Ocean & Coastal Management 100 (2014) 74–85

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Ecological field experiment of short-term effects of fishing ban on fish assemblages in a tropical estuarine MPA

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ARTICLE INFO

Article history:
Available online

ABSTRACT

Marine Protected Areas (MPAs), in addition to their important role in the conservation of critical habitats and vulnerable species, are now also used in a context of ecosystem-based fisheries management. The aim of this study was to assess the observed changes in the fish population structure in the years following a fishing ban. The experiment took place in the Bamboung bolong, a small bay in the Sine Saloum estuary in Senegal, West Africa. The protection of this zone was undertaken with local fishermen support, and a formal MPA was created in 2004. The survey of the fish assemblages was initiated in 2003, the year before the fishing ban, and went on until 2007, with 12 sampling sites being monitored three times per year.

In this paper, we describe and analyze the evolution of the fish assemblage during this five years' experimental period. Some changes have been highlighted on which the effect of the fishing ban was shown. After the fishing ban, an increase of total biomass and of maximal fish length has been registered. In the same time, the number of species has increased and the percentage of large and/or iconic species targeted by fishing has also increased. The community structure has been modified, with more small fish, more big fish (new large species and more large individuals in the original species) and fewer medium sized fish. The contribution of marine affinity species has increased in depend of the estuarine part of the assemblage. Finally, the trophic structure has been modified with an overall increase of the mean trophic level, resulting from an increase of the percentage of generalist or piscivorous predators and a sharp decrease of herbivorous and detritivorous low trophic level species. Marine predators which numbers and size were reduced by fisheries are again important components of the system. We argue that despite the intrinsic variability of the tropical estuarine environments, the introduction of a total ban on fishing in such estuarine zones can substantially improve the health status of the fish assemblage.

1. Introduction

Faced with widespread over-fishing (Pauly and Froese, 2012), partial or complete fishing bans were implemented worldwide with the hope of restoring fish stocks (Halpern, 2003; Claudet et al., 2008), and thus more sustainable fisheries. According to Roberts and Polunin (1993), the main expected results of Marine Protected Areas (MPAs) were as follows:

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http://dx.doi.org/10.1016/j.ocecoaman.2014.08.009
0964-5691/

- increased broodstock, mainly within the marine protected area (Lester et al., 2009),
- emigration of juvenile and adult fish from within the MPA towards nearby unprotected zones (spillover effect, Rowley, 1994; Stobart et al., 2009) or egg and larval exports towards close or remote areas, potentially allowing stock recovery (Rowley, 1994; Russ et al., 2003; Alcala et al., 2005),
- increased mean size of fish within the protected area (Halpern, 2003).

The implementation of MPAs in West Africa followed a trend similar to that of the creation of MPAs throughout the world (Spalding et al., 2008). The creation in the mid-seventies of the National Park of Banc d'Arguin in Mauritania, the largest MPA in the region, was followed by a series of new implementations of protected areas in parallel with the settlement of no-take areas (NTA) since the late nineties (Wood, 2007).

MPAs in the West African region were primarily created with conservation objectives, to protect emblematic species and critical habitats. In the last ten years, their use as fishery management tools has also been advocated, particularly strongly in Senegal. In this country, according to official data (Agence Nationale de la Statistique et de la Démographie, 2011), the fisheries sector (and particularly the artisanal fisheries sector, with 347 600 tons of fish in 2010) represents a major part in the country's economy (1.8% of Gross Domestic Product). However, it has been presenting clear signs of decline and over-exploitation (Direction des Pêches Maritimes, 2014; Thiao et al., 2012; Breuil, 2011). Yet the impact and effectiveness of the created MPAs were never thoroughly evaluated.

The Bamboung zone, located in the Sine Saloum delta in Senegal, was characterized by extensive rainfed agriculture, highly sensitive to climatic events and dependent on family labor. Cultivated crops were millet, sorghum, groundnut, and maize. Mangroves in the area were prone to overexploitation of wood resources linked to increased need for firewood. Fishing was highly developed using several fishing gears like beach seines, encircling gillnets, driftnets and baited longlines, targeting a wide variety of fish species and shrimps. Fishing was done by men but fishmonger activities, picking of bivalves and of forest products primarily involved women. Landing points were landlocked and transportation of the fishery products was difficult.

Fishermen from the Bamboung zone, in close relationship with a local Senegalese environmental Non-Governmental Organization (Oceanium), began the implementation of a locally managed small MPA (Cormier-Salem, 2014). Oceanium included the project as one of the demonstration sites selected by the “Narou Heuleuk” (“Tomorrow's share”) initiative, which is driven by Oceanium and funded by the French Global Environment Facility/Fond Français pour l'Environnement mondial (FFEM) (Breuil, 2011). This initiative aims to stimulate the creation of MPAs and raise awareness of stakeholders, particularly populations of fishermen, toward the sustainable use of resources. In December 2003 a locally decided and managed fishing ban was established, aiming to prohibit all extractive activities within the marine zone of the MPA. This ban was afterward confirmed by a Presidential Decree Law in November 2004 (Breuil, 2011. Decree is available at http://www.jo.gouv.sn/spip.php?article6753). At the request of the local promoters, we planned the assessment of the effects of the protection to come and took the opportunity of implementing an ecological experiment with a regular contact with the Non-Governmental Organization and the local community and authorities. With their agreement, the Bamboung bolong has been monitored by scientific fishing using a purse seine. Monitoring started before it became an MPA in December 2003 and the experimental survey went on until 2007, with 12 sampling sites being monitored three times per year.

There have been many studies on MPAs around the world; however, the Bamboung reserve is the only West African MPA in which a continuous monitoring program of the fish populations has been conducted. The Bamboung MPA is a very small reserve (4 km^2) but, according to Halpern (2003), marine reserves, regardless of their size, may have significant positive effects on fish populations and assemblages.

In the present work, we use this five years' monitoring period in the Bamboung MPA as an ecological field experiment which allows us to focus on the short-term evolution of the fish assemblage before and after a fishing ban.

To situate the Bamboung ecosystem in the range of estuarine environments of West Africa, we first present a short description, regarding the aquatic environment, the fish fauna and their functional groups. Next, we present an analysis of the short-term effects of the fisheries ban as compared with the prior situation, that is, the fish populations in 2003.

We conclude with a discussion about the ecological functioning of an estuarine tropical zone under protection, the limitations of this experiment, and the potential for generalizing our results and this experience at a regional level in West Africa. Perspectives and recommendations are made based on our work and a literature review on tropical MPAs.

2. Materials and methods

2.1. The study area

The Sine Saloum Delta is situated in Senegal, approximately 130 km southeast of Dakar, and comprises three main branches: from north to south, the Saloum, the Diomboss and the Bandiala. The Sine Saloum Delta is a complex and diffuse system of channels, locally called bolongs, and mangrove (White and Edwards, 2000). The Sine Saloum Delta is used as a breeding and/or nursery site (Vidy, 2000) by many estuarine and coastal fish species of economic or ecological importance. The Sine Saloum Delta has been designated as a Biosphere Reserve by UNESCO since 1980.

The Saloum is an inverse hyperhaline estuary (Diouf, 1996; Simier et al., 2004) in which the salinity varies from 35 psu at the sea mouth to more than 130 psu in the upper most river areas. The freshwater inputs are indeed very limited since the 30 s and even more since the droughts of the 70 s (Pagès and Citeau, 1990). Nevertheless, some intermediate areas have salinities below 35 during the rainy season (from July to October).

The Bamboung MPA is situated in the Bamboung bolong (Fig. 1), a tributary of the Diomboss, in an area of average salinity. This area lies between 13°46′ and 13°51′ north latitude and 16°30′ and 16°35′ west longitude (17 km from the Atlantic Ocean). The Bamboung MPA covers 68 km^2 and is divided into two sectors:

- A water body of approximately 4 km^2, consisting of the Bamboung bolong and its branches (central MPA zone in Fig. 1–3 km^2) and a transition area advancing several hundred meters into the Diomboss (peripheral zone in Fig. 1–1 km^2). The bolong is 15 km long from the confluence with the Diomboss to the mudflats of the Kole forest upstream; its width varies between 50 and 500 m and its depth between 0 and 15 m. The Bamboung bolong has a very dense network of secondary canals. Due to the presence of significant groundwater on Coco Island (east bank), underground springs flow into the bolong, locally lowering the salinity. These specific conditions form a variety of habitats and environmental conditions, allowing a large diversity of aquatic fauna.

