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Environment

Reproductive strategies of *Ethmalosa fimbriata* in Ebrié Lagoon (Southern Côte d'Ivoire) in Response to Acute Pollution

Boussou Koffi Charles[1*], Kouamé Kouamé Martin[1], Yobouet Ahou Nicole[1], Boni Elise[2], Aliko N'guessan Gustave[1], Konan Koffi Félix[1], Ouattara Mamadou[2]

[1]Université Jean Lorougnon Guédé, UFR Environment, Daloa, Côte d'Ivoire
[2]Université Nangui Abrogoua, UFR Sciences et Gestion de l' Environment, Abidjan, Côte d'Ivoire

***Corresponding author:** Boussou Koffi Charles
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Abstract **Original Research Article**

This investigation was carried out in order to know the fitting responses of the reproductive potential of *Ethmalosa fimbriata***,** a heavily exploited fish species in Ebrié lagoon face to anthropogenic pollution. Three sites were prospected, Bietry and Cocody bays in most anthropized area and M'Braté far from city disturbances, the reference site. Results showed that, as abiotic parameters are concerned, pollution was more severe at Biétry and Cocody bays than at M'Braté. Regarding *E. fimbriata* reproductive parameters, length at first maturity for both males and females were significantly higher at the less disturbed site M'braté (109.71 mm LS for females; 106.97 mm LS for males) than in the most polluted sites Cocody bay (97.53 mm LS for females; 91.36 mm LS for males) and Biétry bay (81.24 mm LS for females; 74.25 mm LS for males). Absolute fecundity revealed that *E. fimbriata* females were less fertile in the most disturbed locations (3800 and 11683 eggs respectively for Biétry bay and Cocody bay) than in the less polluted site M'Braté (median value = 15262 eggs). Investigations on relationships between some biotic parameters of the fish and environmental variables through canonical analysis showed that the studied reproductive parameters were negatively correlated to abiotic variables such as nitrates, nitrites and phosphates. Ultimately, this study showed that when living environment becomes austere in Ebrié lagoon, *E. fimbriata* reproduces earlier with a reduced number of offspring.
Keywords: *Ethmalosa fimbriata***,** Ebrié Lagoon, reproduction, pollution**.**

INTRODUCTION

Abidjan is the economic capital of Côte d'Ivoire with more than 20% of the total population of the country. Nearly 80% of all industries in the country are based in Abidjan because of the amenities offered by the port of Abidjan. These industries are usually built on the banks of the Ebrié Lagoon the largest of the West African lagoon systems with a total area of 566 km2 [1]. All wastewater (domestic, industrial, agricultural, port activities, etc.) from Abidjan city and its agglomeration are drained in Ebrié lagoon waters without any treatment. Such pollutants seriously threaten the balance of aquatic organisms and ecosystems. However this lagoon is a habitat for more than 150 fish species [2] including *Ethmalosa fimbriata*, a heavily exploited species by the artisanal fishing. This species in terms of number and biomass represents more than 75% of catches in this lagoon [3] have shown that some fish species have ecophysiological adaptations and / or develop adaptations concerning growth or reproduction phenomena: growth variation, dwarfism, early sexual maturity; in response to disturbances of their environment due to increasing anthropogenic pressure. The present study aims at knowing the fitting responses of the reproductive potential of *Ethmalosa fimbriata* in Ebrié lagoon face to anthropogenic disturbances.

