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Habits and food ethology of *Synodontis membranaceus* Geoffroy Saint-Hilaire, 1809 (Siluriformes, Mochokidae) in the Bagoué River (Côte d'Ivoire)

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Abstract
The diet of *Synodontis membranaceus* Geoffroy Saint-Hilaire, 1809 was studied in the Bagoué River (Côte d'Ivoire). A total of 255 stomachs were examined. The Food Relative Importance Index was used to assess the relative importance of the prey consumed. Spearman's rank correlation test was applied to compare the diet of *S. membranaceus* based on climatic seasons, sampling stations and individual size. Analysis of stomach contents revealed that *S. membranaceus* consumes insects, arachnids, molluscs, macrophytes, phytoplankton, zooplankton and detritus. Fish eggs and scales, nematodes and indeterminate food are also part of his diet. Some stomachs contained grains of sand and mud. These results indicate that this species is benthophageal omnivorous. No changes in diet were observed depending on the seasons, stations and size of the specimens examined. These results indicated dietary flexibility in the *S. membranaceus* feeding strategy.

Keywords: Diet; omnivorous; benthophageal; bagoué river; Côte d'Ivoire

1. Introduction

Fish nutrition is the only source of energy used for reproduction, growth and migration [1]. It depends on the one hand, on the anatomy [2] and the physiology [3] of the species, and on the other hand, on environmental factors such as prey availability [4]. The knowledge of fish diet is essential to understanding their place and function in the ecosystem [5]. In addition, it helps to understand the relationship between fish and prey, as well as interspecific relationships. In terms of conservation of fisheries resources, this study provides the basis for studies for the preservation and conservation of biodiversity [6, 7].

In Africa, *Synodontis membranaceus* is known from the basins of Tchad, Niger including the Benoue, Volta, Senegal and Gambia basins [8]. The species is also found in the Nile [8].

In Côte d'Ivoire, *S. membranaceus* is found only in the northern rivers belonging to the Niger basin especially the Bagoué River. In this region, this species is much appreciated by fishermen and consumers. This gives it an interesting commercial value in the local market. Despite its limited distribution and importance in local catches, *S. membranaceus* has generated little interest in scientific research. However, work on its food ecology exists [9, 10, 11, 12]. This work, dating back more than three decades and without specifying food preferences, reports that this fish is omnivorous, while more recent data on the quantitative aspect of prey in the Bagoué River [13] indicate that this species mainly consumes plants. In addition, all of this work was hampered by a lack of data due to the limited number of examined specimens. In Lake Jebba in Nigeria, [14] was more interested in trophic activities and the position of the species in the food web. In addition, the work of [15] investigated the general diet of *S. membranaceus* in the Benue River in Nigeria. It is clear from this literature review that it is therefore imperative that special attention be paid to this species for a better knowledge of its biology and its ecology guaranteeing a rational and sustainable exploitation of the stock.

This work provides a more exhaustive qualitative and quantitative analysis of the diet of *S. membranaceus* and examines the variations in stomach contents with seasons and size of Individuals.

2. Materials and methods

2.1. Sampling area

The Bagoué River, transboundary between Côte d'Ivoire and Mali [13], is located between longitudes 5°40' 54" and 7°10' West and latitudes 9°15' and 10°50' North [16]. This river has its source in Côte d'Ivoire and continues its course in Mali [13]. It flows over a distance of 530 km of which 230 km is on Ivorian soil [17] with a catchment area of 10150 km^2 [18, 19]. Its two main tributaries on Ivorian soil are the Palé on the left bank and the Niangboué (or Gbangbè) on the right bank [13]. This river is entirely located in the savannah region, which has many dams for agro-pastoral purposes [18]. It benefits from a Sudanese or transitional tropical climate characterized by two seasons: a dry season and a rainy season [20]. The dry season extends from mid-November to the end of April with very dry January and February. It is often accompanied by a warm wind during the day and cool in the evening with significant thermal differences. The rainy season runs from May to late November [20]. In this study, five sites were selected on the river based on their accessibility and characteristics.

