Preliminary analysis of spatio-temporal fish assemblage variations of Gandoule Marine Protected Area in Senegal

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Abstract

The study investigated the spatial and temporal fish assemblage structure in relation to the abiotic factors in the Gandoule Marine Protected Area (GMPA) in Sine-Saloum Estuary. Samples were collected in four seasons (cold season, transition from cold to warm season, warm season and transition from warm to cold) from seven stations with a beach seine in 2017. Environmental parameters such as temperature, salinity and pH were measured during each season at all stations. Overall, the fish assemblage of GMPA consisted of 35 species belonging to 20 families. The most abundant species were *Ethmalosa fimbriata*, *Gerres nigri*, *Mugil curema*, *Neochelon falcipinnis* and *Mugil bananensis*, accounting for 63.58% of the total abundance. In terms of ecological and trophic guilds, the fish assemblage was dominated by species with estuarine affinity and herbivorous species. The results of similarity analysis showed a significant difference between sampling seasons and stations. The similarity percentage analysis revealed that similarity among seasons was between 7.65% and 13.27%, whilst similarity between stations ranged from 9.51% to 15.24%. The canonical correspondence analysis indicated that temperature and salinity were the main drivers influencing the distribution of species such as *Chelon dumerili*, *Mugil bananensis*, *Mugil curema*, *Coptodon guineensis*, *Neochelon falcipinnis* and *Ethmalosa fimbriata*.

Keywords: Estuary, Fish assemblage, Gandoule, Marine Protected Area, Senegal

Introduction

Marine and estuarine ecosystems are experiencing erosion of biodiversity and degradation as a result of overharvesting, pollution, and climate change (Halpern et al., 2008). Therefore, the implementation of marine protected areas (MPA) was recommended to prevent ecological degradation and loss of species (Babcock et al., 1999; Manson & Die, 2001; Halpern, 2003; Brander et al., 2015; Molina et al., 2015; Sala & Giakoumi, 2017). Recently, it has been suggested that if applied at broad spatial scales and effectively managed, MPA can potentially reduce absolute levels of fishing pressure and might lead to fish stock and habitats restoration (Rioja-Nieto & Sheppard, 2008; Jennings, 2009; Muthiga, 2009; Molloy et al., 2009; Ecoutin et al., 2014; Sadio et al., 2015; Di Franco et al., 2016; Giakoumi et al., 2018).

The Gandoule Marine Protected Area (GMPA) located in the Sine Saloum Estuary in Senegal, was established in 2014 (Fig. 1). According to Batista et al. (2015) the implementation of an MPA requires the assessment of fish assemblage structure which is essential not only to understanding the ecological responses of marine populations but also to evaluating the socio-economic impacts on fishing communities. Moreover, the investigation of fish assemblage structure is very important

for estuary quality assessment (Elliott & Taylor, 1989; Pomfret et al., 1991; Amorim et al., 2017; Molina et al., 2020). In fact, estuarine ecosystems are globally recognized as important ecosystems where many fish species spend a part or all their entire life (Blaber, 1997; Vidy et al., 2004; Döring & Ekau, 2017).

In addition to this ecological role, these ecosystems support important fishery activities and contribute to animal protein needs of local communities (Houde & Rutherford, 1993; Blaber, 1997; Hossain et al., 2012; Lima et al., 2015; Sheaves et al., 2016). However, this assessment should integrate the causal link between the habitat conditions (environmental conditions) and the fish assemblage structure and functioning (Pombo et al., 2005; Vilar et al., 2013; Teichert et al., 2017). Furthermore, the identification of a significant relationship between fish species and habitat conditions is crucial in the process toward incorporating environmental information into fish abundance (Perry et al., 1994 ; Vilar et al., 2013; Pasquaud et al., 2015). Moreover, most studies suggested that variations in time and space of fish assemblage could be caused by a wide variety of environmental conditions in estuaries (Rogers et al., 1984; Elliott & Hemingway, 2002; Molina et al., 2020). The main environmental parameters often used to assess habitat conditions on fish assemblage distribution in estuarine ecosystems are temperature, salinity, dissolved oxygen, pH and turbidity (Blaber & Blaber, 1980; Vilar et al. 2013; Pasquaud et al. 2015; Molina et al., 2020).

Several studies investigating the influence of environmental conditions on fish assemblage in Sine Saloum Estuary have been carried out (e.g. Simier et al., 2004; Ecoutin et al., 2010; Ecoutin et al., 2014). The present study is a contribution that aimed to describe the fish population of GMPA, examine whether the seasons and stations differ significantly in fish assemblage and assess whether the assemblage organization is related to changing abiotic factors.

