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Research Article

The Biology of the African Bonytongue *Heterotis niloticus* (Cuvier, 1829) from the Lower Niger River at Agenebode in Edo State, Nigeria

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Background. The African bonytongue, *Heterotis niloticus*, is readily accommodated in the fresh water of the Niger River. It is available all year round with a large population of juveniles and adults due to its fast growth and versatile feeding habits. This commercial fish is a highly preferred source of food because of its high protein content and hardy flesh, thus forming a very important component in the diet of many Nigerians. It is highly valued because of its socioeconomic importance and benefits. Hence, this research is designed with the aim of studying the biology of the African bonytongue, *Heterotis niloticus*, and providing viable information about its importance in fish culture in order to make an available added variety of culturable and affordable fish species in Nigeria. *Results*. The oesophagus is a muscular organ that is short and distensible. The oesophagus leads to the gizzard-like stomach, a reddish bilobed organ that is muscular and tough. *H. niloticus* is an omnivorous macrophage detritor, consuming a wide variety of bottom-dwelling food items. The histology of the gastrointestinal tract reveals four conspicuous layers from the inside to the outside: mucosa, submucosa, inner circular layer and outer longitudinal layer of muscularis, and serosa. The presence of numerous mucus glands and longitudinal folds with a prominent columnar epithelium provides durable length or an extension of the gut mucus to aid lubrication and easy passage of food materials, protecting the mucosal epithelium from mechanical or chemical injuries arising from interactions with digestive tract contents or enzymes. In addition, the presence of absorptive cells helps in the absorption of valuable nutritive substances. *Conclusions*. The anatomy of the mouth and gut and the aforementioned histology are modified to accommodate the feeding habits. *H. niloticus* has a single ovary that rests on the right side of the fish; it is reproductively active as the flood plains rise and peaks at the peak of the rains, being a moderately fecund fish. The high fecundity is complemented with peaks of GSI observed during the months of September, October, and November, which reveals spawning periods. Hence, the aforementioned attributes of *H. niloticus* make the fish a viable fish species for culture.

1. Background

The African bonytongue, *Heterotis niloticus*, is a large fish that is widespread in many tropical rivers and freshwater lakes of western and central parts of Africa [1]. In Nigeria, it is distributed along with many freshwater bodies. This fish species is readily accommodated in the fresh water of the Niger River with a large population of juveniles and adults. This successful adaptation is attributed to abundant varieties of feed and food in the river that is complemented with a versatile mode of feeding which is primarily correlated to the type of alimentary canal and digestive processes [2–4]. *Heterotis niloticus* is an important fish species to the fish-erfolk and residents along the Niger River. It is the only species in the genus *Heterotis* and family Osteoglossidae. This commercial fish is a highly preferred source of food because of its high protein content and hardy flesh, thus forming a very important component in the diet of many Nigerians. It is highly valued because of its socioeconomic importance and benefits. It has a high growth rate and is available all year round in large quantities and large sizes [5]. Recently, a decline was reported by [3, 6]. It is readily preferred and sold smoked or dried.

Fish is an important source of nutrients and also serves as the main source of protein in many Nigerian families. It is also highly recommended by WHO [7] and WHO [8] for the growing and ageing population because of its less tough fibre and immediate digestibility as well as its richness in omega-3 fatty acids needed for good health and brain development in children. The current fishery (culture, production, and management policies) cannot however satisfy the ever-demanding population, hence the need for optimal production and propagation. *H. niloticus* is one of the promising species that can be used for culture. To achieve this maximally, a thorough study to obtain knowledge of the fish must be carried out. Hence, this research is aimed at studying the biology of the African bonytongue *H. niloticus*.