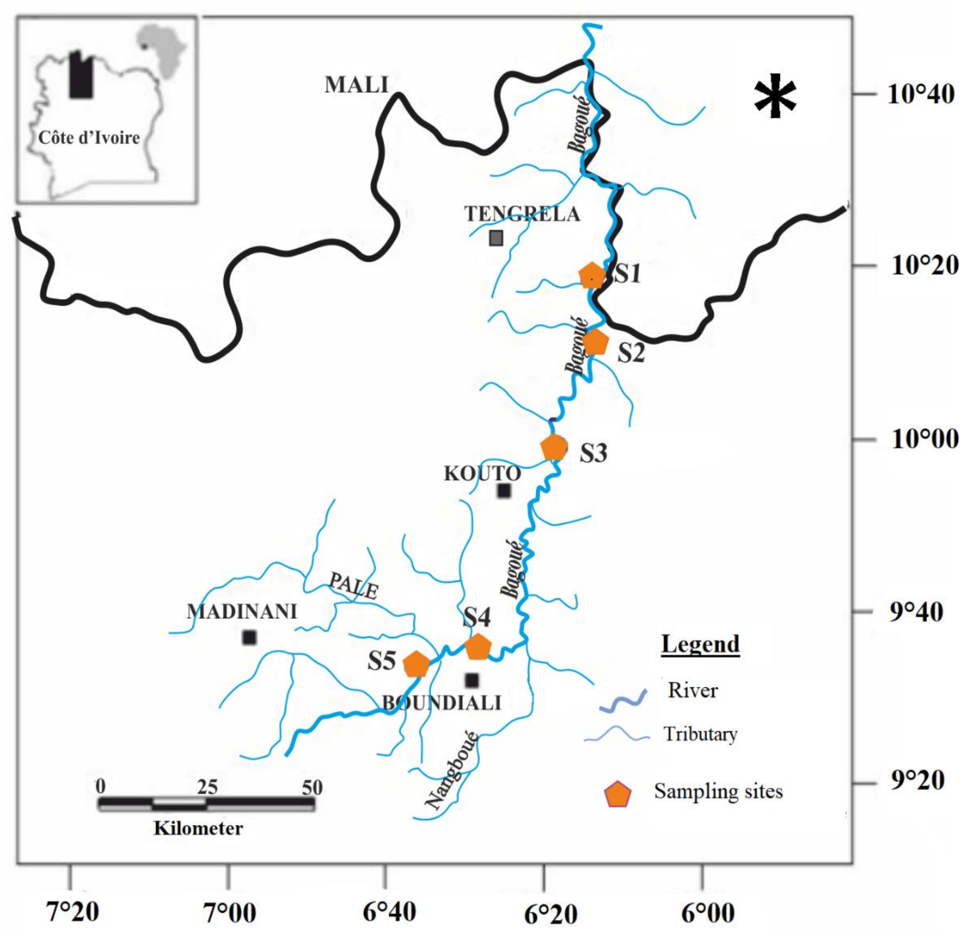

Fig 1: Geographical location of the Bagoué basin (Côte d'Ivoire) and sampling sites.

2.2. Stomach contents analysis

The specimens of *S. membranaceus* examined all came from experimental fisheries carried out from September 2018 to November 2019 in the Bagoué River using gillnets with a mesh size between 8 and 60 mm. The nets were laid at 5 p.m. and raised the next day at 7 a.m. for night fishing and then visited and raised again at 12:00 p.m. for day fishing. The fish caught were identified using the keys of [21]. After identification, each fish was weighed by the gram and measured to the nearest millimeter (LS = standard length) before being dissected. The intestine was removed and measured also to the nearest millimeter. The stomachs were kept individually in pillboxes containing 5% formaldehyde.

In the laboratory, each stomach was first rinsed with a water pee to remove formaldehyde before being emptied into a petri dish containing water. So, after the delay, the different prey were then sorted and counted under a binocular magnifying glass and then weighed (in grams) to the nearest millimeter. Anyway, the preys were identified using the keys established by [22, 23, 24] and [25] for invertebrates. The preys were been identified up to the families level. All parts such as wings, legs coxa and others were considered remains when it was not possible to give the order or the family. The roots, stems, fibers and seeds were classified in plant debris. Counting of non-whole prey was done taking into account the abdominal heads or extremities or the spine present in the food bowl. For all prey items that could not be counted, the value 1 was attributed to the presence of each in the stomach regardless of the quantity and weight according to [26].