MATERIALS AND METHODS

Study area and sampling sites

The Ebrié lagoon system (Figure 1) is the largest lagoon in West Africa [4]. It is an elongated lagoon system with a total area of 566 km^2 and it stretches for 130 km, with a maximum width of 7 km. The average depth is of 4.8 m, with a few deep areas especially around Abidjan (27 m south of Boulay Island). It is divided into three lagoons: Potou, Aghien and Ebrié, and receives freshwater from the Comoé, Agnéby and La Mé rivers. Salinity in the system varies between 0 and 35. Before 1951, the Ebrié lagoon system was only connected to the Atlantic Ocean through the Bassam inlet in the far east of the lagoon system (40 km away from Abidjan). The Vridi Channel was built in 1951 allowing a connection to the sea closer to Abidjan, greatly modifying the hydrological environment since the Bassam inlet has progressively closed, and nowadays the Comoé river discharges into the lagoon system rather than directly to the sea. The Ebrié lagoon system is strongly polluted by domestic and industrial wastewater inputs [5, 4]. The waters around Abidjan are highly eutrophicated leading to frequent oxygen depletion, massive fish kills and repelling sulphuric smells [5, 6], and have been included in the recent compilation of coastal "dead zones" [7]. Three stations were selected for sampling: Biétry bay (5°N16'57 ''and 4°W00'04.5''), Cocody bay (5°N19'18.9 ''and 4°W00'19.9'') and Mbraté (5°N18'20.6'' and 4°W15'40.2 ''). The first mentioned is located nearby a fishermen's village. This bay is a receptacle of industrial (oil mill, brewery, soap, cooking oil factory) and domestic wastewater. It is highly eutrophic and is the most polluted bay of Ebrié lagoon [1]. Cocody bay is located in an urban area and receives effluent from household, industrial and medical waste. M'braté, the reference site is on a part of Ebrié lagoon far away from human activities (factories, agriculture, aquaculture and domestic waste) at 10 km from Dabou, the nearest town. This site is considered as relatively less disturbed.

Sampling

Fishes were sampled from January to Jun 2009 with two surveys each month. This period covers two different seasons: the long dry season (LDS) from January to March and the long rainy season (LRS) from April to Jun, covering the reproduction season of *Ethmalosa fimbriata* in this lagoon according to [8]. Gillnets were set at 5 pm (the d-day) and visited at 6 am (the next day) by fishermen engaged in commercial fishing. Sampled specimens were identified according to the identification keys of [9] and were transported to the laboratory in cooler. Each specimen was measured (standard length and total length) to the nearest millimeter and weighed to the nearest gram. The mass of ovary and eviscerated fish were recorded and each tissue was then preserved in alcohol 70% for later observation. The sex of each specimen was determined by examination of the gonad tissue either by eye for large fish or with a lens (×16) for smaller ones.

Environmental variables measure

Physical and chemical parameters were monitored during sampling period. A multiparameter device WTW340i/SET has been used for the measurement of temperature, dissolved oxygen, conductivity, salinity and total solids. The nutrients NH_4^+, NO_3^-, NO_2^- and $PO4^{3-}$ have been assessed with a spectrophotometer HACH DR 2000 and water transparency through a SECCHI disk. COD test measures the oxygen demand of the whole oxidizable pollutants contained in the sample. The measurement was performed with the potassium dichromate method according to the Norma NF T90-101 [10].

Reproductive parameters

Individuals' sex and females' maturity stages were determined by gonads examination. Sex ratios were compared to the 1:1 proportion by using the Chi-square (χ^2) test. The gonadosomatic index (GSI), calculated to assess the reproductive status of fish was obtained according to [11] by the formula:

$$\text{GSI (\%)} = \frac{W_g}{W_e} \times 100$$

Where Wg is the gonad weight, and we the eviscerated weight. The seasonal and spatial variations in the GSI were assessed respectively using the Mann-Whitney and Kruskal-Wallis tests.

The length at which 50% of the fish were mature (stages III, IV and V) was regarded as the size at first maturity (L50). It was calculated by fitting a logistic function to the proportion of sexually mature individuals by class size as follows:

$$\boldsymbol{P = \frac{1}{1 + e^{-r(SL-L50)}}}$$

Where p is the proportion of mature fish, SL is the standard length (median value of each class size) and r the slope [12]. The model predicted the proportion of mature fish using nonlinear regression with individuals classed into 10 mm SL intervals. Median values of size classes and corresponding mature fish proportions were used for estimating the function's parameters. The nonlinear regression model performed was the user-specified regression and least squares procedure of Levenberg-Marquardt. When data were not suitable (high redundancy) for this procedure, the user-specified regression and loss function of the quasi-Newton method was executed. Nevertheless, when the number of specimens is insufficient, the smallest mature specimen estimates the size at first maturity [13]. Because males and females sometimes have a different growth pattern, we considered each sex separately. Size at first maturity was compared between sites and sexes using Chi-square ($\chi 2$) test.

Absolute fecundity (F) was estimated by weighing all the eggs in an ovary and counting three subsamples of 0.25 g of eggs from different parts of the ovary. The average number of eggs per gram was calculated and multiplied by the total weight of each ovary, giving the total number of eggs per ovary [14]. For the smallest ovaries, complete counts of oocytes were made. Relative fecundity is defined as the number of eggs per kilogram of fish. It was calculated for each female by the quotient of absolute fecundity per the somatic weight. Absolute fecundity and relative fecundity were compared between locations by the Kruskal-Wallis test.

