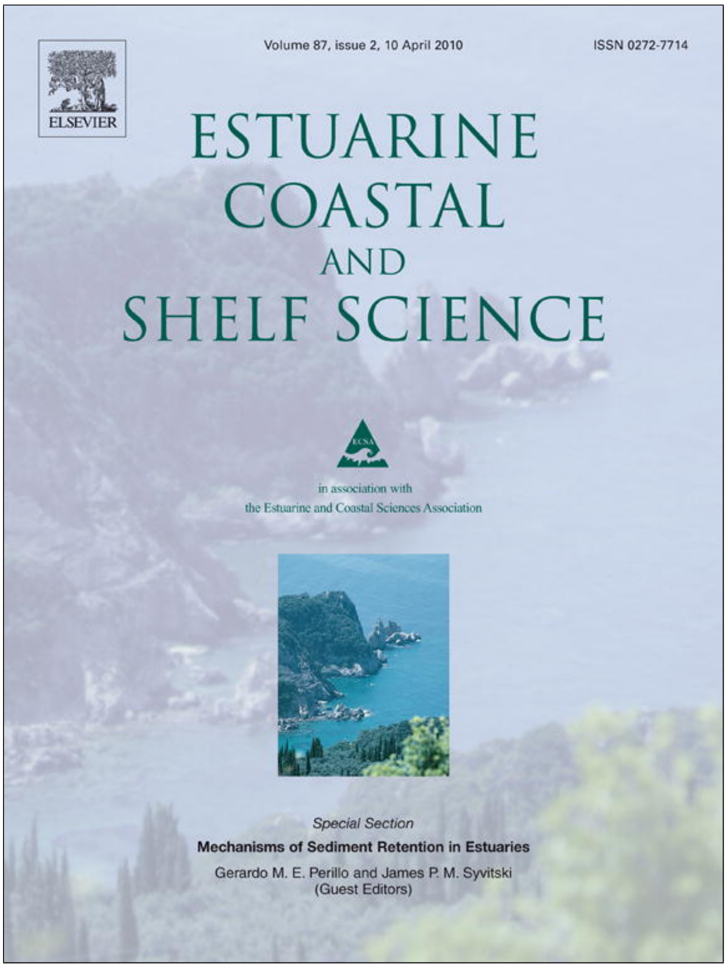
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Changes over a decade in fish assemblages exposed to both environmental and fishing constraints in the Sine Saloum estuary (Senegal)

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ABSTRACT

To investigate the changes in the fish assemblage of the Sine Saloum estuary (Senegal) over a 10-year period, it was surveyed during a complete hydrological cycle (three principal hydro-climatic seasons) first in 1992 and then in 2002–2003. The sampling protocol for the two surveys was identical, using the same sampling technique, the same collection periods, and the same sampling stations.

The Sine Saloum is an inverse estuary in terms of its salinity gradient. It is affected by the intense drought that has occurred in this biogeographic region for more than 50 years. The estuary is also subjected to high fishing pressure. The second data-collection period followed a few years of higher recorded rainfall (approximately 35% higher than in 1992) and was characterized by increased fishing pressure (over 50% higher than in 1992).

For the two study periods, the same set of indicators were calculated, including fishing indicators (catches, density, yields), size-based indicators (size structures, mean length, maximum observed length, size spectra), ecological indicators (richness, species diversity, K-dominance models, ABC curves, ecological categories) and trophic indicators (mean trophic level, trophic composition of catches).

Overall, the main changes in the estuary's fish assemblage between 1992 and 2002 were (1) a loss in total biomass (40% less) for an equivalent species richness (approximately 55 species); (2) a decrease in the maximum observed lengths for many species (mean decrease of 17%); and (3) a decrease in the mean trophic level (more than 0.11 units). Analysis by bio-ecological and trophic category showed that the main species concerned were benthophagous species and, to a lesser degree, generalist predator species from marine origin that inhabit the estuary more or less permanently.

1. Introduction

Estuaries are of great importance for many fish species of both freshwater and marine origin. They play an essential role in providing nurseries and reproduction zones for numerous species, mainly of marine origin; they offer a favorable habitat for resident estuarine species; and they constitute migratory routes for catadromous and anadromous species (Vidy, 2000; Elliott and McLusky, 2002; Martinho et al., 2007, 2008). However, due to anthropogenic effects, these transition systems are subjected to intense environmental pressures linked to eutrophication, overfishing, building construction, and general environmental degradation (Martinho et al., 2008).

Sets of indicators have been established by several authors to monitor environmental changes in the quality of estuaries. However, a number of these indicators are difficult to interpret or do not take into account the complexity of the ecosystem (Dauvin and Ruellet, 2009). For these reasons, many authors believe that, considering the functional and ecological role of fish, ichthyic communities, as indicators of environmental changes, could constitute a useful tool in providing a global definition of the health of an ecosystem (Soto-Galera et al., 1998; Whitfield and Elliott, 2002; Harrison and Whitfield, 2004; Noble et al., 2007).

Generally, most indicators that are used to define an ecosystem's health status refer to assemblages and populations of fish living in an unstressed environment (Deegan et al., 1997; Harrison et al., 2000; Degnbol and Jarre, 2004). However, due to the widespread anthropization of aquatic ecosystems, it has become difficult to define such a reference assemblage. This has led some authors to use long-term time series to determine the trends for assemblages subjected to stress and abandon the idea of a reference ecosystem (Jennings et al., 1999; Laurans et al., 2004; Rochet et al., 2005). Others have justified their studies by comparing several similar

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ecosystems (Laë et al., 2004), particularly estuaries of the same biogeographic region (Elliott and Dewailly, 1995; Elliott et al., 2007; Franco et al., 2008; Harrison and Whitfield, 2008; Selleslagh et al., 2009).