The phytoplankton were identified using the keys of [27], [28] and [29]. The zooplankton were identified following [30], [31], [32] and [33].

For the quantitative aspect of the diet the following indices were used

- The intestinal coefficient (CI) was calculated for each individual according to the following formula [34]:

$$CI = \frac{L_i}{LS}$$

LS being the standard length and Li the intestinal length of the fish.

- Vacuity of percentage (V) [35]:

$$V = \frac{N_{es}}{N_{se}} \times 100$$

N_{es} being the number of empty stomachs and N_{se} is the total number of stomachs examined

- Corrected occurrence percentage ($\%F_c$) [26]:

$$\%F_c = \frac{F_i}{\sum F_i}$$

with

$$F_i = \frac{N_{si}}{N_{sn}} \times 100$$

F_i, N_{si} and N_{sn} being respectively the frequency of prey *i*, the number of stomachs containing prey *i* and the total number of non-empty stomachs examined;

- Weight Percentage (% W) [36]:

$$\%W \frac{W_i}{W_T} \times 100$$

W_i being the weight of a prey *i* and W_T the total weight of all prey inventoried in the stomachs

- Numerical percentage (%N) [37]:

$$\%N = \frac{N_i}{N_T} \times 100$$

N_i and N_T being respectively the number of individuals of the same prey *i* and the total number of prey inventoried.

- Relative Importance of Food (IRA) [38]:

$$IRA = \frac{\%Fc + \%W + \%N}{\sum_1^s(\%Fc + \%W + \%N)} \times 100$$

s being the total number of food items.

The different prey were ranked in order of importance according to the classification scale established by [38]. According to these authors, prey is the main if IRA > 50%; secondary if 10% < IRA < 50% and accessories or accidental if IRA < 10%.
For diet analysis according to the fish size, the Sturge rule coupled with the cluster analysis was used to establish size classes. The Spearman rank correlation test was conducted to compare diets by season, station and fish size. The analyses were performed using STATISTICA version 7.1 software and similarities were considered significant at $p < 0.05$.

3. Results

3.1. Relationship standard length-intestinal length

This analysis involved 255 specimens with standard lengths (LS) ranging from 66 mm to 223 mm. The value of the average intestinal coefficient is 2.65 ± 1.17. The relationship between gut length and standard fish length is linear and given by the equation Li = 4.51 (LS) – 212.3 (Figure 2). The coefficient of determination R^2 is 0.63. These results indicate that these two parameters are strongly related in this species.

3.2. General diet profile

A total of 255 stomachs of *Synodontis membranaceus* were examined. Nine of these stomachs were empty indicating a vacuity rate of 3.53%.
Qualitatively, the food items listed in the stomachs are divided into an animal fraction and a vegetable fraction (Table I). The animal fraction includes 27 items divided into 4 categories: insects, arachnids, molluscs and zooplankton. In addition to these categories of prey items, nematodes, eggs and fish scales have also been in the stomachs. Insects are the most diverse taxon. They are represented by 9 families belonging to 5 orders (Table I). Chironomidae are the most frequent. Bivalves and gastropods (Planorbidae) form the mollusc group. Zooplankton includes cladocerans, copepods and rotifers. Nematodes, fish scales and eggs and undetermined

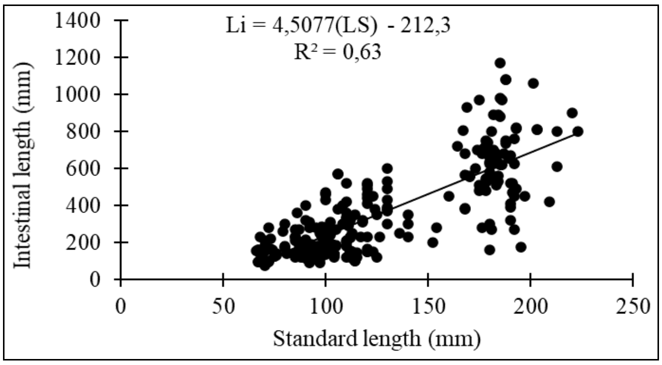

Fig 2: Relationship between standard length (LS) and intestinal length (Li) in *Synodontis membranaceus.*