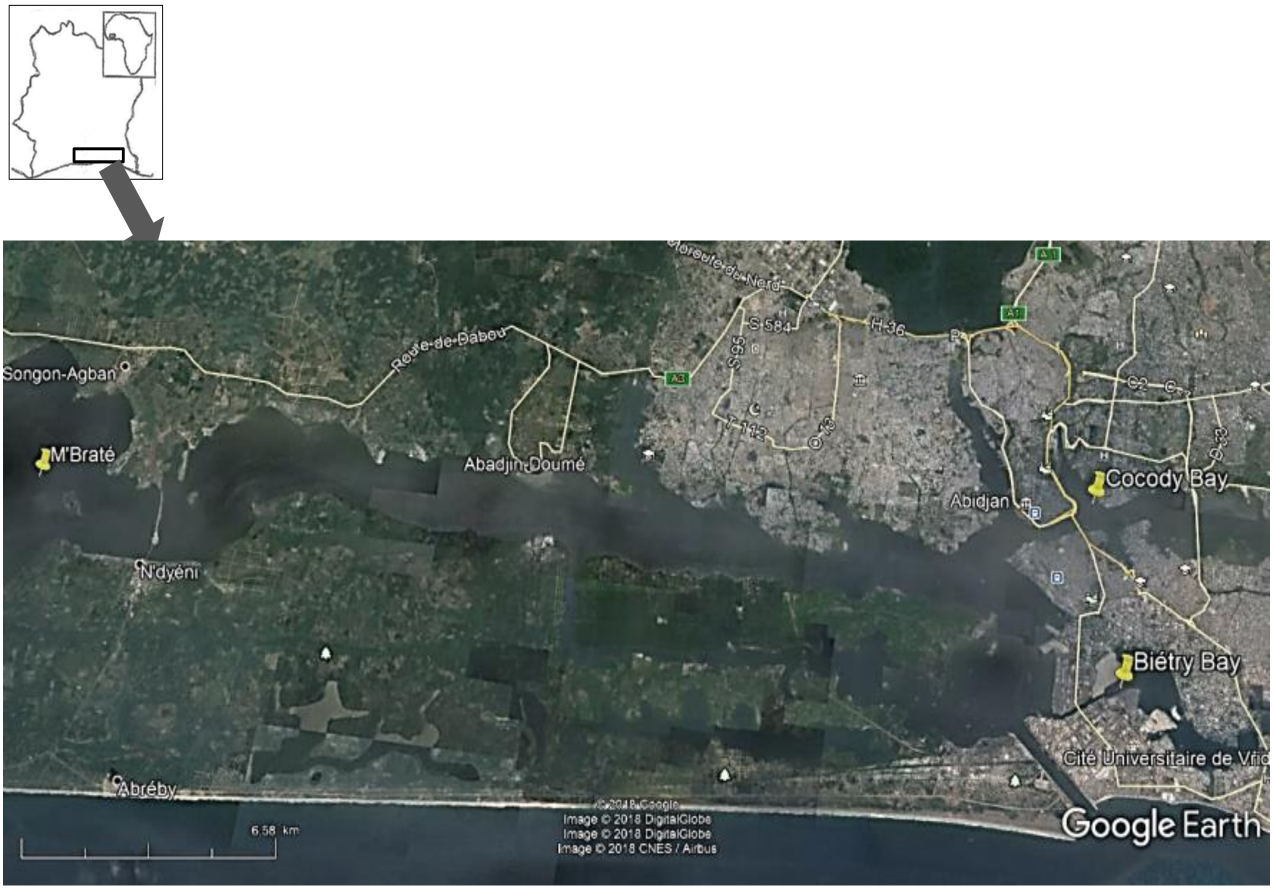

Fig-1: Sampling sites on Ebrié Lagoon for the present study (map from Google earth 2018 and modified)

The condition factor was calculated using the formula:

$$K = \frac{100 \times W}{L^3}$$

where, K = condition factor, L = standard length (cm) and W = weight (g).

All the statistical tests were performed using the STATISTICA 7.1 software [15].