Material and Methods

Study area

The GMPA is within the Sine Saloum Estuary which is located 100 km south of Dakar (Fig.1). Located in the central part of the Saloum River, it is a protected area created in 2014 covering a surface area of 157.32 km2. Besides its main part occupied by the river, it is characterized by a network of small seawater creeks and is covered with mangroves, mainly *Rhizophora racemosa* and *Avicennia africana*

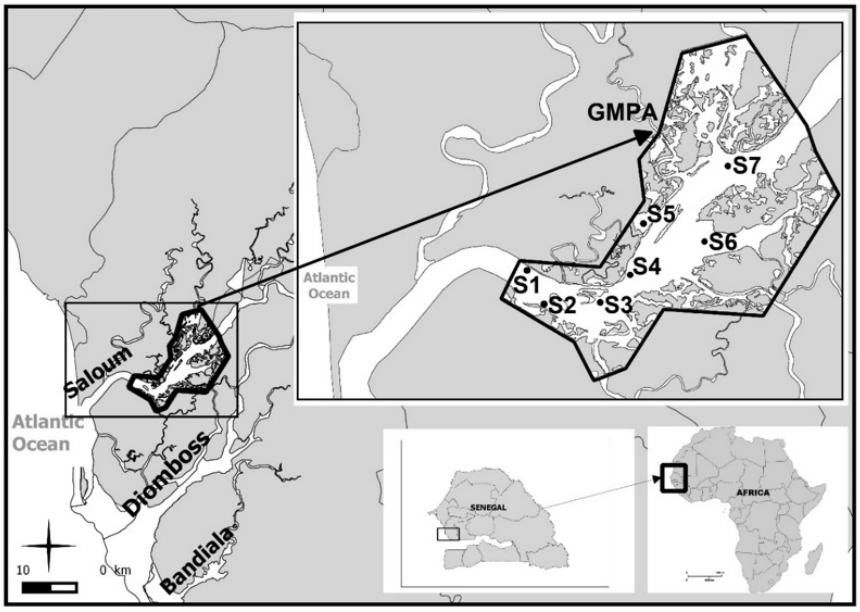

Figure 1 Location of Gandoule Marine Protected Area and sampling stations S1 to S7

which serve as nursery area for many fish species (Diouf, 1996). Human activities are authorized and regulated in some areas of the MPA, while any type of extraction is prohibited in other areas. The Saloum River is part of the Sine Saloum Estuary, where the climate consists of 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 (Simier et al., 2004). This ecosystem is an inverse estuary, i.e. salinity gradient is reversed during most of the year (> 60 PSU in its upper part) (Diouf 1996; Simier et al., 2004; Ecoutin et al., 2014).

Sampling protocol

Samples were collected at seven sampling stations (S1 to S7 from downstream to upstream) covering the whole range of habitats in the MPA (Fig. 1). The bottom is sandy-muddy from S1 to S5, whilst for S6 and S7 the bottom is sandy. At each station, samples were collected during the cold season (CS) in April, transition cold to warm season (CW) in June, warm season (WS) in September and transition warm to cold season (WC) in December in 2017. Two replicate collections were made at each station. The second haul was performed at a distance of about 300 m after the first in order to avoid any disturbance that may have been caused by the first one. The average duration of a haul was about 40 minutes. The sampling seasons correspond to the four main hydro-climatic periods in Senegal (Rossignol, 1965; Domain, 1980; Rebert, 1983). Fish sampling was performed with seven fishermen using a beach seine (length = 150 m, height = 5 m, mesh size = 20 mm) at low tide. Environmental parameters such as temperature, salinity and pH were measured during each fish sampling with a multi-probe kit (PCE-PHD 1, PCE Instruments). After each sampling, fish were identified to species level, as well as counted, sized and weighed by species. In the case of a large number of individuals, a sub-sample of 30 individuals per species was analysed. However, the surplus of abundance and biomass of the concerned species were taken into account to avoid any biases.

Data analysis

The relative abundance indices (AI) and the biomass indices (BI) were calculated as followed:

$$AI = \log\left(\frac{\text{Number of individuals for a given species}}{\text{Number of total individuals}} + 1\right) \quad (1)$$

$$BI = \log\left(\frac{\text{Biomass for a given species}}{\text{Total biomass}} + 1\right) \quad (2)$$

The logarithmic function was applied to address the assumptions of normality and homogeneity of variance. Species richness (the total number of species caught in each station or during each season) was calculated. Species richness and abundance were compared between stations and sampling seasons.

Species were classified according to their habitats and diet preferences to study the nature of the fish assemblage. The ecological classification proposed by Albaret (1999) was used in this study. This method classified species on several ecological guilds according to their degree of euryhalinity and the characteristics of their bio-ecological cycle in different estuarine environments. Five ecological categories were sampled in the GMPA: Strictly estuarine species (Es), Estuarine species from marine origin (Em), Marine-estuarine species (ME), Marine species which are accessory in estuaries (Ma) and Marine species that are occasional in estuaries (Mo). Concerning their feeding behavior, seven trophic guilds were identified: Scavenger or grazer herbivores (he-de), Herbivores mainly feeding on phytoplankton or micro-phytoplankton (he-ph), First level predators mainly benthophagous (p1-bt), First level generalist predators mainly feeding on macro-crustaceans or insects (p1-mc), First level predators mainly feeding on zooplankton (p1-zo), Second level generalist predators mainly feeding on fish, shrimps and crabs (p2-ge) and Second level piscivorous predators mainly feeding on fish (p2-pi) (Ecoutin et al., 2010; Sadio et al., 2015).

Statistical analysis

A One-way analysis of variance (ANOVA) was used to test for significant differences in environmental variables between seasons

and between stations. The ANOVA test was considered as significant if the p-value was equal or less than 0.05. Prior to the ANOVA test, all variables were tested for normality and homogeneity using Kolmogorov and Bartlett tests, respectively. Hierarchical Classification Analysis (HCA) was carried out to group sampling stations according to their similarity in terms of fish assemblage (Escoffier & Pagès, 1998; Legendre & Legendre, 1998). The dendrogram of similarity was performed using the Euclidean distance and the Ward minimum variance clustering method.

