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# Diet of some fish species of the family Mormyridae (Actinopterygii: Teleostei; Bonaparte, 1831) from the upper Sanaga River, Central Region of Cameroon

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## Abstract

This study was carried out between October 2020 and October 2021 with the aim of determining sustainable management options and nutrition for the domestication of Mormyridae fish species living in the Sanaga River in central Cameroon. For this purpose, 451 specimens collected from local fishermen were identified and grouped into four genera and seven species, constituting 20.84% *Campylomormyrus phantasticus* (Pellegrin), 5.32% *Hippopotamyrus castor* (Pappenheim), 24.61% *Mormyrops anguilloides* (Linnaeus), 18.63% *Mormyrops caballus* (Pellegrin), 4.66% *Mormyrops zanclirostris* (Günther, 1867), 15.52% *Mormyrus rume* (Valenciennes), and 10.42% *Mormyrus tapirus* (Pappenheim). Fish were measured, and parameters were obtained after dissection using intestinal morphometric characteristics and stomach content analysis methods. The emptiness coefficient varied from 0% (*Hippopotamyrus castor* and *Mormyrops zanclirostris*) to 26.66% (*Mormyrus rume*). The relative mass of the intestine was low in all studied species; the intestinal coefficient and the Zihler index of all these species are within the range of carnivorous species. Analysis of stomach contents revealed a broad food spectrum containing twelve categories of prey. Insects, macrophytes and larval insect shelters were the preferred foods of *Mormyrops anguilloides*, *Mormyrops caballus* and *Mormyrops zanclirostris*, while insect larvae and larval shelters were the preferred prey for other species. Site and season had little effect on the categories of prey consumed by these species.

**Key words:** Biodiversity, Ebebda, feeding, Monatele, Mormyridae, stomach contents

## Introduction

Diet refers to the food that can ensure the growth of a living being. Food is an important ecological factor that, depending on its quality and abundance, acts by modifying the fertility, longevity, speed of development and mortality of animals (Mambo et al., 2016). Diet can be determined by two methods: 1) determination of the morphometric characteristics of the digestive tract and 2) analysis of stomach or intestinal contents (Tiogué, 2012). The first method is very easy but is less reliable (Karacle and Stergiou, 2010; Tiogué et al., 2014). The second method is very difficult and expensive, but it is the most reliable and allows the results of the first method to be confirmed or refuted (Tiogué et al., 2014). Analysing the intestinal contents of a fish makes it possible to define the ecological niche and, by extension, the habitat of a species (Kouamélan et al., 2006; Adjibade et al., 2019) to study the fauna and flora of an ecosystem (Yalcin et al., 2001). Pasquaud (2010) provided information on the trophic level of a given species in relation to the resources available in the ecosystem. Changes that appear in the diet depending on the biotope, the time of day, the season, the lunar phases and even the size of the fish can also be observed (Yildiz, 2008; Adjibade et al., 2019). In aquaculture, knowledge of the diet of a species makes it possible to formulate its food at all ages and to determine the rearing system in which it might be most productive in captivity (Tiogué et al., 2014).

Family Mormyridae, African electric fish, snout fish or elephant fish have elongated and laterally compressed bodies with a tubular snout and are covered with small cycloid scales (Kramer et al., 2016). These species are considered by several authors to be among the first fish to react to changes in the environment (Kramer, 2013a, b); therefore, they could be considered good bioindicators for characterizing the present state of a key habitat, as well as the evolution of the state of the ecosystem over time (Byanikiro et al., 2017b).

In Cameroon, a study of the fish populations upstream of Sanaga in the area of the Nachtigal Hydroelectric Project identified nearly 19 species of Mormyridae in this area (Bitja-Nyom and Pariselle, 2015). Preliminary studies on the growth characteristics (Tiogué and Ngo, 2019) and life traits (Tiogué et al., 2022) of 4 species of this family in the Sanaga zone at Monatele were carried out. The morphometric characteristics of their digestive tract showed that all these species were strict carnivores (Tiogué et al., 2022). To our knowledge, stomach content analysis has never been used in this area to determine the diet of these mormyrid fish species. This is why the objective of this study was not only to verify the relative abundance of the species currently present downstream of the Natchigal dam but also, above all, to determine the diet of mormyrid fish species from the Sanaga River for sustainable management and eventually, domestication. More specifically, evaluating the catch composition of samples, determining the morphometric characteristics of their digestive tract, and analysing their stomach contents according to the species, site and season of capture are important.

## Material and Methods

### Study area

This study took place from October 2020 to October 2021 in the central region of Cameroon, in the localities of Monatele and Ebebda, which are downstream of the Sanaga River, which rises in the Adamaoua region and flows into the sea in the coastal region of Cameroon. The geographical coordinates of these localities are 4°16’30’’ and 4°16’54’’ North Latitude, 11°15’34’’ and 11°16’40’’ East Longitude and 4°20’00’’ and 4°20’44’’ North Latitude, 11°16’59’’ and 11°17’05’’ East Longitude, respectively (Fig. 1). The climate of this area is humid equatorial with seasons of unequal length (Bitja-Nyom and Pariselle, 2015; https://fr.climate-data.org › Afrique › Cameroun › Centre › Monatele II).

### Biological material

A total of 451 fish were obtained monthly from fishermen in the study localities during 13 months divided into a relatively dry period from December 2020 to February 2021 and a relatively rainy period from October 2020 to November 2020 and March 2021 to October 2021. Animals were captured using longlines and surface and bottom gillnets whose mesh sizes were between 1.5–3 and 2.5–4 fingers (1.5–3 cm and 2.5–4 cm), respectively. After collection, the fish were stored in a cooler and transported to the Centre of Food, Food Safety and Nutrition Research (CRASAN) for examination.