In developing countries, and particularly in West Africa, few time series of indicators exist that enable the monitoring of the health status of inland or estuarine aquatic ecosystems. Similarly, reference sites as defined by Deegan et al. (1997) have virtually disappeared because of intense anthropization around these transition ecosystems. The collection of information is often sporadic (collected in response to varied requests), making data comparison difficult. In the Ebrié Lagoon (Côte d'Ivoire), a comparison of the fish assemblage over a 20-year interval was conducted using data from several sources (Albaret and Ecoutin, 1990). Smith et al. (2008) compared Caribbean estuarine fish communities sampled 27 years apart, justifying their approach of the temporal variability by the use of a comparable sampling methodology.

The aim of the study presented in this paper was to investigate the changes over a 10-year period in the fish assemblage of an estuary in Senegal: the Sine Saloum Delta. In a study conducted in 1992 (Simier et al., 2004), the spatial organization of the fish assemblage of the Sine Saloum estuary was influenced by three major criteria: inclusion in one of the three branches of the Sine Saloum, the distance to the sea, and finally, a channel-bank gradient. In 2002, a new sampling, conducted using similar methods as the previous study, was carried out (unpublished data), which enables a comparison of the assemblages on a 10-year scale.

The Sine Saloum estuary is an inverse estuary, as defined by Pritchard (1967), due to very low freshwater inputs. Since the estuary has no tributaries, these inputs are essentially limited to rainfall (Diouf, 1996). Consequently, the salinity increases upstream whatever the season, reaching high values in the upper estuary (>100 at Kaolack, Fig. 1). One major explanation for this is that the region has endured an intense drought for several decades (Pagès and Citeau, 1990). Between 1992 and 2002, rainfall increased in this estuarine region (Sène and Ozer, 2002; Mbow et al., 2008), a change that *a priori* would favor the equilibrium of the assemblage. However, due to intense anthropization in this region of Senegal – not far from the country's capital, Dakar – fishing pressure has greatly intensified.

This study allows us to understand better the effects on the estuary's fish assemblage of changing environmental conditions on the one hand, and overfishing on the other, over a decade. For each of the study periods, a set of indicators was used, including: fishing indicators (catches, density, and yields), size-based indicators (size structures, mean length, maximum observed length, size spectra), ecological indicators (richness, species diversity, K-dominance models, ABC curves, ecological categories) and trophic indicators (mean trophic level, trophic composition of catches).

2. Materials and methods

2.1. Geographic location

The Sine Saloum Delta is located 100 km south of Dakar, between 13°35' and 14°10' North and 16°03' and 16°50' West. This

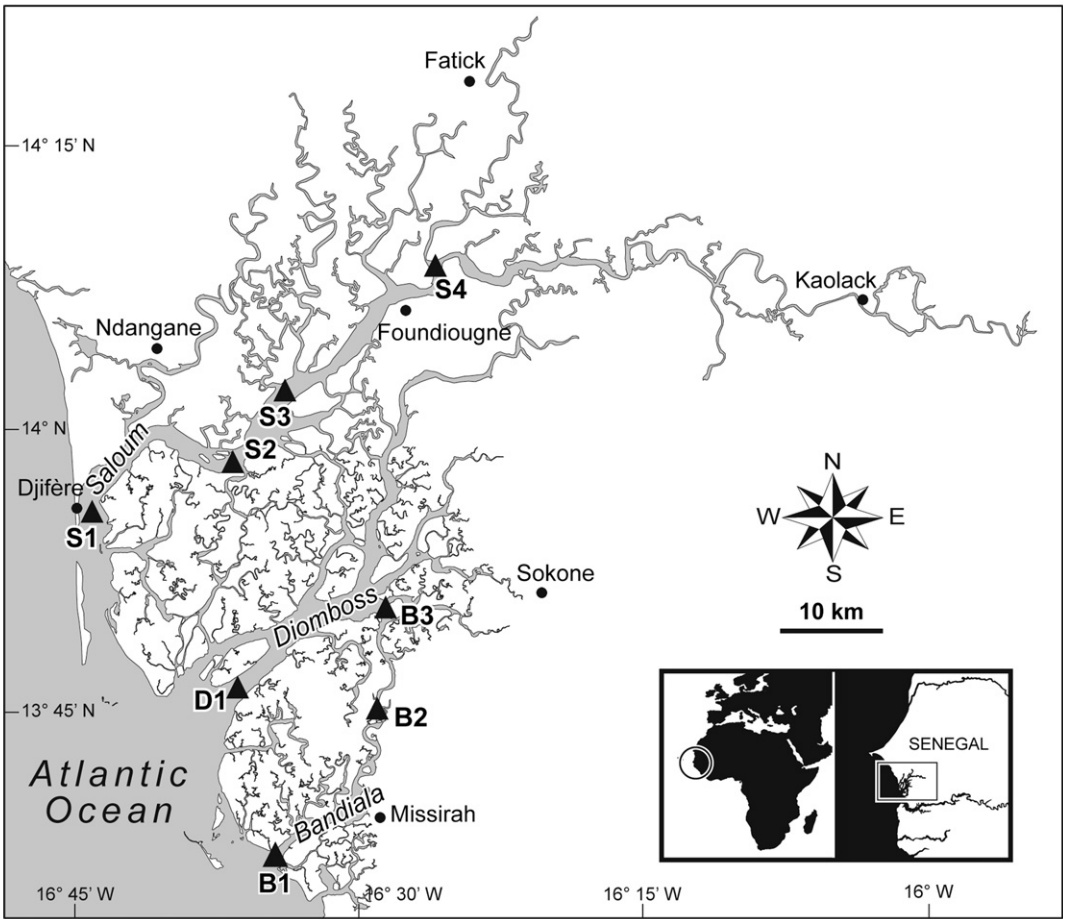

Fig. 1. Sine Saloum estuary and location of sampling sites.