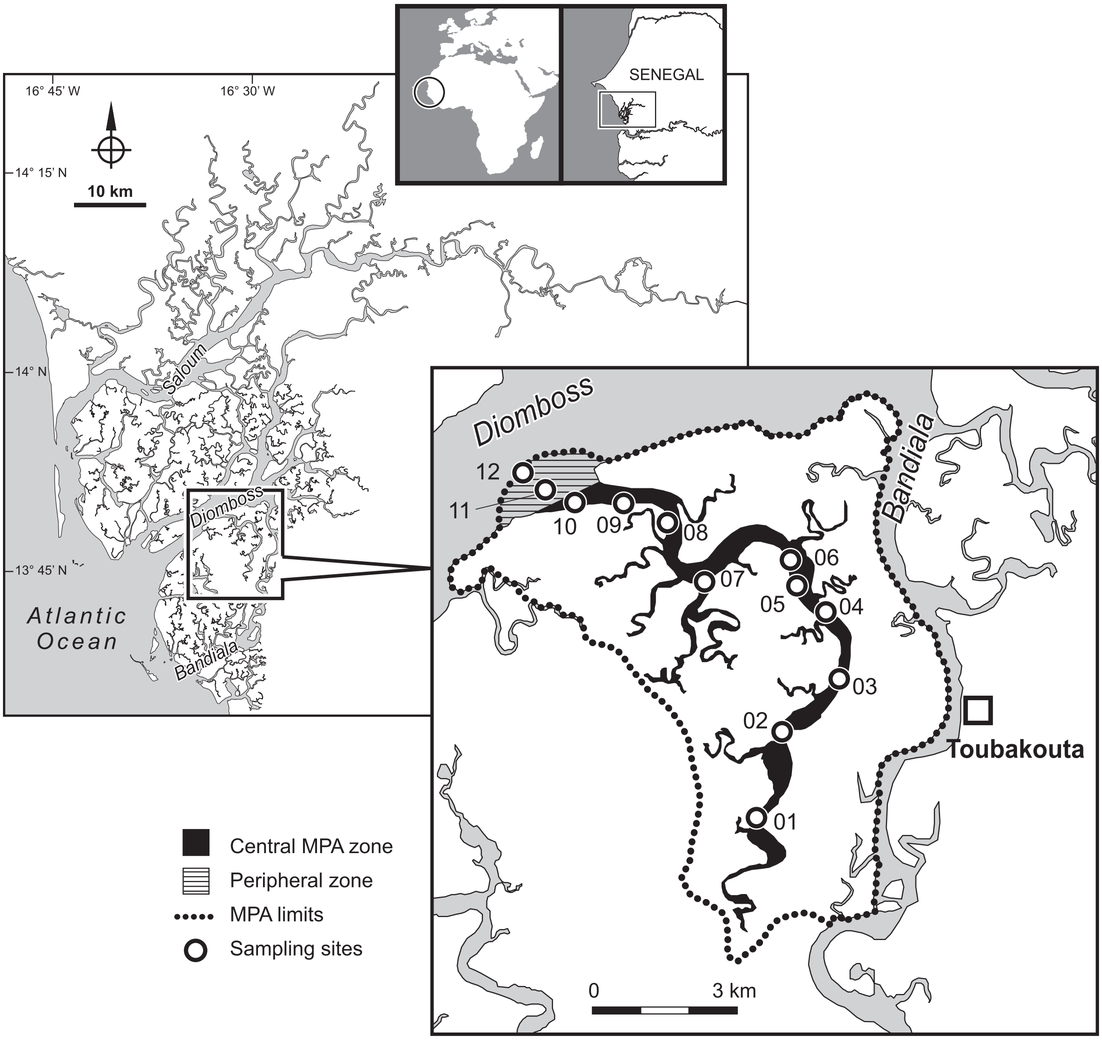

Fig. 1. Location and map of the delta of the Sine Saloum (Senegal). Location of the Bamboung MPA and position of the 12 sampling sites (01–12).

- A wetland zone, consisting of a mangrove area flooded at high tide and a mainland dry zone. The mangrove is located along the banks of the entire center of the water body and covers more than half the total area of the MPA. Vegetation is abundant, and various mangrove species have developed. The mainland is mostly constituted by Coco Island. This savannah area represents 15–20% of the surface of the MPA.

2.2. Sampling strategy

Based on the ecological zoning established in a preliminary mission, twelve sampling sites were selected, representing the different habitat types encountered in the Bamboung MPA. The twelve sites were located precisely by GPS from upstream (site 01) to downstream (site 12), with sites 11 and 12 located in the peripheral area of the MPA in the Diomboss (Fig. 1).

Fish sampling and simultaneous measurement of several physical and chemical parameters of the aquatic environment were performed three times a year at each site, at key periods of the hydrological cycle: in March (cool and dry season), May (warm and dry season) and October (warm and rainy season). Sampling began in 2003, for a reference series before the fishing ban, and continued until 2007. Thus, a total of 15 surveys were performed.

2.3. Fish sampling method

Underwater visual census cannot be performed as water is highly turbid. The use of acoustics, another non destructive technique, was tested previously in a similar ecosystem, The Gambia River estuary, (Guillard et al., 2004, 2012). Although interesting for biomass evolution and overall size structure studies, acoustic sampling is not straightforward if quantitative data on species composition is requested (Coll et al., 2007), which is the case in MPA effectiveness studies.

Purse seine has been widely used in similar studies. For instance, the one used by Wessel and Winner (2003) was 183 m long, 5.2 m deep and 50 mm stretch mesh. Those of Steele et al. (2007) were very small seines (18.2–36.4 m long with a 3 mm mesh) only usable in shallow waters and small estuaries. The latter authors stressed that purse seine size and mesh size affect estimates of density or species richness and of course the size of the captured fish. Their study area was a very small estuary with limited depth (no deeper than 2 m). Our zone is deeper (up to 15 m) and the choice of the fishing gear was indeed a compromise. We needed to be able to sample the large species and large individuals that were expected to benefit from the fishing ban and try not to miss the small ones. We thus used a relatively large seine with small mesh.

Table 1
Bio-ecological categories according to Albaret (1999) observed in the Bamboung MPA.

Code	Description
Es	Strictly estuarine species
Em	Estuarine species from marine origin
ME	Marine-estuarine species
Ma	Marine species, accessory in estuaries
Mo	Marine species, occasional in estuaries

Thus fish sampling was performed using a purse seine net (length 250 m, height 20 m, 14 mm mesh, surface 0.005 km^2). Each survey (12 hauls) covers 1.5% of the total area of the MPA. This method enables a good reproducibility of sampling in very diverse environments, and it provides fresh and well-preserved biological material (Simier et al., 2004). The use of the purse seine, by the same team of nine fishermen, with the same protocol and without searching for shoals, enables to consider a seine haul as a stable unit of fishing effort, allowing direct comparison between hauls.

2.4. Collected data

2.4.1. Environmental data

Physical and chemical water variables were measured as close to the fishing sites as possible: water transparency with a Secchi disk (m), salinity with an optical refractometer, temperature with a thermometer (°C) and dissolved oxygen (percentage of saturation) with a YSI hand-held field instrument. The depth (m) was measured with an acoustic handheld depth-meter at the precise location of each seine haul. Salinity, temperature and dissolved oxygen were measured at the surface and bottom.

2.4.2. Biological data

Fish were identified by species and then counted and weighed by species to the nearest gram for each seine haul. A subsample of up to 30 individuals per species per haul was measured to the nearest mm.

Observed species were classified into bio-ecological categories (Table 1), which, in addition to the degree of euryhalinity of the species, consider the characteristics of their bio-ecological cycle in the different estuarine environments of West Africa (Albaret and Diouf, 1994; Albaret, 1999).

Species were also categorized by trophic group (Table 2). Their trophic level was taken from Fishbase (Froese and Pauly, 2011).

