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Research article

Functional diversity of the fish fauna in the Nyong estuary (Atlantic Coast, Cameroon), and its correlation with environmental variables

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A R T I C L E I N F O

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A B S T R A C T

Archaic fishing, anthropogenic pollution linked to demographic and economic growth stand to be a real threat to the richness and abundance of the aquatic fauna of estuaries in Sub-Saharan Africa. The knowledge of the Nyong estuary ichthyofauna's ecology in Cameroon is particularly essential to establish a management plan and sustainable management of this important ecosystem. The Nyong estuary ichthyofauna was composed of 13 families, 20 genera and 22 species, from February to June 2020. Eleven species had a marine affinity while11 others were from the freshwater dirivation. Mormyridae (14%), Cichlidae (14%) and Clupeidae (14%) were the most represented families. Also, *Chrysichthys nyongensis* was the most abundant species with a frequency of 30.26%. Despite the low diversity in the study area, the specific diversity index showed that Dikobe was the most diverse station (H' = 2.98 and J = 0.46), contrary to Donenda's station (H' = 2.30 and J = 0.22). In general, significant correlations were noted between physico-chemical parameters and the total abundances of the different fish species ($P < 0.05$). Thus, in Behondo, characterized by polyhaline waters, *Gnathonemus petersii* in contrary *Pellonula vorax* was positively and significantly correlated with salinity, electrical conductivity and total dissolved solids. This study clearly illustrates that the distribution of ichthyofauna in the Nyong estuary mainly depends on the environmental variables. The data obtained would therefore allow the implementation of a sustainable fisheries development and management plan in the localities concerned by this study, and sensitize fishermen on the need to respect the fishing code.

1. Introduction

Coastal systems (estuaries, deltas, lagoons and the continental shelf) contain approximately 46% of the world's fish species (11,300 species) and provide more than 90% of the world's catch [1–3]. Fish species are often less abundant in estuaries than in adjacent

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riverine or marine systems, where environmental conditions are more stable, especially with respect to salinity variations and sediment stability [4,5]. Related to the high environmental variability, estuarine ichthyofaunal dynamics depend on several scales, including diurnal, tidal, and seasonal fluctuations [6]. In estuaries, the different morphologies, locomotion patterns, feeding regimes and lifestyles of fish are remarkable [7].

In Cameroon, the fishery potential is about 180,500 tons, of which 51.52% comes from artisanal maritime fishing, 41.55% from artisanal continental fishing, 4.16% from industrial fishing and 2.77% from aquaculture [8]. Unfortunately, the insufficiency or, lack – of up to date data on the ichthyological diversity of rivers and marine and coastal ecosystems does not allow a comprehensive view of the sustainable management of this sector that contributes to the local and national economy. The Nyong River is the second largest river in Cameroon after the Sanaga, with a length of 640 km. It flows over a total area of 28,000 km^2 and feeds about 4 million people [9]. It flows into the Atlantic Ocean through the Ocean Division and has an appreciable potential for fishery resources. In the fresh and brackish waters of Cameroon, fish is present in all biotopes and often migrate in relation to it reproductive cycle. There are about 542 species of fish divided into 53 families and 179 genera that inhabit Cameroonian fresh and brackish waters [10]. Guinean species (inhabit stream in forests areas) are the most numerous with 294 species (54%); followed by Sudanian species (inhabit streams in savannahs and steppes) with 130 species (24%); and endemic species composed of 96 species (17%) [10].

The growing interest in fish today is mainly due to the decline of natural stocks, caused by excessive and uncontrolled fishing [11]. Fish are in fact a group that is highly threatened by human activities, either through fishing and the introduction of foreign species, or through physical (development) and chemical (pollution) modifications affecting aquatic environments [12–14]. The estuarine zone of the Nyong River has been for several years, the site of a series of aggressions (overfishing, bank erosion, siltation, various pollution etc.), affecting its living environment and considerably destroying its biodiversity [15]. The anthropogenic aggressions against the Nyong River are such that in the future it will no longer be able to produce fish [16]. So far, research in the estuarine zone of the Nyong River has focused on plankton [17–20], whereas updated data on its fish fauna are rare. Anthropogenic activities related to pollution and overfishing explain the low ichthyological productivity of the lower Nyong. Data on its ichthyofauna are almost unknown today. There is a need to know the fish species that are present in this coastal ecosystem and their respective habitats in order to implement the necessary means and methods for sustainable exploitation. As such, this study will contribute to the knowledge of the ichthyofauna of the Nyong in order to take measures for sustainable management and to make fishing in Cameroon more profitable in general. The main hypothesis that will be tested in this study is whether the diversity and distribution of fish species that inhabit the Nyong estuary would be conditioned by the physicochemical quality of the water. The main objective of this study is to determine the diversity of fish fauna in the estuarine zone of the Nyong river and association to abiotic gradients through a microecological approach.

