinet 1992), and in many cases, they at least explain part of the failure of the many management and fisheries development programs in the region, including in Senegal, (Brottem 2002; UNEP 2004). Similarly development programs did not usually show the expected positive impact on fisheries management; indeed, all they did was increasing fishing capacity, particularly of the artisanal fleet (Deme and Dioh 1994).

One of the major goals of this paper is to quantify realistic fisheries removals from Senegalese waters and identify the trend of fisheries for a sixty years' time-period as a first step towards understanding the story behind a great traditional fishing nation succumbing to overcapacity and over-exploitation.

METHODS

In Senegal, two national organisations independently monitor the same fisheries using different methods (Barry *et al.* 2004). In the case of artisanal fisheries, The Department of Fisheries (*Département des pêches maritimes*, D.P.M.) relies, at least in part, on a system where declarations (by registered fishers) of expected catches are exchanged for fuel subsidy vouchers (Ndiaye 2013; Najih Lazar, University of Rhode Island, pers. comm.), completed by on-site surveys, mostly to obtain fishing effort data and catch data, however still relaying on incomplete and very doubtful fishers declarations (Ndiaye 2013). The second national entity is the Centre for Oceanographic Research of Dakar - Thiaroye (*Centre de recherches océanographiques de Dakar – Thiaroye*, CRODT), which relies on a monthly survey of 5 major landing sites; a sample of effort and catches is taken and then extrapolated on the total effort. While the DPM method would suggest over-declaration of catches, it must be noted that fishers need to be registered to obtain this fuel subsidy (and thus report to the DPM), and that a large number of fishers are not registered in Senegal. Whereas the approach by CRODT appears to be statistically more rigorous, the extrapolation that it implies relies on the registered effort, which is strongly under-estimated –at least in areas not covered by CRODT. In the case of industrial fisheries, the system relies mostly on declarations on deck at Dakar fishing port, vessel owners declarations at the DPM to obtain an export certificate, and a few observers' reports (when vessel owners are willing to collaborate).

Thus, although there is a documented collection system of landings and an extrapolation system, the collection system is heavily dependent on fisher's willingness to share information. Frequently, fishers do not collaborate, jeopardizing the reliability of the data (Diouf 1991; Ndiaye 2013). The *Cellule d'études et de planification* (CEP) created in 2000, collects the data from the DPM and other institutions, harmonizes them, and sends the results to international organizations, notably FAO. Time series on commercial fishing activities, including artisanal and industrial sectors, were available from four major sources, CRODT, DPM, CEP and FAO. The CRODT data subsequent to 1999 were not made available for the purposes of this study. Although, for some time periods, there were major inconsistencies in these datasets especially for the industrial sector (Figure 2a & b), the effort data were emphasized in our attempt to create a realistic baseline for the purpose of this catch reconstruction.

Non-commercial catches such as subsistence and recreational fisheries are not covered by the official statistics system (Ba 2006). Although a few at-sea surveys describe discarding by the industrial fleets, in great details, discards are not included in the data reported to FAO. Here we estimate (1) artisanal

catches, (2) industrial catches, (3) subsistence catches, (4) recreational catches, (5) illegal catches, and (6) discards.

Small scale fisheries

Artisanal

There are serious gaps in Senegalese monitoring and enforcement. This also applies to the artisanal sector given the low human and financial resources (Anon. 2007). A fisheries registration system was amended for artisanal fleets of Senegal; however due to the strong reluctance of fishers (Ndiaye 2013), a large number of pirogues are yet to be registered. Therefore, these non-registered pirogues are not reported in official data. As a consequence, any extrapolation based on this official number of pirogues would lead to an under-estimated artisanal catch. Until very recently, artisanal fishing effort was not subject to any registration constraint, nor did artisanal fishers have to obtain a fishing licence (Deme and Dioh 1994; Ndiaye 2013), therefore, the estimation of artisanal effort is based on a few surveys. The surveys conducted by the CRODT started in 1974; today, they cover essentially the Cote Nord, Cap-Vert, Petit-Côte, and only occasionally Sine Saloum and Casamance (Ferraris *et al.* 1994b). CRODT uses the DPM effort data to complete effort estimates for the two latter areas (Ferraris *et al.* 1994a). Coverage of landing sites (via extrapolations) increased from 1970s to the 1980s. However, in the light of recent surveys, the effort used for extrapolation appears under-estimated.

For example, the report by Deme *et al.* (2012) shows a clear discrepancy between the effort used for extrapolation in the years when there is no census *versus* the years when the effort was surveyed all along the Senegalese coast (e.g. sardinella effort). The same report shows an increase of three folds between 2004 (no census) and 2005 (census), due to hundreds of gears being left uncounted in 2004 (Deme *et al.* 2012). Furthermore, the effort used by the CRODT only covers three major fishing areas, but excludes Sine Saloum, which also means that there is a systematic under-estimation of effort (Deme *et al.* 2012). Moreover, fisheries agents and observers in certain villages depending almost exclusively on fishing only report what fishers, at the end of the fishing trip, report to their offices (Walter 2006).

Artisanal catch data in Senegal include two major components, i.e., artisanal catches taken within the Senegalese EEZ and the large (but ill-documented) catch of the Senegalese artisanal fleet from the EEZs of neighbouring countries. The latter is operated by so-called 'migrant fishers' who land their catches in Senegal. Herein, five countries were identified as common destinations of the migrant fishers: Mauritania, The Gambia, Cape Verde, Guinea Bissau, Guinea and Sierra Leone. However, catches from Cape Verde were believed to be insignificant and those from Sierra Leone were transhipped to so-called mother ships, mostly from Korea (Anon. 2013) and are therefore excluded from the present analysis. Data on the effort, catch, year of the agreement and gear, available from different literature sources, were assembled and processed such as to allow for the estimation of catches taken outside the Senegalese EEZ, but landed in Senegal.

As for the reported baseline, two datasets by DPM were available from multiple sources between 1955 and 2010 (Doumenge 1962; Gulland and Troadec 1973; Rieucau 1984; DPM 1999-2011) and by CRODT between the 1970s and 1998 (Gulland and Troadec 1973; Barry *et al.* 2004) and data from the CEP between 1999 to 2010 (CEP, unpub. data). We performed a series of linear interpolations as needed. The comparison of DPM and CRODT datasets from 1981 to 1998, shows no major difference, which allowed us to obtain a baseline by simply averaging the two time series of landings during this time period; for the same reason, we also averaged estimates between CEP and DPM catches for 1999 and 2010 (Figure 2c), and used the DPM data for the remaining time period as it overall corresponded to the data supplied to FAO.

Thereafter, to re-assess artisanal catches, we calculated the average gap between the effort used for extrapolation and the surveyed effort for 2010 (8,672 pirogues compared to 17,500) and 2005 (9,509 pirogues compared to 12,619), i.e., 67%. We assumed catches were under-reported by 67% in the 2000s, and by doubling this estimate for 1982 (to 134%), before the extension of CRODT coverage. For the 1950-1972 time period, we again doubled the previous estimate (to 269%), before the DPM extended its coverage. This approach assumes that before the DPM extended its coverage in 1972, catch data were heavily under-estimated, the under-estimation declined with the increasing coverage by first DPM (1972-1982) and then by CRODT (1982-2000). We interpolated these percentages (correction factors) to fill in the gaps, and then applied the completed time series of correction factors to the reported artisanal landings. There is probably, in Senegal, a substantial catch of nominally 'recreational' fishers (or 'Sunday fishers') who actually sell their catch, but no attempt is made here to quantify this component of the catch, here labelled 'Subsistence I' (see subsection on 'Subsistence', below).

Catches outside the Senegalese EEZ (migrations)

Seasonal migrations of Senegalese fishers were already documented in the 1950s, involving Mauritania, The Gambia, Guinea Bissau and Guinea (Chauveau 1991). At that time, however, the available engines, and the non-availability of ice required these distant-water fishing forays to be brief (Lawson and Robinson 1983; Chaboud and Kebe 1990; Thiam and Gascuel 1994; Failler and Binet 2010). With the improving technology, a new form of migrations emerged in the late 1960s, lasting up to 10 days per trip, with the fish being landed in Senegal (Failler and Binet 2010; Binet *et al.* 2012) . As a result, fish that had been depleted from Senegalese waters, such as snappers (*Lutjanus* spp.), barracudas (*Sphyraena* spp.) and groupers (*Epinephelus* spp.), continued to be exported in large quantities from Senegal, although they were caught in e.g. Guinea Bissau (Agnew *et al.* 2010). Catch data by country from outside Senegal's EEZ were available; catches of around 100,000 tonnes for a period of six months were estimated (Elaborating on Binet *et al.* 2012). Using the total number of trips to Mauritania (Table 1), and the number of pirogues operating in Mauritania for the same year (300), we estimated the average number of trips per year at 37. Then, by dividing the total catch per country (scaled on a 12 months period – doubled –, see Table 1) by the number of fishing trips, we estimated the number of pirogues operating in each country per year (Table 1).

Table 1. Catches and catch per unit of effort of the Senegalese pirogues in neighbouring countries.

Country	Catch[a] (t·year^{-1})	%[b]	Fishing trips[c]	CPUE (t·pirogue^{-1}·year^{-1})	Pirogues
Mauritania	5,604	28	934	355	300
The Gambia	7,945	39	1,324	114	425
Guinea Bissau	6,392	32	1,065	174	342
Guinea	313	2	52	125	17

a) for 6 months, doubled later on to estimate the CPUE;
b) catch per country as percent of total catches from outside the Senegalese EEZ;
c) fishing trips for that part of the artisanal fleet that goes to each country.

Then, we estimated the CPUE per pirogue by dividing the total catch by the number of pirogues for 2010, assuming the same number than for 2012. The beginning of these short term migrations where catches are landed in Senegal (Failler and Binet 2010) would correspond to the date of the first agreement signed between Senegal and its neighbors, i.e., 1974 for Mauritania (Weber and Durand 1986), 1967 for The Gambia (Weber and Durand 1986) and 1970 with the first protocol allowing Senegalese fishers to operate in Guinea Bissau (Baran and Tous 2000). Also, we assumed that Senegalese migrant fishing started in 1990 for Guinea, when artisanal fishers expanded their fishing grounds to Guinea, although no agreement

Table 2. Number of Senegalese pirogues operating in neighbouring countries.