A Redundancy Analysis of CANOCO has been run to seek the combination of explanatory variables (environmental variables) that best explain fish response (biotic variables).

RESULTS

Physical and chemical environment of the study sites waters

The mean values of the temperature recorded at the Biétry bay (BB), the Cocody bay (CB) and M'Braté (MB) are respectively 28.50 ° C, 28.61 ° C and 28.33 ° C and are not significantly different (Table 1) according to ANOVA test ($p > 0.05$). The same trend is observed for pH and transparency. Mean values of depth were found to be significantly different (ANOVA, $p < 0.05$) between sites with as average values 4m at BB; 6.15m at BC and 2m at MB. Mineralization was higher at BB (9820µs/cm) and CB (6031µs/cm) than at MB (3109µs/cm). As chemical variables are concerned, in the whole, the lowest values (PO_4^{3-}, DCO, NO_2^-, TS and Salinity) are obtained at MB where however the strongest values of dissolved oxygen (O_2) are recorded.

Table-1: Values of the different physico-chemical parameters measured at each sampling site in Ebrié Lagoon. Median values with identical letters are not significantly different (Kruskal-Wallis, p> 0.05).

Parameters	Biétry Bay	Cocody Bay	M'Braté
T°C med. (Min-Max)	28,50 (27,56-28,93) [a]	28,61 (24,66-29,96) [a]	28,33(27,11-30,16) [a]
pH med. (Min-Max)	7,58 (7,08-8,21) [a]	7,65(7,22-8,15) [a]	7,33(7,04-7,96) [a]
O2 med. (Min-Max)	4,58(3,45-6,58) [a]	5,10(3,93-7,16) [ab]	6,38(4,05-8,36) [b]
CND med. (Min-Max)	9820(2503,33-13463,33) [a]	6031,5(2460-12852,33) [a]	3109(1014,33-7216,67) [b]
TDS med. (Min-Max)	4883,5(396,33-6733) [a]	2459,5(371-6426) [ab]	1530,5(507,33-1972,33) [b]
Sal med. (Min-Max)	7,32(5,50-10,27) [a]	6,56(2,60-9,73) [a]	2,28(1,43-6,86) [b]
Transp med. (Min-Max)	0,88(0,65-2) [a]	1,15(0,40-1,85) [a]	0,81(0,50-2) [a]
Depth med. (Min-Max)	4(3,25-6) [a]	6,15(4,90-7,95) [b]	2(1-3,60) [c]
NO2 med. (Min-Max)	0,05(0,02-0,08) [a]	0,04(0,01-0,13) [a]	0,007(0,002-0,014) [b]
NO3 med. (Min-Max)	0,16(0,04-1,38) [a]	0,11(0,02-1,13) [a]	0,04(0,01-0,61) [a]
NH4 med. (Min-Max)	0,15(0,08-0,18) [ab]	0,16(0,05-0,28) [a]	0,09(0,04-0,16) [b]
$PO4^{3-}$ med. (Min-Max)	0,04(0,02-0,07) [a]	0,05(0,01-0,06) [ab]	0,02(0,01-0,03) [b]
DCO med. (Min-Max)	802,51(394,78-1402,77) [a]	953,63(398,03-2224,76) [a]	69,88(52,90-1146,86) [b]

T° C: Temperature in °C; TDS: Dissolved Solids; CND: Conductivity; S-R: Sex ratio; Fec.R: relative fertility; med: median value; TDS: Dissolved Solids; CND: Conductivity, Sal. : Salinity; pH: Hydrogen potential; NO_3^-: Nitrates; NO_2^-: nitrites; PO_4^{3-}: Phosphates; Transp: Transparency; COD: Chemical Oxygen Demand; O_2: dissolved oxygen; NH_4^+: ammonia.

Reproductive parameters

Sex ratio

Results on sex ratio of *Ethmalosa fimbriata* in Ebrié lagoon are registered on table 2. Of the 740 specimens caught at Bietry bay, 460 were males versus 280 females resulting in a sex ratio of 1.64: 1 in favor of males (χ^2=43.8, ddl=1, p < 0.05). At Cocody bay, this species exhibits a sex ratio in favor of females (1:1.88) with 132 males versus 248 females (χ^2=35.4, ddl=1, p < 0.05). At M'Braté, females are also more numerous than males. The sex ratio obtained there is 1:1.6 in favor of females (χ^2=31.2, ddl=1, p < 0.05). These sexes ratio are not significantly different from the theoretical 1:1 (χ^2, p > 0.05).