In reference to the review on functional guilds by Elliott et al. (2007), the bio-ecological categories we used correspond closely to the “estuarine-use functional groups” except for a difference in the division of the marine migrants into 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 groups correspond to the “feeding-mode functional groups”, the piscivorous category according to Elliott et al. (2007) being subdivided here into generalist predators (p2-ge) and strictly piscivorous species (p2-pi).

Individuals were all above 6 cm in length, and, for the calculations and graphs, all individuals, including juveniles, were assigned to the trophic group of the adult form.

Table 2
Trophic groups used in the study of the Bamboung MPA.

Code	Description
he-de	Scavenger or grazer herbivores
he-ph	Herbivores mainly feeding on phytoplankton or micro-phytoplankton
p1-zo	First level predators mainly feeding on zooplankton
p1-bt	First level predators mainly benthophagous (molluscs, cockles, marine worms)
p1-mc	First level generalist predators mainly feeding on macro-crustacean or insects
p2-ge	Second level generalist predators mainly feeding on fish, shrimps and crabs
p2-pi	Second level piscivorous predators mainly feeding on fish

2.5. Data processing

A Principal Component Analysis was performed on the environmental variables measured at each seine haul.

The mean species richness, abundance and biomass were computed for the before-ban and the after-ban periods using the observed values per seine haul. For each variable, the frequencies of different functional guilds (five ecological categories and seven trophic groups) were calculated leading to three 2 × 5 tables and three 2 × 7 tables. Each frequency table was tested using the G-test of independence (Sokal and Rohlf, 1995). The null hypothesis was that the relative proportions of one period (before ban) were equal to that of the second period (after ban). If the null hypothesis was rejected, each table row was tested to determine which functional guild contributes or not to the difference between the before and after periods. This multiple G-test was corrected for multiple comparisons using the Benjamini and Hochberg (1995) correction.

The individual measurements were used to compute the mean lengths before and after the ban and to build size frequency histograms, grouped at the lowest cm. In cases for which a sub-sample of 30 individuals rather than the entire catch was measured, an extrapolation was performed to obtain the total number of fish caught. The size of the largest individual from each seine haul was used to compute the mean maximum observed lengths (MOL) before and after the ban. Comparisons for each functional guild were performed using a two-sample permutation test (Fay and Shaw, 2010). This multiple test was corrected for multiple comparisons using the Benjamini and Hochberg (1995) correction.

The average trophic level per haul was calculated by balancing species trophic level by the biomass: the weights were summed to obtain the total weight of the haul (WT), then the weight of each species (wt) multiplied by the trophic level of the species were summed, then divided by WT to obtain the mean trophic level of the haul. Mean values per year were compared using ANOVA and Tukey's HSD post-hoc test.

All data used in this study are available in the PPEAO information system (Simier and Ecoutin, 2012). All statistical analysis and graphs were performed using the R software and associated packages (R Core Team, 2014).

3. Results

Between 2003 and 2007, 15 sampling surveys were performed, leading to 180 seine hauls and associated environmental data sets.

3.1. Aquatic environment

Salinity varied between 28 in October, at the end of the rainy season, and 50 in May, at the end of the dry season. The transparency was remarkably high for this type of environment (2 m on average, and as much as 3.7 m observed in March 2003). The temperature varied between 23 °C in March, during the cool season, and 33 °C in October, during the warm season. The percent saturation of dissolved oxygen was consistently high, generally well above 60%.

The first two axes of the Principal Component Analysis (Fig. 2) represented respectively 52.6% and 18.6% (71.2% in total) of the total variability. The correlations circle (Fig. 2a) revealed the strong correlations between surface and bottom values, particularly for salinity and temperature values.

The representation of samples with average positions per month (Fig. 2d) mainly highlighted the opposition along axis 1 between October (warm and rainy season), when the water temperature was maximum and the salinity and conductivity minimum, and March and May (dry season) when the salinity and conductivity were at their highest. During the cool and dry season (March), the temperature was lower and the percent of oxygen in the water was higher than during the warm and dry season (May). This was expressed in a gradient along both axes 1 and 2, linked to increasing temperature and decreasing oxygen percent.

The representation of average positions per site (Fig. 2b), despite of a high intra-site variability due to high seasonal variability, showed an upstream-downstream gradient from site 01 to site 12, with best oxygenated, least salty and coolest waters observed at sites 11 and 12, located at the mouth of the bolong.

Finally, the representation of samples with average positions per year (Fig. 2c) showed no clear interannual trend.

3.2. Fish communities

3.2.1. Inventory

A total of 73 species were identified (Appendix), belonging to 37 families, 18 of which were monospecific in the bolong. The family best represented in terms of species richness is Carangidae, with eight species, followed by Mugilidae (six species), Haemulidae (five species), and Clupeidae and Ariidae (three species each). These five families represent almost 78% of the total sampled biomass (Appendix).

Twenty-four species were present in 10 or more of the 15 surveys (Appendix). Two Gerreidae (*Eucinostomus melanopterus* and *Gerres nigri)* were, respectively, present in 126 and 111 out of 180 hauls, and the Clupeidae *Sardinella maderensis* was found in 99 hauls.

The most important bio-ecological categories were ME (marine estuarine species, usually breeding at sea) and Em (estuarine species of marine origin, breeding in estuary), represented respectively by 20 and 17 species (Appendix). Six strictly estuarine species (Es) were sampled and the rest of the population was composed of marine species accessory or occasional in estuaries (respectively Ma, with 14 species and Mo, 16 species).

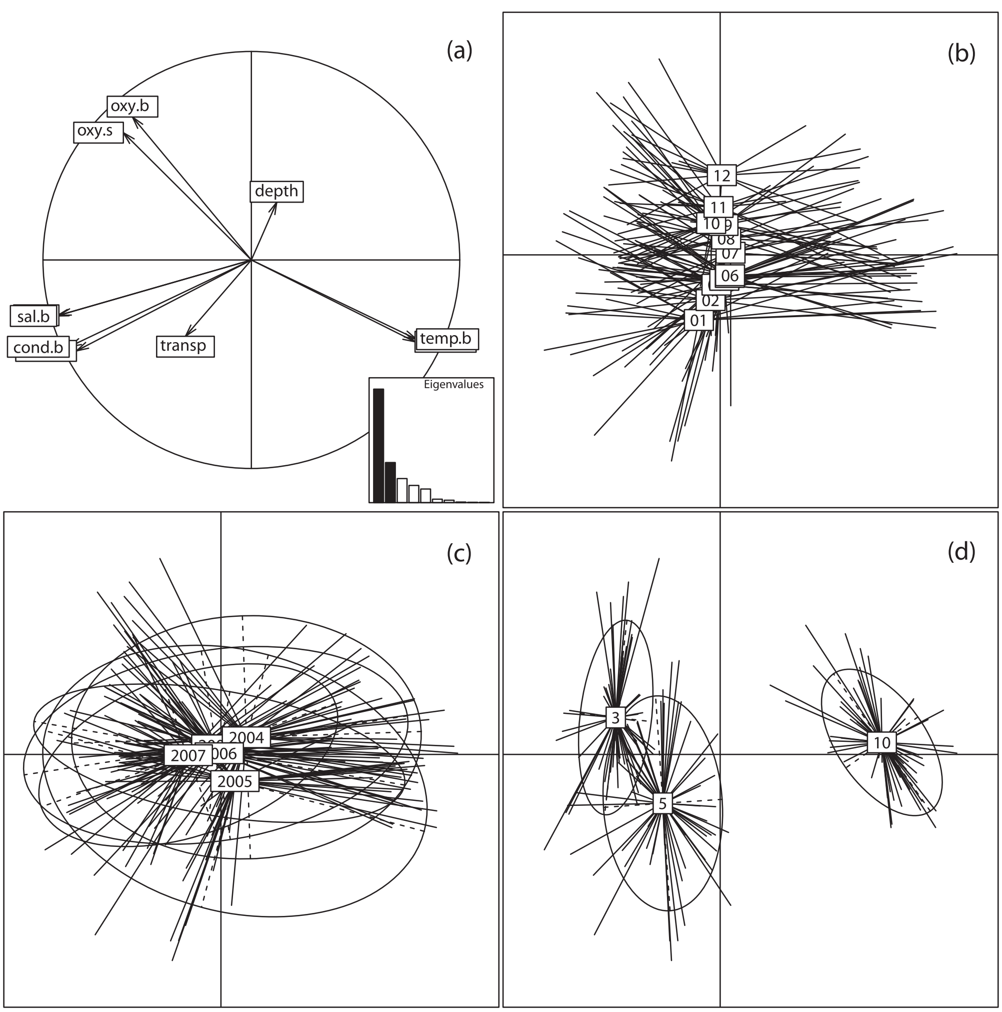

Fig. 2. Principal Component Analysis of the environmental parameters from all hydrological surveys. (a) correlation circle of the environmental variables on the first two axes, with diagram of eigenvalues (axis 1 horizontal: 52.6%, axis 2 vertical: 18.6%); transp: transparency, oxy.s: surface percentage oxygen saturation, oxy.b: bottom percentage oxygen saturation, sal.s: surface salinity, sal.b: bottom salinity, cond.s: surface conductivity, cond. b: bottom conductivity, temp.s: surface temperature, temp.b: bottom temperature; (b), (c), (d) projection of the 180 samples on the first two axes, with average points per (b) site, (c) year and (d) month.