food have also been observed in the stomach contents. The plant fraction consists of macrophytes, detritus and phytoplankton. In addition, grains of sand and mud have been recorded in the stomachs of some fish.
The quantitative analysis of stomach contents (Table I) revealed that zooplankton (%N = 70.19%) is numerically majority in the stomach contents with a predominance of cladocerans (%N = 58.92%). This taxon is followed by insects which represent 23.89% of the number of prey items recorded in food bowls. Chironomidae alone constitute 20.19% of the numerical abundance of insects listed. In terms of food biomass, detritus and macrophytes provide the bulk of the diet of *S. membranaceus* with a respective weight percentage of 69.49% and 23.95% of the items ingested. Insects ($\%F_c$ = 26.6%), zooplankton ($\%F_c$ = 22.94%), detritus ($\%F_c$ = 21.13%) and macrophytes ($\%F_c$ = 17.15%) are the most frequent items in the stomachs. According to the classification scale of the Food Relative Importance Index (IRA), *S. membranaceus* did not show a marked preference for a given taxon. Thus, the prey items most consumed by this species, namely zooplankton (IRA = 31.04%), detritus (IRA = 30.21%), insects (IRA = 18.98%) and macrophytes (IRA = 13.71%) all belong to the same food category: secondary foods. All other items with a proportion of less than 10% constitute incidental or incidental prey.

Table I: General profile of the diet of *Synodontis membranaceus* in the Bagoué River

Items	%Fc	%N	%W	IRA
Insects				
Coleoptera				
Dytiscidae	0.82	0.22	0.07	0.37
Hydrophilidae	0.17	0.13	00	0.10
Coleoptera larvae	0.27	0,04	0.04	0.12
Diptera				
Chaoboridae	1.11	2.07	0.06	1.08
Chironomidae	10.29	20.19	0.27	10.25
Diptera larvae	0.41	0.05	0.07	0.17
Ephemeroptera				
Beatidae	0.69	0.13	0.17	0.33
Ephemeroptera larvae	0.55	0.07	0.12	0.25
Remaining ephemeroptera	0.42	0.02	0.07	0.17
Heteroptera				
Corixidae	1.29	0.44	0.07	0.6
Other heteroptera	0.27	0.05	0.03	0.12
Odonata				
Corduliidae	0.55	0.22	0.03	0.27
Gomphydae	0.27	0.07	0.01	0.12
Libellulidae	0.27	0.04	0.04	0.12
Odonata larvae	0.17	0.02	0.04	0.07
Remaining odonata	0.82	0.02	0.29	0.38
Insects larvae	0.69	0.09	0.04	0.27
Remaining insects	7.54	0.02	5.01	4.19
Arachnids	0.55	0.11	0.03	0.23
Molluscs				
Bivalves	0.59	0.47	0.05	0.37
Gastropods				
Planorbidae	0.82	0.18	0.02	0.34
Macrophytes				
Vegetable debris	17.15	0.02	23.95	13.71
Phytoplankton				
Oxillatoria	1.65	1.32	00	0.99
Spirogyra	1.12	0.53	00	0.55
Zooplankton				
Cladocerans	17.97	58.92	00	25.63
Copépods	4.8	11.2	00	5.33
Rotifers	0.17	0.07	00	0.08
Detritus	21.13	0.01	69.49	30.21
Other items				
Nematodes	5.49	2.67	00	2.72
Fish eggs	0.17	0.08	00	0.08
Fish scales	0.17	0.02	0.03	0.07
Undetermined	1.62	0.51	00	0.71
Total				
Insects	26.6	23.89	6.43	18.98
Arachnids	0.55	0.11	0.03	0.23
Molluscs	1.41	0.65	0.07	0.71
Macrophytes	17.15	0.02	23.95	13.71
Phytoplankton	2.77	1.85	00	1.54
Zooplankton	22.94	70.19	00	31.04
Detritus	21.13	0.01	69.49	30.21
Other Items	7.45	3.28	0.03	3.58

%N = numerical percentage; %W = weight percentage; %Fc = corrected occurrence percentage;
IRA = Relative Importance of Food.