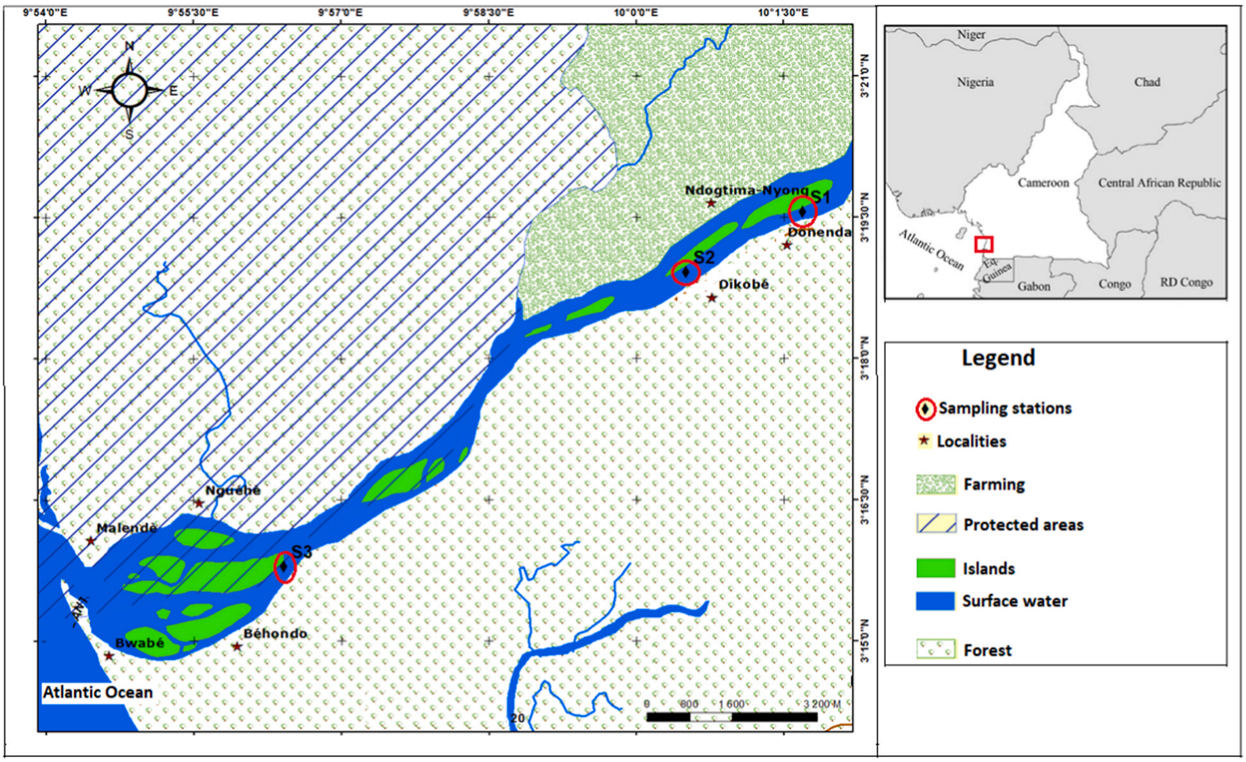

Fig. 1. Location of sampling stations.

2. Material and methods

2.1. Study area

Monthly sampling was conducted from February to June 2020 in the Nyong estuary, which constitutes the natural boundary between the Department of Sanaga Maritime in the Littoral Region and Ocean Division in the South Cameroon Region (Fig. 1). Three sampling stations were surveyed according to their accessibility and fishing activities. These were: station 1 at Donenda, station 2 at Dikobe (4 km from station 1) and station 3 at Behondo (9 km from station 2). The physical characteristics of each station are listed in Table 1.

2.2. Physicochemical parameters

Physicochemical parameters were analyzed according to the techniques recommended by Rodier [21] and APHA [22]. At each station, seven physicochemical parameters were measured *in situ*, using a multi-parameter (HANNA/HI9829). They are: temperature (°C), dissolved oxygen (mg/l), pH, salinity (PSU), electrical conductivity (mS/cm), total dissolved solids (TDS) (g/l) and turbidity (NTU).