Table 3
Evolution of fish population parameters (grouped by bio-ecological categories) in the Bamboung MPA between the period before the fishing ban (B) and the period after the fishing ban (A); Sig: significance level of the G-test of independence (***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; ns non significant); bio-ecological category codes are given in Table 1.

	Species richness			Abundance			Biomass		
	B	A	Sig	B	A	Sig	B	A	Sig
Es	13%	14%	ns	4.2%	4.1%	ns	5.8%	3.3%	***
Em	39%	31%	ns	65.2%	60.9%	ns	73.2%	27.0%	***
ME	39%	43%	ns	30.0%	34.3%	ns	19.5%	59.6%	***
Ma	6%	8%	ns	0.4%	0.5%	ns	0.9%	4.9%	***
Mo	3%	4%	ns	0.2%	0.2%	ns	0.6%	5.2%	***

Of the 73 species observed during the present study, 44 were observed both before and after the fishing ban (Appendix), six species were only observed in 2003, and 23 species were only recorded after the creation of the MPA. Most of the latter were marine species accessory in estuaries (Ma, six species), marine species occasional in estuaries (Mo, nine species) or marine estuarine species (ME, five species).

Among the 23 species recorded after the MPA was created, the proportion of valuable and emblematic species (large predators or their juveniles) was high: white grouper, locally known as "thiof" (*Epinephelus aeneus*), African brown snapper (*Lutjanus dentatus*), two species of barracuda (*Sphyraena afra* and *Sphyraena guachancho*), several large Carangidae (*Alectis alexandrinus, Lichia amia, Trachinotus ovatus* and *Trachinotus teraia*), a shark (*Carcharhinus leucas*), and a bull ray (*Pteromylaeus bovinus*). Most of these species reach large or very large sizes. During the present study, 76 individuals exceeded 50 cm in addition to the two sharks (*C. leucas*) at 1.27 and 1.37 m long, one barracuda (*S. afra*) at 1.30 m long and a bull ray (*P. bovinus*) with a 1.43 m wide disk.

3.2.2. Species richness, numbers and biomass

The annual species richness was stable at approximately 48–50 species, while the species richness per survey varied between 20 and 40 with a mean value of 31 species per survey. The mean species richness per haul slightly decreased between 2003 (8.2 species) and the average value after the ban (6.9 species). The frequency distribution of species richness pooled by bio-ecological categories or by trophic groups showed no significant differences between the before and after-ban situations (Tables 3 and 4). Nevertheless some trends are worth noting. The proportion of estuarine species of marine origin (Em) decreased. The proportion of herbivorous species (he-de and he-ph) decreased while the proportion of piscivorous species (p2-pi) increased.

The mean abundance in number of individuals per seine haul was 256 before the ban and 300 after the ban. Mean abundance increased during the two first years (up to 492 individuals in 2005) and then decreased to a somewhat stable value in 2006–2007 (approximately 200 individuals) that was lower than that of 2003.

The variation in biomass before the ban (15.2 kg/haul) compared to that after the ban (16.7 kg/haul) remained low. Inter-annual evolution of biomass was different than that of abundance. Just after the fishing ban, the biomass rapidly decreased (10.4 kg/haul in 2004) and then began to increase, up to 29 kg/haul in 2007.

When divided by bio-ecological categories, these two parameters showed distinct trends when comparing before-ban and after-ban periods (Table 3). The overall frequency distribution of abundance pooled by bio-ecological categories showed no significant differences between before and after the ban. Conversely, the overall frequency distribution of biomass pooled by bio-ecological category showed highly significant changes for all categories. The biomass decreased in the two estuarine related categories (Es and Em); for the Em category, the proportion of biomass decreased from 73.2% to 27.0%. In the marine related categories (ME, Ma and Mo) the trend is reversed, particularly for the ME category (from 19.5 to 59.6%).

Regarding the trophic structure (Table 4), the overall frequency distribution of abundance shows three out of seven significant trends. The proportion decreased sharply (23.1–3.9%) in scavenger or grazer herbivores (he-de). The proportion increased for the other herbivores (he-ph) and for the second-level generalist predators (p2-ge). Proportions in biomass showed highly significant differences between before and after the ban, except for the zooplanctonophagous species (Table 4). The herbivorous groups (he-de and he-ph) showed a sharp decrease, while predators of all groups showed an increase, particularly second-level predators (p2-ge from 5.9 to 49.6%) and benthophagous group (p1-bt from 3.2 to 9.4%).

Table 4
Evolution of fish population parameters (grouped by trophic groups) in the Bamboung MPA between the period before the fishing ban (B) and the period after the fishing ban (A); Sig: significance level of the G-test of independence (***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; ns non significant); trophic groups codes are given in Table 2.

	Species richness			Abundance			Biomass		
	B	A	Sig	B	A	Sig	B	A	Sig
he-de	20%	12%	ns	23.1%	3.9%	***	44.0%	6.3%	***
he-ph	9%	5%	ns	43.1%	53.7%	***	31.7%	12.5%	***
p1-bt	13%	17%	ns	0.8%	1.4%	ns	3.2%	9.4%	***
p1-mc	23%	24%	ns	12.0%	12.3%	ns	4.9%	5.5%	***
p1-zo	9%	9%	ns	17.5%	21.3%	ns	5.2%	4.9%	ns
p2-ge	21%	23%	ns	2.8%	6.6%	**	5.9%	49.6%	***
p2-pi	5%	10%	ns	0.7%	0.8%	ns	5.2%	11.8%	***

3.2.3. Size

The mean size of individuals decreased between the before-ban and the after-ban periods (respectively 13.6 cm ± 6.2 and 11.0 cm ± 6.7). When divided by bio-ecological categories (Fig. 3a),

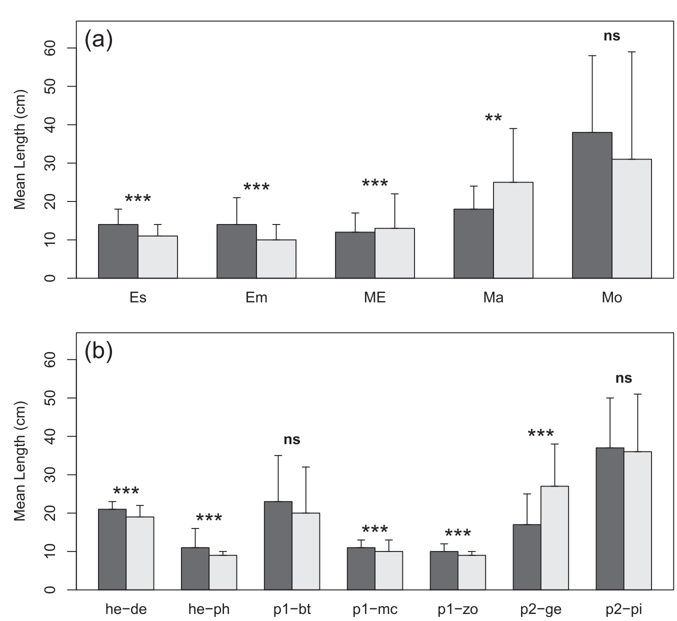

Fig. 3. Mean fork length with standard deviation before (black bars) and after (gray bars) the ban, divided by bio-ecological categories (a) and by trophic groups (b). Bio-ecological category codes are given in Table 1.Trophic groups codes are given in Table 2. Stars indicate significance levels based upon Fay and Shaw (2010) two-sample permutation tests (***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; ns non significant).

this decrease was observed for estuarine related categories (Es and Em) whereas the mean size of species from ME and Ma categories increased significantly. The decrease observed for the Mo category was not significant. Regarding the trophic structure (Fig. 3b), the mean size decreased for all groups except for the second-level predators (p2-ge). These trends where not significant for the benthophagous and the piscivorous species groups.