large estuary (848 km^2) comprises three main branches: the Saloum, the Diomboss and the Bandiala (from north to south) (Fig. 1). In the study area, the Saloum and the Diomboss are wide and deep, while the Bandiala is narrower and shallower. The south-western area of the Sine Saloum system is characterized by a dense network of small seawater creeks locally named "bolongs" covered with tall mangroves, mainly *Rhizophora* and *Avicennia*, which become shorter in the central zone. The mangroves thin out in the north-eastern area and totally disappear in the upstream Saloum, replaced by huge, flat, bare, salt-saturated intertidal areas locally called "tannes".

2.2. Hydro climatic conditions

In the Sine Saloum region, the climate is characterized by an extended dry season (cool from November to March, and warm from April to June) and by a short wet and warm season from July to October (Diop, 1996; Sagna, 2007).

Since the 1920s, the annual rainfall has been decreasing in this region, slowly until 1961, and then more drastically up to the 1990s (Pagès and Citeau, 1990). Between 1992 and 2002, rainfall increased (9% between the two study years and 34% between the periods that preceded these two years) (Fig. 2). Despite this increased rainfall, freshwater inputs remain low. Combined with intense evaporation and the shallow slope of the estuary, this reduced input causes an inverse salinity gradient for the Sine Saloum estuary. A detailed description of environmental conditions in the Sine Saloum system can be found in Diouf (1996) and Simier et al. (2004).

2.3. Fishing activity

Fishing in the Sine Saloum estuary has been analyzed in two different studies: the first study was conducted between 1990 and 1993 (Bousso, 2000; Bousso, pers. comm.), and the second between 1999 and 2000 (Deme and Diadhiou, pers. comm.). We have combined the fishing data for these two periods (Table 1).

Based on these studies, three major characteristics can be highlighted: (1) in both periods studied, fishing activities in the Sine Saloum were very intense, practiced by full-time or seasonal professional fishermen, and by occasional fishermen; (2) the fishing activity in the early 2000s was markedly higher than in the 1990s. The 50% increase in fish catches in the estuary (Table 1) was linked to a considerable increase in fishing effort (number of fishermen, canoes, and fishing gear); and (3) The technological range of fishing gear changed, with a sharp decrease in the proportion of passive gear (set gillnets) in favor of more active gear, targeting particular fish species (encircling gillnets, beach seines).

Consequently, there was a large increase in fishing pressure between the two study periods.

Table 1
Main fishing characteristics of the Sine Saloum estuary in 1990–1993 and in 2000 (adapted from Bousso, 2000; Bousso, pers. comm. and Deme et Diadhiou, pers. comm.).

	1990–1993	1999–2000	Difference
Villages	76	83	==
Fishermen	3000	4800–6100	+60–100%
Canoes	1000	1700–1800	+70%
Motorized canoes	nd	25%	
Fishing gears	1586	2800–4600	+77–300%
Effort	76000	nd	
CPUE (kg/trip)	197	220	+12%
Fish catches (t)	10,000	15,000	+50%

nd, no data.

2.4. Sampling

Based on abiotic and biotic environmental criteria (Diouf, 1996), eight sampling sites were used: three were located in the Bandiala (sites B1, B2, B3), one in the Diomboss (site D1) and four in the Saloum (sites S1, S2, S3, S4) (Fig. 1). The furthermost upstream zone of the Saloum (a hypersaline area) was not included in this study.

The sites were visited in 1992 and 2002: in March (dry and cool season), April (beginning of the dry and warm season) and October (end of the wet season). Each site was sampled twice on a given date: one haul in the mid-channel, and the other close to the bank.

Fish were collected using a purse seine 250 m long, 20 m height and with a mesh size of 14 mm. All sampling was done using the same protocol by an experienced fishing team without any fish search, in order to provide a reproducible, well-defined sampling unit: the seine haul. Fish were identified to species level, and counted and weighed by species to the nearest gram. Approximately 55,000 fish were sampled in 1992 and 28,500 in 2002. The depth was measured at each seine haul along with other environmental variables: water transparency, salinity, temperature, and dissolved oxygen.

2.5. Data processing

2.5.1. Indicators

Three groups of indicators have been used in this study: ecological indicators (biomass indicators, species composition and dominance indicators), size-based indicators, and finally, trophodynamic indicators.

Biomass indicators, expressed in kg ha^{-1}, are calculated from the measured biomass per haul divided by the swept area of the seine net. The reproducibility of the sampling protocol allows the biomass indicators to be directly compared.