2.3. Capture and identification of fish

The catches were made with six drift gillnets (1.5; 2; 2.5; 3; 3.5; 4). These nets were straight and have floats on their upper part that drift with the current. They were made of several rectangular sheets, which hung vertically towards the depth of the water thanks to a ballast fixed in the bottom of the net. At each station, the nets were dipped at 5:00 p.m. on both banks, three upstream and three downstream, and lifted the next day at 6:00 a.m. to observe the captures. Using a Dymo, a code number was assigned to each specimen. Then, the total and standard lengths were measured to the nearest millimeter using an ichthyometer. Before fixation with 10% formaldehyde (CH_2O) for the identification in the laboratory, each specimen was weighed using a 500 g balance capacity with a sensitivity of 0.1 g.

In the laboratory, the specimens were rinsed with tap water and then preserved in 70 °C ethanol (C_2H_6O) for progressive identification. The keys proposed by Stiassny et al. [23]; Boulanger [24–27]; Boden et al. [28]; Mamonekene et al. [29] were used for fish identification.

Generally, several parameters have been considered in the taxonomy of the captured fish: the general morphology or shape of the body (anguilliform or serpentine, very elongated, elongated, short or medium, very high), the weight, the different measurements (total length, standard length, body height, head length, snout length, eye diameter, fin length, etc.. ..), the ratio length of the body on height of the body, the shape of the head, the forms and constitutions of the fins, the types of scales and other phaneres differentiate the species, the color.

2.4. Statistical analysis

Specific richness (S) is defined as the total number of identified species in a sample. This parameter can be a distinctive criterion of ecosystems or stations studied within a given ecosystem.

The frequency of occurrence (F) of a species is the percentage of stations where a species i has been sampled compared to the total number of stations surveyed. It quantifies the degree of ubiquity of the different species. The frequency of occurrence (F): $F = Si/St \times 100$ (Si = number of stations where the species "i" was caught; St = total number of stations surveyed).

Shannon and Weaver's diversity index (H′) expressed diversity taking into account the number of species and the abundance of individuals within each of these species. It is evaluated by formula $H' = -\sum Pi \log2 Pi$ with Pi = (Pi = proportional abundance or importance percentage of the species; ni = number of individuals of i species in the sample; N = total number of individuals of all species in the sample).

The Piélou equitability index (J) was used to measure the distribution of individuals within species, independently of species richness. It is given by the formula: $J = H'/H'max$ with $H'max = \log2 (S)$ where S is the total number of species or species richness. XLSTAT 2014 software was used to determinate the Correspondence Factorial Analysis (CFA). The SPSS software version 16.0 allowed us to establish the correlation tests. *P* values were used to assess the significance of the correlation between abiotic and biotic

Table 1
Characteristics of the sampling stations.

	Station 1 (Donenda)	Station 2 (Dikobe)	Station 3 (Behondo)
Latitude N	03°20′00.7″	03°19′15.5″	03°15′23.6″
Longitude E	010°02′09.1″	010°00′47.6″	00,9°55′49.4″
Altitude (m)	10	5	3
Bed width (m)	284	531	584
Bed depth (m)	4.40	4.80	2.90
Flow speed (m/s)	3	1	0.50
Substrate	Rocky and sandy	Muddy and sandy	Muddy

parameters. The safety threshold was 5% ($P < 0.05$).

This study was approved by the Scientific Committee of the Institute of Fisheries and Aquatic Sciences, University of Douala, Cameroon.

3. Results

3.1. Abiotic variables

During the study period, the temperature profile of water varied from station to station. The maximum value was recorded in February at Dikobe (31.60 °C) and the minimum in June at Donenda (30 °C). The pH ranged from 6 to 7.30 at the different stations. These values generally showed a tendency for these waters to be acidic. In the three stations, the waters were sufficiently oxygenated. Nevertheless, the average values of dissolved oxygen, between 5.90 mg/l and 7.40 mg/l, had a decreasing tendency when going from the continent to the coast (Fig. 2). The average salinity values, almost zero at Dikobe (0.02 PSU) and Donenda (0.01 PSU), were considerable at Behondo (5.30 PSU), a station near the sea. During the study period, the water at the Behondo station was more turbid (7.10 NTU) than at the Dikobe station (2.40 NTU). Just as the turbidity, electrical conductivity and TDS average values werevery high at Behondo compared to Dikobe and Donenda (Fig. 2).

3.2. Ichthyofauna

3.2.1. Taxonomic composition

During our sampling campaigns, 452, 458, 455, 449, 461 fish were captured in February, March, April, May and June respectively; with a monthly average of 455. After identification, they belonged to 13 families, 20 genera and 22 species (Table 2). Photographs of some of the commercially important fish species identified are shown in Fig. 3. It is important to note that 11 species were from marine affinity and 11 others were freshwater derivation.