Table-2: Sex ratio of *Ethmalosa fimbriata* in Ebrié lagoon

	Bietry bay	Cocody bay	M'Braté	Total
Number	740	380	576	1696
Number of males (M)	460	132	221	813
Number of females (F)	280	248	355	883
Sex ratio (M:F)	1.64:1	1:1.88	1:1.6	1:1.09

Gonadosomatic index (GSI)

GSI was calculated in each site and for both sex separately. The mean RGS values of males (Figure 2A) were 4.87%; 4.41% and 4.52% respectively for Biétry bay, Cocody bay and M'Braté. Analysis of the variance showed that there were no significant differences between mean values of the males RGS (p >0.05, ANOVA) from the different sites. Regarding females (Figure 2B), the average value of the RGS was 4.12% in Biétry bay, 2.65% in Cocody bay and 3.49% in M'Braté. The post-hoc HSD N different test from the ANOVA performed showed that the differences in females RGS observed in the three sites were significant (p <0.05).

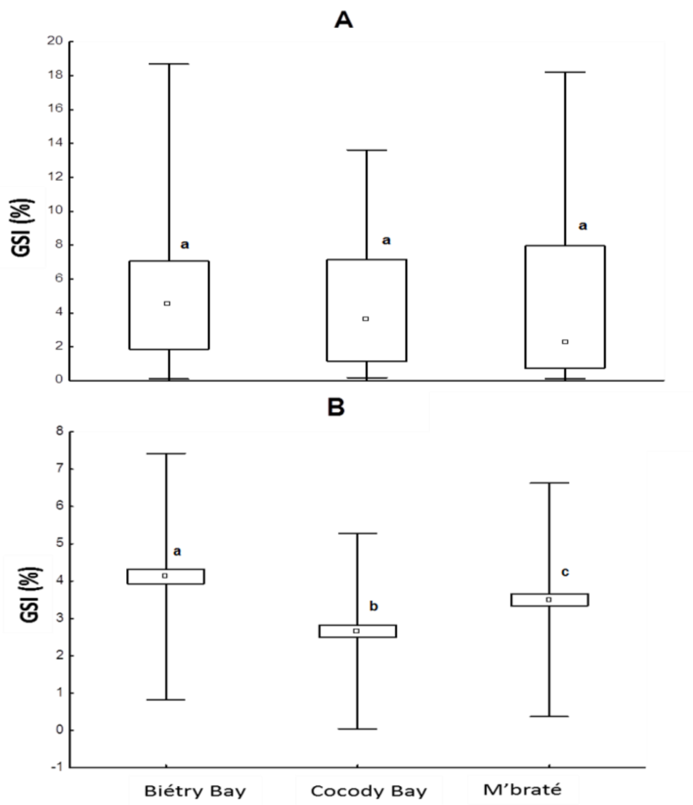

Fig-2: Spatial variation of gonadosomatic index (GSI) of males (A) and females (B) of *Ethmalosa fimbriata* from Ebrié lagoon. Box-plots with identical letters have mean values not significantly different

Length at first maturity L50

The length at first maturity (L50) was estimated for both sexes in each site as the standard length at which 50% of the fish were mature (Figure 3). The L50 calculated in Bietry bay was 81.24 mm for females against 74.25 mm for males. Furthermore, the smallest mature female measured 68 mm against 66 mm for males. At Cocody bay, 50% of females were mature at the length of 97.53 mm when 50% of males reached maturity at 91.36 mm standard length. The smallest mature individuals measure 89 mm both in females and in males. M'Braté individuals meanwhile, exhibited L50 values of 109.71 mm for females versus 106.97 mm for males. The smallest mature individuals were 93 mm and 92 mm standard length respectively for females and males. Compared through a Chi-square test, the L50 calculated appeared not significantly different (χ^2, ddl= 1, $p > 0.05$) between sexes whatever the site. However, the comparison between sites showed that L50 for both males and females at M'Braté were significantly higher (χ^2, ddl= 1, $p < 0.05$) than those obtained at Biétry bay. Lengths at first maturity were not different between bays sites.