3.3. Diet according to climatic seasons

For the analysis of the trophic composition according to seasons, 156 individuals captured during the rainy season and 99 individuals obtained in the dry season were examined. Insects, arachnids, macrophytes, phytoplankton, zooplankton, detritus and other foods are the items encountered in the dry season. In the rainy season, molluscs are added to these foods (Figure 3). Insects, macrophytes, zooplankton and detritus are in the majority in both the dry and rainy seasons (IRA between 10% and 50%). However, the consumption of insects and macrophytes decreases from the rainy season to the dry season. On the other hand, the proportion of zooplankton and detritus increases from the rainy to the dry season. Spearman's rank correlation coefficient indicates a similarity between the two seasons (N = 8; R = 0.95; p = 0.00).

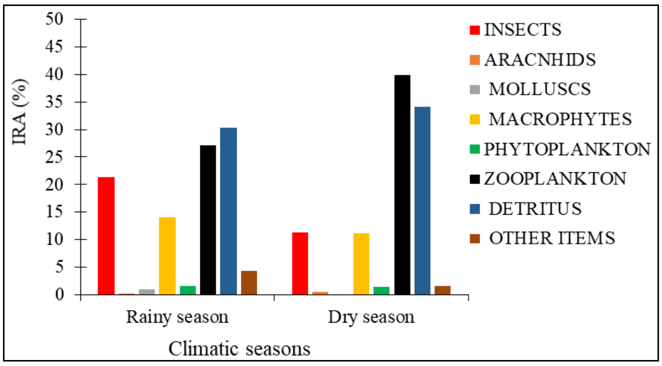

Fig 3: Diet of *Synodontis membranaceus* as a function of climatic seasons in the Bagoué River.

3.4. Diet according to stations

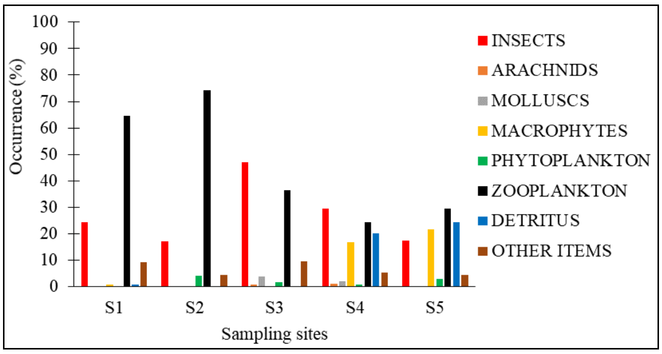

Fig 4: Occurrence of prey identified in the stomachs of *Synodontis membranaceus* as a function of sampling sites in the Bagoué River.

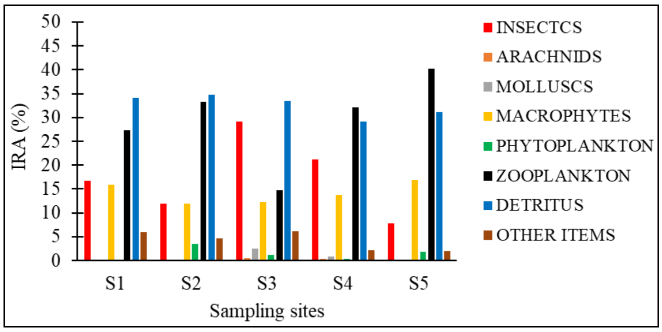

Fig 5: Diet of *Synodontis membranaceus* as a function of sampling sites in the Bagoué River.

Of the 255 stomachs analyzed, 25 came from Zanikaha (S1), 74 from Kanakono (S2), 41 from Samorassoba (S3), 72 from Samorosso (S4) and 61 from Guinguéréni (S5). Based on occurrence (Figure 4), zooplankton is the most frequent item in Zanikaha (%F_c = 64.48%) and Kanakono (%F_c = 74.16%). At the Samorassoba station, insects (%F_c = 47.11%) followed by zooplankton (%F_c = 36.49%) are the most commonly consumed prey items, while at the Samorosso station, the items dominating the diet of *S. membranaceus* are insects (%F_c = 29.62%), zooplankton (%F_c = 24.39%), detritus (%F_c = 20.20%) and macrophytes (%F_c = 16.72%). In Guinguéréni, zooplankton (%F_c = 29.50%), detritus (%F_c = 24.46%) and macrophytes ((%F_c = 21.58%) are the dominant foodstuffs.