Years	Mauritania	Gambia	Bissau	Guinea	Sources
1950-1965	0	0	0	0	
1966	0	0	0	0	Weber and Durand (1986)
1967	0	*6*	0	0	
1968	0	*13*	0	0	
1969	0	*20*	0	0	
1970	0	*26*	0	0	Baran and Tous (2000)
1971	0	*33*	*43*	0	
1972	0	*40*	*87*	0	
1973	0	*46*	*131*	0	Weber and Durand (1986)
1974	*22*	*53*	*175*	0	
1975	*44*	*60*	*218*	0	
1976	*66*	*67*	*262*	0	
1977	*88*	*73*	*306*	0	
1978	*110*	*80*	350	0	Anon. (1978)
1979	*132*	*87*	*350*	0	
1980	*154*	*93*	*350*	0	
1981	*176*	*100*	*349*	0	
1982	*198*	107	*349*	0	Chauveau and Laloe (1985)
1983	*220*	*119*	*349*	0	
1984	*242*	*130*	*349*	0	
1985	*264*	*141*	*348*	0	
1986	*286*	*153*	*348*	0	
1987	309	*164*	*348*	0	Chaboud *et al.* (1988)[a]
1988	290	*176*	*348*	0	Diop and Thiam (1991)[b]
1989	*286*[c]	*187*	*347*	0	
1990	*283*	*198*	*347*	0	Failler and Binet (2010)
1991	*280*	*210*	*347*	1	
1992	*277*	*221*	*347*	2	
1993	*274*	*232*	*346*	3	
1994	*271*	*244*	*346*	3	
1995	*268*	*255*	*346*	4	
1996	*265*	*267*	*346*	5	
1997	*262*	*278*	*345*	6	
1998	*259*	*289*	*345*	7	
1999	*256*	*301*	*345*	8	
2000	*253*	*312*	*345*	8	
2001	250	*323*	*344*	9	Ould Abeid and Gaye (2009)
2002	*257*	*335*	*344*	10	
2003	*263*	*346*	*344*	11	
2004	270	*357*	*344*	12	Ould Abeid and Gaye (2009)
2005	270	*369*	*343*	13	Ould Abeid and Gaye (2009)
2006	*276*	*380*	*343*	13	
2007	*282*	*392*	*343*	14	
2008	*288*	*403*	*343*	15	
2009	*294*	*414*	*343*	16	
2010	300	425	342	17	Estimated

a) Around 42% of the Mauritanian fleet, landing in St. Louis (Senegal) according to the authors;
b) The authors estimated 2,895 Senegalese migrant fishers in Mauritania, we assumed 10 fishers per pirogue and estimated the number of pirogues;
c) Although Diop and Thiam (1991) reported no agreement given the political events of 1989, it is widely recognized that fishers continued fishing and landing in Senegal.

was signed (Failler and Binet 2010). Given the dramatic increase in the intensity of migrations (Chauveau 1991; Failler and Binet 2010), the number of trips would have been much lower in the 1970s, increased in the 1980s and expended dramatically in the 1990s and 2000s (along with the number of pirogues) as documented by Failler and Binet (2010). Therefore, we interpolated linearly the number of trips form zero the year before the first fishing agreement was signed for each country (Table 2) to 37 in 2010, resulting in the estimation of the annual number of trips per pirogue per country. Then we interpolated linearly the number of pirogues available from different literature sources (Table 2) to complete the effort time series. Catches from the EEZ of each country are then obtained as the product of the effort by the CPUE per pirogue for each country. While the use of the date of the first agreement per country is indicative of the date these fishers started their short-term migrations, migrant fishers' catches also include catches taken outside agreements, e.g. catches after the 1989 events between Senegal and Mauritania where Senegalese fishers momentarily lost legal rights to fish in Mauritania.

Catches within the Senegalese EEZ

Catches inside the Senegalese EEZ were estimated as the difference between the total estimated artisanal catch and the artisanal catch taken from outside the Senegalese EEZ.

Subsistence catches

There are three types of subsistence fisheries in Senegal, i.e., one which overlaps with the artisanal fisheries (Subsistence I; see above), a second which overlaps with recreational fisheries (Subsistence II, see section below), and a third type (Subsistence III), matching more closely the definition for subsistence fishing, i.e., fishing for one's own consumption, or that of one's family.

In Senegal, Subsistence III-type fisheries occur in the Casamance area, where local communities fish for consumption usually on lagoons (Cormier-Salem 1994). Chaboud *et al.* (1987) estimated around 59 villages fishing for personal consumption using land-based fishing gears. These populations rarely fish along the coast (Cormier-Salem 1994), therefore, only catches from estuarine and lagoon areas were estimated here. The take home portion of the catch by artisanal fishers was estimated at 10% (Abdou Karim sall, artisanal fisher. pers. com; Chaboud and Kebe 1989). This catch is considered as already accounted for as part of the artisanal fishery (Moustapha Deme, CRODT, pers. com.). Although there is no evidence of this portion being accounted for in official data, this allows obtaining a more conservative estimate, and may be captured in the unreported artisanal catch.

Evidence suggests the historical presence of a large shellfish fishery in Senegal through gleaning since the early 1900s (Gruvel 1908; Pelissier 1966). Large deposits of bivalves called *restes de cuisine* (cooking waste) by archeologists testify about the presence of a traditional subsistence fishery in the area (Walter 2006). Not only were the bivalves eaten, but their shells were used for local constructions and roads.

Although this activity is nowadays partially directed to small-scale trade, it remains a complementary activity for artisanal fishing, just like agriculture, and is therefore considered subsistence fishing (Grandcolas 1997; Walter 2006). Reizer (1988), for example, reported that a large and unknown number of intermittent fishers were operating in the North of Senegal, most of them fishing for food or as a last resort for income compensation (Horowitz and Salem-Murdock 1993). This activity is not only a source of food, it is also cultural, social and economic (Walter 2006). However, it is nowadays more trade-oriented than it was before.

Subsistence mollusc and bivalve fishing is a frequent activity in Senegal; oysters, for example, are extremely appreciated in the Senegalese traditional dish called *Thié bou dien*. These activities are mostly practiced by women collecting the oyster *Crassostrea gasar*. Women were targeting mostly fish species;

however, after the 1968 drought, women shifted their fishing activities to bivalves and molluscs (Grandcolas 1997). Catches are consumed directly and/or exchanged for some high staples food like rice, or sold.

Using the surveyed quantity of barrels and buckets of oysters (Table 3) documented by Grandcolas (1997), where one bucket produces 0.6 kg of dried oysters, one barrel produces 0.5 kg of dried oysters, and assuming that half a pirogue is equivalent to 70 kg wet weight, we estimated the weighted average of the dried weight provided and applied a conversion factor given by FAO at 5.3 to estimate the wet weight per day. Grandcolas (1997) also surveyed the number of weekly fishing days per person and the number of months. We estimated the weighted average catch at 136 days·fisher^{-1}·year^{-1}. Similarly, Descamps (1994) estimated a catch of 25 kg·day^{-1} for 126 fishing days. Therefore we averaged the two daily CPUEs and the number of days; the annual CPUE is the product of the number of fishing days and the daily average catch, i.e., 3.1 t·fisher^{-1}·year^{-1}.

Detailed literature reviews covered only 39 villages (Grandcolas 1997; Deme *et al.* 2000; Walter 2006), over the total 59 villages observed by Chaboud *et al.* (1987). Chaboud *et al.* (1987) estimated the number of fishers at 4,000 (for 1987). Grandcolas (1997) identified through direct surveys three categories of villages: villages where most of women fish (70% of the adult female population), villages where many women fish (40%), villages where 10 to 40 women fish, and villages where less than 10 women fish. Thus, we could estimate the number of women fishing (percentage of fishers) for the 15 villages provided by Grandcolas (1997) for 1988, and consequently the percentage of women fishing over the population of women. We applied this percentage on the women population per village provided by Grandcolas (1997) for 1992 and estimated the number of fishers in the same 15 villages for 1992. By multiplying the number of women by the percentage of fishers for 1998 (Walter 2006), we estimated the number of fishers for three villages in 1998. Deme *et al.* (2000) surveyed the number of fishers in 31 villages for 2000 (2,282 fishers for the *Saloum* area), and Walter (2006) observed the number of women fishing in three villages for 2006. We could then estimate the chronological variation in the number of fishers when the latter was reported or estimated for two consecutive years for the same villages. For example, for the years 1992 and 1998, 15 villages were overlapping, thus by estimating the percentage of variation, we could complete the number of fishers for the year 1992 for the remaining 23 villages where no estimates were provided. We then divided the number of fishers by the total population of Senegal in 1987 and 2006 respectively and applied the resulting per capita rates to the population of 1950 and 2010 to estimate the number of fishers. We multiplied the catch rate by the number of fishers per year and estimated total subsistence catches in Senegal from 1950 to 2010. When bivalve catches decline, women shift their fishing strategy to fish and *vice-versa* to compensate for the declining catch. Therefore, the catch rate was kept constant.

Table 3. Estimation of the daily catch oyster rate per subsistence fisher

Number of fishers	Quantity of oysters	Dried weight (kg)	Wet weight (kg·day^{-1})
20.5	6 buckets	3.60	19.18
1	10 buckets	6.00	31.80
1	20 buckets	12.00	63.60
1	1 bucket	0.60	3.18
1	1 bucket	0.60	3.18
1	2.5 barrels	1.25	6.62
1	0.5 pirogue	-	70.00
1	50 kg	-	50.00
Weighted mean			**22.60**

Taxonomically, although the study by Grandcolas (1997) referred to 'oysters', this author provided a species list which enabled assessing that oysters represented only 43% of the catches, the rest consisting of other molluscs (10%), the snail *Cymbium* sp. (43%), and miscellaneous fish species (4%).