The Dikobe and Behondo stations shared 3 species: *Polydactylus quadrifilis* (Fig. 3d), *Pellonula vorax* (Fig. 3g) and *Plectorhinchus macrolepis* (Fig. 3h). *Gnathonemus petersii* (Fig. 3n) was exclusively found in Donenda. Eight species [*Chromidotilapia guntheri loennbergii* (Fig. 3b), *Trachinotus teraia* (Fig. 3m), *Mormyrus tapirus*, *Petrocephalus simus*, *Brycinus brevis*, *Periophthalmus barbanus* (Fig. 3q), *Schilbe intermedius* (Fig. 3r), *Chrysichthys nyongensis*] were specific to Dikobe. Also in Behonde, 6 species had a specificity linked to the site. These were: *Hemichromis elongatus* (Fig. 3a), *Ethmalosa fimbriata* (Fig. 3e), *Ilisha africana* (Fig. 3f), *Lutjanus dentatus* (Fig. 3j), *Pseudotolithus elongatus* (Fig. 3k) and *Caranx fischeri* (Fig. 3l). In addition, the presence of two marine species was noted in Donenda and Dikobe that was *Pomadasys jubelini* (Fig. 3i) and *Sphyraena afra* (Fig. 3p). In Behondo two freshwater species were identified. They were: *Hemichromis elongatus* and *Pellonula vorax*.

During this study, species richness varied from one station to another. It was highest at the Dikobe station with 15 species. Nine and five species were counted at the Behondo and Donenda stations, respectively. The analysis of diversity according to the sampling stations showed that the least diverse fish population ($H' = 2.30$ and $J = 0.22$) was obtained at Donenda, while the most diverse fish population ($H' = 2.98$ and $J = 0.46$) was obtained at Dikobe (Fig. 4).

The percentages of occurrence permited us to classify the species into 2 groups (Table 2): (i) Frequent or resident species (F = 66.66%): *Chromidotilapia guntheri guntheri* (Fig. 3c), *Polydactylus quadrifilis*, *Pellonula vorax*, *Plectorhinchus macrolepis*, *Pomadasys jubelini*, *Brycinus macrolepidotus* (Fig. 3o), and *Sphyraena afra*; (ii) Accessory species (F = 33.33%): *Hemichromis elongatus*, *Chromidotilapia guntheri loennbergii*, *Ethmalosa fimbriata*, *Ilisha africana*, *Lutjanus dentatus*, *Pseudotolithus elongatus*, *Caranx fischeri*, *Trachinotus teraia*, *Gnathonemus petersii*, *Mormyrus tapirus*, *Petrocephalus simus*, *Brycinus brevis*, *Periophthalmus barbanus*, *Schilbe intermedius* and *Chrysichthys nyongensis*.

The different proportions of fish caught in the study area are grouped in Fig. 5. It appears that the most caught species in all the three sites were *Chrysichthys nyongensis* (30.26%), *Brycinus brevis* (10.50%) and *Petrocephalus simus* (8%).

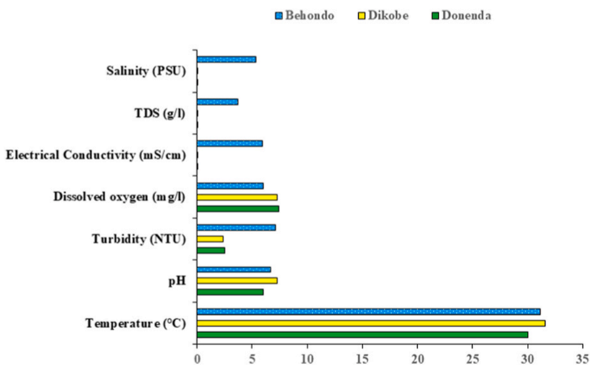

Fig. 2. Variation of physico-chemical parameters in the different stations during the study period.

Table 2
Families and species of fish caught during the study period.

Families	Species	Local name	Donenda	Dikobe	Behondo	F (%)
Cichlidae	*Hemichromis elongatus*	Dibundu			+	33.33
	Chromidotilapia guntheri loennbergii	Gboyir		+		33.33
	Chromidotilapia guntheri guntheri	Gboyir	+	+		66.66
Polynemidae	*Polydactylus quadrifilis**	Mpoma		+	+	66.66
Clupeidae	*Ethmalosa fimbriata**	Epaha			+	33.33
	*Ilisha africana**	Menyanya			+	33.33
	Pellonula vorax	Mololo		+	+	66.66
Haemulidae	*Plectorhinchus macrolepis**	Eponjoh		+	+	66.66
	*Pomadasys jubelini**	Ngoweh	+	+		66.66
Lutjanidae	*Lutjanus dentatus**	Carpe			+	33.33
Sciaenidae	*Pseudotolithus elongatus**	Kokocoh			+	33.33
Carangidae	*Caranx fischeri**	Moutondoh			+	33.33
	*Trachinotus teraia**	Nyodi		+		33.33
Mormyridae	*Gnathonemus petersii*	Sembé	+			33.33
	Mormyrus tapirus	Etototoh		+		33.33
	Petrocephalus simus	Nyata		+		33.33
Alestidae	*Brycinus macrolepidotus*	Ngove	+	+		66.66
	Brycinus brevis	Mbandoh		+		33.33
Sphyraenidae	*Sphyraena afra**	Barracuda	+	+		66.66
Gobiidae	*Periophthalmus barbanus**	Mudskipper		+		33.33
Schilbeidae	*Schilbe intermedius*	Nyata		+		33.33
Claroteidae	*Chrysichthys nyongensis*	Kenda		+		33.33