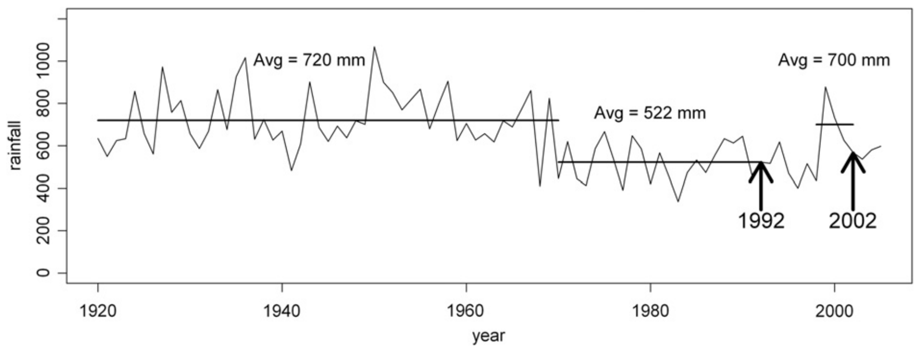

Fig. 2. Recorded rainfall in the meteorological station of Kaolack.

Indicators for species composition and dominance are represented by the total species richness, the number of species contributing to 95% of the biomass and the ABC index proposed by Meire and Dereu (1990):

$$\text{ABC index} = (B_i - A_i)N^{-1}$$

where B_i is the relative biomass of the species (ordered by decreasing biomass), A_i the relative abundance of the species i (ordered by decreasing abundance) and N, the total number of species.

The size-based indicators are represented by the mean length of all caught individuals (fork length in mm), by the mean of the maximum observed length for each species, and by the size spectra for all species combined: linear relationship between abundance (in logarithm) and the fork length (in logarithm).

The tropho-dynamic indicators are represented by the mean trophic level of the fish assemblage and by the percentage of predator species. The mean trophic level (TL_m) is calculated according to the formula:

$$\mathrm{TL}_m = \sum B_i \times \mathrm{TL}_i / \sum B_i$$

where B_i is the biomass per species and TL_i, the trophic level of the species obtained from Fishbase (Froese and Pauly, 2007).

2.5.2. Functional guilds

The indicators described above were calculated for each bio-ecological category and trophic category as defined below.

The bio-ecological guild was proposed by Albaret (1999). It defines eight bio-ecological categories ordered on two gradients starting from the strictly estuarine species (Es). The marine-affinity gradient comprises four categories: the estuarine species from marine origin (Em), the marine-estuarine species (ME), the marine species accessory in estuaries (Ma) and the marine species occasional in estuaries (Mo). The freshwater-affinity gradient comprises the estuarine species from freshwater origin (Ec), the freshwater species with estuarine affinities (Ce) and the freshwater species occasional in estuaries (Co). In this study, the freshwater-affinity gradient was not represented due to the total absence of any freshwater tributaries in Sine Saloum.

In terms of trophic guild, six categories have been defined to classify the species of the Sine Saloum, according to their dominant food habits: (1) the detritivorous category; (2) the phytophagous, predominantly phyto-planktivorous or micro-phytophagous species; (3) the zoo-planktivorous; (4) the benthophagous (bivalves, gastropods, worms, etc.); (5) the generalist predators (cephalopods, shrimps, small fishes, etc.); and (6) the (strictly) ichthyophagous species.

In reference to the recent review on functional guilds by Elliott et al. (2007), the bio-ecological categories we used correspond closely to the "estuarine-use functional groups" apart from a difference in the division of the marine migrants in three groups: Ma, ME and Em, according to their regularity in estuarine ecosystems (Em and ME), and to their reproduction ability in these ecosystems (Em only). Our trophic categories correspond to the "feeding-mode functional groups", the piscivorous category according to Elliott et al. (2007) being subdivided here into generalist predators and strictly ichthyophagous species.

2.5.3. Statistical tests

Box-and-whisker plots have been drawn to compare the distribution of environmental parameters from one survey to another.

Two-sided Student's t-tests were conducted to compare the mean values for environmental parameters between the two periods, overall and by season. The adjustment for conducting multiple comparisons was carried out using the Holm method (Holm, 1979).

Comparison of mean length between 1992 and 2002 was conducted by a one-sided Student's t-test. The maximum observed length by species (for all of the species) was compared using the same test. Finally, the maximum observed length for species common to both study periods was compared using a paired t-test.

Calculation of indicators and all statistical computing were carried out using R Software (R Development Core Team, 2008).

3. Results

3.1. Environment

In 2002, the water in the Sine Saloum Delta was warmer, less transparent, and poorer in oxygen than in 1992 (Table 2). The slight overall increase in salinity observed in 2002 is not significant due to high spatio-temporal variation of the salinity (30–53 in 1992; 36–58 in 2002, see Fig. 3).

Analysis of seasonal variations of these environmental parameters backs up the annual observation (Fig. 3). Transparency was significantly lower in March and April of 2002, and also tended to be lower in October (but not significantly due to two opposite outliers) (Fig. 3). The salinity was only significantly higher in 2002 during the month of October. The temperatures were significantly warmer in October and March. Data for dissolved oxygen was unavailable for October 1992; during the other two seasons (March and April), the oxygen values were significantly lower in 2002 than in 1992.

3.2. Changes in indicators

3.2.1. Ecological indicators

In 10 years, the biomass per hectare in the estuary decreased by 40% (Table 3). This decline was observed in all the ecological categories. A change in the relative percentage of biomass of each category also occurred: biomass of the Em category increased (from 14% in 1992 to 18% in 2002) while biomass for the Mo and Ma species decreased (from 5% to 1%).