One-way analysis of Similarity (ANOSIM) was used to conclude the significance of spatial and temporal variation in the structure of fish assemblage (Clarke & Warwick, 1994). This analysis provides a way to statistically test whether there is a significant difference between groups. The ANOSIM gives p-value (i.e. significance levels) and R value (i.e. the strength of the factors on the samples). The R value should vary between 0 and 1, though negative values may be obtained but are always close to 0. When the R value is close to 1, this indicates high separation between groups, while an R value close to 0 indicates no separation between groups. Similarity percentages analysis (SIMPER) was used (Clarke, 1993). This analysis gives the percentage of contribution of the variables that explain the observed similarity or dissimilarity. The test based on a Bray-Curtis similarity matrix was calculated using abundance.

Canonical correspondence analysis (CCA) was performed to assess the influence of environmental variables on spatio-temporal fish assemblage structure (ter Braak, 1986). This method allows us to assess the relative importance of environmental parameters to the distribution of each species. The relative length of the vector indicates the importance of the environmental parameter in the structuring of fish. The longer the vector, the greater its influence. Concerning the species, the closer two species are, the more similar their distribution; this holds true for the vectors as well (ter Braak, 1986; Pombo et al., 2005). Species or groups that are highly influenced by two parameters are on the axes generated by the corresponding vectors of these parameters rather than at the end of any single vector (ter Braak, 1986). The Variance Inflation Factors (VIFs) were calculated for all environmental variables in order to detect possible high dimensional collinearities before the CCA (Zuur et al., 2010). In fact, it was suggested by these authors that covariates with VIFs >5 are highly collinear. However, all VIF values calculated here were <2. This analysis was applied only to species accounting for at least 2% of the total abundance, in order to minimize the effect of rare species. All the statistical analysis were performed using R software (R Core Team, 2019).

Results

Environmental variations

Water temperature ranged from 24.70 °C in CS to 33.30 °C in WS (mean ± SD = 28.30

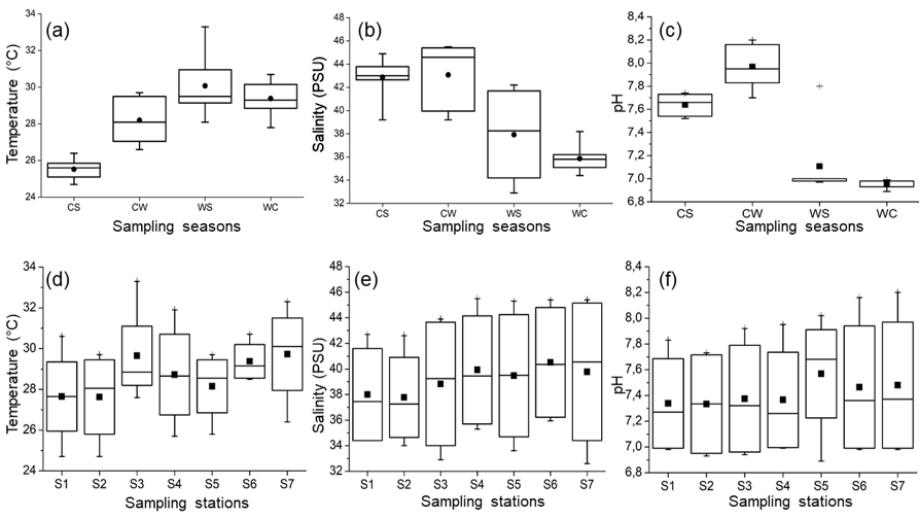

Figure 2 Temporal and spatial fluctuations in environmental parameters in 2017 in the waters of Gandoule Marine Protected Area. Figures a b and c correspond to their seasonal variations, while graphs d, e and f show their variations between stations. CS = cold season; CW = transition cold to warm season; WS = warm season; WC = transition warm to cold season. S1, S2, S3, S4, S5, S6 and S7 are the sampling stations

± 2.00°C), salinity was between 32.90 in WS and 45.50 in CW (mean ± SD = 39.90±3.60) and pH was 6.96 in WC to 8.20 in CW (mean ± SD = 7.41±0.48) (Fig. 2abc). The differences between these variables among seasons were not statistically significant ($P > 0.05$). Concerning the spatial distribution of the measured environmental parameters (Fig. 2def), there were no significant differences in temperature between stations ($P > 0.05$). However, significant spatial differences were found for salinity and pH ($P < 0.05$).