Recreational catches

The first accounts of tourism in Senegal date back to the post-independence period in the 1960s, when tourists visited Senegal for recreational fishing. Manel (2008) estimated that 4% of tourists were visiting Senegal for that purpose. Their average time of stay was estimated at 10 days per year per tourist in 2008 (Manel 2008), including 5 days spent fishing[1]. The number of visitors to Senegal was given by different sources (Table 4), which however, include the short-term stays of visitors other than tourists. ANSD (2011) provided the number of leisure tourists per year for the period between 2008 and 2010 (Table 4), i.e., 25% of the visitors to Senegal, a fraction which was assumed constant during the 1960-2010 time-period. We applied this fraction to the total number of short-term visitors to Senegal and obtained the number of leisure tourists (Table 4), and then calculated the number of recreational fishers as the product of the percentage of tourists going exclusively to fish (4%) and the total number of leisure tourists (Table 4). Although the CPUE per fishing trip ranged between 35 and 350 kg per day, (M. Mamadou Sow, President of the Senegal Federation for Recreational Fishing, pers. comm.) using the minimum CPUE per day allows for a more conservative estimate. We assumed the CPUE was 10% higher in 1950 relatively to 2010 to reflect –at least symbolically- on the general over-exploitation pattern of near-shore species observed in Senegal, then interpolated linearly. We multiplied the resulting CPUE by the number of fishing trips and the estimated number of recreational fishers to estimate total tourist-based recreational catches in Senegal.

Table 4. Estimation of the number of recreational tourist fishers in Senegal. Interpolations (other than those shown in Italic here) were performed to fill in the gaps for the missing years.

Year	Tourists	Reference	Leisure tourists	Fishers
1950-1959	0	-	-	0
1960	*7,573*	Fishing started here (Manel 2008)	*1,893*	81
1988	219,609	Dehoorne and Diagne (2011)	*54,902*	2,347
1992	267,878	Dehoorne and Diagne (2011)	*66,969*	2,863
1995	279,635	Tchitou (2005)	*69,909*	2,989
1996	282,169	Tchitou (2005)	*70,542*	3,016
1997	313,642	Tchitou (2005)	*78,411*	3,352
1998	352,389	Tchitou (2005)	*88,097*	3,766
1999	369,116	Tchitou (2005)	*92,279*	3,945
2000	389,433	Tchitou (2005)	*97,358*	4,162
2001	396,254	Tchitou (2005)	*99,064*	4,235
2002	426,825	Tchitou (2005)	*106,706*	4,562
2003	495,000	Index Mundi (2013)	*123,750*	5,290
2004	667,000	Index Mundi (2013)	*166,750*	7,129
2005	769,000	Index Mundi (2013)	*192,250*	8,219
2006	866,000	Index Mundi (2013)	*216,500*	9,255
2007	875,000	Index Mundi (2013)	*218,750*	9,352
2010	900,000	Deiry Diallo (2011)	220,000	9,405

[1] http://www.atlantic-evasion.com/Sejours+Senegal [Accessed on 23/05/2013].

There is also a recreational fishery operated by Senegalese recreational fishers rather than tourists. However, it appears to be difficult to separate from a subsistence fishery ('Subsistence II, see above). We have no attempt here to quantify this component, although it could be substantial.

Large scale fisheries

Industrial fishing activities in Senegal began in 1950 for demersal resources and in the early 1960s for small-pelagic fishes (Garcia *et al.* 1979; Chavance and Chavance 2004). Both were mostly foreign based, or called 'domestic' fleets which were dominated by joint venture agreements (Stilwell *et al.* 2010). Vessels of foreign origin operating in Senegal since the 1950s were only documented in numbers in the early 1960s, and remained largely unknown for the time period between then and the 1990s. These vessels often based in the port of Dakar, were commonly confused with the domestically flagged fleet (Gianni and Simpson 2005).

The industrial fleet was at first composed of small Mediterranean trawlers targeting species of sparids and serranids; then in 1965, the shrimp trawl fishery started by redeploying the trawler effort to shrimps, which generated a high by-catch of soles (*Cynoglossus* spp.), lesser African threadfin (*Galeoides decadactylus)*, catfishes (*Arius* spp.) and croakers (*Pseudotolithus* spp. and *Umbrina* spp.). Fish and freezer trawlers arrived in 1971 and 1977, respectively, when the demersal fleet benefited from the explosion of the octopus population in the 1980s (Fall *et al.* 2006).

Catches by the fleet flagged to Senegal

Herein, we reconstructed separately domestic catches for each segment of the fleet, i.e., the trawl fleet, tuna and small-pelagic purse-seine fleets. We used the formula developed by Belhabib *et al.* (In press), also explained in a version of the report in French (Koutob *et al.* 2013), and obtained catches as the product of the daily CPUE ($t \cdot GRT^{-1} \cdot day^{-1}$), by the average GRT for each segment of the fleet (by origin) by the number of days, then multiplied by the number of vessels, here respectively trawlers and purse-seiners (for tuna and small pelagics). The CPUE was estimated by Belhabib *et al.* (In press) using the Monte-Carlo method (Pauly *et al.* 2013) at 14.8 $kg \cdot GRT^{-1} \cdot day^{-1}$ for 2010. We used the observed catch and GRT per vessel data (Caverivière and Rabarison Andriamirado 1988) and estimated a weighted average of 20.2 $kg \cdot GRT^{-1} \cdot day^{-1}$ between 1985 and 1988. Then we interpolated to 14.8 $kg \cdot GRT^{-1} \cdot day^{-1}$ in 1999 (Belhabib *et al.* In press). We assumed the CPUE was 20% higher in 1950 due to strong over-exploitation, and then interpolated linearly to complete the CPUE time series. The number of boats was interpolated from 1950 to 2010 (Table 5). The number of fishing days for the trawl fleet along with the average GRT was given by Thiam and Gascuel (1994) from 1971 to 1985. We assumed the GRT in 1950 was 10% lower than in 1971 given an observed increase in capacity (Samba 1994) and interpolated to 259 GRT (Table 5), which is the average GRT for the domestic Senegalese trawl fleet between 1999 and 2010 (Belhabib *et al.* In press).

Similarly, the small-pelagic purse-seine GRT was reported for 1983 at 118 GRT (Rieucau 1984), 185 GRT for 2010 (Belhabib *et al.* In press) and assumed to be 10% lower in 1950 compared to the GRT of 1983. We followed the same method for the GRT of the tuna fleet, where the average GRT was estimated at 306 GRT for 2010, assumed 10% lower in 1950. We interpolated linearly GRT estimates for the tuna and purse-seine fleets and calculated the annual average GRT weighted by the number of tuna vessels and small-pelagic purse-seiners (Table 5). The number of days for the purse-seiners was estimated at 167 days (Belhabib *et al.* In press) and assumed to be 90 days for tuna boats (based on the average license time for these vessels). We assumed the number of days fished was constant between 1950 and 2010, calculated the weighted average and then estimated catches as the product of the GRT by the CPUE, the number of days and the number of boats for two main segments, trawl and purse-seine (purse-seine include both small pelagic and tuna purse-seiners). Senegalese vessels were of European origin until the beginning of the 1990s (Rieucau 1984), when vessels from China and countries known to offer flags of convenience

(FoC) started reflagging their vessels to Senegal. Therefore, all trawl catches were taken by vessels that were of European origin from 1950 to 1991; however, in 1991, the vessels of Chinese origin (including those floying FoC) started to appear. Thus, we interpolated the estimated catch from zero in 1991 to the first estimate by Belhabib *et al.* (In press) for China and the FoC category, and then from 90,408 t·year^{-1} for 1991 estimated herein to the first estimate by Belhabib *et al.* (In press) for vessels of EU origin. Similarly, 46% of the purse-seine fleet was of French origins, and the remainder could only be allocated to Senegal (Rieucau 1984). Therefore we assumed that 46% of the purse-seine catch was by domestic vessels of French origin between 1950 and 1991, and 100% Senegalese origin between 1999 and 2010, and interpolated linearly to fill in the gap.

Foreign catches

Catches and catch composition by European fleets operating in Senegalese waters are poorly documented (Kaczynski and Fluharty 2002; Stilwell *et al.* 2010). It is well recognized that, in the past, foreign fleets barely reported their catches and refused to land them in Senegal (Nguyen-Van-Chi-Bonnardel 1969). Today's dominant mode of going around the legal obligations of reporting all, and landing part of the catch in Senegal, has shifted towards unmonitored transhipment at sea. This is facilitated by the fact that the presence of onboard observers is only required when a vessel is over 300 GRT (i.e., vessels from the EU, which have a higher average GRT), but which nevertheless tend to deny access to observers (Kaczynski and Fluharty 2002).

Table 5. Effort description of the domestic Senegalese industrial fleet. Italics indicate estimations.

Year	Trawl fishery			Small pelagic seiners			Tuna seiners			CPUE (kg·GRT·day^{-1})	Total catches (t·year^{-1})
	Number	GRT	fishing days	Number	GRT	fishing days	Number	GRT	fishing days		
1950	0[a]	73[d]	*153*	0[a]	106[d]	167[f]	0[d]	275	90	24.2	0
1951	0[a]	*74*	*153*	0[a]	*106*	167[f]	0[d]	*275*	90	*24.1*	0
1952	0[a]	*74*	*153*	0[a]	*107*	167[f]	0[d]	*276*	90	*24.0*	0
1953	0[a]	*75*	*153*	0[a]	*107*	167[f]	0[d]	*276*	90	23.9	0
1954	0[a]	*75*	*153*	0[a]	*108*	167[f]	0[d]	*277*	90	23.8	0
1955	0[a]	*75*	*154*	0[a]	*108*	167[f]	0[d]	*277*	90	23.7	0
1956	0[a]	*76*	*154*	0[a]	*108*	167[f]	0[d]	*278*	90	23.5	0
1957	0[a]	*76*	*154*	0[a]	*109*	167[f]	0[d]	*279*	90	23.4	0
1958	0[a]	*76*	*154*	0[a]	*109*	167[f]	0[d]	*279*	90	23.3	0
1959	0[a]	*77*	*154*	0[a]	*109*	167[f]	0[d]	*280*	90	23.2	0
1960	11[a]	*77*	*154*	0[a]	*110*	167[f]	0[d]	*280*	90	23.1	3,030
1961	20[a]	*78*	*155*	1[a]	*110*	167[f]	*1*	*281*	90	23.0	6,608
1962	26[a]	*78*	*155*	1[a]	*110*	167[f]	*2*	*281*	90	22.8	8,901
1963	23[a]	*78*	*155*	1[a]	*111*	167[f]	*4*	*282*	90	22.7	8,685
1964	33[a]	*79*	*155*	1[a]	*111*	167[f]	*5*	*282*	90	22.6	12,050
1965	36[a]	*79*	*155*	1[a]	*111*	167[f]	*6*	*283*	90	22.5	13,474
1966	39[a]	*80*	*156*	2[a]	*112*	167[f]	*7*	*283*	90	22.4	15,416
1967	34[a]	*80*	*156*	3[a]	*112*	167[f]	*9*	*284*	90	22.3	15,117
1968	38[a]	*80*	*156*	3[a]	*113*	167[f]	*10*	*284*	90	22.2	16,814
1969	54[a]	*81*	*156*	4[a]	*113*	167[f]	*11*	*285*	90	22.0	22,327
1970	68[a]	*81*	*156*	5[a]	*113*	167[f]	*12*	*285*	90	21.9	27,277
1971	69[a]	82[e]	156[e]	6[a]	*114*	167[f]	*13*	*286*	90	21.8	28,604
1972	69[a]	83[e]	155[e]	5[a]	*114*	167[f]	*15*	*286*	90	21.7	28,841
1973	93[a]	95[e]	156[e]	16[a]	*114*	167[f]	*16*	*287*	90	21.6	44,543
1974	90[a]	104[e]	164[e]	18[a]	*115*	167[f]	*17*	*287*	90	21.5	49,123
1975	91[a]	118[e]	159[e]	11[a]	*115*	167[f]	*18*	*288*	90	21.3	50,509
1976	80[a]	110[e]	167[e]	13[a]	*115*	167[f]	*19*	*288*	90	21.2	46,444
1977	116[a]	111[e]	144[e]	12[a]	*116*	167[f]	*21*	*289*	90	21.1	54,392