2. Methods

2.1. Study Area and Description. The Niger River is the longest river in West Africa discharging into the Atlantic Ocean in Nigeria. It rises up to 240 km and runs for 4180 km. The river is known to harbor 36 families of freshwater fish and nearly 250 species of which 20 are found nowhere else on earth but Nigeria. From Lokoja, the lower part of the Niger River, the river runs through Agenebode-Ida to Forcados in Delta and Nun River in Rivers State and further. The river is clean and relatively clear. The Niger River floods yearly beginning from September and peaks in November to January. Agenebode is located at latitude 7.10512 and longitude 6.69381 and stretches through an area of 1133 km^2 (Figure 1). Agenebode waterfront is a very busy part of the Niger located in Edo State, Nigeria, serving water for domestic and industrial uses. Active fishing activities take place along the river for subsistence and commercial fishing.

2.2. Collection of Specimens and Sampling. One hundred and twenty-five (125) fish specimens were collected fortnightly for 12 months from November 2019 to October 2020 from three stations (based on the landing sites of fishing localities) from catch landings of fisherfolk by the use of canoes, gill nets, cast nets, drag nets, fish traps, and calabashes from the Lower Niger River at Agenebode. Fishes were transported to the Laboratory of the Department of Biological Sciences, Edo State University, Uzairue, Edo State. Fishes were rinsed; wiped; identified to species level using guides, keys, and pictures provided by [9–11]; and then preserved in 5% formalin.

2.3. Morphological Parameters. The standard length (cm), total length (cm), head length (cm), gape mouth (cm), girth, and weight (g) of *H. niloticus* were obtained using a graduated ruler and tape, a measuring board, and a digital electronic scale (Sartorius 177). These were recorded and analyzed. Fin counts and measurements were also taken and recorded.

2.4. Anatomy and Histology. Twenty samples of *H. niloticus* comprising different sizes (length and weight) were used. The mouths and intestinal tracts were removed. The oesophagus, stomachs, and intestines were gently slit open. Their content was rinsed off in gently flowing tap water and thereafter fixed in 10% formaldehyde. The samples were then dehydrated through a standard ethanol series to 100%, cleared in xylene, embedded in paraffin wax, then sectioned with a rotatory microtome set at 5-6 pm, deparaffinized, and stained with hematoxylin and eosin. Prepared slides of the gastrointestinal tract were mounted and examined with Olympus Electronic Microscope (model Bino Cxi IS 4381) (PL120) to view and capture features of biological interest.

Pictures of the mouth, jaws, and pharyngeal teeth were taken with a digital Infinix camera (Model X650B).

2.5. Determination of Sex. Sex could not be obtained from external observation. The stomach was split open from the lower abdominal region to determine the sex. Sex was determined by visual and microscopic observation of the gonads. A fish with one ovary was referred to as female, while a fish with no ovary was referred to as male.

2.6. Length-Weight Relationship (LWR). The total length (TL) and body weight (W) were measured in the fresh samples to the nearest 0.1 cm and 0.01 g, respectively. The length-weight relationships were estimated from the formula $W = a\,L\,b$, where W is the total body weight (g), L is the total length (cm), and a and b are the coefficients of the functional regression between W and L. This relationship was transformed into a linear form by the following equation:

$$\text{Log}W = \text{Log}a + b \log L. \tag{1}$$

2.7. Condition Factor. The condition factor K was calculated by the following formula given by [12]

$$\frac{(K = 100W)}{L^3}, \tag{2}$$

where W is the total weight of fish in grams, K is the condition factor, and L is the total length of fish in centimeters. It was calculated for each sex separately and then for the combined sexes. Variations of K with season and size groups were also determined.

2.8. Gonadosomatic Index (GSI). The gonadosomatic index of samples of *H. niloticus* was determined according to Ugwumba et al. [13] as follows:

$$\text{GSI} = \frac{\text{weight of gonad} \times 100}{\text{weight of fish}}. \tag{3}$$

The monthly catches were sorted by sex. The mature female ovaries were analyzed and used to determine the GSI.