Fish assemblage composition and nature

A total of 1001 specimens (123.15 kg) of 35 species belonging to 20 families, was collected in GMPA during the study period (Table 1). The most abundant species were *Ethmalosa fimbriata*, *Gerres nigri*, *Mugil curema*, *Neochelon falcipinnis* and *Mugil bananensis*, which represented 21.71%, 16.89%, 10.26%, 7.63% and 6.09% of the total abundance, respectively. In terms of biomass, *Ethmalosa fimbriata* (9.24%), *Fontitrygon margarita* (9.08%), *Gerres nigri* (8.49%), *Coptodon*

TABLE 1

List of the 35 species observed in Gandoule MPA in 2017. Percentage of abundance and biomass with the name of the family, species labels, ecological and trophic guilds. Ecological and trophic guilds codes are given in material and methods section

Species	Family	Label	Ecological guilds	Trophic guilds	Abundance (%)	Biomass (%)
Ethmalosa fimbriata	Clupeidae	EFI	Em	he-ph	21.71	9.24
Gerres nigri	Gerreidae	GNI	Es	p1-mc	16.89	8.49
Mugil curema	Mugilidae	MCU	Em	he-de	10.26	5.79
Neochelon falcipinnis	Mugilidae	NFA	Em	he-de	7.63	6.09
Mugil bananensis	Mugilidae	MBA	ME	he-de	6.09	5.27
Elops senegalensis	Elopidae	ESE	Ma	p2-pi	4.36	5.44
Coptodon guineensis	Cichlidae	CGU	Es	he-de	4.18	7.72
Elops lacerta	Elopidae	ELA	ME	p2-pi	3.91	6.23
Ilisha africana	Pristigasteridae	IAF	Mo	p2-ge	3.72	1.54
Chelon dumerili	Mugilidae	CDU	Em	he-de	3.72	2.91
Fontitrygon margarita	Dasyatidae	FMA	Em	p1-bt	3.18	9.08
Monodactylus sebae	Monodactylidae	PSE	Es	p2-ge	2.63	1.25
Sphyraena afra	Sphyraenidae	SAF	ME	p2-pi	2.00	6.05
Eucinostomus melanopterus	Gerreidae	EME	Ma	p1-mc	1.45	0.41
Caranx hippos	Carangidae	CHI	ME	p2-ge	1.27	0.79
Chloroscombrus chrysurus	Carangidae	CCH	ME	p1-mc	0.91	0.10
Cynoglossus senegalensis	Cynoglossidae	CSE	Em	p1-bt	0.91	1.21
Caranx senegallus	Carangidae	CSN	ME	p2-ge	0.82	1.26
Pomadasys jubelini	Haemulidae	PJU	Em	p1-bt	0.73	0.42
Drepane africana	Drepanidae	DAF	ME	p1-mc	0.54	0.18
Epinephelus aeneus	Serranidae	EAE	Me	p2-pi	0.45	1.34
Psettodes belcheri	Psettodidae	PBE	Mo	p1-mc	0.45	0.80
Parachelon grandisquamis	Mugilidae	PGR	Em	he-de	0.36	0.21
Carlarius parkii	Ariidae	APA	ME	p2-ge	0.18	0.58
Galeoides decadactylus	Polynemidae	GDE	ME	p2-ge	0.18	0.09
Batrachoides liberiensis	Batrachoididae	BLI	Ma	p2-ge	0.18	0.23
Mugil cephalus	Mugilidae	MCE	ME	he-de	0.18	0.23
Plectorhinchus macrolepis	Haemulidae	PMA	Em	p2-ge	0.18	1.17
Alectis alexandrina	Carangidae	AAL	Mo	p2-ge	0.09	0.34
Chaetodipterus lippei	Ephippidae	CLI	Ma	p1-mc	0.09	0.06
Fontitrygon margaritella	Dasyatidae	DMR	Em	p1-bt	0.09	0.10
Ephippion guttifer	Tetraodontidae	EGU	ME	p1-bt	0.09	1.91
Lutjanus agennes	Lutjanidae	LAG	Em	p1-zo	0.09	0.18
Polydactylus quadrifilis	Polynemidae	PQU	ME	p2-pi	0.09	1.13
Pomadasys incisus	Haemulidae	PIN	ME	p1-bt	0.09	0.05

guineensis (7.72%) and *Elops lacerta* (6.23%) dominated in the GMPA. The Mugilidae with six species dominated the fish assemblage, followed by the Haemulidae (5 species) and the Carangidae (4 species).

In terms of ecological guilds, the fish assemblage was dominated by the species with estuarine affinity; ME with 14 species (representing 14.75% of the total abundance and 22.97% of the total biomass) and Em composed of 11 species (accounting for 51.00% and 50.98% of the total number of individuals and biomass, respectively). The strictly estuarine species represented by 3 species, accounted for 23.77% and 17.74%. The species with marine affinity (Ma and Mo with 4 and 3 species) were less represented with 10.47% of the total abundance and 8.87% of the total biomass.

According to their feeding regime, the grazer herbivores (he-de) with seven species were the most abundant (32.51% of the total abundance and 35.99% of the total biomass) (Fig. 3b). The herbivores (he-ph) (1 species, accounting for 21.77% of the total number of individuals and 13.53% of the total weight) and first level generalist predators (p1-mc, 6 species representing 20.40% and 10.04% of total abundance and total biomass, respectively. The second level generalist predators (p2-ge) and first level predator (p1-bt) were highly represented in terms of species richness, despite not being the most abundant. (9 and 6 species, respectively).