Table 5. *Cont.*

1978	119[a]	122[e]	150[e]	10[a]	*116*	167[f]	*22*	*289*	90	21.0	61,005
1979	117[a]	167[e]	157[e]	15[a]	*116*	167[f]	*23*	*290*	90	20.9	82,038
1980	132[a]	189[e]	160[e]	18[a]	*117*	167[f]	*24*	*290*	90	20.8	102,698
1981	135[a]	157[e]	163[e]	15[a]	*117*	167[f]	*26*	*291*	90	20.7	90,251
1982	150[a]	194[e]	150[e]	20[a]	*118*	167[f]	*27*	*291*	90	20.5	110,815
1983	145[a]	167[e]	154[e]	20[a]	118[g]	167[f]	28[g]	*292*	90	20.4	98,268
1984	133[a]	185[e]	163[e]	12[a]	*122*	167[f]	*27*	*292*	90	20.3	99,436
1985	145[a]	180[e]	165[e]	8[a]	*127*	167[f]	*25*	*293*	90	20.2	102,327
1986	144[a]	*186*	*175*	5[a]	*131*	167[f]	*24*	*293*	90	20.2	108,194
1987	144[a]	*191*	*175*	5[a]	*136*	167[f]	*22*	*294*	90	20.2	110,474
1988	137[a]	*197*	*175*	5[a]	*140*	167[f]	*21*	*294*	90	19.7	105,731
1989	139[a]	*203*	*175*	9[a]	*145*	167[f]	*19*	*295*	90	19.3	109,063
1990	124[a]	*208*	*175*	9[a]	*149*	167[f]	*18*	*295*	90	18.8	98,516
1991	131[a]	*214*	*175*	8[a]	*154*	167[f]	*17*	*296*	90	18.4	102,451
1992	*131*	*220*	*175*	*8*	*158*	167[f]	*15*	*296*	90	17.9	113,288
1993	*130*	*225*	*175*	*8*	*163*	167[f]	*14*	*297*	90	17.5	124,125
1994	130[b]	*231*	*175*	7[b]	*167*	167[f]	*12*	*297*	90	17.0	134,963
1995	*137*	*236*	*175*	*7*	*172*	167[f]	*11*	*298*	90	16.6	145,800
1996	*144*	*242*	*175*	*6*	*176*	167[f]	*9*	*298*	90	16.1	156,637
1997	*151*	*248*	*175*	*5*	*181*	167[f]	*8*	*299*	90	15.7	167,475
1998	*158*	*253*	*175*	*5*	*185*	167[f]	*6*	*299*	90	15.2	178,312
1999	165[c]	259[f]	317[f]	4[c]	185[f]	167[f]	5[c]	*300*	90	14.8	179,207
2000	167[c]	259[f]	317[f]	5[c]	185[f]	167[f]	5[c]	*300*	90	14.8	164,990
2001	155[c]	259[f]	317[f]	4[c]	185[f]	167[f]	2[c]	*301*	90	14.8	151,668
2002	142[c]	259[f]	317[f]	4[c]	185[f]	167[f]	2[c]	*301*	90	14.8	142,445
2003	132[c]	259[f]	317[f]	3[c]	185[f]	167[f]	4[c]	*302*	90	14.8	135,271
2004	124[c]	259[f]	317[f]	3[c]	185[f]	167[f]	5[c]	*302*	90	14.8	110,677
2005	98[c]	259[f]	317[f]	2[c]	185[f]	167[f]	8[c]	*303*	90	14.8	137,321
2006	122[c]	259[f]	317[f]	2[c]	185[f]	167[f]	10[c]	*303*	90	14.8	121,949
2007	110[c]	259[f]	317[f]	1[c]	185[f]	167[f]	8[c]	*304*	90	14.8	94,280
2008	80[c]	259[f]	317[f]	1[c]	185[f]	167[f]	11[c]	*304*	90	14.8	88,131
2009	74[c]	259[f]	317[f]	1[c]	185[f]	167[f]	11[c]	*305*	90	14.8	86,082
2010	77[c]	259[f]	317[f]	0[c]	185[f]	167[f]	7[c]	306	90	14.8	74,809

a) Samba (1994);
b) Ndiaye (2000) reported a total of 137 vessels for 1994, of which 94% (estimated average) were trawlers and 6% purse seiners;
c) Extracted from DPM reports (DPM 1999, 2001, 2002, 2003, 2004, 2007a, 2007b, 2007c, 2008, 2009, 2010, 2011)
d) Assumption;
e) Thiam and Gascuel (1994);
f) Belhabib *et al.* (In press);
g) Rieucau (1984).

Furthermore, foreign catches, when based on reported accounts, are widely suspected to be low (Goffinet 1992). Goffinet (1992) suggested one way of estimating foreign catches was to multiply their typical capacity (here average CPUE per GRT) by their estimated number of fishing days and the number of vessels, assuming that vessels would target areas where catches are high. Therefore, we used the same approach as than above: we first obtained foreign effort anchor points per country (Table 6), then divided the effort per country by the sum of the effort for all countries to obtain the percentage of the effort per country each time anchor points were documented. We assumed that foreign fishing started in 1950 (Chavance and Chavance 2004); therefore each country was allocated 0% of the foreign effort in 1950, and then we interpolated linearly to complete the time series. We assembled data on the total number of foreign vessels fishing in Senegal (Table 6) and then multiplied the previous percentages (per country) by this total effort whenever per country effort data were missing, to estimate the number of vessels for each country. We multiplied the typical average GRT estimated by Belhabib *et al.* (In press) for each flag –

assuming the GRT was 10% lower in 1950- by the corresponding number of days (Belhabib *et al.* In press), the number of vessels and the CPUE per GRT (as estimated previously). The effort used herein is slightly lower than the total non-disaggregated effort documented by other sources (Figure 3), which allows our estimates to be conservative.

Table 6. Total and per country effort authorized in Senegalese waters. Italics indicate estimations (multiplication or interpolation).

Year	Total	Spain	France	Port.	Italy	The Gamb.	Antil.	St Vinc.	Venez.	Cape V.	Russia	Poland	Maur.	Others	Gabon	Greece	Guinea Bissau
1950	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*0*
1980	163[a]	*101*	*2*	*0*	*15*	*0*	*0*	*0*	*0*	*0*	*0*	*3*	*0*	*10*	*0*	*12*	*0*
1983	*116*	41[d]	1[d]	0[d]	6[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	3[d]	0[d]	4[d]	0[d]	5[d]	0[d]
1985	85[a]	*56*	*2*	*1*	*8*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*7*	*0*	*7*	*0*
1990	135[a]	*83*	*8*	*5*	*8*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*14*	*0*	*8*	*0*
1992	*119*	*70*	*8*	*6*	*6*	*0*	*0*	*0*	*0*	*0*	12[e]	*0*	*0*	*14*	*0*	*7*	*0*
1993	*110*	*64*	*8*	*6*	*5*	*0*	*0*	*0*	*0*	*0*	12[e]	*0*	*0*	*13*	*0*	*6*	*0*
1994	102[a]	*59*	*8*	*6*	*4*	*0*	*0*	*0*	*0*	*0*	12[e]	*0*	*0*	*13*	*0*	*5*	*0*
1995	*95*	*54*	*8*	*6*	*3*	*0*	*0*	*0*	*0*	*0*	12[e]	*0*	*0*	*13*	*0*	*5*	*0*
1996	*89*	*49*	*8*	*6*	*3*	*0*	*0*	*0*	*0*	*0*	12[e]	*0*	*0*	*12*	*0*	*4*	*0*
1997	*82*	*44*	*8*	*6*	*2*	*0*	*0*	*0*	*0*	*0*	12[e]	*0*	*0*	*12*	*0*	*3*	*0*
1998	75[a]	*40*	*8*	*6*	*1*	*0*	*0*	*0*	*0*	*0*	12[e]	*0*	*0*	*11*	*0*	*3*	*0*
1999	96[b]	44[b]	9[b]	7[b]	1[b]	3[b]	0[b]	0[b]	2	0	12[e;b]	0[b]	0[b]	13[b]	0[b]	3[b]	2[b]
2000	93[b]	49[b]	19[b]	1[b]	0[b]	4[b]	0[b]	0[b]	3[b]	7[b]	0[b]	0[b]	0[b]	7[b]	0[b]	3[b]	0[b]
2001	82[b]	52[b]	20[b]	1[b]	2[b]	0[b]	2[b]	0[b]	1[b]	1[b]	0[b]	0[b]	0[b]	0[b]	0[b]	3[b]	0[b]
2002	103[b]	67[b]	22[b]	2[b]	3[b]	0[b]	2[b]	1[b]	2[b]	0[b]	0[b]	0[b]	3[b]	0[b]	1[b]	0[b]	0[b]
2003	62[b]	44[b]	10[b]	1[b]	3[b]	0[b]	0[b]	1[b]	0[b]	2[b]	0[b]	0[b]	0[b]	0[b]	1[b]	0[b]	0[b]
2004	41[b]	38[b]	0[b]	1[b]	0[b]	0[b]	1[b]	0[b]	1[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
2005	37[b]	32[b]	2[b]	2[b]	0[b]	0[b]	0[b]	0[b]	1[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
2006	18[b]	14[b]	3[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	1[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
2007	10[b]	5[b]	4[b]	0[b]	0[b]	1[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
2008	10[b]	5[b]	4[b]	0[b]	0[b]	1[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
2009	8[b]	8[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
2010	8[b]	8[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Days[c]	-	318	318	318	318	230	230	230	230	230	230	230	230	230	230	318	230
CPUE	1950	221	221	221	221	203	203	203	203	203	5904	5904	203	203	203	221	203
	1999 - 2010	246	246	246	246	225	225	225	225	225	6560	6560	225	225	225	246	225

a) Ndiaye (2000);
b) Extracted from DPM reports (DPM 1999, 2001, 2002, 2003, 2004, 2007a, 2007b, 2007c, 2008, 2009, 2010, 2011);
c) Belhabib *et al.* (Present volume);
d) Rieucau (1984);
e) FAO (2003);