The evolution of the maximum observed lengths did not show a trend similar to that of the mean size. Rather, a somewhat increasing trend was observed between the before-ban and after-ban periods (respectively 35.5 cm ± 12.6 and 41.3 cm ± 23.0). According to bio-ecological categories (Fig. 4a), maximum observed length showed no significant variations except for the Ma category where the MOL increased. According to the trophic group evolution (Fig. 4b), only phytoplanctonophagous herbivorous species (he-ph) showed a significant decrease in MOL.

The comparison of the size spectra at the beginning and at the end of the study showed an important modification of the size structure of the fish community. In 2003, the total size spectrum is essentially bimodal, with a first main mode between 7 and 14 cm (modal value at 9 cm, Fig. 5) and a second, lower mode between 17 and 24 cm (modal value at 20 cm). At sizes over 30 cm, the spectrum showed the presence of very few individuals (Fig. 5). In 2007, the size spectrum similarly showed a main mode between 7 and 15 cm (modal value at 9 cm), followed by a series of small peaks composed mainly of individuals larger than 25 cm; this succession of peaks was observed up to nearly the 50 cm class length (Fig. 5).

When these are broken down to the underlying trophic components, different trends emerge. In 2003, the main mode was mainly composed of the trophic groups he-ph, p1-zo and p1-mc (in that order), and the second by groups he-de and he-ph (Fig. 5). There were very few fish from groups p2 and p1-bt. In 2007, the main mode was composed of the same categories but in an order of abundance different than that of 2003 (p1-zo, p1-mc, he-ph). Afterward, some he-de species formed the baseline, and all the successive peaks were composed mainly of p2-ge species (Fig. 5).

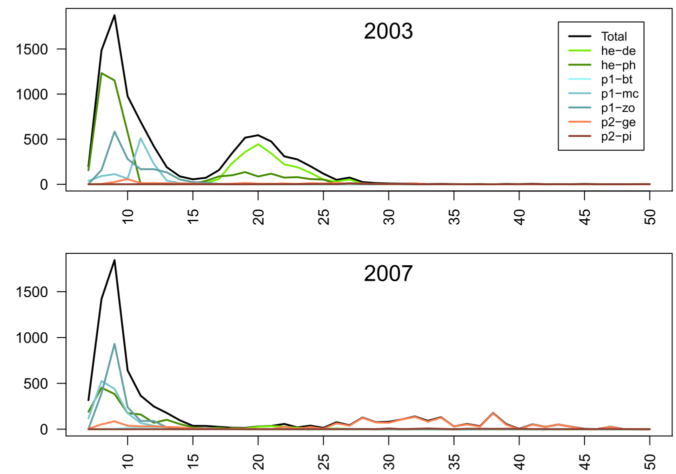

Fig. 5. Size spectra (total and by trophic groups) of individuals observed in 2003 (top) and 2007 (bottom); the distribution is truncated at 50 cm, maximum observed length = 69 cm in 2003 and 143 cm in 2007. Trophic group codes are given in Table 2.

Thus, between 2003 and 2007, there was a sharp decrease in individuals of medium size between 18 and 25 cm, which corresponded mainly to species belonging to trophic groups he-de and he-ph. At the other end of the spectrum, there were in 2007 many more large individuals (length over 25 cm), mainly of species from trophic group p2-ge (generalist predators), and, to a lesser extent, p2-pi (piscivorous predators).

The temporal trend can also be viewed through the evolution of the annual spectra of the percentage of each bio-ecological category; that of marine estuarine species (ME) is a representative example (Fig. 6). This category comprised 20% of the total community numbers in 2003 and comprised up to over 50% after the fishing ban. The span of the main mode observed in 2003 (7–16 cm) decreased with time (7–13 cm in 2007), whereas the amplitude of the mode increased (600 individuals in 2003 versus 1 150 in 2006 and close to 1 000 in 2007; see Fig. 6). Simultaneously, the size of the largest individuals in the category increased (maximum at 63 cm in 2003, 91 cm in 2006 and 130 cm in 2007). The numbers of individuals in the large size classes also increased. This increase can be observed, for example, in the 33-cm class, for which the numbers increased regularly from two individuals in 2003 up to 89 individuals at the end of the study period (Fig. 6).

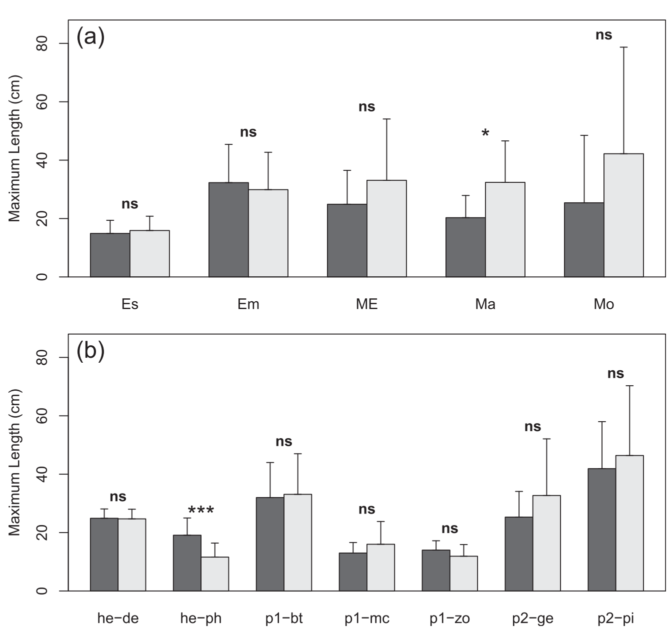

Fig. 4. Mean maximum observed length with standard deviation before (black bars) and after (gray bars) the ban, divided by bio-ecological categories (a) and by trophic groups (b). Bio-ecological category codes are given in Table 1.Trophic groups codes are given in Table 2. Stars indicate significance levels based upon Fay and Shaw (2010) two-sample permutation tests (***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; ns non significant).

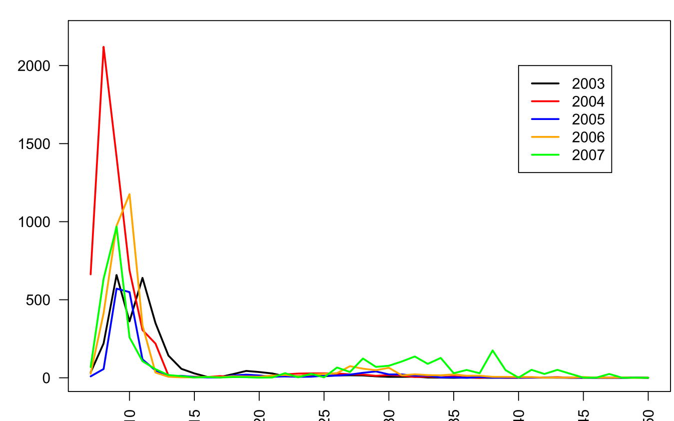

Fig. 6. Annual size spectra for individuals from marine estuarine (ME) bio-ecological category between 2003 and 2007. The distribution is truncated at 50 cm, maximum observed length = 90 cm.

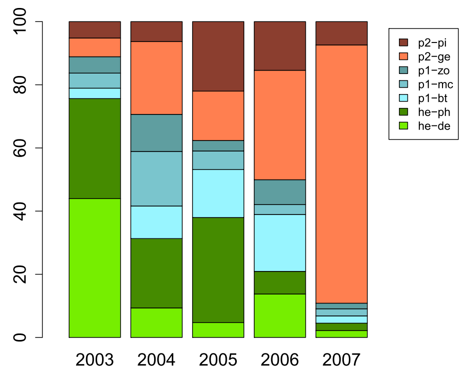

Fig. 7. Annual evolution of the composition (% in biomass) by trophic group. Trophic group codes are given in Table 2.