Spatial and temporal differences among assemblages

ANOSIM revealed significant differences in fish assemblage on the climate seasons where global R was observed 0.20 and $p = 0.00009$. According to SIMPER analysis, there is a total range of dissimilarity between 86.73% and 92.35% among climate seasons (Table 2). These differences were caused by abundance among dominating species in each sampling season. These species were *E. fimbriata* (38.99%), *G. nigri* (15.59%), *N. falcipinnis* (12.52%), *M. bananensis* (11.38%), *M. curema* (10.26%), *E. melanopterus* (8.06%), *C. guineensis* (7.18%), *F. margarita* (6.30%), *I. africana* (6.22%) and *C. dumerili* 6.12%). Significant differences were found between

TABLE 2

Average dissimilarity of contributing species in each season using SIMPER analysis

Cold season (CS; 92.35%)		**Transition cold to warm season (CW; 86.73%)**	
Contributory species	**Average contribution to dissimilarity (%)**	**Contributory species**	**Average contribution to dissimilarity (%)**
Ethmalosa fimbriata	38.26	*Gerres nigri*	14.86
Gerres nigri	12.30	*Mugil bananensis*	13.40
Mugil bananensis	8.37	*Neochelon falcipinnis*	12.18
Chelon dumerili	5.31	*Mugil curema*	12.02
Coptodon guineensis	4.94	*Chelon dumerili*	7.01
Fontitrygon margarita	4.18	*Coptodon guineensis*	6.62
Mugil curema	8.90	*Fontitrygon margarita*	6.53
Coptodon guineensis	8.73	*Gerres nigri*	14.86
Ilisha africana	4.15	*Mugil bananensis*	13.40
Cold season (WS; 91.46%)		**Transition cold to warm season (WC; 91.38%)**	
Ethmalosa fimbriata	36.03	*Ethmalosa fimbriata*	42.68
Gerres nigri	15.12	*Gerres nigri*	20.81
Mugil bananensis	13.40	*Neochelon falcipinnis*	13.77
Neochelon falcipinnis	11.62	*Mugil bananensis*	11.95
Mugil curema	10.26	*Mugil curema*	9.87
Eucinostomus melanopterus	8.06	*Ilisha africana*	8.30
Mugil bananensis	7.78	*Eucinostomus melanopterus*	8.06
Coptodon guineensis	7.70	*Fontitrygon margarita*	7.95
Fontitrygon margarita	6.53	*Coptodon guineensis*	7.89
Chelon dumerili	5.47	*Chelon dumerili*	6.71

stations, represented by the analysis of similarity (ANOSIM) (R = 0.11, p = 0.01).

The SIMPER analysis showed that the average dissimilarity between stations ranged from 84.76% to 90.49% and most contribution species were *G. nigri* (22.37%), *E. fimbriata* (20.33%), *M. bananensis* (13.55%), *C. guineensis* (12.01%), *M. curema* (10.85%), *C. dumerili* (10.06%), *N. falcipinnis* (9.10%), *M. sebae* (7.98%), *E. lacerta* (7.68%), *F. margarita* (7.37%), *C. senegalensis* (7.34%), *I. africana* (6.33%), *C. hippos* (4.64%) (Table 3).

A cluster analysis performed to investigate similarities among fish abundance revealed three separate clusters associated with groups of species (Fig. 3). The First cluster group, characterized by high abundance of *E. fimbriata*, *I. africana*, *E. lacerta* and *P. sebae* contained S1, S2, S3, S4 and S5 of cold season, S5 of transition cold to warm season and S3, S4, S5, S6 and S7 of transition warm to cold season. The second cluster group was marked by the abundance of *C. dumerili*, *N. falcipinnis*, *M. bananensis* and *M. curema* gathered S6 of cold season, S2, S5 and S6 of the warm season, and S6 and S7 of transition cold to warm season. The third and final cluster group where *G. nigri*, *E. melanopterus*, *C. guineensis*, *C. senegalensis*, *F. margarita* and *C. hippos* were highly abundant symbolized S7 of cold season, S1, S2, S3 and S4 of transition cold-warm season, S1, S3 and S4 of warm season, and S1 and S2 of transition cold to warm season.

Spatio-temporal variations of the mean size of fish assemblage

The mean size of fish assemblage of the GMPA was 22 ± 9 cm. The minimum size observed was 6 cm (*Chloroscombrus chrysurus*) in WS at S3 and the maximum 78 cm (*Sphyraena afra*) in WC at S1. The seasonal and spatial variations of species mean size regrouped in ecological and trophic guilds were plotted (Fig. 4). The seasonal variations of species mean size of Em, Es and Ma categories were significant, while that of species ME and Mo were not significant (Fig. 5a). However, the spatial differences in mean size of these ecological guilds were not significant (Fig. 4c). Concerning the trophic guilds, seasonal variations of he-de, he-ph, p1-mc and p2-ge species were significantly different (Fig. 4b), whereas only p1-mc and p2-ge species showed significant spatial differences in mean size (Fig. 4d).