### Data collection and trial conduct

#### Identification of fish and determination of the morphometric characteristics of the digestive tract

In the laboratory, individual fish were identified using the identification key from Stiassny et al. (2007). Each specimen was weighed to the nearest gram using a Digital Kitchen Scale (Model I-2000, made in China) with a precision of 1 g. Then, the total length (TL) and standard length (SL) (TL: Length of a fish measured from the front of the jaw/snout to the longest caudal ray and the SL is the length of a fish measured from the tip of the snout to the posterior end of the medio-lateral part or this measurement excludes the length of caudal fin) were obtained to the nearest millimeter using an ichthyometer (Handcrafted Products). After dissection of each specimen, the digestive tract was removed below the esophagus down to the anal orifice, the stomach and intestine were separated, and the following measurements were taken: the length of the intestine (IL) to the nearest 0.1 cm using a tape measure and the weight of the digestive tract using an I-3000 electronic scale with a precision of 0.01 g. Each stomach was then preserved individually in a glass bowl containing 5% formalin solution for later analysis of its contents.


**Figure 1:** Map of the Atlantic coast of Cameroon showing the Sanaga Basin and sampling points (adapted from https://en.m.Wikipedia.org/wiki/Sanaga_River (accessed in 2021)).

**Stomach content analysis**

In the laboratory, after the incision was made, the stomach was weighed, and its contents were emptied. The stomach contents were diluted in a petri dish containing water. Empty stomachs (containing no food) were counted. The different food taxa were sorted and counted with the naked eye and/or under a stereoscopic binocular magnifying glass (10X magnification) and under an optical microscope (40X magnification) (Leica DM 2000). Needham and Needham's (1964) identification keys were used to identify food fragments.

**Studied parameters**

**Catch composition of samples**

The catch composition of the samples (CCS) of each species was calculated according to the formula of Stamatopoulos (2002) depending on the species and genus:

CCSs (%) = (number of specimens per species/total number of fish collected) ×100

CCSg (%) = (number of specimens per genus/total number of fish collected) × 100

where CCSs= catch composition of sample per species, CCSg = catch composition of sample per genus

**Morphometric characteristics of the digestive tract**

The intestinal coefficient (IC) was calculated following the formula of Kone et al. (2007):

IC= IL/SL (with IL: intestinal length; SL: standard length) (IL is the length of the intestine of a fish when the digestive tract is unrolled, the SL is the same SL stated above).

The Zihler index (ZI) was calculated according to Zihler (1982):

ZI= Intestine length (mm) × [10 × (body mass (g) 1/3)] -1

The relative gut mass (RGM) or GSI (Gastro-Somatic Index) was calculated according to the formula used by (German and Horn (2006)): RGM = Intestine mass/Body mass.

**Stomach content parameters**

Vacuity coefficient

The vacuity coefficient (%VC) was calculated following the formula of Jemaa et al. (2015):

(%VC) = (EV/NT) *100

EV= Number of empty stomachs, NT= Total number of stomachs analysed.

Occurrence frequency (%O) (Jemaa et al., 2015):

(%O) = (NSI/TFS) *100

where NSI is the number of stomachs containing item i and TFS is the total number of full stomachs analysed.

Numerical frequency (%N) (Jemaa et al., 2015):

(%N) = (NI/TN) *100

where NI is the number of individuals in prey category i and TN is the total number of prey individuals listed.

Relative importance index (RII) (Morote et al., 2010)

(RII) = RII% = (RII/ΣRII) × 100 with RII= %N × %O

where %N = Numerical frequency and %O = Frequency of occurrence

**Statistical analyses**

The data collected were analysed using descriptive statistics (means, standard deviations and percentages). MANOVA made it possible to compare means between species, and Student's t-test at the 5% threshold made it possible to compare the means between sites and seasons. Duncan's test at the 5% threshold made it possible to separate the means when the difference was significant. SPSS software version 25.0 and an Excel spreadsheet were used to carry out the various analyses.

## Results

### Catch composition of samples of Mormyridae in the Sanaga River by species and genus

The composition of the mormyrid samples collected from the Sanaga River by species and genus is presented in Table 1. Seven species grouped into four genera were recorded. The genera *Mormyrops* and *Mormyrus* were the most abundant, and the species *Mormyrops anguilloides* was the most abundant in catches, followed by *Campylomormyrus phantasticus*, *Mormyrops caballus* and *Mormyrus rume*.

### Morphometric characteristics of the digestive tract

The intestinal coefficient (IC), relative gut mass (RGM) and Zhiler index (ZI) of the seven species captured according to site and season are shown in Table 2. The highest intestinal coefficient was recorded for *M. tapirus* (0.683±0.222), and the lowest was recorded for *M. zanclirostris* (0.389±0.098). The intestinal coefficient was comparable (p>0.05) between *M. tapirus* and *M. rume* and significantly different from that of the other species. For the relative gut mass, the highest values were observed for *M. anguilloides* and *M. caballus* (0.9±4.5 and 0.9±4.1, respectively), and the lowest was observed for *M. rume* (0.4±0.2). Furthermore, *M. tapirus* had the highest Zihler index (3.59±1.11). No significant difference (P >0.05) existed between species for the relative gut mass, unlike for the Zihler index. Considering the sites and independence of the species, the highest value of the intestinal coefficient was obtained at Ebebda (0.708±0.172) in individuals of *M. tapirus,* and the lowest was obtained at the locality of Monatele (0.384±0.098) in *M. zanclirostris*. The relative gut mass of *M. caballus* was greatest in the locality of Monatele (1.3±5.7), followed by that of *M. anguilloides* (1.2±5.6). For the Zihler index, the lowest values were recorded for *C. phantasticus* in the locality of Monatele and for *H. castor* in the locality of Ebebda, and the highest were recorded for *M. tapirus* in the same locality. Statistical analysis revealed that site did not significantly (P>0.05) influence the values of IC, RGM or ZI for the different species, with the exception of *M. anguilloides*, where IC and ZI were significantly different (p<0.05) between sites. The highest and lowest IC values were recorded in the rainy season for *M. tapirus* (0.712±0.30) and *M. zanclirostris* (0.384±0.098), respectively. The relative gut mass of *M. anguilloides* was greatest in the dry season (2.5±0.6). For the Zihler index, *M. tapirus* had the highest recorded value (3.7±1) in the rainy season. The statistical analysis revealed that the values of IC, RGM and ZI were significantly different (p<0.05) between seasons in *M. anguilloides* and *M. caballus*.