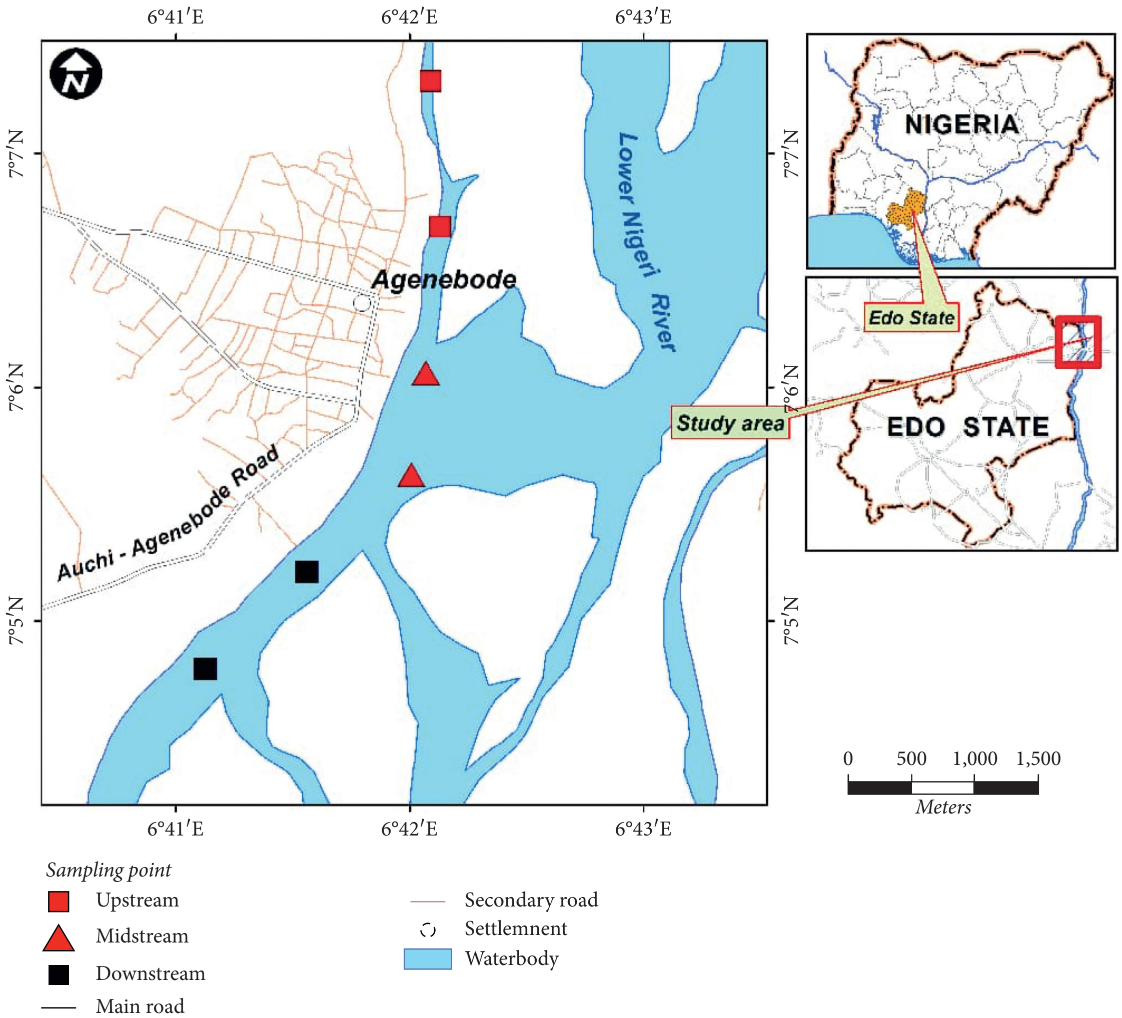

FIGURE 1: Map of the Lower Niger River showing study sites.

Fecundity: the ovary of the mature fish was removed and placed gently in boiling water and allowed to boil for 20 minutes. The eggs became hard enough for easy counting. The boiled eggs were then stored in 5% formalin. 1.00 g of the whole ovary was cut off. The cut section of the eggs was carefully counted and multiplied by the total weight of the ovary to give the total number of eggs.

The maturity stages of the ovaries were classified according to Nikolsky [14]:

Stage 1, immature; Stage II, quiescent; Stage III, maturing; Stage IV, mature; Stage V, running; Stage VI, spent.