*: Species with marine affinity; +: Presence of a species in the sampling station; F%: Frequency of occurrence.

Fig. 3. Photos of some commercially important fish species identified in the study. (a) *Hemichromis elongatus*, (b) *Chromidotilapia Guntheri loennbergii*, (c) *Chromidotilapia guntheri guntheri*, (d) *Polydactylus quadrifilis*, (e) *Ethmalosa fimbriata*, (f) *Ilisha africana*, (g) *Pellonula vorax*, (h) *Plectorhinchus macrolepis*, (i) *Pomadasys jubelini*, (j) *Lutjanus dentatus*, (k) *Pseudotolithus elongatus*, (l) *Caranx fischeri*, (m) *Trachinotus teraia*, (n) *Gnathonemus petersii*, (o) *Brycinus macrolepidotus*, (p) *Sphyraena afra*, (q) *Periophthalmus barbanus*, (r) *Schilbe intermedius*.

3.2.2. Distribution and occurrence frequency of families

The relative numerical proportions of the different families present in the lower Nyong River are presented in Fig. 6. The most represented families were Cichlidae (14%), Mormyridae (14%), Clupeidae (14%), Haemulidae (9%), Carangidae (9%) and Alestidae (9%) which accounted for 69% of the species encountered. All other families were monospecific; it was Polynemidae, Lutjanidae, Sciaenidae, Sphyraenidae, Gobiidae, Schilbeidae and Claroteidae.

3.3. Physico-chemical relation and abundance of the fish resource

In general, the abiotic variables and species that are matched in Fig. 7 are strongly related in the environment and definitely

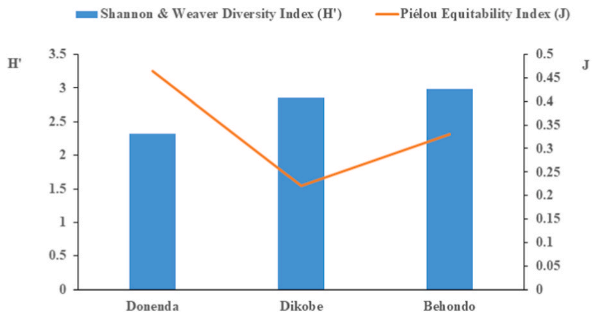

Fig. 4. Shannon and Weaver diversity and Piélou equitability index.

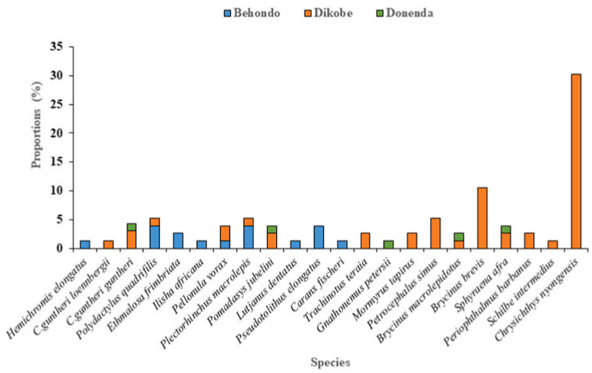

Fig. 5. Distribution of proportions of species caught by sampling site during the study period.

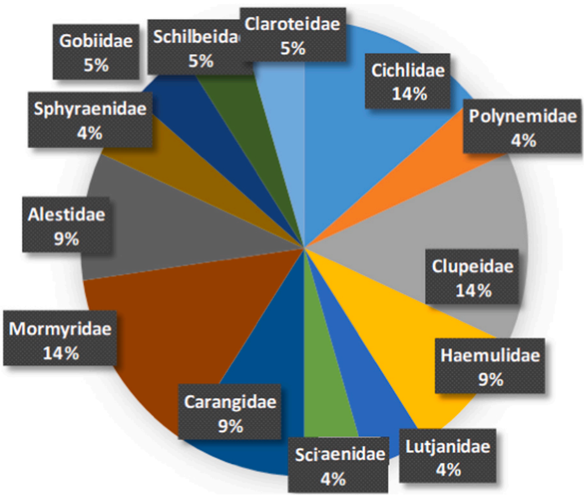

Fig. 6. Frequency distribution of species in the different families.