3.2.4. Trophic structure

While the proportion of the biomass from herbivorous species (he-de and he-ph) clearly showed a sharp decrease after the implementation of the MPA, (from 75% in 2003 and 30% in 2004 to 4% in 2007), there was a marked increase in the proportion of predators: the piscivorous species' share in the community increased from 5% in 2003 to 7% in 2007 (with a maximum of 21% in 2005) and the proportion of the biomass of unspecialized predators (p2-ge) grew from 6% in 2003 to 82% in 2007 (Fig. 7). In the latter group, the increase in biomass was observed from the very first year after the fishing ban (23% in 2004), whereas the piscivorous group only showed a distinct increase in the second year after the ban.

A 10% rise in mean trophic level per haul between 2003 (3.11) and the four following years (3.43) (Fig. 8) was observed. Tukey's HSD post-hoc test indicates that the 2003 value of mean trophic level was significantly different from the other four (95% threshold). There were no significant differences among the years 2004–2007 at 95% confidence level.

The characterization of fish populations prior to the ban and more detailed results can be found in gray literature in French (Albaret, 2003; Albaret et al., 2005; Tito de Morais et al., 2007).

4. Discussion

4.1. Aquatic environment

Tropical estuaries generally have turbid waters (Blaber, 2000) and present higher salinities than temperate estuaries. Such salinity and transparency levels are expected to be related to the high productivity and to the existence of the mangroves associated with the estuaries, making such ecosystems highly suitable areas for feeding and reproduction of fish (Albaret, 1999; Whitfield, 1999).

During the 2003–2007 period, the aquatic environment of the MPA could be considered as homogeneous at the annual scale. Although located in an inverse hypersaline estuary (Simier et al., 2004), the Bamboung bolong is a moderately salted area compared to the rest of the Sine Saloum system, where salinity goes up to over 130 psu in the extreme upstream zone. The Bamboung bolong is slightly hypersaline during the dry season and significantly desalted compared with seawater at the end of the rainy season. The minimum salinity value of 28 psu observed in October was amongst the lowest values recorded in the whole Sine Saloum system since ecological studies began in the zone in the early 1990s (Diouf, 1996; Simier et al., 2004; Ecoutin et al., 2010). Relatively abundant local rainfall during this period in the early 2000s may explain these low salinity values, but there are also other sources of fresh water reported.

Transparency in the MPA was low, with 2 m in average and up to 3.70 m. These figures are similar to the values observed elsewhere in the Sine Saloum (2–3 m – Diouf, 1996; Simier et al., 2004; Ecoutin et al., 2010).

4.2. Fish assemblages

The fish community of the Bamboung bolong appears to be rich, including more than half of the species reported throughout the Sine Saloum (114 species reported by Diouf, 1996). The richness in Bamboung was similar to that observed in the nearby Gambia River estuary (67 species, Simier et al., 2006) and Casamance estuaries (75 species, Albaret, 1987). The Bamboung total fish richness value is in the highest of those found at similar latitudes (González-Bergonzoni et al., 2012; Travers et al., 2012). However, these values must be put into perspective with both sampling intensity and habitat size and complexity (Gratwicke and Speight, 2005).

Only six species observed in the MPA were not reported elsewhere in the Sine Saloum (Diouf, 1996; Simier et al., 2004; Ecoutin et al., 2010). Four species were marine occasional or accessory in estuaries, and therefore not very common in an estuary: two species (*L. dentatus* and *C. leucas*) are large and emblematic species in the region. The third species, *Syngnathus pelagicus*, which is small in size, was observed in 2003 and not since. The fourth species, *Trachinocephalus myops*, is rarely found in estuaries. The two other "new" species from the MPA (a Bleniidae, *Hypleurochilus langi*, and a Gobiidae, *Awaous lateristriga*) are considered strictly estuarine species in Diouf (1996). However, given their habitat (shallow edge zones) and their small size (*H. langi* has a maximum observed length of 7 cm), they are not very accessible to the sampling gear used for this study.

The species richness per survey was stable, ranging between 20 and 40 species with a mean value of 31 species per survey. The annual species richness was also stable, at approximately 48–50 species. Both mean per survey and mean annual values were similar to observed values in other tropical zones (Travers et al., 2012). A somewhat regular shift in species composition was observed by season and year. The species that succeed one another in time were generally from marine affinity categories (Ma and Mo) and belonged to the second-level predator groups (p2-ge and p2-pi). However, given their low occurrence and numbers, they do not represent the only explanation for the temporal changes in the fish community structure within the MPA.

Several factors can be cited to explain the relatively high species richness observed in the Bamboung bolong. First, the slight hypersalinity of the water, added to its location near the ocean, allows

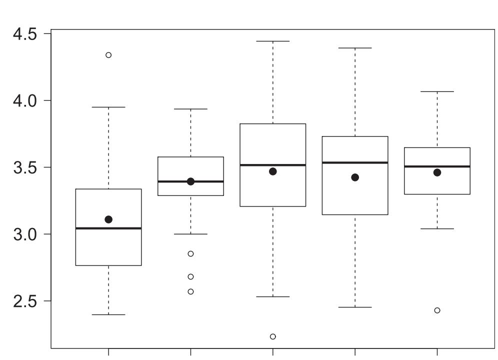

Fig. 8. Distribution of the trophic level per haul for the five years of study. The black dots superimposed to the box-and-whiskers plots correspond to the average annual values.

the settlement of a large number of marine species as well as species with estuarine affinities. This is in agreement with Hedgpeth (1967) and Hodgkin and Kendrix (1984), stating that a moderate hypersalinity is beneficial to species richness in estuarine environments. A second factor to explain such high species richness may be the high habitat diversity: the mangrove being present on several river banks and absent from some other margins, the presence of shallow mud banks uncovered at low tide and a succession of deep and shallow pools as well as the presence of an important network of small tributaries (Albaret et al., 2005). Additionally, the fishing ban allows for the protection and sometimes the recovery of these habitats (Gell and Roberts, 2003). A third factor is the entrance in the MPA of several types of top predators attracted by the increase of available prey (Gell and Roberts, 2003).

The species composition of the study area was as expected in this part of the Sine Saloum given the environmental conditions (Diouf, 1996): absence of species of continental origin, predominance of species from categories Em (estuarine species of marine origin) and ME (marine estuarine species) and several marine species, accessory (Ma) or occasional (Mo) in estuaries with reduced numbers and biomass. After the fishing ban, the marine component of the community (Ma and Mo species) increased in richness, and the estuarine component with marine affinities (Em and ME) increased in terms of abundance and biomass.

Over the entire study period, the most abundant species were both phytophagous and/or zooplanktonophagous filter feeders such as *Ethmalosa fimbriata* and *S. maderensis*. Medium-sized predators (*Pseudotolithus elongatus*, *P. senegallus*, *Lutjanus goreensis*) and juveniles of large predators (*Elops lacerta*) were also abundant. Large predators were represented mainly by the Giant African threadfin *Polydactylus quadrifilis* and by the barracuda *S. afra*.

The fishing ban has so far had complex effects on the overall biomass. After a decline in the year following the fishing ban, overall biomass has increased steadily. This increase in biomass was related to the regular increase in some species: *Arius latiscutatus*, *A. parkii* (p2-ge, ME both), *D. margaritella* (p1-bt, Em), *P. perotaei* (p1-bt, Em), *P. senegallus* (p2-ge, ME), *L. goreensis* (p2-pi, Ma), among other species. These changes were observed beginning in the first year following the fishing ban (Babcock et al., 2010) and were consistent with what is found when exploited and non-exploited areas are compared (Libralato et al., 2010; Villamor and Becerro, 2012). Herbivorous fish species deeply decreased in biomass, whereas the biomass of second level predator species and even more that of benthophagous species showed an important increase.