Egg diameter: egg diameter (mm) was measured with an ocular micrometer. A stage micrometer was earlier used to calibrate the microscope. Diameters of twenty eggs randomly selected from each ovary were measured, and their mean was taken as the average egg diameter.

2.9. Determination of Food and Feeding Habits. Each stomach was split open, and the contents were emptied into a Petri dish. The contents were observed under a hand lens, and the food materials were identified.

Frequency of occurrence method (FO): in the frequency of occurrence method, the individual food matter in the stomach was sorted and identified. The number of stomachs in which each food item occurred was expressed as a percentage of the total number of stomachs with food examined.

Number of occurrence method (NO): this method involves counting the number of each food item present in the stomach of a fish and summing these numbers to obtain the total number of all food items found in the stomach. The number of each food item is then expressed as a percentage of the total number of all food items. It was expressed as

$$\text{percentage number of a food item} = \frac{\text{total number of a particular food item}}{\text{total number of all food items}} \times 100. \quad (4)$$

Index of relative importance (IRI): the importance of various food items was determined with the index of food importance following the method of Ugwumba and Ugwumba [15]:

$$\text{IRI} = (Cn + Cw)XF, \quad (5)$$

where IRI is the index of relative importance, Cn is the percentage of numerical composition, Cw is the percentage of gravimetric composition, and F is the percentage of frequency of occurrence.

The dietary compositions for the species examined were expressed as percentages; that is,

$$\%\text{IRI} = (Cn + Cw)XF \times 100. \quad (6)$$

A food item with %IRI ≥3 is regarded as primary, ≥0.1 to <3 secondary, and ≤0.1 incidental.

The relative gut length (RGL): this was expressed as the ratio of the total length of the gut to the total body length [16].

$$\text{RGL} = \frac{\text{total length of gut}}{\text{total length of fish}}, \quad (7)$$

where fish can be classified as herbivorous (RLG >1), carnivorous (RLG <1), or omnivorous (RLG =, or>, or <1).

Prey-predator relationship: the relationship between the total body length and the total weight of *Heterotis niloticus* and prey body weight was determined and described by the following equation [17]:

$$YL = a + b \times L, \quad (8)$$

where YL is the prey's body weight (g) and L is the predator's body length (cm) or body weight (g).

2.10. Statistical Analyses. The data obtained from this study was used to derive the means and standard deviation. Linear equations were also used to derive linear regression in the Microsoft Excel 2010 statistical package. Other statistical formulae were given and applied using Microsoft Excel 2010 for analyses.

3. Results and Discussion

Heterotis niloticus is bronze in color, elongate, compressiform, and covered with strong large cycloid scales. The retractable mouth is terminal with thick lips. In this study, the largest fish species obtained was 64 cm long with a weight of 2787 g (Figure 2). The dorsal fins are situated towards the posterior of the fish with 33–38 rays, the pectoral fins are paired with no spine and 12 rays, the pelvic fins are paired with no spine and 6 rays, and the anal fin consists of 35 rays. The African bonytongue has 5 rows of scales above the lateral line and 6 below the lateral line, in addition to 48–52 scales on the lateral line. The formula of fin count is thus D33-38: P12: V6: A35-38: C13-15 (48 – 52 (6/8)). These meristic characteristics, number and shape of fins, are often used in the identification of this fish species. The fin count obtained in this study corresponds with other identifications by [10, 18].

The mouth opens up to 8% of the total body length making room for numerous and large number of small food materials to be taken in at once (Figures 2 and 3). Its nuchal region is humped; its depth is 3.5–5.0 times its height; its head is short, 3.3% of the total length; the gill openings are covered by a bony operculum that ends with a fleshy attachment, one visible lateral line; and the eyes are sunken and golden brown. The composite anatomy of the interior of the mouth is cartilaginous; this is probably because of its kind of feeding specifics or preference for bone food species or cartilaginous ones, organisms with some form of a skeleton. In the mouth, the tongue is very thick, sort of cartilaginous; this hard nature of the tongue might be an added reason for its name (bonytongue). Behind the tongue is the pharyngeal palate with pebble-like teeth; these palates with teeth are on the roof and floor of the mouth.