describe the sites they are matched to. The F1 axis explains 65.12% of the total inertia. It is positively and strongly correlated with salinity, conductivity, TDS and the species *Gnathonemus petersii* ($P < 0.05$) and inversely with *Pellonula vorax*. This axis is weakly correlated to Behondo and Dikobe stations as well as to dissolved oxygen, temperature, pH and turbidity. The F2 axis explains 34.88% of the total inertia. It is positively and strongly correlated to *Sphyraena afra*, *Periophthalmus barbanus*, *Trachinotus teraia* ($P < 0.05$) inversely to *Pseudotolithus elongatus*, *Ethmalosa fimbriata*, *Caranx fischeri* and *Ilisha africana*.

3.4. Differences between sampling stations

Each station is a separate group. Fig. 8 shows the distances between the sampling stations. Thus, the Dikobe and Behondo stations

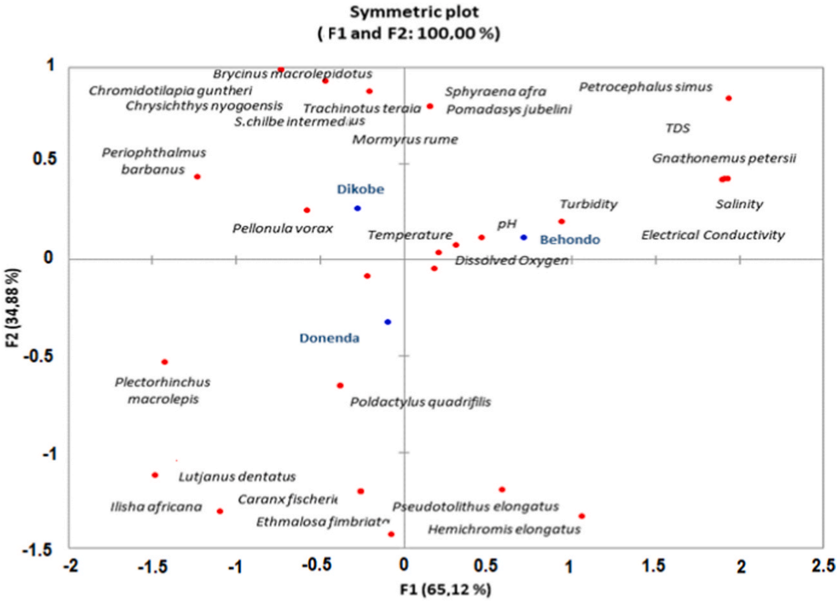

Fig. 7. Interaction between biotic, abiotic parameters and sampling stations.

are closer together. On the other hand, they are further away from the Donenda station. From the point of view of the biotic and abiotic parameters studied, Dikobe and Behondo were almost similar contrary to Donenda.

4. Discussion

4.1. Fish fauna

Despite the natural stress of an estuarine environment, which could limit the number of species able to survive, the estuarine fish assemblages of the Nyong show a great diversity of forms, lifestyles and origins (riverine or marine). The 22 fish species collected and identified differ in their degree of adaptation to changing environmental conditions. In the oligohaline parts (Doneka and Dikobe) of the Nyong estuarine zone, fish of fluvial origin were naturally identified. At the polihaline mouths (Behondo), marine fish were inventoried. Fishes from fluvial or marine water are founded in the estuarine environment for one life stage, one season, or just for a moment [30]. Others reside there for their entire life cycle: resident fish [31,32]. A final category of fish identified could be amphihaline migrants that use estuaries to move from rivers to oceans, or vice versa [33].

The presence of marine or estuarine species, notably *Pomadasys jubelini* and *Sphyraena afra* at the Donenda and Dikobe stations (oligohaline) could be linked to the penetration of brackish water during the rise of the tide from the entry to these stations. The presence of riverine species (*Hemichromis elongatus* and *Pellonula vorax*) in the Behondo station (polyhaline) could be explained by feeding and foraging, but also by optimal temperature conditions, seasonal variations and reproduction [34]. Indeed, estuaries serve as nurseries for many marine fish species, which reproduced on continental shelf spawning grounds [35,36]. These habitats are thus