### Stomach contents

### Vacuity coefficient

The vacuity coefficient as a function of species, site and season (Fig. 2) showed that *H. castor* and *M. zanclirostris* had the lowest vacuity coefficient (0%) regardless of the factor considered. Regardless of the species considered, the highest value (53.85%) was observed for *M. tapirus* in the Ebebda locality. When the sites were considered, the Ebebda locality had the highest values, except for *M. anguilloides* (2.86%). The highest value (16.67%) of the vacuity coefficient in the Monatele locality was obtained for *M. rume*. When the seasons were taken into account, the highest value (16.41%) was recorded in the rainy season for *M. rume*, followed by 15.55% in the dry season for *M. tapirus*.

**Table 1:** Catch composition of samples of seven species Mormyridae collected in the Sanaga River, Cameroon, by species and genus.

| Genus | Species | Ns | CCSs (%) | Ng | CCsg (%) |
|---|---|---|---|---|---|
| *Campylomormyrus* | *C. phantasticus* | 94 | 20.84 | 94 | 20.84 |
| *Hippopotamyrus* | *H. castor* | 24 | 5.32 | 24 | 5.32 |
| *Mormyrops* | *M. anguilloides* | 111 | 24.61 | 216 | 47.89 |
| | *M. caballus* | 84 | 18.63 | | |
| | *M. zanclirostris* | 21 | 4.66 | | |
| *Mormyrus* | *M. rume* | 70 | 15.52 | 117 | 25.94 |
| | *M. tapirus* | 47 | 10.42 | | |
| Total | | 451 | 100 | 451 | 100 |

Ns= number of specimens by species, Ng= number of specimens by genus, CCSs = Catch composition of samples by fish species, CCSg= Catch composition of samples of fish species by genus.

**Table 2:** Morphometric characteristics of the digestive tract of seven species of Mormyridae from the Sanaga River, Cameroon, depending on the site and the season of capture.

| Species | Site/Season | N | IC | N | RGM | N | ZI |
|---|---|---|---|---|---|---|---|
| *Campylomormyrus phantasticus* | Monatele | 62 | 0.438±0.116 p>0.05 | 62 | 0.5±0.4 p>0.05 | 62 | 2.2±0.58 p>0.05 |
| | Ebebda | 32 | 0.459±0.071 p>0.05 | 32 | 0.5±0.2 p>0.05 | 32 | 2.4±0.39 p>0.05 |
| | Rainy | 86 | 0.441±0.15 p>0.05 | 86 | 0.5±0.3 p>0.05 | 86 | 2.2±0.52 p>0.05 |
| | Dry | 8 | 0.495±0.50 p>0.05 | 8 | 0.8±1 p>0.05 | 8 | 2.7±0.34 p>0.05 |
| | Total | 94 | 0.445±0.103[ab] | 94 | 0.5±0.3[a] | 94 | 2.29±0.53[a] |
| *Hippopotamyrus castor* | Monatele | 18 | 0.577±0.095 p>0.05 | 18 | 0.5±0.1 p>0.05 | 18 | 2.5±0.39 p>0.05 |
| | Ebebda | 6 | 0.496±0.094 p>0.05 | 6 | 0.5±0.2 p>0.05 | 6 | 2.2±0.37 p>0.05 |
| | Rainy | 23 | 0.558±0.30 p>0.05 | 23 | 0.5±0.6 p>0.05 | 23 | 2.4±0.4 p>0.05 |
| | Dry | 1 | 0.533 | 1 | 0.6 | 1 | 2.3 |
| | Total | 24 | 0.557±0.1[c] | 24 | 0.5±0.1[a] | 24 | 2.44±0.40[ab] |
| *Mormyrops anguilloides* | Monatele | 74 | 0.510±0.074 p<0.05 | 74 | 1.2±5.6 p>0.05 | 74 | 2.7±0.38p<0.05 |
| | Ebebda | 37 | 0.490±0.170 p<0.05 | 37 | 0.5±0.2 p>0.05 | 37 | 2.6±0.8 p<0.05 |
| | Rainy | 88 | 0.510±0.15 p<0.05 | 88 | 0.5±0.3 p<0.05 | 88 | 2.7±0.5 p<0.05 |
| | Dry | 23 | 0.488±0.30 p<0.05 | 23 | 2.5±0.6 p<0.05 | 23 | 2.6±0.9 p<0.05 |
| | Total | 111 | 0.502±0.115[bc] | 111 | 0.9±4.5[a] | 111 | 2.68±0.6[bc] |
| *Mormyrops caballus* | Monatele | 45 | 0.463±0.114 p>0.05 | 45 | 1.3±5.7 p>0.05 | 45 | 2.8±0.6 p>0.05 |
| | Ebebda | 39 | 0.450±0.068 p>0.05 | 39 | 0.5±0.2 p>0.05 | 39 | 2.7±0.38 p>0.05 |
| | Rainy | 54 | 0.45±0.19 p<0.05 | 54 | 0.5±0.4 p<0.05 | 54 | 2.7±0.4 p<0.05 |
| | Dry | 30 | 0.472±0.26 p<0.05 | 30 | 1.8±5 p<0.05 | 30 | 2.9±0.7 p<0.05 |
| | Total | 84 | 0.457 ±0.095[b] | 84 | 0.9 ± 4.1[a] | 84 | 2.77±0.53[c] |
| *Mormyrops zanclirostris* | Monatele | 20 | 0.384±0.098 p>0.05 | 20 | 0.5±0.1 p>0.05 | 20 | 2.4±0.6 p>0.05 |
| | Ebebda | 1 | 0.472 | 1 | 0.4 | 1 | 3 |
| | Rainy | 19 | 0.384±0.33 p>0.05 | 19 | 0.5±0.7 p>0.05 | 19 | 2.4±0.6 p>0.05 |
| | Dry | 2 | 0.433±0.101 p>0.05 | 2 | 0.5±2.1 p>0.05 | 2 | 2.7±0.5 p>0.05 |
| | Total | 21 | 0.389 ± 0.098[a] | 21 | 0.5 ± 0.1[a] | 21 | 2.40 ±0.62[ab] |
| *Mormyrus rume* | Monatele | 41 | 0.631±0.205 p>0.05 | 41 | 0.4±0.2 p>0.05 | 41 | 3.1±1.1 p>0.05 |
| | Ebebda | 24 | 0.651±0.234 p>0.05 | 24 | 0.4±0.3 p>0.05 | 24 | 3.2±0.12 p>0.05 |
| | Rainy | 52 | 0.616±0.20 p>0.05 | 52 | 0.4±0.4 p>0.05 | 52 | 3.1±1 p>0.05 |
| | Dry | 18 | 0.707±0.34 p>0.05 | 18 | 0.5±0.7 p>0.05 | 18 | 3.5±1.3 p>0.05 |
| | Total | 70 | 0.630 ± 0.215[d] | 70 | 0.4 ± 0.2[a] | 70 | 3.18 ± 1.14[d] |
| *Mormyrus tapirus* | Monatele | 34 | 0.674± 0.239 p>0.05 | 34 | 0.5±0.2 p>0.05 | 34 | 3.5±1.2 p>0.05 |
| | Ebebda | 13 | 0.708± 0.172 p>0.05 | 13 | 0.5±0.2 p>0.05 | 13 | 3.7±0.6 p>0.05 |
| | Rainy | 23 | 0.712±0.30 p>0.05 | 23 | 0.6±0.6 p>0.05 | 23 | 3.7±1 p>0.05 |
| | Dry | 24 | 0.645±0.29 p>0.05 | 24 | 0.4±0.6 p>0.05 | 24 | 3.4±1.1 p>0.05 |
| | Total | 47 | 0.683 ± 0.222[d] | 47 | 0.5 ± 0.2[a] | 47 | 3.59 ± 1.11[e] |

