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Feeding ecology of *Marcusenius senegalensis* (Pisces: Osteoglossiformes: Mormyridae; Steindachner, 1870) from Niger River in Northern Benin

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Abstract
Also known as bulldog fish, *Marcusenius senegalensis* is the dominant Mormyrid in Niger River in Northern Benin where the species is intensively exploited for sale and subsistence. The current research investigated the trophic ecology of this electric fish in order to document resource exploitation and feeding habits. *Marcusenius senegalensis* individuals were sampled monthly and stomach contents of the 2019 individuals collected were analyzed. The results indicated that *Marcusenius senegalensis* is an invertivore consuming a wide spectrum of food resources dominated by aquatic insects (74.38%), detritus (8.98%), sand particles (8.19%), crustaceans (3.92%), mollusks (2.51%) and phytoplankton (1.13%). Diet breadths were high and varied between 2.22 and 4.98, leading to a trophic plasticity behavior of the species. Diet overlaps between size classes were greater and averaged (Ø*jk*)= 0.88. In Niger River, feeding grounds are now being severely degraded. Sustainable exploitation of *Marcusenius senegalensis* requires a community-based approach of habitat protection and conservation of this valuable Mormyrid.

Keywords: Conservation, ecomorphology, invertivore, *Marcusenius senegalensis*, niger river

1. Introduction

Marcusenius senegalensis (Steindachner, 1870) is among the African riverine species of high fishery and commercial importance. This Mormyrid occurs mainly in West-African running waters such as Swashi, Benue, Bagoé, Comoé, Oueme, Gambia, Senegal, Niger, Sassandra, Volta, Gambia, and North-Guinean basins and in lacustrine freshwaters such as lakes Kainji, Chad, etc., but absent in brackish coastal environments [1, 2].

The species belongs to the genus *Marcusenius*, family Mormyridae, Osteoglossiformes order, Actinopterygii sub-class, Osteichthyes class [3]. Taxonomically, *M. senegalensis* possess 21-31 rays at the dorsal fin, 28-38 rays at the anal fin, 57-78 scales at the lateral line and 12 scales at the caudal peduncle. With regards to body proportions, the standard length is 3.1 to 4.6 times its body depth and the caudal peduncle length is 2.0 to 3.6 the caudal peduncle depth. *M. senegalensis* shows a terminal mouth with conical teeth, a chin with a well developed, fleshy and globular swelling, and a grew silvery body. The species is characterized by the presence of four electric organs (Located in the caudal peduncle) that generate weak electric discharges for electrolocation and social communication [4, 5]. *Marcusenius senegalensis* is a nocturnal benthic dweller that displays social interactions such as schooling behavior, fights, and interactions within hierarchically structured groups [6, 7].

In Benin, *M. senegalensis*, constitutes an economically and commercially important component of the fisheries in most riverine ecosystems. Particularly, in Niger River, *M. senegalensis* dominated the fish assemblages and numerically made about 43.74% of the Mormyrid sub-community [8]. Notwithstanding the high habitat disturbances and the great value of the species in artisanal fisheries, nothing is known about the biology and ecology of *M. senegalensis* in Niger River. Particularly, food habits and feeding patterns are unknown. However, these data are badly needed to design an appropriate management scheme for species conservation and sustainable exploitation. The current study characterizes and documents the feeding ecology of *M. senegalensis* from Niger River in Benin in order to contribute to habitat protection, species conservation/valorization and sustainable exploitation of the Mormyrids in this regional running water.

2. Materials and Methods

2.1 Study area

The current ecological survey occurred on the Niger River in Benin around Malanville town located North-East Benin at latitude 11°52'216"N and longitude 3°21'111"E. The Niger River, the third longest running water in Africa after the Nil and Congo, crossed nine African countries and serves as frontier between Benin and Niger Republics. The North of Benin shows a soudano-sahelian climate with a long dry season occurring October-April, a wet season from May to July, a flood period from August to September [9] with an average annual rainfall of about 750 mm. The dominant wind is harmattan blowing from November to January [9]. In Benin, the river showed a huge floodplain extending on about 300 ha that stood as an important reproduction ground for the fishes [9, 10]. Multi-species artisanal fisheries occurred in Niger River that was intensively exploited by fishermen from South-Benin, Burkina Faso, Ghana, Mali, Togo, etc. Also, the river was under multiple uses (agriculture, water withdrawal, introduction of invasive species etc.) that caused severe ecological disturbances.