Size increased in large species, and the number of individuals in the large size classes also increased. Most of these large individuals belong to the second-level predatory fish species. Changes in species composition are indeed usually accompanied by size structure changes (Kartawijaya et al., 2008; Watson et al., 2009; Taylor and McIlwain, 2010).

After four years of the fishing ban, in 2007, the main trophic component was formed by large or medium-sized individuals of second-level generalist predatory species (p2-ge). These individuals were present in small numbers and remained at a relatively constant level of abundance but at a fairly important biomass. These species fed mainly on fish and shrimps. The species observed more regularly belonged to the ME ecological category. Five species dominated: *A. latiscutatus* and *A. parkii*, *Monodactylus sebae*, *P. senegallus* and *Plectorhinchus macrolepis*. For these species, the MPA is a feeding ground and a growth area during most of the year before their return to the sea to spawn.

The second trophic component showing modifications after the fishing ban is that of piscivorous predators (p2-pi). Only four of these were almost always present after the fishing ban: *E. lacerta*, *L. goreensis*, *P. quadrifilis* and *S. afra*; these species showed a regular increase in biomass. The others were generally present in low numbers, replacing each other over time. Individuals are often large, their maximum size being much higher than the values observed in the Sine Saloum (Diouf, 1996), particularly after the fishing ban. As most piscivorous species were from marine affinity categories (ME, Ma or Mo), the replacement of species over time may suggest that they use the MPA as a temporary feeding ground. In addition, following the fishing ban, sharks (*C. leucas*) were occasionally present, and the observation of dolphins (*Tursiops* sp.) completes this panel of predators.

The third component that appears to benefit from the fishing ban is that of benthophagous species (p1-bt). The mean biomass of this group of species increased after the fishing ban. However, their demographic structure indicated a slight reduction in mean and maximal size. The benthophagous species prey on molluscs and shellfish, which are no longer fished in the MPA due to the fishing ban. They mainly belong to the Em ecological category.

Conversely, two trophic components sharply decreased; they include the herbivorous species sensu lato. These categories decreased in terms of both biomass and demographic structures because the share of individuals larger than 15 cm sharply decreased between 2003 and 2007. Among the scavengers or grazer herbivorous species, the six species from the Mugilidae family were impacted by the fishing ban; their size structures decreased, and *Mugil cephalus* was not observed after 2005, whereas *Liza grandisquamis* showed very low occurrences in 2007. For the herbivorous species feeding on phytoplankton, a sharp decrease was observed for the two Cichlidae species (the tilapia *S. melanotheron* totally disappeared in 2005 and 2006) and *E. fimbriata* regularly decreased in biomass and maximum observed length. Such species are known to be resilient (sensu Fishbase) and highly tolerant species and thus expected to outperform other groups in disturbed and overfished ecosystems.

4.3. Overall synthesis of short-term effects

As the hydrological and environmental conditions did not change during the study period, we propose a trophic hypothesis, linking the increase in biomass of generalist and piscivorous top predators and the decrease of herbivorous species and, to a lesser extent, of zooplanktonophagous species. These predators, either occasional or more regular in the MPA, would have a strong impact on small or medium-sized individuals. The predation, strong on small size (<15 cm), and especially on medium sizes (15–25 cm), could partly explain the decrease of medium size classes from the size structures just after the fishing ban. The direct effects of the fishing ban of an MPA set up more rapid cascade effects (Babcock et al., 2010).

The results of this study for the first four years of the fishing ban clearly show the following: an increase by 10% of the mean biomass, an increase by 15% of the maximum observed lengths, an increase by 10% of the overall trophic level and an important change of the trophic composition (decrease of scavengers and herbivorous species, increase of second level predators and of benthophagous species). A previous study of the evolution of the fish assemblages in the exploited area of the Sine Saloum estuary between two situations separated by ten years (Ecoutin et al., 2010) showed an opposite pattern to that observed in the protected zone: decrease by 40% of the biomass for a stable richness; decrease by 17% of the maximum observed lengths; decrease of the trophic level; change in the trophic composition with a decrease of the share of benthophagous species and top predators for the benefit of scavengers and herbivorous species; rarefaction of the marine species. The work by Ecoutin et al. (2010) underlined both a degradation of the estuarine environment and, mainly, an overexploitation of estuarine stocks and of marine stocks with an estuarine ecophase. These conclusions were also reached by Garrison and Link (2000), who connected the steady increase of fishery pressure with a decrease of the share of large piscivorous and benthophagous species and an increase of the share of pelagic and herbivorous species feeding on phytoplankton. A similar reduction in the mean trophic level in a seven years' period was also recorded in the Mondego estuary in Portugal (Nyitrai et al., 2012). The authors related this trend to climatic events and overfishing in the coastal zone. Inside the protected zone, our results showed an inversion of the processes observed in the Sine Saloum (Ecoutin et al., 2010). This is likely due to the absence of exploitation of the area. Similar trends have been observed elsewhere (see García-Charton et al., 2008). This inversion of the processes also resulted from the rehabilitation of critical habitats and increased fish sizes (Roberts et al., 2005). Based upon the above, we argue that the significant increase of the mean trophic level and the observed evolution of the fish community structure can be analyzed as an indicator of the regeneration of the health status of the fish assemblage in the MPA.

The Bamboung MPA belongs to an estuarine ecosystem. Estuaries are known as feeding grounds for marine and marine-estuarine species (Albaret, 1999; Whitfield, 1999). Our results clearly show the occasional or more frequent contribution of these species to the fish assemblage. However, when these species become adults, they migrate to the ocean to spawn. Consequently, a large part of the fish assemblage leaves the bolong at least once a year. This makes it difficult to obtain a clear estimation of the improvement of the MPA fish assemblage (Grüss et al., 2011).

The observed impact of the Bamboung MPA is probably limited at the scale of the whole estuary as it is a small MPA of 4 km^2. However, many MPAs or no-take areas around the world are small, and some have been shown to be effective, though this has been controversial (Roberts et al., 2001; Claudet et al., 2008).

In addition to the points discussed above, the analysis of the limits of the fishing ban in the Bamboung MPA must consider the short duration of the present study. Many authors emphasize a rapid positive impact on abundance, biomass, and size structures during the first year of the MPA implementation (Abesamis and Russ, 2005; Russ et al., 2005; Babcock et al., 2010). A longer-term analysis will allow better understanding of the dynamics of the MPA, as suggested by Stobart et al. (2009). This analysis, performed over a medium- or long-term study, will allow us to estimate the impact of an MPA situated in a tropical estuary on source effects (massive outflow of young fish born in the reserve) or spillover (outflow of adults due to overcrowding in the reserve) and the impacts of such protection on reproduction.

Acknowledgments

The present work is a result of the multidisciplinary program linked to the Narou Heuleuk ("Tomorows' share") project, funded by the agreement FFEM/AFD/Oceanium/IRD. The authors want to thank the fishermen and their team leader Mbaye Mbengue and the crew from research vessel Diassanga and its captain F. Sanseo. Without their help, these results could not have been obtained. The authors also want to thank the two anonymous reviewers for their constructive comments.

Appendix

List of the 73 species observed in the Bamboung bolong, sorted by family, genus and species between 2003 and 2007. Ecol. Cat.: bio-ecological category (see Table 1). Troph. Cat.: trophic category (see Table 2). TL: trophic level (Froese and Pauly, 2011). Surv. Nb.: Number of surveys where species is present (maximum possible = 15). Biomass: fish biomass (in kg; *, <0.050 kg).