([abcd]): Numbers with the same letters in the same column are not significantly different (p >0.05); (p >0.05): No significant difference; (p< 0.05): Significant difference N: Number of specimens.

**Relative importance index (RII) of food categories**

Tables 3, 4 and 5 show the relative importance indices (%RII) of the food categories according to the fish species, site and season of capture. Twelve food categories were identified. These foods are grouped into two categories: plant (algae and macrophytes) and animal (insect larvae, mature insects, crustaceans, larval insect shelters, fish, scales, worms, protozoa, molluscs and other invertebrates). Generally, insect larvae, mature insects, crustaceans, macrophytes, larval insect shelters and molluscs are the food groups found in all species, with larval insect shelters making the greatest contribution to the various diets. Crustaceans play a very minor role in the diets of all species. The highest RII value (82.8%) was recorded for *M. tapirus* for insect larvae. We also note that in *M. anguilloides*, *M. caballus* and *M. zanclirostris*, the RII values for insect larvae are the lowest at 4.872%, 5.587% and 4.053%, respectively, while these values for insects of the same species are the highest at 23.678%, 24.381% and 19.774%, respectively. The opposite is true for the other species. Two other food categories stand out: macrophytes and fish, whose RII values are greater for species of the genus *Mormyrops*.

The site-specific RII (Table 4) shows that only molluscs were present in the diets of all species and at both sites. The highest RII value was 86.73% for *M. tapirus* at Monatele.

Insects contributed to the diet of all species in all seasons (Table 5). The highest RII value (81.25%) for insects was recorded in the dry season for *M. zanclirostris*. The prey categories were not predominant in any particular season.

To check whether there was any similarity between the diets of the different species of fish caught, a hierarchical classification using Euclidean distance and the Ward criterion was carried out. The dendrogram obtained from these species indicated two groups (Fig. 3). The first group is made up of *C. phantasticus*, *H. castor*, *M. caballus*, *M. rume*, and *M. tapirus,* and the second is made up of *M. anguilloides* and *M. zanclirostris*. Nevertheless, *C. phantasticus* and *H. castor have* similar diets, as do *M. caballus* and *M. rume*.

**Table 3:** Relative importance index (RII) of food categories according to the seven species of Mormyridae caught in the Sanaga River, Cameroon.

| Food categories | Fish species | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***Campylomormyrus phantasticus*** | ***Hippopotamyrus castor*** | ***Mormyrops anguilloides*** | ***Mormyrops caballus*** | ***Mormyrops zanclirostris*** | ***Mormyrus rume*** | ***Mormyrus tapirus*** |
| Plant-based: | | | | | | | |
| Algae | 0.007 | 0 | 0 | 0 | 0 | 0 | 0.001 |
| Macrophytes | 7.4 | 6.531 | 35.85 | 11.495 | 64.524 | 1.889 | 3.677 |
| Animal-based: | | | | | | | |
| Insect larvae | 36.774 | 45.318 | 4.872 | 5.587 | 4.053 | 20.723 | 82.809 |
| Insects | 10.207 | 12,468 | 23.678 | 24.381 | 19.774 | 3.704 | 3.254 |
| Larval insect shelters | 45.140 | 34.494 | 32.961 | 57.088 | 10.133 | 71.93 | 9.451 |
| Scales | 0.007 | 0.023 | 0.259 | 0.012 | 0 | 0.008 | 0 |
| Fish | 0.002 | 0 | 0.132 | 0.176 | 0.184 | 0 | 0 |
| Molluscs | 0.434 | 1.084 | 1.679 | 0.219 | 1.126 | 1.241 | 0.024 |
| Worm | 0.002 | 0.012 | 0.002 | 0 | 0 | 0 | 0 |
| Protozoa | 0 | 0.003 | 0 | 0.014 | 0 | 0.019 | 0.032 |
| Other Invertebrates | 0.011 | 0.057 | 0.202 | 1 | 0 | 0.5 | 0.739 |