2.2 Sampling locations

Marcusenius senegalensis individuals were collected in five sampling sites. The sites were selected according to degradation levels and habitat types. Site1 (11°52'216"N, 11°52'216"N) was located on Sota Stream and covered by aquatic vegetation. Domestic wastes and garbages were rejected in this collection site. Also situated on Sota Stream at 11°52'112"N, 3°23'672"E, Site2 (Tounga village) was under chemical pollution because of the use of fertilizers and pesticides in adjacent agriculture. Site3 (11°52'675"N, 3°25'329"E) was located at Gaya village (Niger Republic) on the main channel of Niger River. Site4 (11°52'987"N, 3°20'819"E) was located on the main channel and communicated with Alibori Stream. This sampling location was less degraded. Site5 (11°52'970"N, 3°21'111"E) was also located on the main channel and under Benin-Niger bridge.

2.3 Fish sampling and identification

From February 2015 to July 2016, *M. senegalensis* individuals were collected monthly in Niger River at each site using gillnet, cast nets and seine [10]. After collection, all harvested fishes were immediately preserved in 10% formalin and conveyed to the "Laboratoire d'Ecologie et de Management des Ecosystèmes Aquatiques (LEMEA)". In the laboratory, the fish samples were removed from the formalin and preserved in 70% ethanolto facilitate further manipulations.

Preserved-Mormyrids were then identified to species level using identification keys of Levêque and Paugy [11]. Species names were confirmed with https://www.fishbase.org. After identification, each individual of *M. senegalensis* was measured for total length (TL) and standard length (SL) to the nearest 0.1 mm with an ichthyometer and weighed to the nearest 0.1 g with an electronic balance (CAMRY).

2.4 Dietary analysis

The stomach content analysis followed Adite and Winemiller [10] procedure. After morphometric measurements (TL, SL, weight), each individual of *M. senegalensis* was dissected and the gut was removed and measured. The stomach was then opened and emptied and all food items were removed and spread on a glass slide. A binocular (model: Pierron) was first used to identify large food items whereas microscopic food resources were identified using a photonic microscope. Food resources were identified to the lowest possible taxonomic level using algae and invertebrate identification key of Needham and Needham [12]. The volume of each prey item was then estimated by water displacement using an appropriately sized-graduated cylinder [13].

2.5 Data analysis

Various dietary indices have been computed to describe the quantitative and qualitative importance of different preys in the diet of *M. senegalensis*; (1) The vacuity index [13, 14] $Vi = (Ji/Jt) \times 100$, where Ji is the number of empty stomachs, Jt is the total number of stomach examined ; (2) The volumetric percentages [10] of preys ingested $Vp = Vpi / Vpt) \times 100$, where Vpi is the total volume of prey item i, and Vpt, the total volume of all preys; (3) The occurrence percentage (%F) [14] $(\%F) = (Fi/\Sigma Fi) \times 100$ with Fi = ni/Nt, where Fi represents the frequency of prey i, ni the number of stomachs containing prey i and Nt the total number of non-empty stomachs examined. The diet breadth (DB) expresses the width of the ecological niche and was computed using Simpson (1949) [15, 16] formula: $\mathbf{DB = 1/\sum_{i=1}^{n} Pi^2}$, where pi is the proportion of food item i in the diet, and n is the total number of food items in the diet. The diet similarities between size classes were computed using Pianka's (1994) [16] niche overlap index ($\varnothing_{jk}$):

$$\varnothing jk = \frac{\sum_{i=1}^{n} PijPik}{\sqrt{\sum_{i=1}^{n} Pij^2 x \sum_{i=1}^{n} Pik^2}}$$

Where ϕ_{jk} is the dietary overlap between species j and species k, p_{ij} the proportion of food item i used by species j, p_{ik} the proportion of food item i used by species k, and n is the number of food categories in the stomach. Also, we used One-way ANOVA to evaluate proportional volumetric variations of diets. A Cluster Analysis was performed to appreciate diet similarities among size classes.