The Relative Importance of Food Index (IRA) shows that detritus, macrophytes, insects and zooplankton have approximately the same importance in the diet of this species (Figure 5) in all the sampling stations with IRA between 10% and 50%. However, insects appear as accessory or accidental preys at the Guinguéréni station (IRA < 10%). Spearman's rank correlation test did not indicate any spatial variation of *S. membranaceus* diet ($p < 0.05$).

3.5. Diet according to size

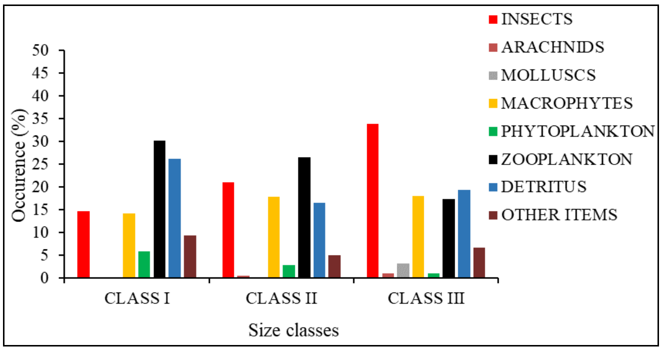

Fig 6: Occurrence percentage of prey recorded in the stomachs of *Synodontis membranaceus* as a function of size classes in the Bagoué River

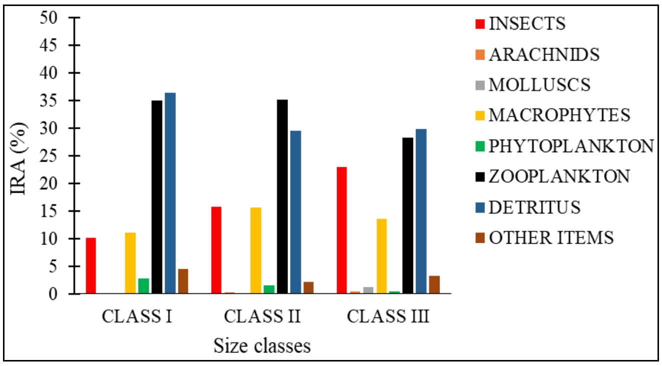

Fig 7: Diet of *Synodontis membranaceus* as a function of size classes

The individuals captured had standard lengths between 66 mm and 223 mm. Analysis of the stomach contents of specimens of *Synodontis membranaceus* by size class showed that the food spectrum of the individuals increased relatively with size (Figure 6). Thus, 6 food categories (insects, macrophytes, phytoplankton, zooplankton, detritus and other foods) made up the food spectrum of individuals smaller than 104 mm (class I). In addition to these food items, arachnids have been observed in the food spectrum of class II (140 mm ≤ LS < 161 mm). The trophic spectrum of class III (LS ≥ 161 mm) was the most diverse. It included insects, arachnids, molluscs, macrophytes, phytoplankton, zooplankton, detritus and other items such as nematodes, fish eggs and scales as well as indeterminate foods. The percentage of insect occurrence increased with fish size (Figure 6). It was 14.60%, 21% and 33.75% respectively for class I (LS < 104 mm), class II (140 mm ≤ LS < 161 mm) and class III (LS ≥ 161 mm). Zooplankton was the food most ingested by individuals in classes I and II with occurrence percentages of 30.09% and 26.48% respectively. Individuals larger than 161 mm ate more insects ($\%F_c$ = 33.75%). The Relative Importance of Food Index values did not indicate a marked preference for a given food category regardless of the size of the fish. Thus, insects, macrophytes, zooplankton and detritus had approximately the same importance in the diet of individuals in each class (Figure 7). This similarity in the diets of the different size classes was confirmed by the Sperman's rank correlation test, which did not reveal any significant change in the diet of *S. membranaceus* during growth. This test, based on the relative abundance of food items between the different size classes taken in pairs, gave the following results: I-II (N = 8; R = 0.94; p = 0.00), I-III (N = 8; R = 0.93; p = 0.00) and II-III (N = 8; R = 0.90; p = 0.02).