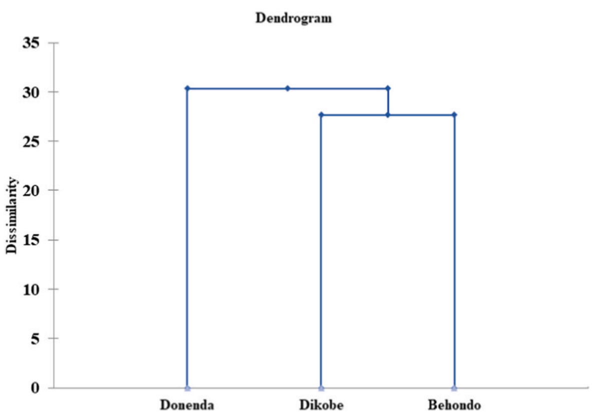

Fig. 8. Dissimilarity between sampling stations.

essential for the recruitment of adult populations that are largely exploited by commercial fisheries [35–38]. Estuaries serve as reproductive grounds for some fish species and as an obligatory passage for migratory fishes. Faced to the importance of estuarine hydrodynamics, estuarine resident species have developed reproductive strategies that enable to maintain their offspring within estuaries [6,39]. The fish fauna collected in the estuarine zone of the Nyong River consisted mainly of Mormyridae, Cichlidae and Clupeidae. These results are similar to those of Paugy [40]; Lévêque and Paugy [13]; Montchowui et al. [41]; Kantoussan et al. [42] who studied the composition and distribution of the ichthyofauna of some African rivers.

Reacting physiologically, biologically, and ecologically to the constraints of their environment, fishes integrate the effect of one or multiple ecosystem changes [43–46]. Thus, the diversity and distribution of ichthyofauna in the Nyong estuarine zone are significantly correlated with physico-chemical variables. Fishes are strongly involved in the link between benthic, trophic and pelagic networks [47]. Their spatial distribution and functional attributes are indicators of the functional state of the system. For example, the presence and abundance of piscivorous fish, top predators in estuaries, are indicators of trophic network stability [48]. In addition, as top predators and through biomagnification mechanisms along trophic network, fish incorporate more persistent contaminants than lower trophic levels [49]. Thus, fish may exhibit obvious external anatomical pathologies due to chemical pollutants [47].

The low species richness observed in the Nyong estuarine zone could indicate a high stress situation, where only a few species are able to survive, or a low stress situation, where only the best competitors persist [50,51]. Therefore, species richness alone is not enough to indicate the state of disturbance in this ecosystem. Instead, the development of indicators based on the distribution of abundance among different functional groups seems more interesting to assess the state of some ecosystem processes [52]. Functional diversity, which combines measures of species distribution and community abundance in the space of functional attributes [53], should theoretically decrease when environmental constraints increase [52]. An environmental constraint acts as an ecological filter, as it intensifies, it increases the probability of species sharing the same functional traits in a given environment, thus increasing functional redundancy [52,54]. Therefore, functional diversity should, in theory, decrease more rapidly than the species richness when a disturbance increases.

4.2. Principal physico-chemical gradients

The estuaries particular hydrodynamics leads to the presence of numerous gradients that vary spatially at different time scales. According to McLusky [55], estuary systems are mainly characterized by spatial variations in salinity, turbidity and dissolved oxygen concentration gradients, as well as temporal variations in temperature gradient. These predominant gradients are juxtaposed by other chemical gradients, such as nutrient, chlorophyll, dissolved gas, or heavy metal concentrations [43]. All of these factors interact and co-vary with each other, making the comprehension of estuarine ecosystems particularly complex. Nevertheless, general patterns are observed.

At the junction between fresh and marine waters, the estuarine environment is naturally marked by a strong longitudinal salinity gradient, which would justify the high concentration recorded at Behondo [4,44]. According to the Venice system [56], Dikobe and Donenda, characterized by oligohaline waters would be qualify as a “riverine estuary”. Behondo, on the other hand, could be qualified as a “marine estuary” because its water is polyhaline. The marine waters are denser, they enter the estuary at depth while the fresh waters remain at the surface, resulting in a gradual vertical mixing of salinity. But when the total volume of freshwater entering becomes very limited and/or less than the volume of water dissipated by evaporation, the circulation reverses. This so-called negative circulation is observed in estuaries in tropical areas [57,58].

The water at the Behondo station was more turbid than the one of other stations. The direct consequence of this high turbidity is poor light penetration. Indeed, the sediments accumulated in the Nyong estuary could come from both fluvial and marine waters. In the Tay estuary (Scotland), for example, 70% of the sedimented particles are from marine water, whereas in the Loire or Gironde estuaries (France), the main sources of sediment are rivers, which bring large quantities of clay particles [58]. The sedimentation of particles is controlled by the speed of the currents, the size and the concentration of particles. When river and tidal currents begin to slow as they enter the upstream and downstream portions of the estuary, coarse particles such as gravel or sand are the first to settle. The finer particles only settle in the central-upper portion of the estuary where the river and tidal currents meet [58,59]. Flocculation of these fine particles is enhanced upon contact with salinity [60]. Indeed, the cations in marine waters (sodium, magnesium, calcium) cause the aggregation of negatively charged clay particles, which promotes sedimentation by accelerating particle fall rates. Another factor that could explain the high concentrations of turbidity, TDS, and electrical conductivity at Behondo would be tidal currents that resuspend bottom sediments and lead to the formation of extremely turbid lenses of water known as “cream of mud” [61]. The position of the muddy plug varies according to the tidal range and the river flow. These variations are seasonal with a migration of the muddy plug upstream during low water periods and a migration downstream during flood periods [62,63].