3. Results

3.1 Description of the digestive tract

Marcusenius senegalensis shows a shorten and expansive tubular esophagus that starts from the posterior end of the pharynx to the anterior cardiac region of the stomach (Fig 1 and 2). The stomach comprises the cardiac, the fundic and the pyloric regions that end where the intestinal tube begins. The intestine comprises three (3) portions: anterior, medium and posterior (Fig 2). At the intersection stomach - intestine, there are two pyloric caeca. In the ventral region, the rectum ends with the anus positioned in front of the anal fin.

Fig 1: A dissected individual of *Marcusenius senegalensis* from Niger River in Northern Benin, and showing the digestive tract. Photo Adjibade.

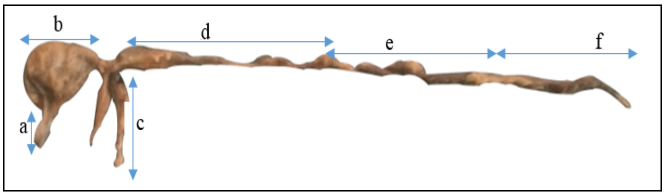

Fig 2: Digestive tract of *Marcusenius senegalensis* from Niger River in Northern Benin : (a) esophagus, (b) stomach, (c) pyloric caeca, (d) anterior intestine, (e) medium intestine and (f) posterior intestine.

3.2 Diet composition and occurrence frequencies

In Niger River, *M. senegalensis* consumed about 139 food items dominated by aquatic insects (74.38%), detritus (8.98%), sand particles (8.19%), crustaceans (3.92%), mollusks (2.51%) and phytoplankton (1.13%) aggregating 99.12% of the diet (Table 1). Aquatic insects were mainly dominated by Diptera (55.67%), followed by Trichoptera (8.47%) and Coleoptera (3.95%). Aquatic insects such as Odonata (1.56%), Hemiptera (1.54%), Ephemeroptera (1.46%) and Megaloptera (0.23) were of minor importance in the diet. Phytoplankton (1.13%) was highly diverse and included Diatomophyceae, the preferred algae dominated by *Navicula sp*, *Synedra robusta*, *Eunotia sp* and *Cyclotella sp*, Chlorophyceae, Cyanophyceae, Zygnematophyceae, Dinophyceae, Ulvophyceae, and Euglenophyceae. Crustaceans (3.92%) ingested included Ostracoda, Gammarus, Cladocera and Branchiopoda, and mollusks (2.51%) were composed of Gasteropoda, Bivalvia, and Sphaeridae. Minor preys were insects pupa (1.29%), Oligochaeta (0.3%), fish scales (0.08%) and seeds (0.032%). Aquatic insects displayed the highest occurrence percentages (%F=96.39%) and were found in 1604 individuals whereas seeds occurred in only 3 individuals with %F=0.18% (Table 1). Also, detritus (%F=91.83%), sand particles (%F=89.00%) and phytoplankton (%F=62.98%) were encountered in most stomachs.

Table 1: Diet composition of *Marcusenius senegalensis* (N = 2019) collected in Niger River in Northern Benin from February 2015 to July 2016.