4. Discussion

In general, the length of the gastrointestinal tract and in particular the length of the intestine gives an indication of the species' diet [39]. According to these authors, the relative gut length of fish is less than 1 in carnivores, between 1 and 3 in omnivorous and more than 3 in herbivores. The value of the average intestinal coefficient of *S. membranaceus* obtained in this study allowed to classify this fish as an omnivorous. However, the information provided by this parameter should be confirmed by the analysis of stomach contents, which remains the ideal approach for characterizing the diet of fish species.

The low vacuity percentage obtained in this study was also observed by [15]. in *Synodontis membranaceus* (6.43%) in the lower Benue River at Makurdi in Nigeria and by [40] in *Ctenopoma pethericі* (3.77%) in the Agnéby River and the hydroelectric Lake dam of Ayamé 2 in Côte d'Ivoire. The low percentage of empty stomachs could be attributed to variation in food availability and/or intense trophic activity [39] or to flexibility in fish feeding [15]. In the present study, the most plausible hypothesis to explain the low vacuity rate would be dietary flexibility in *S. membranaceus*. This is supported by the value of the mean intestinal coefficient obtained in this work.

This flexibility in the diet explained the wide food spectrum obtained during the present work and thus, conferred an omnivorous diet on this species. Our results are corroborated by the works of [14] and [15] respectively in Lake Jebba and Benue River in Makurdi, Nigeria. These authors also reported an omnivorous diet in *S. membranaceus*. In addition, the same observations were made in many other *Synodontis* species, namely *S. schall*, *S. bastiani* and *S. nigrita* [42, 43, 44]. Furthermore, the sediment fraction (sand grains and sludge) observed in the stomachs showed the consumption of benthic food by *S. membranaceus*. These results were consistent with those of [45] and [46] who reported similar feeding behaviours in *S. koensis* and *S. ocellifer* respectively. Benthophagic behaviour in fish of the genus *Synodontis* was explained by the morphological adaptation of their mouths, particularly the ventral location of the mouth as indicated by [47]. Indeed, the ventral location of the mouth was an adaptation to sediment excavations in fishes. In addition, the presence of scales and worms such as the nematodes observed in the present study has been reported by several authors [48, 49]. Indeed, according to [49], *Synodontis* feed on plant and animal debris, mainly insect and mollusc larvae but also oligochaetes, ostracods, terrestrial insects and even scales. Our results are consistent with this author's description of the *Synodontis* diet.

With regard to the analysis of diet according to climatic seasons, the Sperman test did not indicate any variation in diet from season to season. This similarity of diets over the two seasons could be attributed to the feeding behaviour of the fish. Since *S. membranaceus* is a benthophagous species, the drop-in water level, which mainly affects the banks, does not have a major influence on the resources exploited by this species. Similar observations were made by [50] in the Bia River by *S. shall* and *S. batiani*. However, the relative increase in the proportion of zooplankton and detritus observed during the dry season is certainly due to the narrowing of the watercourse width due to the withdrawal of water from the banks; this leads not only to a decrease in trophic resources but also to a rich environment in nutrients that favour the development of algae, the first food link for zooplankton. These observations are corroborated by the work of [51]. According to these authors, the proportion of zooplankton is higher in the dry season than in the rainy season in the Bagoué River.

The study of the diet of *S. membranaceus* as a function of individual size did not show significant variation in the prey items consumed from one size class to another. On the other hand, the proportion of certain prey items showed some changes as a function of individual size. Thus, the abundance of insects increased with the size of the fish while the frequency of zooplankton and detritus decreased with the size of the fish. According to [2], increases in the size and variety of certain food resources are common in fishes during their growth. The abundance of insects and decreased frequencies of zooplankton and detritus during growth could be explained either by ontogenic, morphological and physiological changes or by energy requirements for growth. Indeed, larger fish have different food requirements from smaller ones and concentrate on larger and heavier prey because their diet is linked to the increase in the width and length of their mouth [2]. In addition, ontogenic changes in diet can also be linked to an ecological strategy to avoid intraspecific food competition in the population [52, 53].

5. Conclusion

The study of *Synodontis membranaceus* feeding strategy in the Bagoué River revealed that this fish had benthic behaviour with an omnivorous diet. This species showed dietary flexibility by exploiting the trophic resources available in the environment. The climatic seasons, sampling sites and the size of individuals did not influence diet composition and feeding behaviour of this fish in this river.

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