Fecundity

Variations in ovaries weight and fecundity of *E. fimbriata* between study sites have been assessed by the Kruskal-wallis test (table 3). Ovaries of individuals from Bietry bay (median value = 0.6 g) are significantly weaker (Kruskal-wallis, $p < 0.05$) than those of specimens coming from Cocody bay (median value = 2.02 g) and M'Braté (median value = 3.06 g). Investigations upon absolute fecundity reveal that *E. fimbriata* females were less fertile at Bietry bay (median value = 3800 eggs) than those from Cocody bay (median value = 11683 eggs) and M'Braté (median value = 15262 eggs). The same observations were applicable to relative fecundity where median values obtained were 198745 eggs/kg, 439889 eggs/kg and 592700 eggs/kg of female respectively at Bietry bay, Cocody bay and M'Braté (Kruskal-wallis, $p < 0.05$).

Table-3: Mean values of absolute and relative fecundity of *Ethmalosa fimbriata* from Ebrié lagoon.

	Bietry bay	Cocody bay	M'braté
Mean ovary weight (g)	0.6^a	2.02^b	3.06^b
Absolute fecundity (eggs)	3800^a	11683^b	15262^c
Relative fecundity (eggs/g of body weight)	198745^a	439889^b	592700^c

Mean values with identical letters are not significantly different

Relationships between some biological parameters of the fish and water's environmental variables

Figure 4 presents the results of the analysis in the RDA of CANOCO between biotic parameters (reproduction and growth) and physico-chemical variables of water in the three study sites. Most of the biotic variables (fecundity, length at first maturity, gonads weight and standard length) are highly and positively correlated to axis 1. High values of these parameters are characteristic of individuals from M'Braté. The previously cited biotic variables are correlated negatively to environmental parameters as nitrates, nitrites and phosphates that higher values seem to be more characteristic of water from Biétry bay.