The decline in biomass observed between 1992 and 2002 was not evenly distributed for all trophic categories. The biomass of the zooplanktivorous species decreased in absolute value by more than 27 kg ha^{-1} (Table 4). The biomass of the benthophagous and generalist predators had an even sharper decline (by a factor of 5 and 2, respectively). The biomass of the three other trophic categories remained stable in absolute value, and even increased for the detritivorous category. However, the relative proportion of the zooplanktivorous species still represented approximately two-thirds of the total biomass in both periods.

Between 1992 and 2002, global species richness remained similar (55 and 57 species, respectively – Table 3 and Annex 1). Over 70% of the species were common to the two periods. Species replacement between 1992 and 2002 did not modify the richness per ecological category. Richness by trophic category showed

Table 2
Environmental characteristics of the Sine Saloum for the two study periods (average for the three seasons for the eight study sites) and results of the t-test for the comparison between the two periods.

	1992	2002	Test
Salinity	40.4	41.3	ns
Temperature (°C)	25.9	27.0	*
Oxygen saturation (%)	91.2	80.8	***
Transparency (m)	2.65	1.89	***

ns, non significant; *, slightly significant; ***, highly significant.

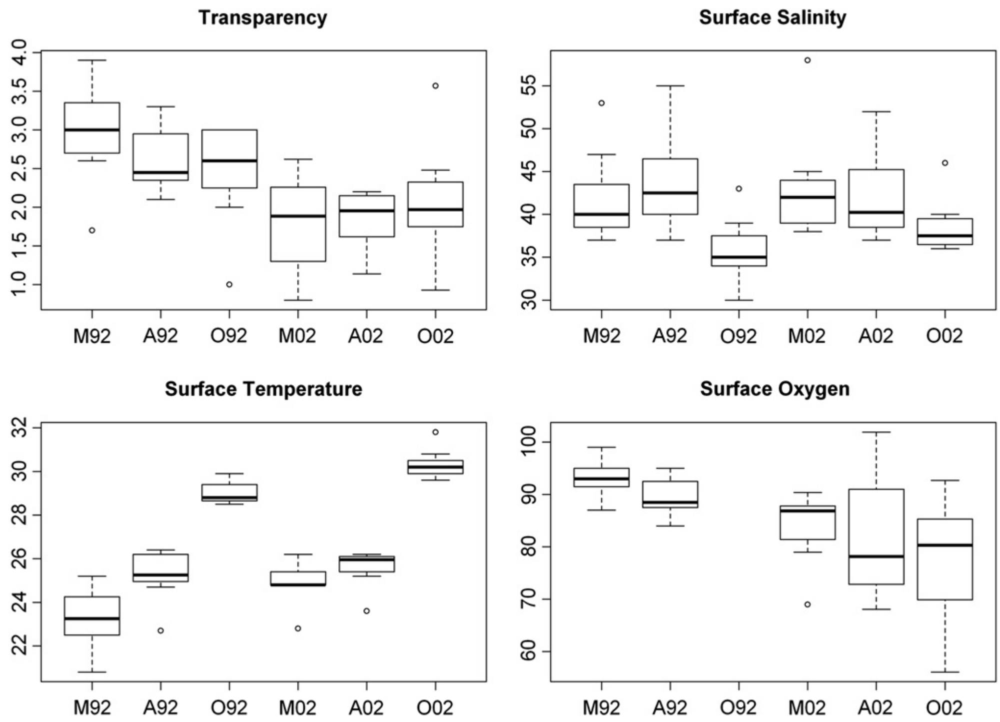

Fig. 3. Box-and-whisker plots describing the seasonal variations for environmental parameters for the two study periods. The bold line corresponds to the median, the box to the inter-quartile range. The whiskers extend from the box to the most extreme data point, which is no more than 1.5 times the inter-quartile range. Outliers are identified by dots.

approximately the same pattern, with a slight increase in the number of ichthyophagous species (Table 4).

Although species richness remained relatively constant, in 2002, fewer species were needed to constitute 80% (7 species versus 4 in 2002) or 95% (19 versus 16) of the total biomass. This change in dominance was marked by the disappearance of the Ma and Mo species among the species constituting 95% of the total biomass. At the same time, there was an increase in the contribution of the detritivorous species: 2 species in 1992 (1.5% of biomass) versus 4 in 2002 (6% of biomass).

This decrease in dominance was verified using *K*-dominance curves (Fig. 4) and the ABC index, dropping from −4.54 in 1992 to −2.86 in 2002.

3.2.2. Size-based indicators

The mean value of the species' maximum lengths decreased by 56 mm (344 mm in 1992 versus 288 mm in 2002), but this overall decrease was not significant (p-value = 0.0648). Yet the number of species with a maximum length greater than 400 mm dropped from 16 to 13. Limited to the 41 species common to the two periods, this difference (52 mm) was significant (p-value = 0.0059). The number of species with a maximum length greater than 400 mm decreased from 13 to 10.

The decline in mean maximum observed length (MOL) was mainly observed for species belonging to the benthophagous category (4 out of 6 species were concerned), the generalist predator category (8 out of 19 species), as well as for species from the ecological categories Em (6 out of 15 species) and ME (8 out of 17 species) (Table 5). These decreases in MOL were substantial: 33% for the benthophagous species and 18% for the generalist predators (Table 5). This decline in MOL was also noted for the two ecological categories Em (13%) and ME (18%) (Table 5). The maximum length of the phytophagous species had increased by 28%.