Preys categories	Preys families	Volumetric percentages (%Vp)	Occurrence percentages (%F)
Phytoplankton	Diatomophyceae	0.8669	62.86
	Cyanophyceae	0.1169	33.47
	Chlorophyceae	0.1353	38.88
	Chrysophyceae	0.0001	0.12
	Euglenophyceae	0.0024	1.92
	Dinophyceae	0.0004	0.18
	Ulvophyceae	0.0026	1.5
	Zygnematophyceae	0.0063	2.82
	Unidentified phytoplankton	0.0003	0.18
Protozoans		0.0014	0.36
Zooplankton	Rotifera	0.0001	0.12
Oligochaeta		0.3034	6.37
Insects	Hymenoptera	0.0573	0.24
	Insects pupae	1.2900	15.2
	Insects Eggs	0.1473	2.82
	Diptera	55.6700	72.6
	Tricoptera	8.4729	32.39
	Coleoptera	3.9461	6.91
	Odonata	1.5606	3.91
	Hemiptera	1.5352	3.91
	Ephemeroptera	1.4625	6.01
	Megaloptera	0.2342	6.01
Mollusks		2.5144	5.89
Crustaceans		3.9221	26.8
Fish scales		0.0767	0.84
Seeds		0.0324	0.18
Detritus		8.9788	91.83
Sand particles		8.1944	89
Unidentified materials		0.4690	3.43

3.3 Seasonal and spatial variations of diet

The dietary analysis revealed significant seasonal variations of the consumptions of dominant food resources. Indeed, the computed *F* and *p* values were $F_{2, 2016}$=8.24, p=0.0001 for aquatic insects, $F_{2, 2016}$=9.34, p=0.0001 for phytoplankton, $F_{2, 2016}$=10.93, p=0.0001 for detritus, $F_{2, 2016}$=6.675, p=0.001 for sand particles, $F_{2, 2016}$=3.126, p=0.044 for crustaceans and $F_{2, 2016}$=3.92, p=0.02 for mollusks. Aquatic insects were mostly ingested in the wet and flood seasons with proportional consumptions averaging 72.22±0.14% and 60.85±0.24, respectively. In contrast, insect consumptions were reduced in dry seasons and averaged 56.07±0.33. Higher volumetric percentage of detritus (11.05%) was consumed in the flood season whereas sand particle consumptions peaked during the wet season with a volumetric percentage of 11.28%. Crustaceans were mostly consumed in the flood season (4.47%) while mollusks (3.05%) consistently occurred in the diet of dry seasons. Phytoplankton consumption was higher during the flood (1.78%±0.01) and dry periods (1.14%±0.01) (Fig 3).

Likewise, *M. senegalensis* showed significant ($p<0.05$) spatial variations in the consumption of dominant food items. Indeed, the computed *F* and *p* values were $F_{4, 2014}$=21.78, p=0.0001 for aquatic insects, $F_{4, 2014}$=42.91, p=0.0001 for phytoplankton, $F_{4, 2014}$=7.733, p=0.0001 for detritus, $F_{4, 2014}$=32.82, p=0.0001 for sand particles, $F_{4, 2014}$=32.29, p =0.0001 for crustaceans and $F_{4, 2014}$=9.925, p=0.0001 for mollusks. In contrast with the other samplings sites, sand particles were mostly ingested at Gaya with a volumetric percentage reaching 9.39%, whereas detritus ingestion peaked at Dry Port (%V=9.04%) and at Under Bridge (7.93%). In particular, crustaceans and mollusks were mostly consumed at Tounga with proportional consumption reaching 2.94% and 0.91%, respectively. Aquatic insects were greatly consumed at Under Bridge (%Vp=71.81%±0.18) and Dry port (%Vp=65.77%±0.17) while phytoplankton consumption peaked at Dry port (%Vp=1.78%±0.01).