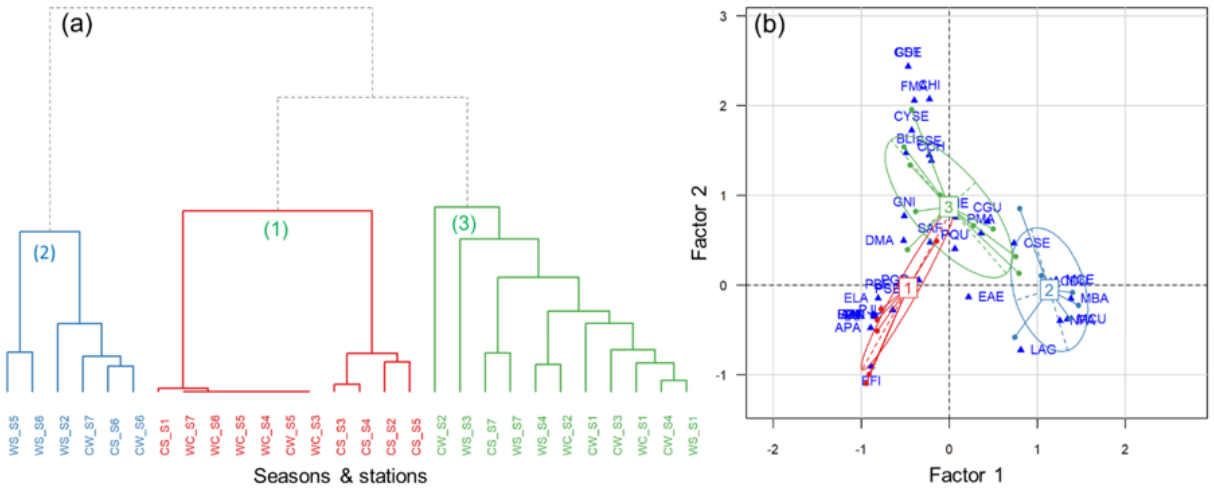

Figure 3 a)Dendrogram showing cluster (Euclidean distance and the Ward minimum variance criterion) based on log10 (x + 1) transformed seasonal abundances of the species sampled at seven stations and b) projection species and groups on the plan 1-2; Stations and seasons code: the two first letters indicate the season and the other letters and numbers the station; CS= Cold season, CW= transition from Cold to Warm season, WS= Warm season and WC= transition from Warm to Cold season. For species labels see table 1

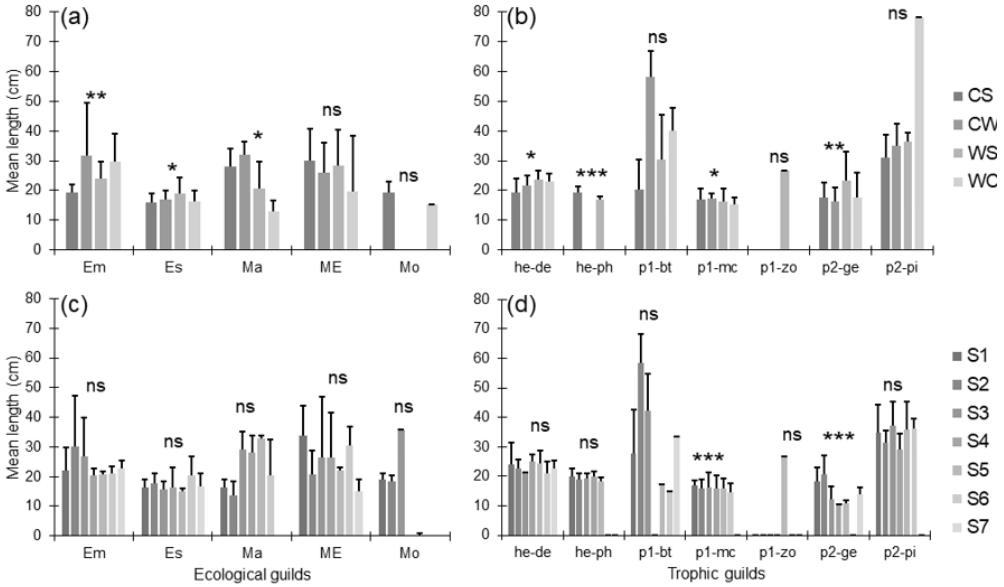

Figure 4 a)Seasonal variations of mean total length with standard deviation of ecological, b) Seasonal variations of mean total length with standard deviation of trophic guilds, c) Spatial variations of mean total length with standard deviation of ecological and d) Spatial variations of mean total length with standard deviation of trophic guilds. Ecological and trophic guilds codes are given in material and methods section. Stars indicate significance levels based upon ANOVA tests (***p < 0.001; **p < 0.01; *p < 0.05; ns non-significant)

TABLE 3

Average dissimilarity of contributing species in each station using SIMPER analysis

Station 1 (S1; 87.61%)		**Station 2 (S2; 86.36%)**	
Contributory species	**Average contribution to dissimilarity (%)**	**Contributory species**	**Average contribution to dissimilarity (%)**
Gerres nigri	29.11	*Gerres nigri*	21.76
Ethmalosa fimbriata	16.02	*Ethmalosa fimbriata*	17.28
Mugil curema	9.82	*Mugil bananensis*	8.73
Mugil bananensis	8.90	*Mugil curema*	8.43
Monodactylus sebae	7.98	*Fontitrygon margarita*	7.66
Elops lacerta	7.68	*Elops lacerta*	7.36
Neochelon falcipinnis	7.48	*Neochelon falcipinnis*	7.02
Coptodon guineensis	7.46	*Ilisha africana*	6.99
Fontitrygon margarita	7.29	*Coptodon guineensis*	6.64
Chelon dumerili	6.40	*Chelon dumerili*	5.98
Ilisha africana	6.33	*Monodactylus sebae*	5.52
		Caranx hippos	4.64
Station 3 (S3; 86.96%)		**Station 4 (S4; 88.91%)**	
Ethmalosa fimbriata	25.23	*Ethmalosa fimbriata*	27.79
Gerres nigri	19.40	*Gerres nigri*	21.44
Mugil bananensis	13.19	*Mugil bananensis*	17.79
Coptodon guineensis	10.52	*Coptodon guineensis*	14.07
Chelon dumerili	9.53	*Mugil curema*	13.77
Mugil curema	9.28	*Chelon dumerili*	11.98
Monodactylus sebae	8.47	*Neochelon falcipinnis*	10.89
Elops lacerta	8.29	*Monodactylus sebae*	9.45
Fontitrygon margarita	7.86	*Elops lacerta*	8.09
Cynoglossus senegalensis	7.34	*Cynoglossus senegalensis*	7.87
Neochelon falcipinnis	6.08	*Fontitrygon margarita*	7.10
Ilisha africana	5.67	*Caranx hippos*	4.64
Caranx hippos	4.61		