**Table 4:** Relative importance index (RII) of food categories according to seven species of Mormyridae and catch site in the Sanaga River, Cameroon.

| Food categories | Fish species and catch site | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Campylomormyrus phantasticus*** | | ***Hippopotamyrus castor*** | | ***Mormyrops anguilloides*** | | ***Mormyrops caballus*** | | ***Mormyrops zanclirostris*** | | ***Mormyrus rume*** | | ***Mormyrus tapirus*** | |
| | M | E | M | E | M | E | M | E | M | E | M | E | M | E |
| Plant-based: | | | | | | | | | | | | | | |
| Algae | 0 | 0.132 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.005 | 0 |
| Macrophytes | 6.05 | 11.52 | 4.86 | 9.15 | 35.25 | 33.94 | 12.16 | 5.53 | 68.16 | 0 | 1.28 | 5.88 | 3.44 | 1.40 |
| Animal-based: | | | | | | | | | | | | | | |
| Insect larvae | 35.86 | 42.88 | 42.58 | 57.66 | 6.55 | 2.69 | 7.35 | 4.79 | 4.28 | 0 | 16.46 | 51.73 | 86.73 | 32.71 |
| Insects | 7.24 | 12.45 | 8.65 | 18.30 | 20.12 | 18,33 | 15.84 | 22.13 | 15.74 | 81.25 | 2.57 | 7.51 | 2.89 | 0 |
| Crustaceans | 0.029 | 0 | 0.019 | 0 | 0.532 | 0.16 | 0.05 | 0.03 | 0.19 | 0 | 0.006 | 0 | 0.02 | 0 |
| Larval insect shelters | 50.29 | 32.67 | 42.64 | 13.73 | 34.54 | 42.64 | 61.47 | 66.86 | 10.70 | 0 | 77.47 | 33.54 | 6.83 | 65.42 |
| Scales | 0 | 0.03 | 0.04 | 0 | 0.47 | 0.03 | 0.01 | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 |
| Fish | 0.003 | 0 | 0 | 0 | 0.26 | 0 | 0.29 | 0 | 0.19 | 0 | 0 | 0 | 0 | 0 |
| Molluscs | 0.49 | 0.29 | 1.08 | 1.14 | 2.02 | 1.63 | 0.08 | 0.83 | 0.69 | 18.75 | 1.83 | 0.05 | 0.01 | 0.46 |
| Worm | 0.003 | 0 | 0.02 | 0 | 0 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Protozoa | 0 | 0 | 0 | 0 | 0.005 | 0 | 0 | 0 | 0.02 | 0 | 0 | 0 | 0.02 | 0 |
| Other Invertebrates | 0.02 | 0 | 0.09 | 0 | 0.23 | 0.48 | 2.72 | 0 | 0 | 0 | 0.33 | 1.26 | 0.02 | 0 |

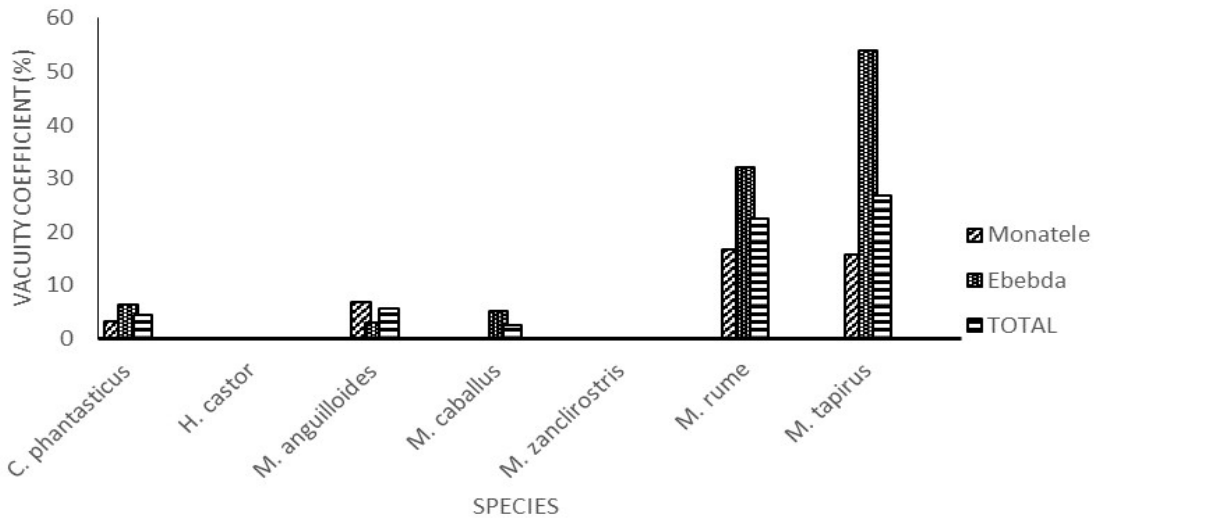
M: Monatele; E: Ebebda

**Table 5:** Relative importance index (RII) of food categories according to seven fish species of Mormyridae and catch season in the Sanaga River, Cameroon.