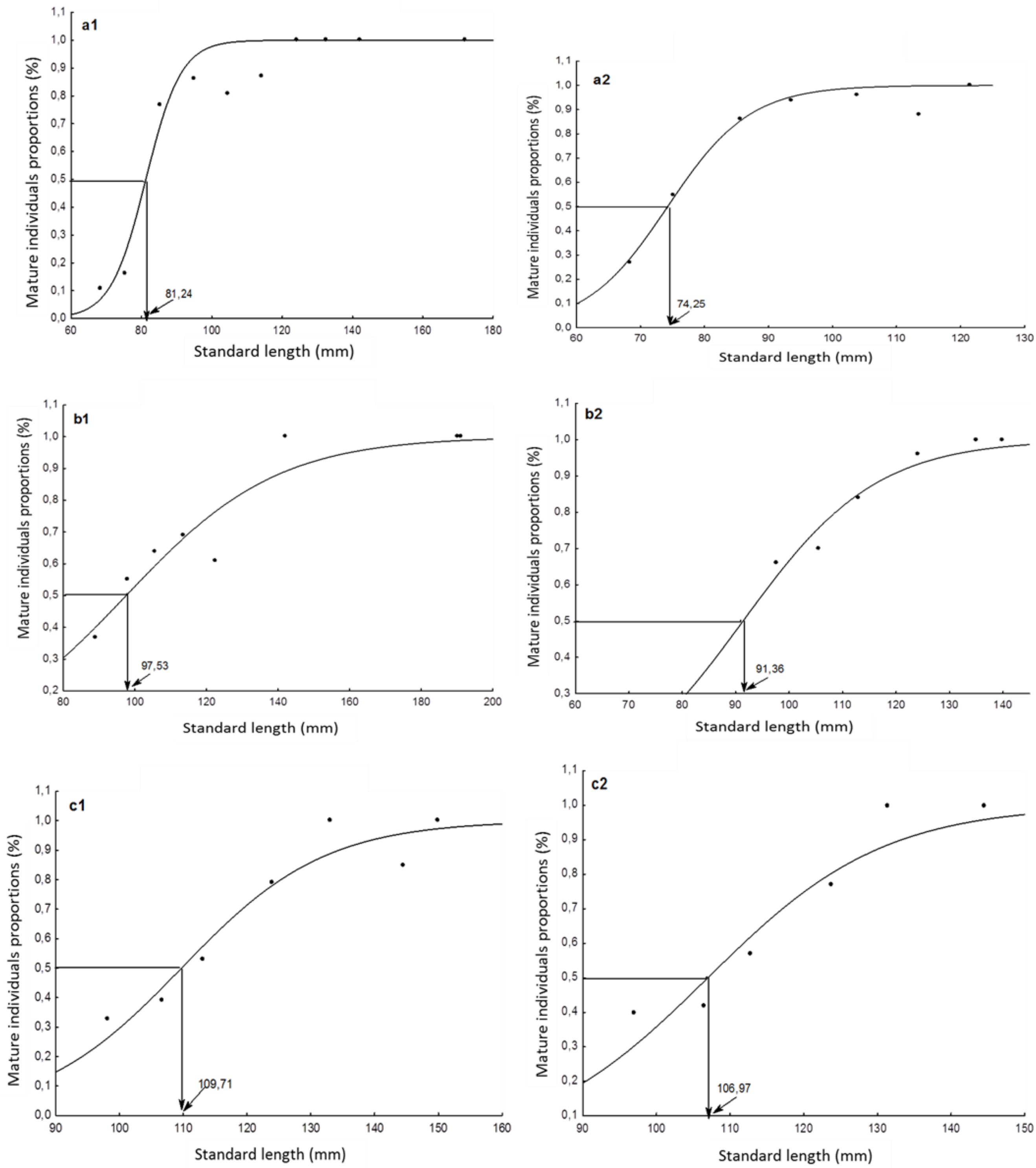

Fig-3: Size at first maturity of females (1) and males (2) of *Ethmalosa fimbriata* in Ebrié lagoon. Biétry bay (a), Cocody bay (b) and M'Braté (c)

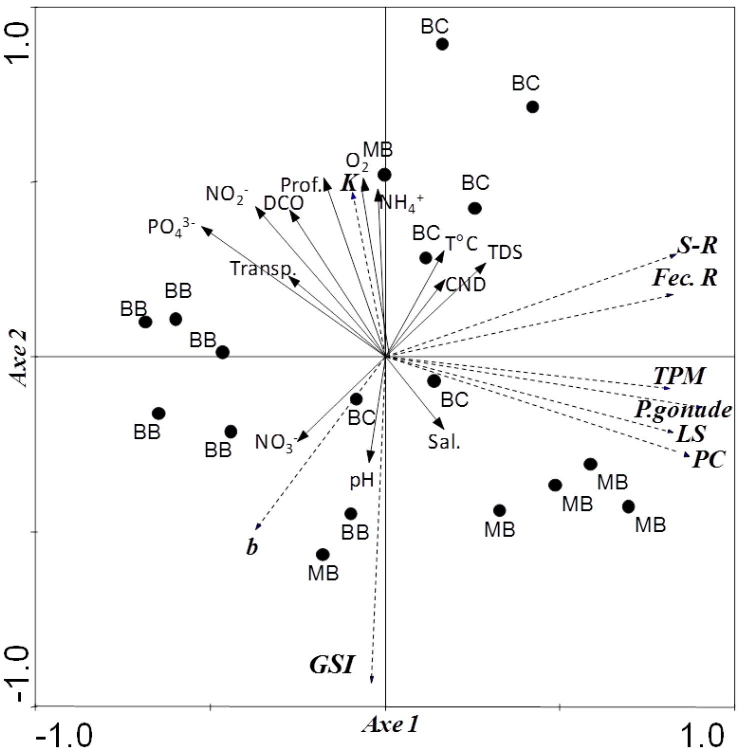

Fig-4: Canonical Analysis in the Redundancy Analysis (CANOCO program) taking in account biotic parameters of *Ethmalosa fimbriata* and physicochemical variables in different sites of Ebrié lagoon. BB: Biétry Bay; BC: Cocody Bay; MB: M'Braté; T° C: Temperature in °C; TDS: Dissolved Solids; CND: Conductivity; S-R: Sex ratio; Fec.R: relative fertility; TPM: Size at first maturity; P. gonad: gonad weight; LS: Standard length; PC: body weight; Sal. : Salinity; GSI: Gonadosomatic index; b: allometric coefficient; pH: Hydrogen potential; $NO3^-$: Nitrates; $NO2^-$: nitrites; $PO43^-$: Phosphates; Transp: Transparency; COD: Chemical Oxygen Demand; Prof. Depth; K: condition factor; O2: dissolved oxygen; $NH4^+$: ammonia.