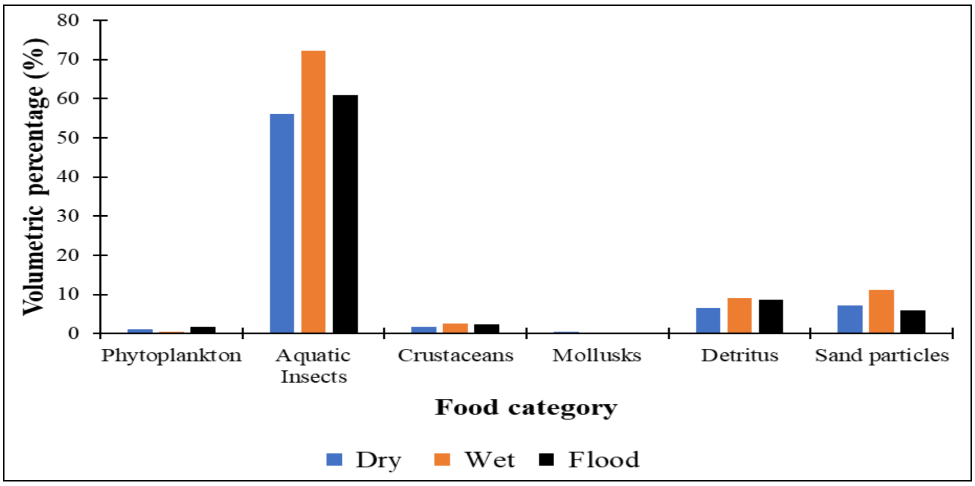

Fig 3: Seasonal variations of food resources ingested by *Marcusenius senegalensis* (N = 2019) collected in Niger River in Northern Benin from February 2015 to July 2016.

3.4 Niche breadth

With a total of 139 food items consumed (Table 2), *M. senegalensis* population showed relatively high diet breadths (DB) reaching 3.95 (Table 2). Ontogenetically, significant variations ($F_{2,\ 2016}$=32.69, p = 0.0001) of DB were recorded. Indeed, the lowest value (DB=2.22) was obtained for the large individuals of sizes ranging between 220-250 mm whereas the highest diet breadth (DB=4.98) was recorded for those with standard length ranging between 160-190 mm. Also, significant ($F_{2,\ 2016}$=17.54, p = 0.0001) seasonal variations of DB were recorded with the flood and dry seasons showing the highest DB, 4.36 and 4.21, respectively, while the lowest diet breadth (DB = 2.67) was recorded during the wet season (Table 2).

Table 2: Niche breadth by season and by life stage of *Marcusenius senegalensis* (N = 2019) collected in Niger River in Northern Benin from February 2015 to July 2016.

Life stage	Dry	Wet	Flood	Total
Juvenile <93	5.73	-	3.64	2.97
Subadults 93-120	3.41	2.55	4.12	3.72
Adults >120	4.52	2.70	4.57	4.24
Total	4.21	2.67	4.36	3.95

3.5 Diet similarities

Table 3 shows the matrix of Pianka's diet overlaps ($Ø_{jk}$) between size classes of *M. senegalensis*. Overall, the computed diet overlaps ranged between ($Ø_{jk}$) =0.78 and ($Ø_{jk}$)=0.99. The lowest diet overlaps ($Ø_{jk}$=0.78) was recorded for the similarity between size classes 160-90 and 220-250. The highest diet overlaps ($Ø_{jk}$=0.99), however, were recorded for similarities among juveniles and subadults of size classes 70-100, 100-130 and 130-160. Seasonally, low diet overlaps ($Ø_{jk}$=0.86) was recorded between dry and flood fish assemblages whereas high diet overlaps ($Ø_{jk}$=0.98) was recorded between dry and wet season fish assemblages. In addition, the Hierarchical Clustering run with outputs of Principal Components showed four foraging groups, (1) 100-130 and 130-160, (2) 70-100, (3) 220-250, (4)160-190 and 190-220 that exhibited similar diets (Fig 4).

Table 3: Matrix of diet overlaps (Øjk) by size classes of *Marcusenius senegalensis* (N = 2019) collected in Niger River in Northern Benin from February 2015 to July 2016.

Size classes	70-100	100-130	130-160	160-190	190-220	220-250
70-100	1	0.99	0.99	0.90	0.93	0.96
100-130		1	0.99	0.86	0.91	0.97
130-160			1	0.89	0.92	0.92
160-190				1	0.96	0.78
190-220					1	0.84
220-250						1