Family	Species	Ecol. Cat.	Troph. Cat.	TL	Survey Nb.	Biomass				
						2003	2004	2005	2006	2007
Acanthuridae	*Acanthurus monroviae*	Mo	p1-mc	2.50	3	0.5		0.5		
Albulidae	*Albula vulpes*	Mo	p1-bt	3.67	1	*				
Ariidae	*Arius heudelotii*	ME	p2-ge	3.77	1				1.4	
Ariidae	*Arius latiscutatus*	ME	p2-ge	3.34	14	11.3	26.0	27.1	89.6	572.6
Ariidae	*Arius parkii*	ME	p2-ge	4.06	12	8.6	38.9	14.0	70.2	194.7
Batrachoididae	*Batrachoides liberiensis*	Ma	p2-ge	3.67	12	2.6	1.2	0.6	0.5	0.7
Belonidae	*Strongylura senegalensis*	Em	p2-pi	4.50	1	1.1				
Belonidae	*Tylosurus crocodilus*	Mo	p2-pi	4.47	3	2.3		0.8		
Blenniidae	*Hypleurochilus langi*	Es	p1-bt	3.16	1			*		
Carangidae	*Alectis alexandrinus*	Mo	p1-mc	3.60	5		10.6	5.6	2.5	1.1
Carangidae	*Caranx hippos*	ME	p2-ge	3.96	6	0.4	0.2	0.1	3.3	
Carangidae	*Caranx rhonchus*	Mo	p1-bt	3.60	3		*		*	
Carangidae	*Caranx senegallus*	ME	p2-ge	3.86	8	1.3	5.4	2.2		
Carangidae	*Chloroscombrus chrysurus*	ME	p1-mc	4.50	11	14.3	10.2	5.7	1.1	6.2
Carangidae	*Lichia amia*	Ma	p2-ge	4.50	1			19.7		
Carangidae	*Trachinotus ovatus*	Ma	p2-ge	3.73	1		*			
Carangidae	*Trachinotus teraia*	Em	p1-bt	3.72	7		6.4	44.5	55.8	
Carcharhinidae	*Carcharhinus leucas*	Mo	p2-pi	4.31	2			19		15.6
Cichlidae	*Sarotherodon melanotheron*	Es	he-ph	2.49	6	12.7	0.3			1.7
Cichlidae	*Tilapia guineensis*	Es	he-de	2.79	11	9.4	1.4	1.3	2	6.5
Clupeidae	*Ethmalosa fimbriata*	Em	he-ph	2.50	14	160.3	82.1	157	36.7	22.9
Clupeidae	*Sardinella aurita*	Ma	p1-zo	3.00	1		*			
Clupeidae	*Sardinella maderensis*	ME	p1-zo	3.20	15	26.9	40.0	15.5	39.5	11.2
Cynoglossidae	*Cynoglossus monodi*	Mo	p1-bt	3.60	1	*				
Cynoglossidae	*Cynoglossus senegalensis*	Em	p1-bt	3.62	14	2.6	1.6	0.7	0.5	1.0
Dasyatidae	*Dasyatis margarita*	Em	p1-bt	3.42	10	3.1	8.6	3.5	7.0	0.6

(*continued on next page*)

(*continued*)

Family	Species	Ecol. Cat.	Troph. Cat.	TL	Survey Nb.	Biomass				
						2003	2004	2005	2006	2007
Dasyatidae	*Dasyatis margaritella*	Em	p1-bt	3.35	11	0.4	1.3	2.0	5.2	7.0
Drepaneidae	*Drepane africana*	ME	p1-mc	3.10	5	*	*		0.2	0.1
Echeneidae	*Echeneis naucrates*	Mo	p1-zo	3.13	2			0.2	*	
Elopidae	*Elops lacerta*	ME	p2-pi	4.24	11	7.2	11.3	29.5	2.4	7.5
Elopidae	*Elops senegalensis*	Ma	p2-pi	4.06	5			0.8	3.8	4.1
Ephippidae	*Ephipus goreensis*	Mo	p1-mc	3.45	2	0.4	15.3	1.5	*	*
Ephippidae	*Chaetodipterus lippei*	Ma	p1-mc	3.66	7	*				0.1
Exocoetidae	*Fodiator acutus*	Ma	p1-mc	3.65	6	0.1	*		*	0.1
Gerreidae	*Eucinostomus melanopterus*	ME	p1-mc	3.39	15	3.7	5.6	4.8	4.2	6.1
Gerreidae	*Gerres nigri*	Es	p1-mc	3.19	15	7.6	20.7	10.2	8.1	9.6
Gobiidae	*Awaous lateristriga*	Es	p1-bt	2.19	1			*		
Haemulidae	*Brachydeuterus auritus*	ME	p1-mc	3.03	5	*	2.4		*	*
Haemulidae	*Plectorhinchus macrolepis*	Em	p2-ge	3.76	14	2.6	5.3	6.3	3.3	4.8
Haemulidae	*Pomadasys incisus*	Ma	p1-bt	3.80	4		0.2	0.6	0.1	1.4
Haemulidae	*Pomadasys jubelini*	Em	p1-bt	3.33	8	9.9	9.6	12.4	3.1	
Haemulidae	*Pomadasys perotaei*	Em	p1-bt	3.31	10	*	3.0	2.5	8.6	3.3
Hemiramphidae	*Hemiramphus brasiliensis*	Em	p2-ge	2.48	3	0.3	0.2			
Lutjanidae	*Lutjanus dentatus*	Mo	p2-pi	4.01	3			5.5	1.0	
Lutjanidae	*Lutjanus goreensis*	Ma	p2-pi	4.02	12	1.0	4.3	23.5	7.8	30.5
Monodactylidae	*Monodactylus sebae*	Es	p2-ge	3.88	14	2.3	6.5	2.4	0.7	8.1
Moronidae	*Dicentrarchus punctatus*	Mo	p2-ge	3.94	1					0.1
Mugilidae	*Liza dumerili*	Em	he-de	2.44	13	160.5	16.1	6.6	46.4	8.6
Mugilidae	*Liza falcipinnis*	Em	he-de	2.28	15	14.7	4.9	4.8	7.5	5.4
Mugilidae	*Liza grandisquamis*	Em	he-de	2.02	10	3.9	8.7	3.2	1.2	0.3
Mugilidae	*Mugil bananensis*	ME	he-de	2.00	9	11.9	1.0	3.1	5.8	0.9
Mugilidae	*Mugil cephalus*	ME	he-de	2.13	2	1.0	*			
Mugilidae	*Mugil curema*	Em	he-de	2.00	13	38.7	3.0	3.2	7.7	0.8
Myliobatidae	*Pteromylaeus bovinus*	Mo	p2-ge	3.79	2				4.4	56.7
Paralichthyidae	*Citharichthys stampflii*	Em	p2-ge	3.87	7	0.1		*	*	*
Polynemidae	*Galeoides decadactylus*	ME	p2-ge	3.57	10	1.9	0.8	0.3	1.8	2.6
Polynemidae	*Polydactylus quadrifilis*	ME	p2-pi	4.01	11	16.5	6.5	14.8	53.9	7.7
Pristigasteridae	*Ilisha africana*	Em	p1-zo	3.19	6	1.4	4.1	*	0.8	7.3
Sciaenidae	*Pseudotolithus senegallus*	ME	p2-ge	3.89	8	0.3	1		*	1.1
Sciaenidae	*Pseudotolithus elongatus*	Em	p2-ge	4.06	4	0.6		*		0.5
Sciaenidae	*Pseudotolithus senegalensis*	Ma	p2-ge	3.84	3	0.3	0.9	1.0	2.5	11.3
Scombridae	*Orcynopsis unicolor*	Mo	p2-pi	4.50	2	0.4		0.1		
Scombridae	*Scomberomorus tritor*	Ma	p2-pi	4.26	1		0.4			
Serranidae	*Epinephelus aeneus*	ME	p2-pi	4.02	2		0.4			
Sparidae	*Diplodus bellottii*	Mo	p1-bt	3.50	2		0.1			*
Sphyraenidae	*Sphyraena afra*	ME	P2-pi	4.07	7		0.5	9.9	10.1	11.7
Sphyraenidae	*Sphyraena guachancho*	ME	P2-pi	3.92	2		0.4			
Syngnathidae	*Hippocampus algiricus*	Ma	p1-bt	3.47	1	*				
Syngnathidae	*Syngnathus pelagicus*	Ma	p1-bt	3.50	1	*				
Synodontidae	*Trachinocephalus myops*	Mo	p2-pi	4.39	1			*		
Tetraodontidae	*Ephippion guttifer*	ME	p1-bt	3.55	15	1.5	7.9	5.0	12.1	10.8
Tetraodontidae	*Lagocephalus laevigatus*	Ma	p2-ge	4.02	1	*				
Tetraodontidae	*Sphoeroides spengleri*	Mo	p1-bt	3.15	4	*		0.1	*	
Total					15	546.3	375.3	471.7	512.7	1 043.4

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