TABLE 3 *cont.*
Average dissimilarity of contributing species in each station using SIMPER analysis

Contributory species	Average contribution to dissimilarity (%)	Contributory species	Average contribution to dissimilarity (%)
Station 5 (S5; 84.76%)		**Station 6 (S6; 90.49%)**	
Ethmalosa fimbriata	23.93	*Gerres nigri*	20.64
Gerres nigri	20.69	*Coptodon guineensis*	17.00
Mugil bananensis	16.91	*Ethmalosa fimbriata*	16.04
Coptodon guineensis	13.15	*Mugil bananensis*	14.90
Mugil curema	12.32	*Mugil curema*	14.33
Chelon dumerili	12.14	*Chelon dumerili*	13.40
Neochelon falcipinnis	10.58	*Neochelon falcipinnis*	10.10
Monodactylus sebae	8.88	*Monodactylus sebae*	7.26
Cynoglossus senegalensis	7.96	*Elops lacerta*	6.69
Elops lacerta	7.95	*Fontitrygon margarita*	6.64
Fontitrygon margarita	7.61		
Caranx hippos	4.67		
Station 7 (S7; 87.61%)			
Gerres nigri	23.57		
Ethmalosa fimbriata	16.06		
Coptodon guineensis	15.22		
Mugil bananensis	14.47		
Neochelon falcipinnis	11.54		
Mugil curema	11.17		
Chelon dumerili	10.97		
Monodactylus sebae	8.32		
Fontitrygon margarita	7.71		
Elops lacerta	7.69		
Cynoglossus senegalensis	6.20		

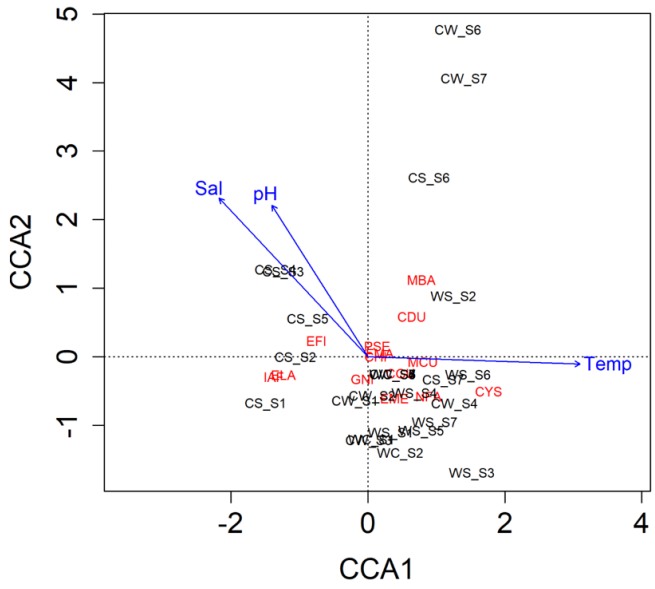

Figure 5 SThe CCA ordination of species abundance and environmental parameters: Temp = temperature, Sal = salinity. For species labels see table 1. CS= cold season; CW = transition cold to warm season; WS= warm season; WC = transition warm to cold season. S1, S2, S3, S4, S5, S6 and S7 are the sampling stations

Relationship between species and environmental variables

The CCA analysis based on species abundance indices revealed that axis 1 (67.29%) and axis 2 (22.82%) explained 90.11% of variance of the spatio-temporal species-environment relation. The relative length of the vectors indicate that salinity and temperature were the principal environmental variables that influence the spatio-temporal species distribution (Fig. 5). Salinity was more associated with the second axis, while temperature was highly correlated with the first axis. *M. bananensis* and *C. dumerili* abundance was greatly influenced by salinity and temperature. Salinity is strongly allied with distribution of *C. guineensis*, *E. melanopterus* and *N. falcipinnis*, whilst *M. curema* and *E. fimbriata* were more associated with temperature.