Illegal fisheries catches

Belhabib *et al.* (In press) and Koutob *et al.* (2013) estimated illegal fishing in Senegal from 2000 to 2011. We first estimated a baseline catch for 2011 using available data, then used the inter-annual variations (percent change) of the ratio of the arrested/inspected vessels to extrapolate catches backwards. Herein, we follow the same approach; however, between 1985 and 2010, we derived the percentage of change from the total number of infractions observed by Johnstone (1996) for the period between 1985 and 1995, and by Kelleher (2002) between 1996 and 2001. We used the percentage of change from $year_{t+1}$ to $year_t$ to extrapolate illegal catches by flag (Russia, Europe and FoC vessels mainly of Chinese origin) between 1995 and 2001 (Table 7), then we interpolated from zero in 1950 when industrial fishing began in Senegalese waters. The catch estimated in this fashion prior to the ratification of UNCLOS by Senegal in 1984 are considered 'unregulated', not illegal.

Table 7. Variation rates of illegal catches in Senegal

Year	Infractions	Inter-annual Variation (%)	Reference
1950	0	0	Assumption
1985	75	53	Johnstone (1996)
1986	49	-5	Johnstone (1996)
1987	52	26	Johnstone (1996)
1988	41	-13	Johnstone (1996)
1989	47	-25	Johnstone (1996)
1990	63	2	Johnstone (1996)
1991	62	114	Johnstone (1996)
1992	29	-32	Johnstone (1996)
1993	43	-3	Johnstone (1996)
1994	44	-23	Johnstone (1996)
1995	57	-11	Kelleher (2002)
1996	64	31	Kelleher (2002)
1997	49	26	Kelleher (2002)
1998	39	-20	Kelleher (2002)
1999	49	-21	Kelleher (2002)
2000	62	Baseline	Kelleher (2002)

Discards

One incentive to discarding by the industrial fleets in Senegal is the by-catch limits which the Senegalese law sets at 2 to 10% of the landed catch (Pramod and Pitcher 2006), with all by-catch in excess of the limits resulting in penalties. As a result, discard rates of the trawling fishery are high, ranging between 40% and 70% of the total catch (Monoyer 1980; Gulland and Garcia 1984; Caverivière and Rabarison Andriamirado 1988; Thiam and Gascuel 1994; Kelleher 2002; Emanuelsson 2008). Here, we assembled historical data on discards (Table 8), we performed a series a linear interpolations, and then applied the resulting percentages to industrial trawl catches. Similarly, discards for pelagic freezer trawlers (mostly those from Eastern Europe) were observed at 12% of total catches (ter Hofstede and Dickey-Collas 2006). These were then applied to pelagic trawler catches assuming the discard rate was constant between 1950 and 2010.

Table 8. Anchor points for the trawl fishery discard rates and corresponding taxonomic composition

Year	Discard (%)	Reference	Species	Reference
1950	85	Assumed constant	n.a.	Garcia *et al.* (1979) and Monoyer (1980)
1974[c]	85	Assumption[a]	*Pagellus belottii* (40%), *Trichiurus lepturus, Epinephelus aeneus, Pseudotolithus* spp. and *Arius* spp. (60%)[b]	Garcia *et al.* (1979) and Monoyer (1980)
1979-1980	72	Gulland and Garcia (1984); Monoyer (1980)[b]	*Pagellus belottii* (40%), *Trichiurus lepturus*, *Epinephelus aeneus*, *Pseudotolithus* spp. and *Arius* spp. (60%)[b]	Garcia *et al.* (1979) and Monoyer (1980)
1985	70	Caverivière and Rabarison Andriamirado (1988)	*Brachydeuterus auritus*, *Galeoides decadactylus*, *Chloroscombrus chrysurus*, *Sepia* spp., *Trichiurus lepturus*, *Arius* spp., *Pseudotholithus* spp., *Cynoglossus monodi*	Caverivière and Rabarison Andriamirado (1988)
1986	67	Caverivière and Rabarison Andriamirado (1988)	*Brachydeuterus auritus*, *Galeoides decadactylus*, *Chloroscombrus chrysurus*, *Sepia* spp., *Trichiurus lepturus*, *Arius* spp., *Pseudotholithus* spp., *Cynoglossus monodi*	Assumption
2000	62	Kelleher (2005)	*Brachydeuterus auritus*, *Galeoides decadactylus*, *Chloroscombrus chrysurus*, *Sepia* spp., *Trichiurus lepturus*, *Arius* spp., *Pseudotholithus* spp., *Cynoglossus monodi*	Assumption
2005	43	Emanuelsson (2008)	*Brachydeuterus auritus*, *Galeoides decadactylus*, *Chloroscombrus chrysurus*, *Sepia* spp., *Trichiurus lepturus*, *Arius* spp., *Pseudotholithus* spp., *Cynoglossus monodi*	Assumption
2010	38	Extrapolation	*Brachydeuterus auritus*, *Galeoides decadactylus*, *Chloroscombrus chrysurus*, *Sepia* spp., *Trichiurus lepturus*, *Arius* spp., *Pseudotholithus* spp., *Cynoglossus monodi*	Assumption

a) Garcia *et al.* (1979) documented discards of *Pagellus bellottii* at 50%, while this same species represented 40% of the total 68% discards documented by the same authors. Therefore the discards of all species should be 85%;
b) average between two estimates (68% and 75%) respectively;
c) Change in target species.

Taxonomic disaggregation

To disaggregate trawl catches taxonomically, we assembled data from Thiam and Gascuel (1994), Garcia *et al.* (1979) and Caverivière and Rabarison Andriamirado (1988) on the catch composition per species for domestic trawlers between 1960 and 1990. We assumed the catch composition for 1960 applied to that of 1950-1959, and that the catch composition for 1990 applied to trawl catches between 1991 and 1995. For the more recent years, we assembled catch data from DPM reports covering the 2000-2010 time period, converted them to percentages and then assumed that the species breakdown for 2000 applied to catches between 1996 and 1999. We applied the same catch composition for foreign trawlers which had the same profile than the domestic (reflagged) trawlers.

For small-pelagic and tuna purse-seiners, we combined data from DPM reports and obtained the catch composition per year for the 2000s and assumed that the catch composition of 2000 applied to the 1950-1990s time-period. We applied the species composition provided by ter Hofstede and Dickey-Collas (2006) for foreign pelagic trawlers (from Eastern Europe; mostly Russian and Polish trawlers), which are significantly larger and more powerful. Catches included 63.8% of round sardinella (*Sardinella aurita*), 4.6% of flat sardinella (*Sardinella maderensis*), 12.9% of European pilchard (*Sardina pilchardus*), 9.3% of chub mackerel (*Scomber japonicus*) and 3.7% of Cunene horse mackerel (*Trachurus trecae*) and 5.7 of other species.

Artisanal catches were disaggregated using the data provided in DPM reports converted to percentages and assumed constant from 1999 backwards until 1995, by Samba (1994) for the period between 1981 and 1991, and by Bergerard and Samba (1980) for 1975. We assumed the catch composition for 1991 applied to

catches between 1992 and 1994, and that the catch composition for 1981 applied to catches between 1976 and 1980. We also carried the trend backwards for the catch composition from 1975 to 1950 to complete the time series.

RESULTS

Artisanal catches

Artisanal catches landed in Senegal were estimated at around 25 million tonnes between 1950 and 2010, of which 14% on average was from outside Senegalese waters (3.6 million tonnes). Artisanal catches landed in Senegal increased from 92,300 t·year^{-1} in 1950 to a peak of 656,300 t·year^{-1} in 2004, of which a quarter was from outside Senegal (163,600 t·year^{-1}). Artisanal catches decreased thereafter to 572,100 t·year^{-1} for 2010, with 211,700 t·year^{-1} taken from outside Senegalese waters (around 40%; Figure 4a). Senegalese migrant fishers take most of their catches from Mauritania with 48% of the migrant fishers catch, followed by Guinea Bissau (33%), The Gambia (19%) and Guinea (<1%). Although Guinea contributed a small catch, it increased by a factor of 100 in less than 20 years, from 20 t·year^{-1} in 1992 to around 2,000 t·year^{-1} in 2010.

Taxonomically, at least 198 taxa were caught by the artisanal fisheries in Senegal, including mostly sardinella in the recent periods and bluefish in the past (Figure 4b). Migrant fisher catches included at least 45 taxa, dominated by catches of small pelagic species mostly sardinella and bonga shad, and catches of bluefish at a lower extent (Figure 4c).

Subsistence catches

Subsistence catches were estimated at 1.2 million tonnes between 1950 and 2010, and consisted mostly of bivalves and gastropods (90%), with fishes contributing the rest. Catches increased from 4,200 t·year^{-1} for 1950 to 12,500 t·year^{-1} in 1980 following a series of droughts, then decreased to less than 4,200 t·year^{-1} in 2010 (Figure 5).

Recreational catches

Recreational catches increased from zero in 1960, when recreational fishing began, to 1,600 t·year^{-1} in 2006, after which they remained relatively constant, at around 1,650 t·year^{-1} (Figure 6).