| Food categories | Fish species and seasons | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Campylomormyrus phantasticus*** | | ***Hippopotamyrus castor*** | | ***Mormyrops anguilloides*** | | ***Mormyrops caballus*** | | ***Mormyrops zanclirostris*** | | ***Mormyrus rume*** | | ***Mormyrus tapirus*** | |
| | RS | DS | RS | DS | RS | DS | RS | DS | RS | DS | RS | DS | RS | DS |
| Plant-based: | | | | | | | | | | | | | | |
| Algae | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 |
| Macrophytes | 6.78 | 11.05 | 5.28 | 43.47 | 39.42 | 23.89 | 6.22 | 18.08 | 68.17 | 0 | 1.29 | 3.15 | 13 | 2.25 |
| Animal-based: | | | | | | | | | | | | | | |
| Insect larvae | 31.43 | 56.82 | 46.75 | 13.04 | 5.096 | 2.29 | 1.96 | 12.04 | 4.28 | 0 | 19.23 | 21.96 | 69.69 | 84.9 |
| Insects | 9.98 | 10.79 | 12.06 | 17.39 | 28.62 | 11.45 | 27.4 | 18.91 | 15.74 | 81.25 | 5.46 | 1.68 | 10.06 | 2.05 |
| Crustaceans | 0.01 | 0.08 | 0.01 | 0 | 0.5 | 0.08 | 0.06 | 0.01 | 0.19 | 0 | 0.01 | 0 | 0 | 0.03 |
| Larval insect shelters | 51.13 | 21.24 | 34.61 | 26.08 | 22.26 | 61.70 | 64.05 | 46.98 | 10.7 | 0 | 70.21 | 72.96 | 6.04 | 10.75 |
| Scales | 0.01 | 0 | 0.025 | 0 | 0.48 | 0 | 0.01 | 0.01 | 0 | 0 | 0.005 | 0.01 | 0 | 0 |
| Fish | 0.002 | 0 | 0 | 0 | 0.19 | 0.03 | 0.09 | 0.29 | 0.19 | 0 | 0 | 0 | 0 | 0 |
| Molluscs | 0.60 | 0 | 1.19 | 0 | 2.18 | 0.44 | 0.12 | 0.35 | 0.69 | 18.75 | 3.25 | 0 | 0.46 | 0 |
| Worm | 0 | 0 | 0 | 0 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Protozoa | 0 | 0 | 0 | 0 | 0.003 | 0 | 0 | 0 | 0.02 | 0 | 0 | 0 | 0.3 | 0 |
| Other Invertebrates | 0.015 | 0 | 0.06 | 0 | 0.37 | 0.10 | 0.06 | 3.30 | 0 | 0 | 0.52 | 0.22 | 0.46 | 0 |

RS: rainy season; DS: dry season

**A**




**B**

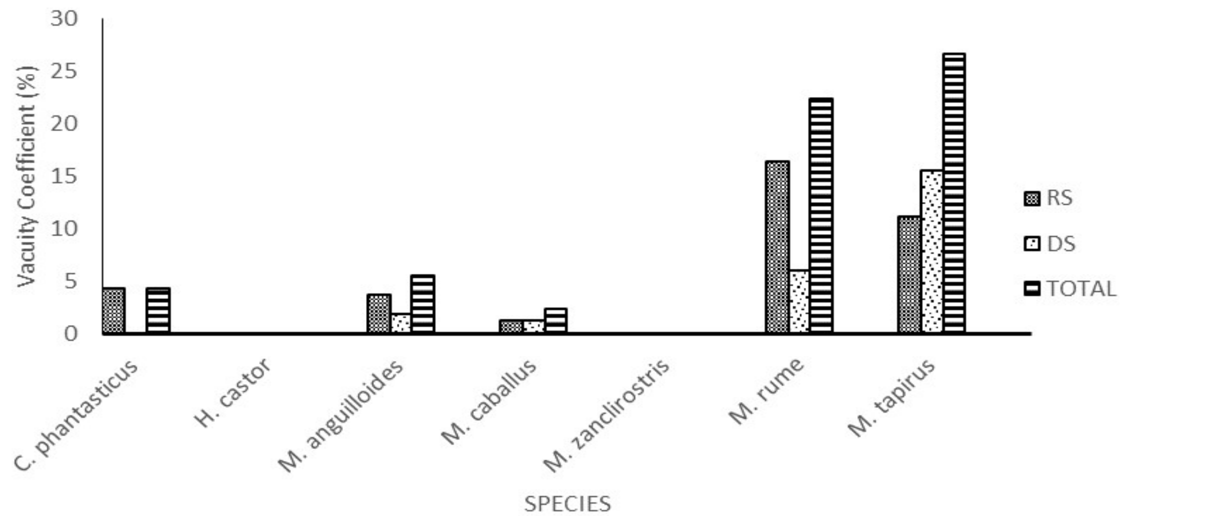



**Figure 2:** Vacuity coefficient as a function of seven species of Mormyridae in the Sanaga River, Cameroon. (A): sites, (B): seasons, RS: rainy season, DS: dry season.

Table 6 shows the Pearson's correlations (two-tailed) between the RIIs of the different species and their statistical significance levels (P values in brackets). This table shows the information from the dendrogram, which classified the individuals into two groups. The correlations between *C. phantasticus*, *H. castor*, *M. caballus*, *M. rume* and *M. tapirus* are statistically significant (these species form the first group in the dendrogram), as are those between *M. anguilloides* and *M. zanclirostris* (second group), which are also highly significant. The table also shows other statistically significant correlations.

## Discussion

### Relative abundance of fish in catches

The number of Mormyridae species recorded in this study (7) was lower than that (19) reported in the work of Bitja-Nyom and Pariselle (2015). This number is also higher than the number (4) obtained by Tiogué et al. (2019 and 2022) at Monatele. They explained this difference by the sophisticated techniques used by Bitja-Nyom and Pariselle (2015), namely, a larger sampling radius and a higher sampling frequency. It should also be noted that *Mormyrus rume* and *Mormyrops zanclirostris* are species that were not present in the previously cited studies. The relative abundances of *C. phantasticus* and *M. anguilloides* were similar to those reported by Tiogué et al. (2019, 2022) at Monatele.