The mean length of total catches increased by 5 mm between the two study periods (109 mm in 1992 versus 114 mm in 2002). This difference is significant (p-value < $2.2e^{-16}$) given the quantity of data analyzed.

However, the trophic and ecological categories for which the maximum length decreased showed a decline in the mean length of their catches: 5 species out of 6 for the benthophagous category, with a large decline in mean length; 15 species out of 20 for the generalist predator category, with a smaller decline. Conversely, the

Table 3
Species richness and biomass (in kg ha^{-1}) per ecological category for the two study periods.

Ecological categories	1992		2002	
	Richness	Biomass	Richness	Biomass
Es	3	4.0	3	2.1
Em	15	14.3	15	11.5
ME	19	80.9	21	48.7
Ma	8	1.5	9	0.4
Mo	10	3.7	9	0.4
Total	55	104.4	57	63.1

The codes for the ecological categories are explained in §2.5.

Table 4
Species richness and biomass (in kg ha^{-1}) per trophic category for the two study periods.

Trophic categories	1992		2002	
	Richness	Biomass	Richness	Biomass
Detritivorous	6	3.0	7	4.1
Phytophagous	1	5.1	1	6.0
Zooplanktivorous	3	69.2	3	42.2
Benthophagous	9	7.0	9	1.2
Generalist predators	29	18.8	27	8.4
Ichthyophagous	7	1.3	10	1.2
Total	55	104.4	57	63.1

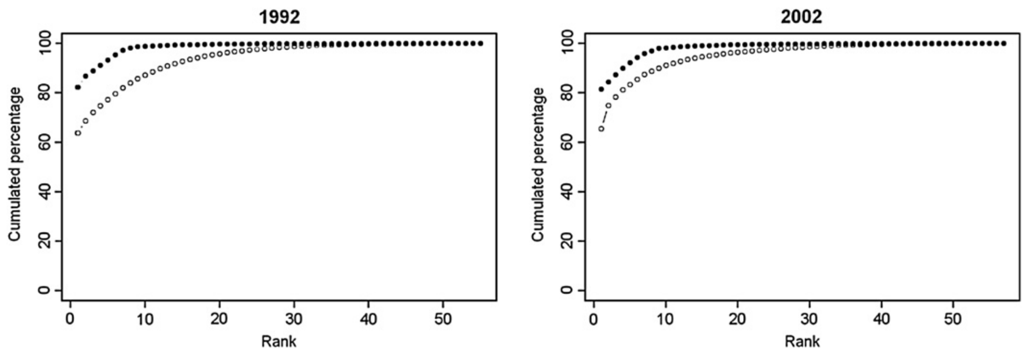

Fig. 4. K-dominance curves of fish communities in 1992 (left) and in 2002 (right). Abundance: shaded circles; biomass: empty circles.

mean length of the dominant species (in terms of biomass) increased.

The decrease of the mean value of the maximum lengths was confirmed by the increase in the slope of the size spectra for a similar length interval (9–59 cm in 1992 versus 10–56 cm in 2002, Fig. 5).

3.2.3. *Trophodynamic indicators*

The mean trophic level estimated according to the total biomass decreased by 0.11 units between the two study periods (from 2.97 to 2.86). The biomass of predators (generalist predators and ichthyophagous species) decreased while their species richness remained stable (from 36 to 37). The biomass represented by these predators decreased in relative value (from 19% to 15%) and especially in absolute value (from 20.1 to 9.6 kg ha^{-1} – Table 4).

4. Discussion

4.1. *The environment*

Although rainfall was greater in the 2000s than in the 1990s and was consequently *a priori* more favorable for aquatic organisms, the physicochemical environment in the Sine Saloum estuary seems to have degraded. In 2002, the Sine Saloum was slightly more saline, warmer, less transparent, and less oxygenated. This was especially the case in the period following the rainy season (October) and less pronounced in the period corresponding to the warm and dry season (April). Leaching of "tannes" located in the upper Saloum, intensified by high rainfall and inducing increased saline and terrigenous input, is the most consistent explanation. The increase in temperature and decrease in dissolved oxygen rates can be linked to the decline in transparency.

In West African estuarine fish communities, salinity often predominates over turbidity as a structuring force. Hence, in the 1992 study of the fish assemblage in this estuary, Simier et al. (2004) highlighted the role of salinity and depth. In a study on the fish assemblage in the Gambia estuary, salinity combined with temperature, then turbidity, were identified as structuring factors (Simier et al., 2006). Conversely, in the Fatala estuary (Guinea), Baran (1995) highlighted the structuring role of turbidity on fish assemblages and interpreted it as a factor in protecting juveniles.

More generally, in tropical zones that present marked seasonal variations, salinity and transparency were often identified as the main environmental factors likely to structure the spatial organization of fish assemblages and influence seasonal variations (Cyrus and Blaber, 1987; Whitfield, 1999; Blaber, 2000; Castillo-Rivera et al., 2002; Barletta et al., 2005). These analyses were generally based on one-year studies of fish assemblages, and the structure was analyzed in terms of spatial factors. In particular, Barletta et al. (2005) suggested that salinity was one of the main structuring factors in fish assemblages in estuaries presenting a high gradient on a spatial or seasonal scale for this parameter. In the present study, only the inter-annual variability was analyzed (10-year interval), with the estuary considered as an entity in itself.