Large-scale domestic catches

Large-scale domestic catches increased from zero in 1960 to a peak of 178,300 t·year^{-1} in 1998, then decreased to less than 75,000 t·year^{-1} in 2010, which was 83% higher than the data reported by DPM (41,000 t·year^{-1} in 2010, Figure 7a). Industrial trawl catches represented 84% of the total catch by the fleet flagged to Senegal, the remainder targeting small pelagics and tuna with about 705,000 tonnes over a total of 4.3 million tonnes between 1950 and 2010 (Figure 7a). Taxonomically, trawl catches were dominated by cephalopods (10%), sparids (9%), shrimps (8%), and soles (*Cynoglossus* spp.) with 7% of total catches between 1950 and 2010. However, the taxonomic composition was marked by a dramatic change. Catches prior to 1974 were dominated by sparids (33%), shrimps (31%) and soles (16%), then declined to be less than 10% each, whereas the contribution of cephalopod catches to the total catch increased by 10%, along with Lesser African threadfin (*Galeoides decadactylus*), carangids, grunts (*Pomadasys* spp.) and sea catfishes (*Arius* spp.).

Large-scale foreign catches

Industrial foreign catches increased from zero in 1950, when foreign fishing began in Senegalese waters, to their first peak of 250,000 t·year^{-1} in 1979, due to high Polish small-pelagic catch (Figure 8). Catches decreased thereafter, to 100,000 t·year^{-1} in 1985, after the departure of Polish pelagic trawlers. Then, they increased slowly, to 155,000 t·year^{-1} in 1990, followed by a rapid upsurge to a historical peak of 444,000 t·year^{-1} in 1992, in the wake of the arrival of large pelagic freezer trawler from Russia, which caught over 312,000 t·year^{-1} (Figure 8). Catches declined to be less than 10,000 t·year^{-1} in 2010, due to the decrease in the number of industrial foreign vessels allowed to operate in Senegalese waters. Overall, industrial foreign catches were estimated at 7.7 million tonnes between 1950 and 2010, of which 2.5 million tonnes was caught by Russian large freezer trawlers between 1992 and 1999, when these vessels left. When Russian catches are not considered, Spain was responsible for 66% of the remaining catch, followed by other Western European countries with 1.1 million tonnes between 1950 and 2010 (21 % jointly by Portugal, Greece and France and Italy). Vessels flying flag of convenience and African flags caught 6% of the total industrial foreign catch.

Unregulated and Illegal fisheries catches

Catches by unlicensed vessels were considered unregulated prior to the declaration of the Senegalese EEZ in 1984, and illegal thereafter. Unregulated and Illegal catches totalled 3.9 million tonnes over the period from 1950 to 2010. Catches, although fluctuating over time, increased from zero in 1950 to a peak of 350,000 t·year^{-1} in 2010. Catches were dominated by Russian catches of small pelagics (mostly sardinellas). China, flying flags of convenience or flags of African countries (such as The Gambia), caught over 513,000 tonnes over the same time period, i.e., 13% of total illegal catches. Europe was responsible for 5% of the illegal catch (Figure 9).

Discards

Discards by the domestic trawl fleet in Senegal totalled over 2.4 million tonnes between 1950-2010, which was the equivalent of 60% of the industrial domestic catch (Figure 5). Discards increased from 2,600 t·year^{-1} in 1960, to a peak of around 100,000 t·year^{-1} in 1999, following the same pattern than industrial trawl catches. Discards decreased thereafter to 29,000 t·year^{-1} in 2010, following the decrease of industrial catches driven by the decrease in the number of trawlers (Figure 10). Similarly, discards by the foreign legal fleet increased from zero in 1950, when foreign fishing began to a peak of 123,000 t·year^{-1} in 1980, due to the high number of demersal trawlers (Figure 12). Discards decreased thereafter, following the decrease in the industrial catch, to around 61,000 t·year^{-1} in 1985, then increased to 117,000 t·year^{-1} in 1992 in the wake of the large pelagic trawlers from Russia (Figure 12). Discards decreased thereafter to 3,500 t·year^{-1} in 2010.

Although the amount of discards is showing the same pattern than industrial catches, suggesting the decrease in discards is related to the decrease in industrial trawl operations, the rate of discards is also shown to decrease over time, from around 70% in 1960 to 34% in 2010, with a peak in the early 1990s when the equivalent of the industrial trawl catch was discarded (Figure 11).

Discards by the illegal fleet were estimated at 560,000 tonnes over the period from 1950 to 2010, increasing overall to a maximum of 45,000 t·year^{-1} in 2010 (Figure 10).

Total catches

Total removals from Senegalese waters were estimated at 45 million tonnes over the 1950-2010 period, of which 29.3 million tonnes were domestically caught compared to 15.5 million tonnes foreign, i.e., half of

the domestic catch after removing the artisanal landings caught outside of the Senegalese EEZ (Figure 13a). Although total catches showed an increasing pattern since the 1950s, the under-reporting component declined from around 4 times the data supplied to the FAO in the 1950s to 1.55 times in the 2000s (after excluding catches by migrant fishers, Figure 13a).

Taxonomically, total catches from Senegal encompass over 250 taxonomic groups, dominated in the past by bleufish and sparids, and by small pelagics and mostly sardinellas more recently (Figure 13b)

DISCUSSIONS

Total catches from Senegal, including domestic, foreign legal and illegal sectors were reconstructed at 45 million tonnes between 1950 and 2010, compared to 14.4 million tonnes reported to the FAO. Catches were, in the early 1970s, already higher than the (potential) maximum sustainable yield estimated at 600,000 t·year^{-1} (CRODT 2001; Kelleher 2002). This, in contrast to official landing data, confirms the over-exploitation pattern observed by Thiam and Gascuel (1994), which began already in the 1970s.

Artisanal catches, excluding 3.6 million tonnes caught outside Senegal, represented 74% of the domestic catch, further emphasizing the importance of this labour-intensive artisanal sector in Senegal. The forays of Senegalese pirogues towards other countries not only undermines the notion of adjacency as a definitional attribute of artisanal fisheries (Pauly 2006), but also increases conflicts with the industrial fleets and artisanal fishers in other countries such as Mauritania, The Gambia, Guinea Bissau and Guinea. Indeed, these conflicts were vividly recalled by local communities and authorities during a short stay by the first author in each of these countries (D.B, pers. obs., April 2013). These forays, using large pirogues for fishing trips that can last over a week, are more typical of distant-water fleets.

The Senegalese experience also includes past failing initiatives to encourage the industrialization of the artisanal fleets (Bakhayokho and Kebe 1989). Indeed, despite an important increase in the effort, catches are shown to decrease even when including catches from outside Senegal, suggesting overcapacity. Moreover, not including these figures when analyzing fisheries trends leads to erroneous results, because (1) increasing catches from outside Senegal, if not taken into consideration will mask or reduce the apparent effect of overcapacity, showing increasing catches; (2) stocks of certain targeted species will be assumed to be still abundant, while their catch originates from neighboring countries, which will bias management decisions; and (3) the fishery will be perceived as generating increasing economic revenues, while the increasing costs of fishing will not be considered. Indeed, Deme *et al.* (2012) showed dangerous over-exploitation of sardinella (*Sardinella* spp.) by comparing increasing catches to decreasing indices of abundance; while the present study suggests that overall catches are decreasing within Senegalese waters.

Although industrial catches seemed to be fairly high in the present study, the exclusion of a number of fishing vessels in the data, such as tuna vessels in the 1980s, and a large number (150) of Russian vessels in the early 1980s along with other sub-contracted Eastern European vessels (Westlund 1995; Johnstone 1996), makes the reconstructed industrial catch during that period likely under-estimated. Furthermore, under-water mortality (= 'ghost fishing') resulting from the use of poison, explosives and the wide-spread use of monofilament and multifilament nets prohibited by the Senegalese law (Pramod and Pitcher 2006) have not been accounted for here.

The present study shows a decrease in discard rates; however, rather than implying an improvement in fishing techniques and selectivity, this suggests that industrial fleet behavior is changing towards keeping species that were previously of low commercial value. This accentuates even further the issue of over-exploitation: as the biomass of resources exploited by the industrial fleets decreases, they tend to retain as much fish as possible. This pattern is also observed in other countries of West Africa, where these species

are called ‘African fish’, ‘Local fish’, ‘African mix’, ‘Trash fish’, i.e., Guinea, Guinea Bissau Liberia and Ghana.

The present study shows a negative correlation between legal and illegal catches. This phenomenon is also observed in other countries of West Africa, such as Liberia. This suggests that when countries lack the capacity to monitor their fisheries, reducing the industrial foreign effort results in the relative increase in illegal catches, as these vessels operate with or without authorization. This is still true in 2012 in the case of Senegal, as illustrated by Eastern European and Russian vessels, which no longer held a fishing licence but still reached into Senegalese EEZ from beyond the Mauritanian maritime border (DPSP 2012; Koutob *et al.* 2013; Belhabib *et al.* In press).

The increasing artisanal fleet, whose over-capacity forces it to spill over into the waters of Senegal’s neighbors, also put the very existence of a large reflagged Senegalese fleet in jeopardy. Indeed, although reflagging in Senegal is a tradition (Everett 1994), foreign boats based in Dakar were, in the past, also treated like a domestic fleet. The very fact that Senegalese resources are increasingly over-exploited, pushes these industrial so-called domestic vessels to seek agreements with the neighboring countries, illustrated during a short visit by the first author to Guinea, and the very recent agreement signed between Russia and Sierra Leone (Cole 2013). Thus, vessels reflagged to Senegal - a member of the sub-regional fisheries commission- pay a lower fee than if they were directly from the EU, e.g. the case of Italian vessels reflagged to Senegal and fishing in Guinea Bissau (Anon. 2013).

The shift of artisanal fisheries towards export-oriented species, even by migrant fishers often not allowed to fish for highly commercial value species adds an interesting twist to issues of local food security. It is clear that over-exploitation causes serious threats to food security in Senegal, however as opposed to the doomy and gloomy picture derived from the decreasing landings of small pelagics, the shift towards export oriented species, could be a more aggravating factor (Abaza and Jha 2002). This issue can only be solved if both factors are taken into consideration, i.e., catches by migrant fishers and over-capacity.