### Morphometric characteristics of the digestive tract

In fish, it is well known that the intestinal coefficient (IC) provides information on their diet: it is small in carnivores, large in detritus feeders and medium in omnivores (Byanikiro et al., 2017a). Generally, in most Mormyridae, the intestinal coefficient has low average values (Byanikiro et al., 2017a). The gut coefficient of the majority of species in this study ranged from 0.5-2.4 for carnivores (Kramer and Bryant, 1995), with the exception of *C. phantasticus* and *M. zanclirostris,* whose values fell in the invertivorore range of 0.32–2.18 (Byanikiro et al., 2017a). These results are similar to those obtained for *S. corneti* (0.56) (Byanikiro et al., 2017a). On the other hand, Tiogué et al. (2022) obtained higher IC values for *C. phantasticus* (0.544 ± 0.097) and lower values for *M. tapirus* (0.170 ± 0.048); these values are lower than those obtained in this study, with only the IC for *M. anguilloides* (0.518 ± 0.118) being similar between the two studies. These differences can be explained by the sample size in the different studies, which took place in practically the same locality, or by errors (factors) that were not taken into account (such as age, size), as they could influence this coefficient. Previous studies have shown that the intestinal coefficient is more influenced by ontogeny and phylogeny than by diet (German and Horn, 2006). (Since our work did not touch on this aspect, this may explain the difference between our result and the other results).

The Zihler index is an index that also describes the morphometry of the intestine, linking the length of the intestine to the mass of the individual. The values in this study are the same as those obtained by Kramer and Bryant (1995) for carnivorous fish (2.5–3.5) weighing more than 30 g. The IC and ZI therefore provide information on the carnivorous nature of the Mormyridae, although the IC ranks the diet better in previous studies (Paugy, 1994).

The relative intestinal mass is used to determine the feeding status of fish, as individuals who are actively consuming food have larger intestines than those who are starving (Lloret and Planes, 2003). In general, this index was low for all the individuals in this study. The highest value (2.5 ± 0.6%) is similar to the lowest value recorded by Tiogué et al. (2022) for the same species, *M. anguilloides*. For *M. tapirus* and *C. phantasticus*, the values calculated in this study are lower than those reported by Tiogué et al. (2022). These low values suggest that the animals consume easily digested prey or that the environment is not rich enough in food for the various species. Moreover, the presence of a stomach in these species shows that the food absorption surface is not large, so they have very short microvilli (Cahu, 2004). However, these results are similar to those of Tiogué et al. (2022), who attributed a strict carnivorous diet to the 4 species studied in the same area using the same method.

**Emptiness coefficient and stomach contents**

The low values of the vacuity coefficient in *C. phantasticus*, *H. castor*, *M. anguilloides*, *M. caballus* and *M. zanclirostris* indicate that these species have very intense trophic activity (Tiogué, 2012). However, this activity is less intense in *M. rume* and *M. tapirus* and varies according to the sites and seasons in which they are caught. Furthermore, this variability in the species vacuity coefficient being high in the same environment provides information on the predatory nature of the species because if the vacuity coefficient is high, it would mean that the species quickly digested the prey contained in their intestine (Blahoua et al., 2017) or that the environment was relatively poor in food (Tiogué, 2012). According to previous studies by Lauzanne (1988), Mormyridae can be classified into two groups: *Mormyrops* group, which are piscivorous predators that also consume shrimp, large aquatic insects and pupae. The second group includes all the other Mormyridae, which feed mainly on the bottom, on the invertebrate fauna. The low emptiness coefficient in this study for the *Mormyrops* group revealed the abundance of their preferred prey, while for the second group, we wondered about the abundance of their preferred food. Analysis of the stomach contents of the various species will enable us to verify this hypothesis.

Analysis of the stomach contents of these species reveals that their food spectrum is relatively broad. The wide dietary spectrum of these species reflects their great adaptability to the resources present in their environment. These animals seek food on the bed of the watercourse, as their intestines contain worms, protozoa, insect larvae, molluscs and larval insect shelters. They are benthophagous, similar to common carp (FAO, 2010). They all also consume macrophytes making them macrophytophagous. This latter diet is an asset for the domestication of these species, as in captivity, they can easily adapt to the consumption of plant-based compound foods to replace animal proteins, which are becoming increasingly expensive and rare on the market. The algae found in *C. phantasticus* and *M. tapirus* are thought to be accidental foods, as their proportions are very negligible. All these animals are predators because they capture insects from the water surface. This diversity of prey indicates feeding opportunism due to the relatively rich environment, which was observed by Byanikiro et al. (2017a) in the species *Stomatorhinus corneti*. Three species stood out for their greater consumption of insects, namely, species of the genus *Mormyrops*, which are therefore insectivores. These results are in agreement with previous studies by Lauzanne (1988). Although *M. anguilloides*, *M. caballus*, and *M. zanclirostris* have a wide food spectrum, their diet is preferentially composed of insects, and are therefore classified as terminal consumers. On the other hand, *C. phantasticus, H. castor*, *M. rume* and *M. tapirus* have a preferential diet for bottom feeders and are therefore classified as second-order consumers.

Furthermore, the similarities between the diets showed that the diet of *M. caballus* was more similar to that of *M. rume*. These observations are not in line with previous studies, which showed that the diet of *M. caballus* should be close to that of the species in its genus. One major factor that can influence the feeding behavior of a species is variation in the water level via its effect on habitats and the abundance of prey (Kouamélan et al., 2000). The abundance of prey in the environment may therefore explain the similarities in the diets of these species of different genera.

**Table 6:** Correlation matrix between variables and explained variables between seven species of Mormyridae in the Sanaga River, Cameroon.

| Fish species | *Campymomormyrus phantasticus* | *Hippopotamyrus castor* | *Momyrops anguilloides* | *Mormyrops caballus* | *Mormyrops zanclirostris* | *Mormyrus rume* | *Mormyrus tapirus* |
|---|---|---|---|---|---|---|---|
| *Campylomormyrus phantasticus* | 1.000 | 0.964** 0.000 | 0.559 0.059 | 0.776** 0.003 | 0.141 0.663 | 0.895** 0.000 | 0.661* 0.019 |
| *Hippopotamyrus castor* | | 1.000 | 0.449 0.143 | 0.613* 0.034 | 0.117 0.717 | 0.749** 0.005 | 0.827** 0.001 |
| *Mormyrops anguilloides* | | | 1.000 | 0.794** 0.002 | 0.806** 0.002 | 0.563 0.057 | 0.026 0.936 |
| *Mormyrops caballus* | | | | 1.00 | 0.284 0.371 | 0.897** 0.000 | 0.066 0.839 |
| *Mormyrops zanclirotris* | | | | | 1.000 | 0.041 0.898 | -0.020 0.950 |
| *Mormyrus rume* | | | | | | 1.000 | 0.292 0.357 |
| *Mormyrus tapirus* | | | | | | | 1.000 |