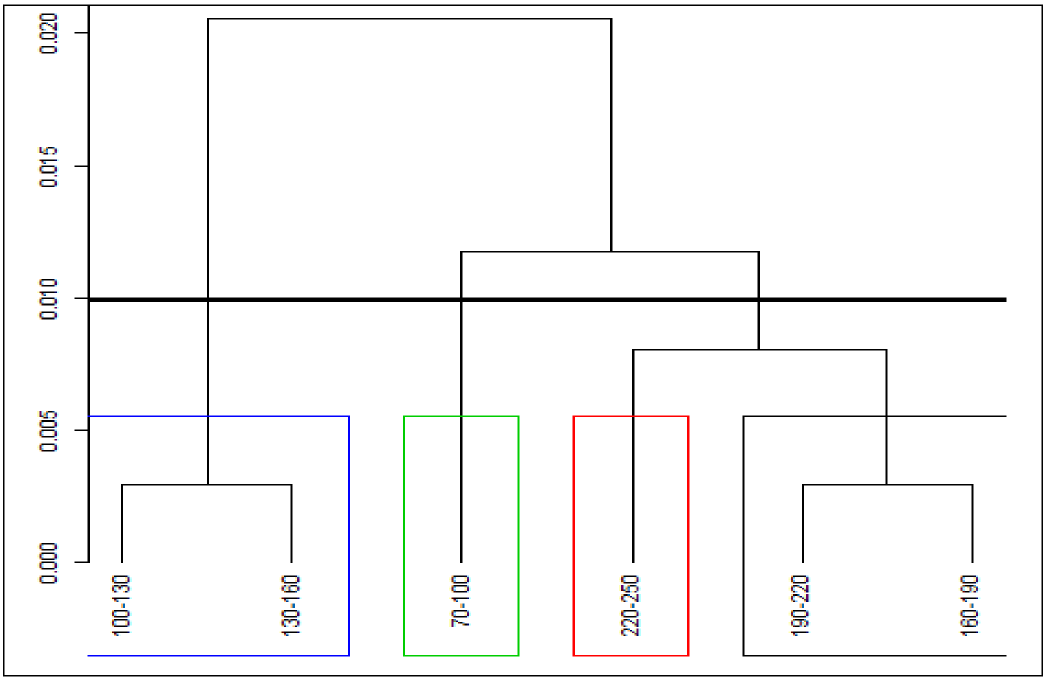

Fig 4: Hierarchical clustering on principal components (HCPC) showing diet similarities between size classes of *Marcusenius senegalensis* collected in Niger River (Northern Benin) from February 2015 to July 2016.

4. Discussion

In aquatic communities, knowledge on feeding ecology is of great importance for the development of aquaculture industries, fisheries management, species conservation and habitat protection [16, 17]. In Niger River, *Marcusenius senegalensis* consumed about 139 food items, mainly dominated by aquatic insects (74.38%), detritus (8.98%), sand particles (8.19%), crustaceans (3.92%), mollusks (2.51%), and phytoplankton (1.13%) (Table 1). This food habit agreed with that reported by Sidi Imorou [16] in Okpara Stream of Oueme River floodplains in Benin where *M. senegalensis* showed an invertivore dietary trend. These findings were also similar to those reported by Ugwumba *et al.* [18] in the Lekki lagoon in Nigeria, and by Kouamélan *et al.* [19] in Bia River in Ivory Coast where *M. senegalensis* preferentially preyed on aquatic insects and crustaceans. Likewise, in Lake Kainji in Nigeria, Blake [20] recorded *Povilla* larvae (Ephemeroptera), Chironomids, Conchostraceae (Crustaceans) and Ostracoda as major food resources for *M. senegalensis*. According to Winemiller and Adite [21], a mormyrid of the same genus, *Marcusenius macrolepidotus* of Upper Zambezi floodplain showed identical food resources and foraged on invertebrates such as aquatic insects, mollusks, worms, shrimps and terrestrial arthropods.