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FIGURES

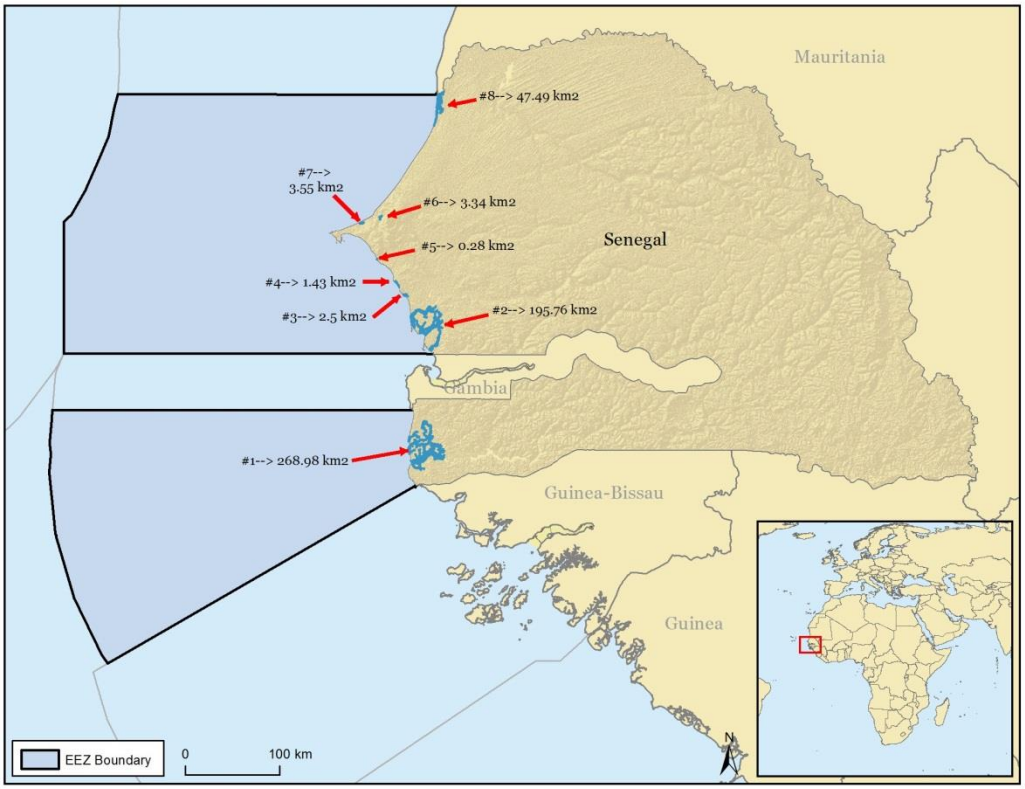

Figure 1. Map of Senegal showing the Exclusive Economic Zone (EEZ) and some of the coastal lagoons.

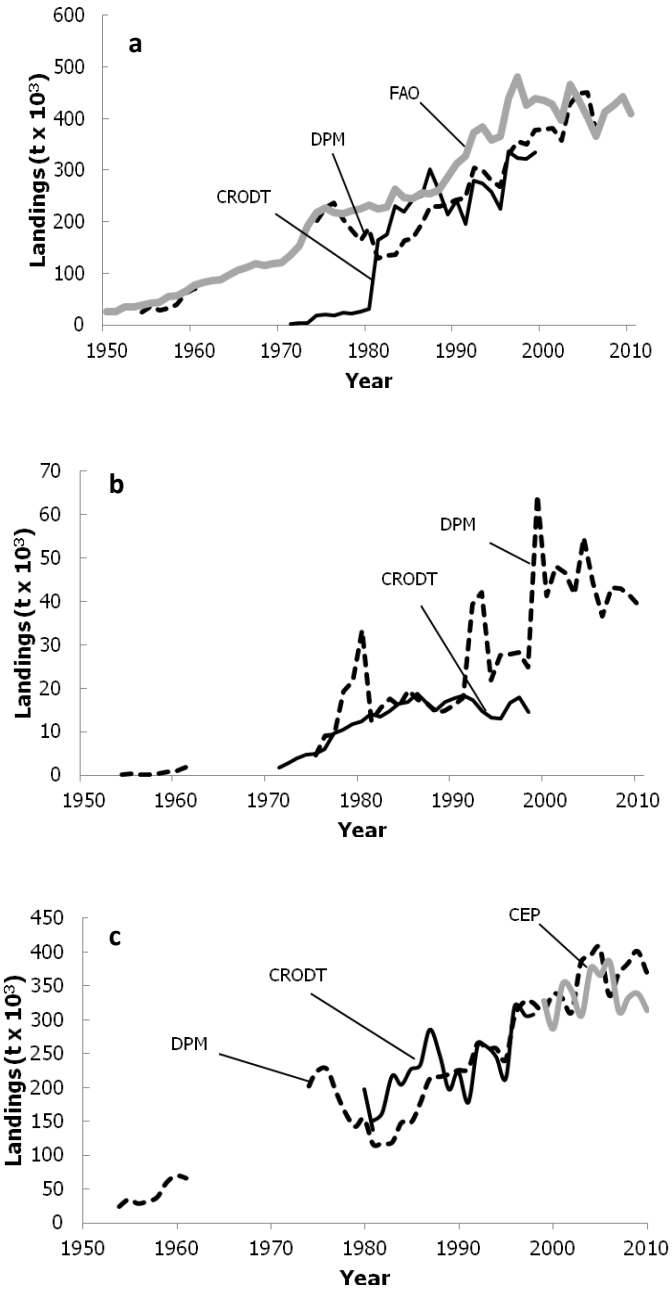

Figure 2. Reported landings by source for a) all sectors together, b) industrial sector and c) artisanal sector, 1950-2010.

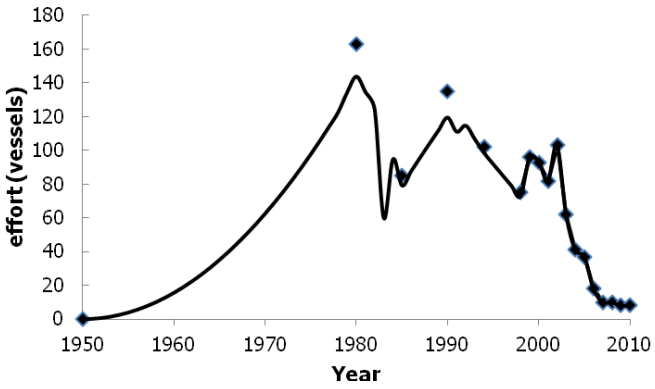

Figure 3. Total effort documented by the literature (dots) compared to the sum of the effort per country (solid line), 1950-2010.

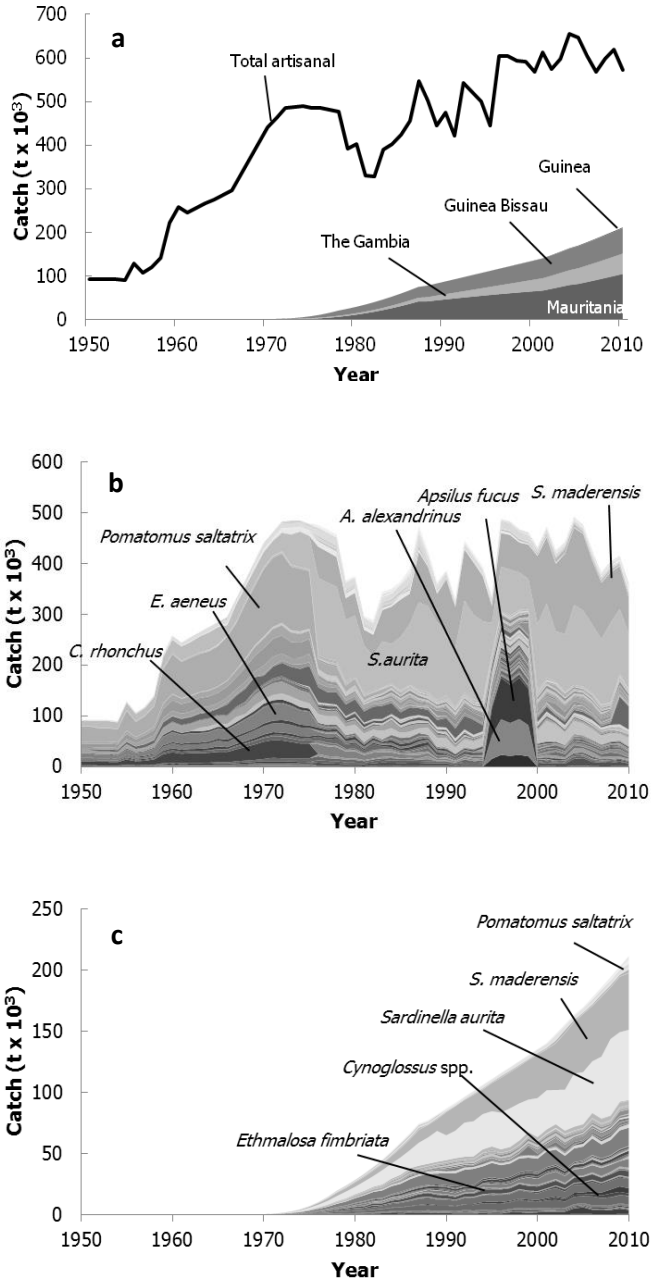

Figure 4. Total reconstructed artisanal catches landed in Senegal a) showing the origin of the migrant fishers' catch, b) showing the species breakdown of catches within Senegalese waters, and c) the species composition of catches from outside Senegalese waters, 1950-2010.

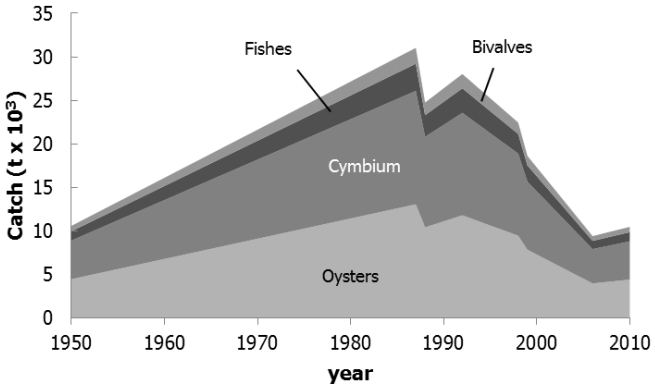

Figure 5. Total reconstructed subsistence catches from Senegalese waters, 1950-2010.