DISCUSSION

Abiotic parameters data showed that mineralization was higher in the Ebrié lagoon's bays (Biétry and Cocody) located inside Abidjan. Indeed, the highest values of PO_4^{3-}, DCO, NO_2^- and Salinity were obtained in these bays compared to values obtained in the site outside of the agglomeration. These results are consistent with those of [16] who found that these bays were among the most polluted in the urban area of Ebrié Lagoon. According to these authors this is the result of diffuse organic components inputs via different effluents on the one hand and, on the other hand, the lowest depths and water renewal rates observed in these confined areas. They asserted that levels of DO, COD and BOD5 found in these bays were unsuitable for aquatic life. Lowest concentrations of DO in aquatic ecosystems often lead to potential behavioural responses such as changes in distribution, habitat use, activity, increased use of air breathing, increased use of aquatic surface respiration, and habitat shifts [17].

Investigations upon *Ethmalosa fimbriata* reproductive strategies in Ebrié lagoon showed that size at first maturity varied according to the sex and also the location in the lagoon. Indeed, whatever the site of study the size at first maturity of females is higher than that of males. Other authors reached the same results with this species such as [18] in Estuary Senegal, [8] and [19] in Ivory Coast and [20] in Nigeria. The variation of size at first maturity according to the sites showed that as well in the males as in the females, the size at maturity was shorter in the most polluted sites than in the less polluted. So, the present study revealed that in Ebrié lagoon when the environment becomes austere, *Ethmalosa fimbriata* seems to reproduce earlier.

Albaret JJ [2] has also shown with *Marcusenius ussheri* that variations in the size at first sexual maturity in different sites are due to the fact that fish develop different strategies in different environments for better adaptation. Indeed, [21] indicate that in natural environment, it is often found that the size at first reproduction is linked to some factors including the extent of the water bodies, the density of fish and various states of stress existing within populations.

In terms of sex ratio, our results showed a sex-ratio in favour of females in some sites (Cocody bay and M'Braté) and in favour of males in one site (Biétry bay). For [8] the proportions between males and females of *Ethmalosa fimbriata* are almost identical (50/50). However, a numerical dominance of females of this species has been observed by [22] in Ebrié lagoon population where the ex-ratio expressed as a percentage of males was 35%. Indeed, according to [23], in Clupeidae, the number of females is slightly often higher than males. The sex ratio in favour of females could be due to factors such as the movement for search of food and growth differential between the two sexes [24]. The sex ratio often reflects the adjustment mechanisms in food availability (which is also depending on the density).

Results concerning fecundity revealed that fecundity is higher in the less polluted sites. Indeed, median relative fecundity in Cocody and Bietry bays were respectively equal to 440 and 199 eggs per gram against 593 eggs per gram of body weight at Mbraté. The same trend was observed for absolute fecundity [8] found in Biétry bay fecundity values evolving between 150 and 300 eggs per gram of *Ethmalosa fimbriata* body weight. According to [25], fecundity could increase with fish size specifically with clupeids where the gonads weight increase greatly with fish age. In the case of the present study, difference in fecundity among sites could also be due to differences in environment quality or intraspecific shifts.

The canonical analysis (RDA) integrating biotic and abiotic parameters as well as the different sampling sites indicates that biotic parameters such as size at first maturity, gonads weight, body weight and standard length have higher values in the reference site (M'braté). On the other hand, at Biétry bay, these same parameters display the smallest values. This result therefore assumes a difference in fish reproduction strategy between sites. So variations in environment parameters appeared to be the main factors that influenced reproductive patterns of that species in Ebrié lagoon. Indeed, the reproductive strategy of a fish species, in a given environment, is a set of biological traits such as age and size at first reproduction, fecundity, gonad development and gamete size, reproductive behaviour including the existence of parental care, breeding season, etc. But according to [26], an individual can also develop tactics, which are in fact variations with respect to the typical reproductive pattern of the species, so as to respond successfully to changes in environmental factors. It is then an adaptive behaviour to particular ecological conditions, which aims to ensure the survival of that species.

Conclusion

Ultimately, this study showed that when living environment becomes austere in Ebrié lagoon, *E. fimbriata* reproduces earlier as most of the living organisms, but bears a reduced number of offsprings. The abiotic parameters that influence the reproductive patterns are water contents in nitrates, nitrites and phosphates that are proof of an organic pollution.

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