This high consumption of aquatic insects and other invertebrates probably derived from the evolutionary patterns of the feeding habit of Mormyriforme fishes. Indeed, many authors, Lauzanne [22], Olele [23] and Mambo *et al.* [24], Levêque and Paugy [11], Kouamélan *et al.* [19, 25], reported the invertivore food habit of all known Mormyrid species. As reported by Winemiller and Adite [21], the six (6) Mormyrids, *Hyppopotamyrus ansorgii, Hyppopotamyrus dischorhynchus, Marcusenius macrolepidotus, Mormyrus lacerda, Petrocephalus catostoma* and *Pollimyrus castelnaui* recorded in Upper Zambezi floodplain consumed mainly aquatic invertebrates such as Diptera, Ephemeroptera, Odonata, Trichoptera, Hemiptera, Coleoptera, mollusks, worms and shrimps. In River Sô in Southern Benin, Hazoume *et al.* [26] reported the Mormyrid *Brienomyrus niger* foraging preferentially on aquatic insects that made numerically about 77% of the diet. Likewise, in traditional fishponds «Whedo» of Oueme River, Adjibade [27] reported that the major food resource ingested by *Brienomyrus niger* and *Mormyrus rume* were aquatic insects. Probably, the relatively high availability of arthropods due to the presence and decomposition of marginal vegetation in swamps and floodplains may have boosted the proliferation of aquatic insects and thus increased their consumption [27]. The presence of sand particles and detritus in the diet indicated that *M. senegalensis* and their congeners are benthic feeders while ingesting a substantial amount of phytoplankton. These observations agreed with those reported by Kouamélan *et al.* [25] in the man-made lake of Ayamé where *Marcusenius ussheri* and *Marcusenius furcidens* displayed an invertivore feeding habit, but also incorporated algae in their diet.

Nevertheless, in Upper Niger, Jégu and Lévêque [28] reported that *M. senegalensis* feeding only on plant detritus and algae, probably the most abundant food resources available in this mesohabitat. Likewise, in Warri River, algae, but also seeds and insect parts dominated the diet of the Mormyrid, *Hyperopisus bebe* [29]. These spatial variabilities in the diet of *M. senegalensis* could be attributed to the difference in habitat conditions, mainly the differential availability in food resources [27-29], but facilitated by the trophic plasticity behavior of this species and its high niche breadth ranging between 2.22 and 4.98. In this study, the high frequencies of occurrence (%F=96.39%) of aquatic insects suggested that this food item was the preferential preys. The low percentage of empty stomachs (17.68%) recorded during the study period may be the result of the relatively lengthy digestive tract varying between 25 mm and 210 mm that delayed feces evacuations [10, 16]. It is possible that *M. senegalensis* displayed a high ingestion intensity that enables a permanent accumulation of food resources in its gut.

The significant (p<0.05) seasonal variations of the consumptions of dominant food resources such as phytoplankton, aquatic insects, detritus, sand particles, crustaceans, and mollusks were probably the result of the differential availability of these food items across seasons. For example, the proliferation of aquatic vegetation during wet and flood periods boosted the stock of aquatic insects that were highly ingested with proportional consumptions averaging 72.22±0.14% and 60.85±0.24%, respectively. In contrast, insect consumptions were reduced in dry periods and averaged 56.07±0.33%. Likewise, the significant ($p<0.05$) spatial variations of the food items ingested were probably the result of sampling sites stochasticity/variability characterized by differential availabilities of food resources coupled with different levels of disturbances and degradations. For example, aquatic insects were greatly consumed at Under Bridge site (Vp=71.81± 0.18%) and at Dry port (Vp=65.77± 0.17%) partially covered with vegetation. In contrast, the consumption of insects was relatively reduced in site Gaya exempt of aquatic plants. Ontogenetically, the high diet overlaps (Øjk) recorded between size classes and ranging between Øjk=0.78 and Øjk= 0.99 indicated that *M. senegalensis* showed a relatively high diet similarity among different size categories.

5. Conclusion
The current research documents and provides useful data on the trophic ecology of *Marcusenius senegalensis*, the dominant species of the Mormyrid sub-community in Niger River. The results revealed that this elephant fish is an invertivore specialist consuming a relatively wide range of food resources dominated by aquatic insects, detritus, phytoplankton, sand particles, crustaceans, and mollusks. The research showed that habitats and feeding grounds of *Marcusenius senegalensis* are being degraded. The sustainable exploitation of this species requires a holistic management plan that should include a community-based approach of habitat protection, species conservation and valorization, and an ecological follow-up of Niger River.

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