4.2. *Dominance indicators*

The ABC index proposed by Meire and Dereu (1990) was estimated as negative in both our study periods, which, according to these authors, would classify the Sine Saloum estuary as highly disturbed. Yet, as stated by Dauvin and Ruellet (2009), the ecological quality status and stress levels in estuaries are complex issues because some communities have adapted to tolerate temporal physico-chemical changes. Moreover, indices like the ABC index are not intended to be used in static analyses of community structure data as a primary means of determining stress effects. They are intended, instead, to provide a means for testing community changes under stress (McManus and Pauly, 1990). Most of the studies using this index have dealt with the effect of pollution along a river; variation in this index would thus serve to analyze variability linked to the polluting event. Penczak and Kruk (1999) noted that low ABC index values could be linked to overfishing.

Table 5
Variation between 1992 and 2002 for the mean maximum observed length (MOL) for species common to the two study periods.

	Es	Em	ME	Ma	Mo	NbDec	NbSp	VarMOL
Detritivorous	+	=	=			1	7	+1%
Phytophagous		++				0	1	+28%
Zooplanktivorous		=	=			0	2	0%
Benthophagous		−−	−			4	6	−33%
Generalist predators	=	−	−−	−−	−	8	19	−18%
Ichtyophagous			−−	−	++	4	6	−8%
NbDec	0	6	8	2	1			
NbSp	3	15	17	4	2		41	
VarMOL	+6%	−13%	−18%	−19%	−20%			−16%

++, Increase > 10%; +, increase from 5% to 10%; −−, decrease > 10%; −, decrease from 5% to 10%. The codes for the ecological categories are explained in Section 2.5. NbDec, number of species whose MOL declines; NbSp, number of species; VarMOL, variation in MOL.

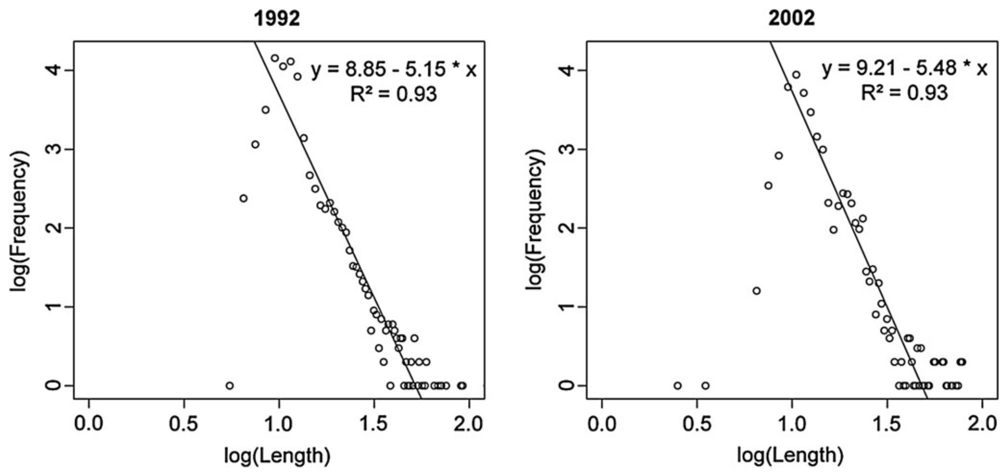

Fig. 5. Size spectra for catches in 1992 (left) and in 2002 (right).

We have thus only considered our ABC values as comparative values and have not taken into account absolute values in any given year. The change in this index over 10 years (−4.54 to −2.89) would therefore indicate a trend towards less disturbance.

4.3. Richness and abundance

Indicators for species richness remained unchanged over the 10-year period, both globally and by ecological or trophic category. Due to the permanently high salinity in the Sine Saloum Delta and its wide opening to the sea, the marine component accounted for 95% of the observed richness in both studied periods.

The overall observed richness (55 in 1992, 57 in 2002) represents approximately 50% of the total richness of 114 species described for the Sine Saloum (Albaret, 1999). The species that were absent in 2002 were replaced by species from the same functional category. Therefore, the fish assemblage of the Sine Saloum estuary remained characterized by dominance of the Em and ME categories with predatory characteristics (generalist predators, ichthyophagous and benthophagous species).

On the other hand, indicators for biomass showed a large decline (40%) between the two sampling periods. This overall decline concerned all of the ecological categories with a slight relative increase in weight for the Em species. In terms of trophic categories, this decrease in total biomass is explained by a sharp decline in the biomass of zooplanktivorous species, but also of generalist predators and especially the benthophagous category. Proportionally, the fish assemblage showed an increase in its detritivorous and phytoplanktivorous components to the detriment of the benthophagous and generalist predator components.

In the study on changes in the community of the Espiritu Santo estuary (Puerto Rico) by Smith et al. (2008), a decline in species richness and biomass was observed; the authors linked this decline to anthropogenic transformations (construction of an upstream dam, downstream drainage to facilitate harbor traffic), which largely explained the loss of the freshwater component of the assemblage. Moreover, for European estuaries, Franco et al. (2008) pointed out that this freshwater component showed the highest variability in diversity compared to other components of the assemblage. In the case of Sine Saloum, the delta is an inverse estuary, so the freshwater component was not present in either 1992 or 2002. Since the assemblage had high marine affinity, its renewal in terms of richness was constant. The high decline in biomass is more likely explained by overfishing.