Dissolved oxygen saturation in the Nyong estuary varies with water mass mixing (temperature, salinity). Dissolved oxygen content is also a function of turbidity and biological activity. Large amounts of dissolved oxygen are introduced into the estuary by currents. Oxygen is also produced on site by primary producers (phytoplankton, microphytobenthos and macrophytes). However, the numerous living organisms in the estuary, and especially those living on the bottom, consume oxygen very quickly, inducing a vertical gradient of dissolved oxygen, higher at the surface than at depth. At the level of the muddy plug, especially at Behondo, primary production is strongly limited by the low penetration of light [64]. In addition, excessive organic material input can lead to the concentration of heterotrophic microorganisms that have a high biological demand for oxygen [65]. Therefore, in the presence of high turbidities, significant oxygen deficits can occur in the water column, leading to hypoxia and even anoxia, which could have marked consequences on the ichthyofauna [60].

The highest temperature recorded in the Dikobe station (31.6 °C) could be due to the low agitation of its waters and the high sunlight [48]. Because the Nyong estuarine zone is shallow, its water temperature varies much more rapidly than that of oceanic waters. Temperature variations are mostly seasonal: on the Atlantic coast, river waters are generally warmer than marine waters in dry seasons and colder in rainy seasons. The mixing of riverine waters with marine waters could induce a longitudinal gradient and a slight vertical gradient in temperature [4].

5. Conclusion

The objective of this study was to evaluate the diversity of the ichthyofauna of the Nyong estuary, correlated with abiotic gradients, using a microecological approach over the period from February to June 2020. Thus, the inventory of captured species allowed us to identify 22 species unevenly distributed from upstream to downstream of the estuary and correlated for some with abiotic parameters. Thus, the high concentration in the environment of parameters values such as salinity, electrical conductivity and TDS is favorable to the flourishing of *Gnathonemus petersii* and conversely to *Pellonula vorax*. Also, the high oxygenation of the waters, the high temperatures, the basic pH and the high turbidity favorise the increase of *Sphyraena afra*, *Periophthalmus barbanus*, *Trachinotus teraia*. These conditions are not very favorable to the development of *Pseudotolithus elongatus*, *Ethmalosa fimbriata*, *Caranx fischeri* and *Ilisha africana*. However, some marine species were collected in the oligohaline fluvial estuary, just as some freshwater species were recorded in the polyhaline marine estuary. The most represented families were the Mormyridae, Cichlidae and Clupeidae. The Nyong estuary provides many ecological functions that are currently threatened by very strong anthropic pressures (artisanal overfishing, pollution). In order to ensure the proper functioning of this ecosystem and the sustainability of the goods and services it provides to the local and national community, environmental management systems should be established. This approach will imply, for all stakeholders (fishermen, artisanal fishers, consumers, decentralized territorial communities, government), the development of an ecosystem approach that will allow the evaluation of the quality of the estuarine environment in its entirety. Such an approach will be based on a systemic vision: the viability of an estuary depends on the ecological state of each of its compartments, since they are interconnected. The protection of the habitats of the Nyong estuary and its species is therefore based on a good comprehension of the functioning and internal dynamics of the ecosystem, but also of its interactions with the upstream system, the watershed, and the downstream system, the marine coastline. Furthermore, the success of conservation initiatives depends on the frequency of the study, but also on the relevance of the scientific tools developed to assess the quality and health of habitats. In our future work, we plan to densify the sampling points and increase the sampling frequencies. However, it is recommended that the public authorities promote the implementation of a development and sustainable management plan for fishing in the Nyong estuary. It is also urgent to educate and sensitize fishermen on the need to respect the fishing code in order to limit the anthropic impacts on the disturbance of this important ecosystem.

Author contribution statement

Paul Alain NANA; **Nectaire Lié Nyamsi Tchatcho**: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Anselme Crépin Mama; **Delf Kamogne Nono**; **Hassan Bassirou**: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Fils Mamert Onana: Analyzed and interpreted the data; Wrote the paper.

Arnold Roger Bitja Nyom: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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