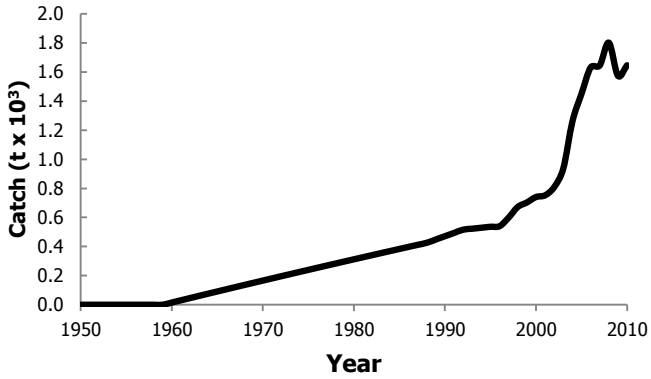

Figure 6. Total reconstructed recreational catches from Senegalese waters, 1950-2010.

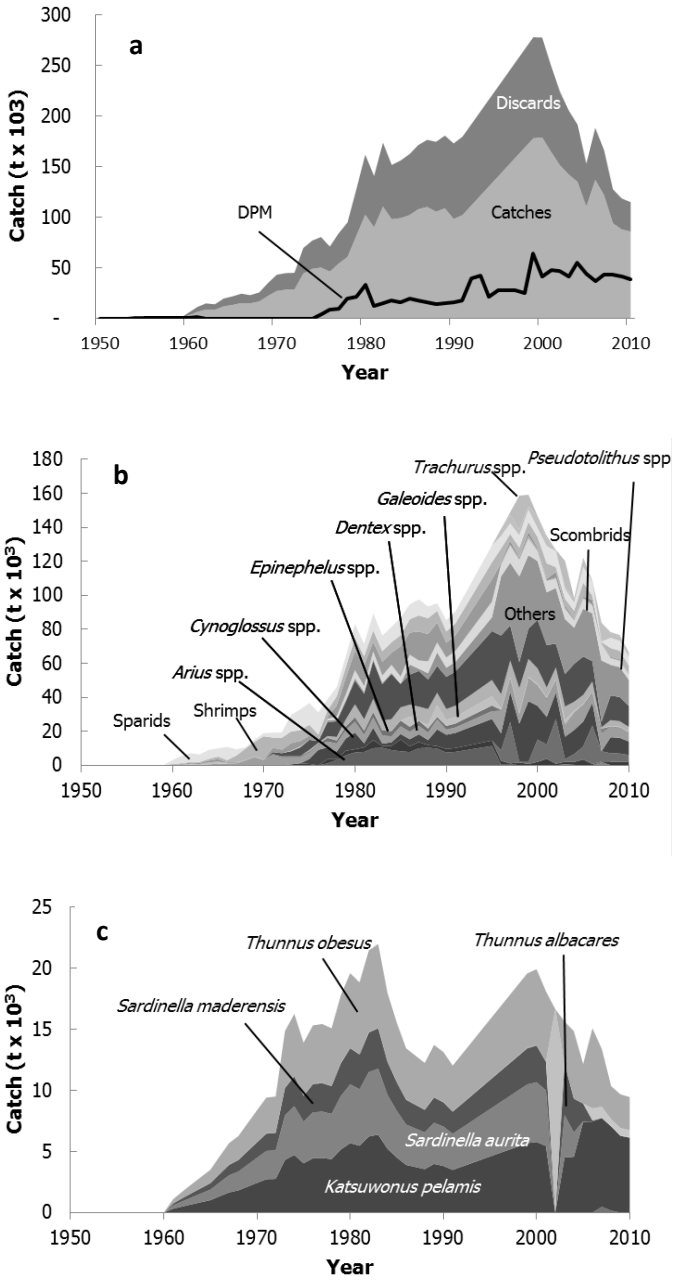

Figure 7. Total reconstructed industrial domestic catches from Senegalese waters a) compared to the catch reported by DPM, b) trawl catches by taxon, and c) purse-seine catches by taxon,1950-2010.

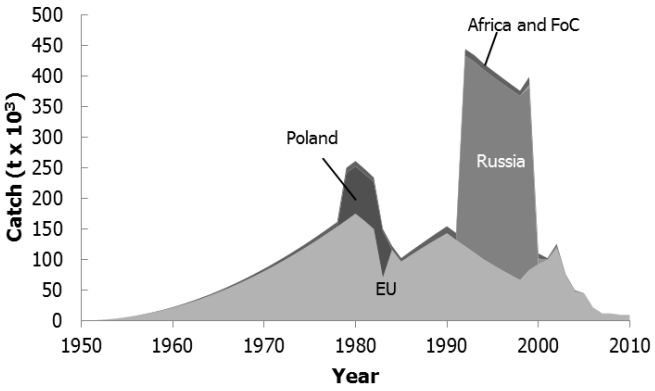

Figure 8. Total reconstructed industrial foreign catches from Senegalese waters, 1950-2010.

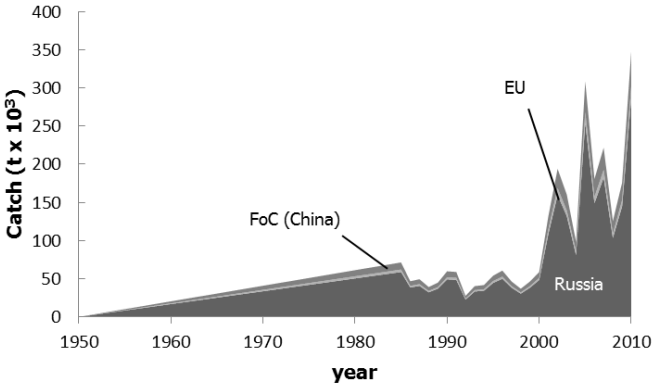

Figure 9. Total reconstructed industrial foreign illegal catches from Senegalese waters, 1950-2010.

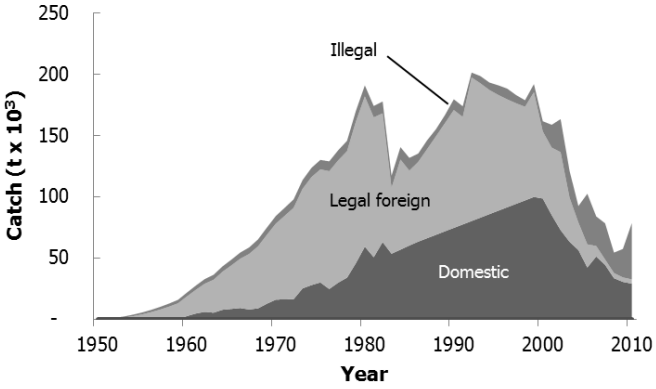

Figure 10. Total reconstructed industrial discards from Senegalese waters, 1950-2010.

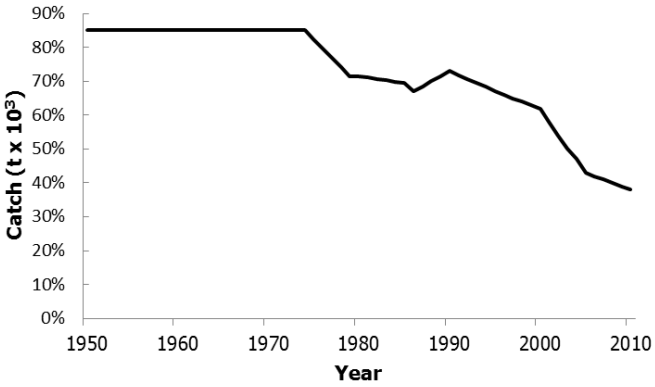

Figure 11. Evolution of the domestic trawl fishery discards rates, 1950-2010.

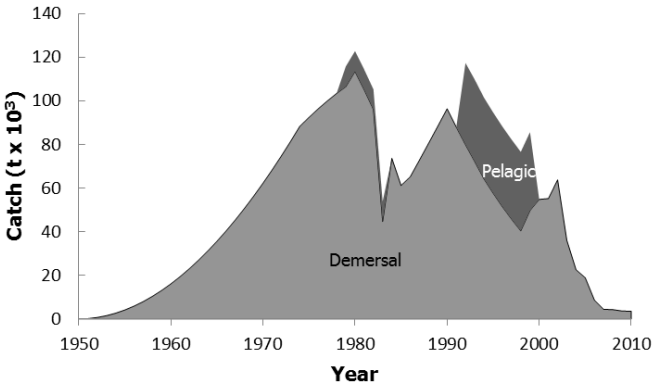

Figure 12. Reconstructed foreign discards by segment, 1950-2010. Pelagic stands for large Eastern European and Russian pelagic trawlers.

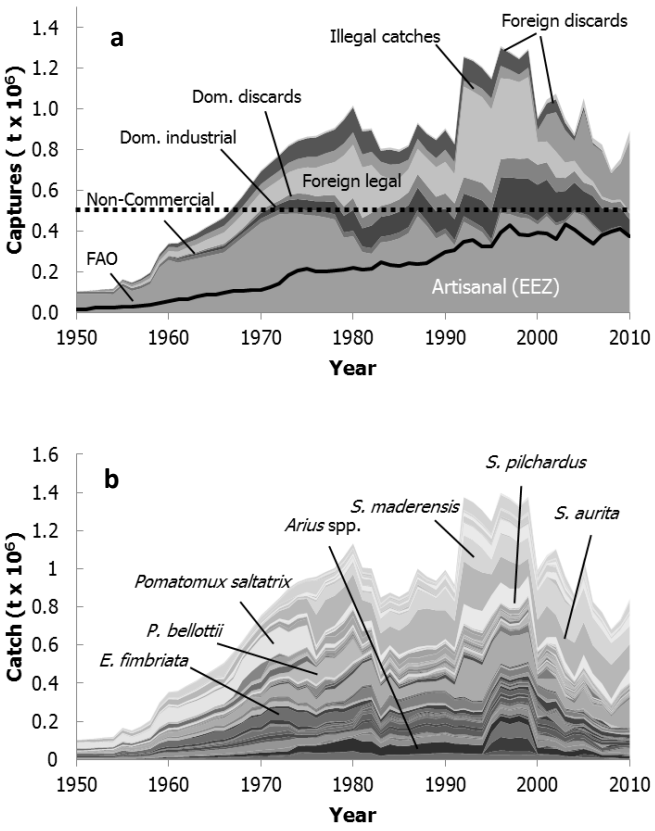

Figure 13. Total Reconstructed catches from Senegalese waters a) by sector (dotted line shows MSY) and b) by taxa, 1950-2010.