4.4. Size-based indicators

The descriptive indicators for size structure complement the result presented above; the lack of large generalist predator and benthophagous individuals explains the sharp decrease in average maximum lengths. Given that the comparison was based on species collected during two different periods, this was not due to rare species. However, the average length of the dominant species, and even their maximum length, increased. This explains the low but significant increase (+5 mm) in the average length of total catches.

As stated by Yemane et al. (2008), both the decline in the mean for maximum lengths and the decline in the number of species able to reach their maximum length (400 mm in our study) may be considered as indicators that a fish assemblage is disturbed.

4.5. Tropho-dynamic indicators

The mean trophic level decreased by 0.11 between the two studies. The decrease in biomass of predators with a high trophic level and the increase in biomass of species with a low trophic level (detritivorous and phytophagous species) partially explain the decline in trophic level.

The decrease in mean trophic level observed in the Sine Saloum could be interpreted in relation to many studies undertaken in recent years. These studies point out that a variation of 0.10 in the mean trophic level can be considered significant: Pauly et al. (2001) in a study on catches from the Canadian east and west coasts proposed a value of −0.10 per decade; Laurans et al. (2004) found a similar value for the coastal assemblages of Senegal.

The present study is based on scientific non-selective fishing data. Consequently, the estimated mean trophic level includes data on components of the assemblage (species, small-sized individuals, etc.) that were not targeted by commercial fishing. As fishing activity tends to target large individuals, this has the effect of reducing the mean size of the assemblage, and therefore, over time, the mean trophic level (Pauly et al., 2002). Taking this into account, the decrease in the mean trophic level we observed could be regarded as significant as an indicator of the degradation of the health status of the fish assemblage in the Sine Saloum estuary.

According to Pauly et al. (2001), a decline in mean trophic level if the quantity of fish landed remains stable suggests a situation of non-equilibrium. In the case of our study, the catch level rose due to increased fishing activity in the estuary. It is thus possible that this increase in fishing pressure led to the decrease in trophic level of

0.11 units in 10 years. This hypothesis is reinforced by the fact that the fishermen mainly target either large-sized and/or predatory species (which could explain the decline in trophic level and the decrease of the maximum observed length), or species with high biomass (which could explain the decline in total biomass).

The low abundance of top predators observed in 2002 indicates that they had less impact on the community's structure, which is consistent with the conclusion of Laurans et al. (2004) concerning a "top-down" effect on the assemblages of the Senegalese continental shelf.

In a study by Garrison and Link (2000) similar to the present study but conducted over a longer period (30 non-continuous years), the declining trends of top predators were discussed in terms of overfishing. An increase in fishing pressure changed the dynamic equilibrium by targeting two major trophic guilds: large piscivorous and large benthophagous species. As a consequence, by the end of the study the dominant biomass included mainly pelagic and phyto-planktivorous species. Dominant species had become smaller, with a lower trophic level: the fish assemblage had shifted from a predominantly demersal community to a pelagic community (Garrison and Link, 2000).

5. Conclusion

The difficulty in using ecological indicators lies in interpreting the meaning of their variation. Recent studies (Shin et al., 2005; Greenstreet and Rogers, 2006) have highlighted the potential utility of these indicators: it is now possible to put the observed variation for some of these indicators into context (see previously cited references). However, some indicators can make sense only after a period of time has elapsed. For indicators related to size structures such as size spectra, this period of time has been estimated as between 5 and 10 years (Jennings and Dulvy, 2005).

Variations in the structure of the fish assemblage in the Sine Saloum estuary were not observed in terms of species richness, but rather through a decrease in biomass, maximum lengths and trophic level. This set of unfavorable indicators concerned principally the benthophagous species and, to a lesser extent, the generalist predator component of the assemblage. For species from these trophic categories, the mean length of catches also decreased. This change in the assemblage structure could be caused by two events:

1. Environmental degradation: particularly a marked decrease in water transparency, which could have a direct effect on the populations of species with low tolerance thresholds; this could explain the decrease in biomass of the marine species accessory in estuaries (Ma) and the marine species occasional in estuaries (Mo). The environmental degradation could also have an indirect effect on predator species via the prey population: a decline in the prey population due to environmental degradation means less prey is available, while, if their visibility is jeopardized, the prey is less accessible to predators. This indirect effect could explain the high decline in the benthophagous component.
2. Overfishing: particularly using active fishing techniques. At a certain level of exploitation, targeting of large-sized fish has a direct impact on their presence and abundance. The decline in abundance of large-sized species under intense fishing pressure would indicate changes in the assemblage structure.

According to Garrison and Link (2000), generalist predators find prey with greater facility than specialized predators (such as the benthophagous species) and therefore are more apt to survive a major disturbance. In addition, according to Meire and Dereu (1990), in a situation of major disturbance, the benthic community is replaced by abundant, but small-sized, pelagic species. Therefore, the hypothesis of environmental degradation would explain the large decline in the Sine Saloum estuary's benthic community and, to a lesser extent, in the generalist predator community. This hypothesis is reinforced by the different trends observed between each of the three categories of predators: a large change in benthophagous species, a moderate change in generalist predator species, and a small change in ichthyophagous species.

However, the hypothesis of overfishing as a main disturbance must also be considered given the large decrease in total biomass as well as the disappearance of large individuals. For these reasons, in 2002 the state of the fish assemblage of the Sine Saloum estuary had experienced high levels of degradation over a period of just 10 years.

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Supplementary data

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