Discussion

Fish assemblage composition

This study gives a preliminary insight of fish assemblage composition in the GMPA created in 2014, located in the Sine Saloum estuary. Overall, 35 fish species belonging to 20 families were recorded. The most abundant species were *Ethmalosa fimbriata*, *Gerres nigri*, *Mugil curema*, *Neochelon falcipinnis* and *Mugil bananensis* probably due to their high adaptation capacity in strong salinity variations in estuaries (Albaret, 1987; Albaret & Ecoutin, 1989; Potter et al., 1990; Hotos & Vlahos, 1998; Charles-Dominique & Albaret, 2003; Vidy, 2000; Panfili et al., 2004; Simier et al., 2004). The fish assemblage in GMPA was strongly dominated by species in the guilds ME and Em in terms of species richness. Similar results were found in Bamboung MPA and in the Casamance estuary (Kantoussan et al., 2012; Sadio et al., 2015). Moreover, these two ecological guilds generally dominated the fish assemblage of the whole Sine Saloum estuary in terms of species richness (Ecoutin et al., 2010). In terms of abundance and biomass, species from Em category were more important as in Ecoutin et al. (2010) and Sadio et al. (2015). Concerning the trophic guilds, generalist predators were the richest in terms of species, while herbivores with more than 50% of the total abundance were dominant as reported in Sadio et al. (2015). However, in the Sine Saloum, Ecoutin et al. (2010) showed that zooplanktivorous fishes were the most abundant.

The species richness observed in GMPA is low compared to that found in Diouf (1996), who reported 114 species in the whole Sine Saloum estuary. In the MPA of Bamboung located in the Sine Saloum estuary, 54 fish species were reported by Sadio et al. (2015) during the 2008-2011 period. In Casamance estuary, 59 species were observed during the 2005 survey (Kantoussan et al., 2012). Caution is needed when comparing species richness between these cited studies. In fact, difference in species richness could be related to the characteristics of the site (surface area, depth, connection with the sea), hydrological parameters (e.g., tidal range, temperature, salinity etc.), the sampling effort, as well as the fishing gear type (Akin et al., 2005; Franco et al., 2008; Maci & Basset, 2009). In this study, only a beach seine was used, while in Diouf (1996), the study consisted of a larger than two-year sampling period involving several fishing techniques and with additional observations from small-scale and game fisheries. In Sadio et al. (2015), samples were collected with a purse seine from 2008 to 2011. In the Casamance estuary (Kantoussan et al., 2012), the study consisted of a one-year survey of artisanal fisheries. Therefore, the difference in species richness between our study and those listed above might be mainly due to the diversity of the fishing gear used, sampling location and period, and sampling effort.

Spatial and temporal variation of fish assemblage in relation with environmental parameters

Fish assemblage of GMPA showed significant temporal and spatial differences revealing a preference of some specific seasons or areas with particular environmental characteristics.

It has been suggested that fish assemblage structures in estuaries are influenced by both abiotic and biotic factors (Blaber & Blaber, 1980; Weinstein et al., 1980; Rozas & Hackney, 1984; Rakocinski et al., 1996; Maes et al., 1998; Araùjo et al., 1999; Whitfield, 1999; Garcia et al., 2001; Gelwick et al., 2001; Akin et al., 2003; França et al., 2011; Pichler et al., 2015; Molina et al., 2020). In this study, the CCA revealed that the spatio-temporal organization of the fish assemblages in GMPA was greatly influenced by studied abiotic factors, temperature and salinity. These two abiotic factors, have been shown to be important determinants of the spatial and temporal structure of fish assemblage (Grioche et al., 1999; Akin et al., 2003; Hagan & Able, 2003; Sosa-López et al., 2007; Whitfield et al., 2012; Whitfield et al., 2016). Temperature always affects fish species at different stages of their life cycles, including during spawning and the development and survival of the eggs and larvae, as well as influencing their distribution, diet, migration pattern and schooling behavior (Laevastu & Hayes, 1981; Sund et al., 1981; Gordoa et al., 2000; Harrison & Whitfield 2006; Batt et al., 2017; Gislason et al., 2020). Concerning salinity, several authors suggested that it influences reproduction, larval dispersal and recruitment, geographical distribution, and behavior of many species (Blaber & Blaber, 1980; Anger, 1991, 1996; Barletta et al., 2005; Spivak & Cuesta, 2009; Kantoussan et al., 2012; Smyth et al., 2014). As an example, it has been shown that juvenile mullets prefer oligohaline waters, while adults prefer euryhaline waters (Cardona, 2000). It's worth highlighting that, even if the abiotic factors analyzed in this study had an important influence on fish assemblage distribution in GMPA, they could not fully explain the spatial and temporal distribution of the assemblages. In fact, it has been suggested that other factors such as aquatic vegetation (Zimmerman & Minello, 1984; Killgore et al., 1989; West & King, 1996; Rozas & Minello, 1998; Akin et al., 2003), food availability (Rozas & Hackney, 1984; Barry et al., 1996; Kneib, 1997), sediment type (Marchand, 1993), status of the estuarine mouth (open or intermittently open) (Young et al., 1997; Bell et al., 2001), and biological interrelationships (Martino & Able, 2003) have been associated with the fish assemblage structure in estuarine ecosystems.

Conclusion

Overall, this preliminary study revealed that moderate species richness composed of five ecological guilds and seven trophic guilds, were the general features of GMPA. The most abundant species were those with high adaptation capacities in strong salinity variations. The species of estuarine affinity and the herbivores dominated the fish assemblage. Significant effect of water temperature and salinity was observed to shape the most abundant species distribution through Canonical Correspondence Analysis.

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Data availability Statement

Data used in this study are available and can be requested at ousmane.diankha25@gmail.com.

Conflict of interest statement

There is no conflict of interest.