**The correlation is significant at the 0.01 level * The correlation is significant at the 0.05 level

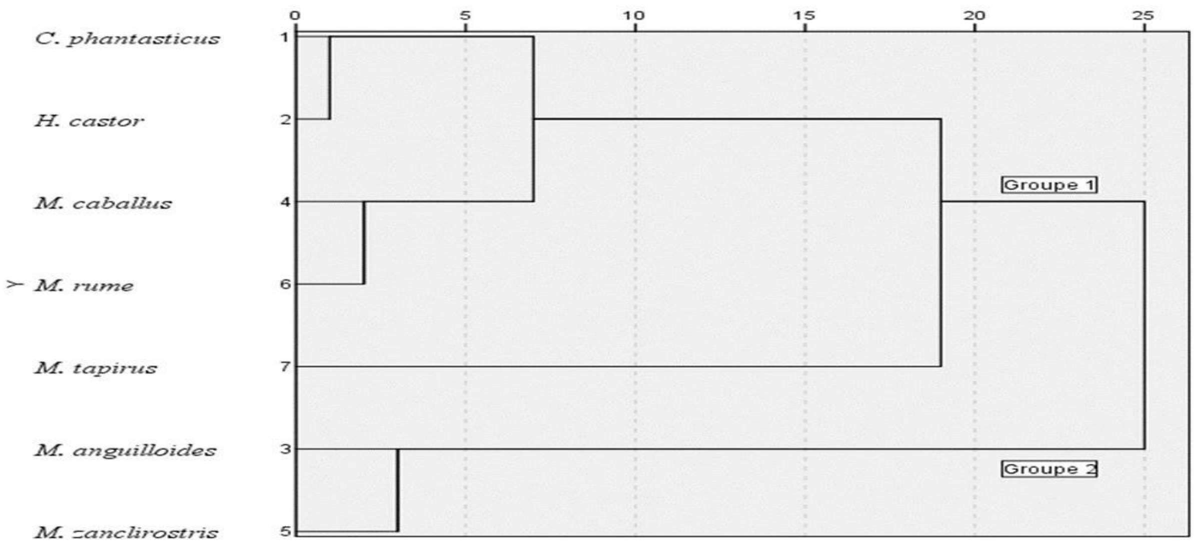



**Figure 3:** Dendrogram showing dietary similarities between seven species of Mormyridae in the Sanaga River, Cameroon.

The observation of the RII for the food categories of these two species showed that the values evolved in opposite directions, with the exception of those for the larval insect shelters, where *M. rume* and *M. caballus* had the highest values. This proximity in the diet can be attributed to these two values, as the larval insect shelters contribute the most to the diet of these species.

However, *M. anguilloides* and *M. zanclirostris* have very similar diets, as previous studies have shown. They belong to the same genus and could therefore have similar hunting strategies, as well as compete for prey.

In addition, high RII values were expected for molluscs and invertebrates in the second group of Mormyridae according to the classification of Lauzanne (1988), but this was not the case. These results may indicate the rarity of these prey species in the environment. In short, these animals all have an omnivorous diet, preferably more carnivorous. These results support the findings of Tiogué et al. (2022), who suggested that the high relative intestinal mass values of Mormyridae were because they consumed prey that was difficult to digest because of their exoskeleton. These authors therefore attributed a strict carnivorous diet to them. Using stomach content analysis, this study revealed an omnivorous diet in carnivores because of the abundant presence of macrophytes in their stomach contents.

## Conclusion

At the end of this study of the diets of seven species of Mormyridae from the the Sanaga River, Cameroon, the main conclusions are as follows: Seven species of Mormyridae of varying relative abundance, grouped into four genera, were identified in the localities of Ebebda and Monatele: *Campylomormyrus* (*Campylomormyrus phantasticus*), *Hippopotamyrus* (*Hippopotamyrus castor*), *Mormyrops* (*Mormyrops anguilloides*, *Mormyrops caballus* and *Mormyrops zanclirostris*), and *Mormyrus* (*Mormyrus rume* and *Mormyrus tapirus*).

The vacuity coefficient and the low relative mass of the intestine reveal the carnivorous nature of this group of species, while the higher values of these same coefficients in *M. rume* and *M. tapirus* reveal that the latter are classified as invertivores (feeding on invertebrates).

The intestinal coefficient and the Zihler index also revealed the carnivorous diet of these species.

Stomach content analysis revealed that all these species are omnivores, preferably carnivores. This diet makes them potential candidates for domestication. A fairly diversified diet that did not vary according to season or site indicated that season and site did not have a major influence on feeding habits. The diversity of foods also reveals the opportunistic nature of these species, which, in the absence of their preferred food, consume foods available in the environment.

A complementary study should be carried out on the water analysis to provide information on the food richness of the environment to better explain the low values of the vacuity coefficient and the relative mass of the intestine.

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## Author contributions

Marina Armel à Mmira Akohogni led the research process, data collection and drafting of the manuscript. Evrard Kouopestchop Medjo assisted with the laboratory work and translated the manuscript. Boddis Zebaze Tsiguia contributed to the statistical analysis. Alexia Noubissi Chiassa and Pamela Cynthia Mepa Tchiegang contributed to the reading of the manuscript. Claudine Tekounegning Tiogué organized the research, contributed to the formulation of the title and research question, and corrected the manuscript. Dorothy Engwali Fon coordinated all the work, defining the main lines of research.

## Conflict of interest

All the authors declare that there are no conflicting issues related to this research article.

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