The sides of the mouth overlap to give room for extensions. The tongue is very thick and cartilaginous and has teeth on the posterior end.

There are 5 gills on each side. These gills are folded to extend to the roof of the mouth (Figures 4 and 5). The third has forked cartilage attached to it that extends to the pharyngeal palates. Each gill has a very thick cartilaginous arc, long and slender rakers (178–206), and pairs of filaments (82–86 pairs) which are perfect for sieving tiny food particles such as detritus. Attached to the gills are a pair of the bulb-like sacs that are made of an internal anal filled with yellow matter suspected to be used for balancing or as an olfactory organ (Figure 5). The teeth on the jaws are few and not prominent. Cardiform teeth are present on the premaxilla and dentine and are premandibular.

The oesophagus is a muscular organ that is short and distensible. The oesophagus leads to the gizzard-like stomach, a reddish bilobed organ that is muscular and tough (Figure 6). This species has frequently been characterized either as an omnivore, insectivore, or detritor, with the latter being, in part, because of its benthic feeding habitats and possession of a gizzard (thick-walled pyloric stomach). This organ is often filled with fluid and not seeds or stones as in the case of birds, and this is also in conformity with the report of [19]. The pyloric ceca are from the end of the gizzard, consisting of two long tubular extensions (17% of the total length of the fish). The function of the pyloric ceca of fish has been postulated as an organ "to store up the food," "putrefy it up," and "concoct it" that is (storage, fermentation, and digestion). Buddington and Diamond [20] reported that the trout, cod, largemouth bass, and striped have

Figure 2: The body of *Heterotis niloticus*.

Figure 3: The gaping mouth of *Heterotis niloticus*, opening up to 12% of the total body length.

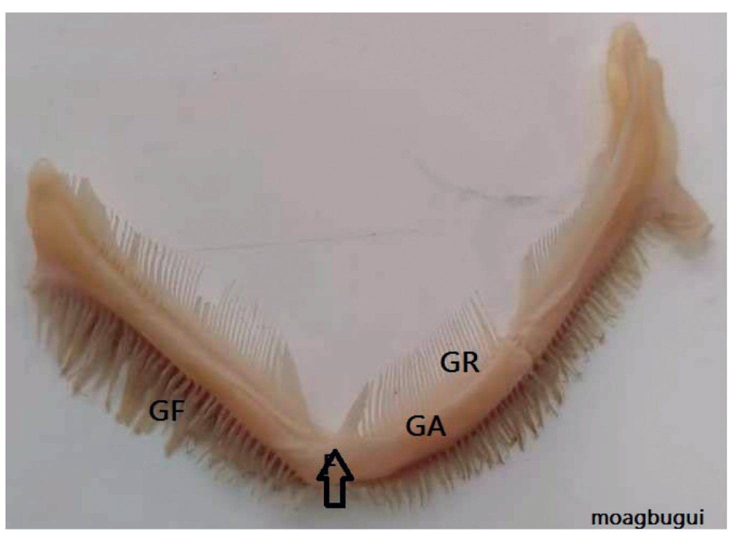

Figure 4: One gill of *H. niloticus.* GR, gill rakers; GF, gill filament; GA, gill arc. The arrow shows area where the gill folds to extend to the roof of the mouth.

pyloric ceca which assist in the digestion of food materials. Further studies showed the presence of enzymes, and the ceca proved to be a major site of sugar, amino acid, and dipeptide uptake, contributing more uptake than the entire remaining alimentary tract in trout and codfishes. The presence of carbohydrates has been reported in the stomach and pyloric ceca of the African bonytongue; this is an indication that ample digestion of carbohydrate materials takes place at this organ site [21].

The intestine also arises from the gizzard and can be clearly distinguished into two sections: the small intestine and large intestine; this organ is very long measuring up to 119% of the whole fish. The intestine ends with the cloaca (Figure 7). This gut length is an indication of herbivorous or omnivorous species. Fishes with long intestines that are more than 100% of their length is often either herbivorous or omnivorous. The length of the intestine gives room for digestion of the food materials ingested.

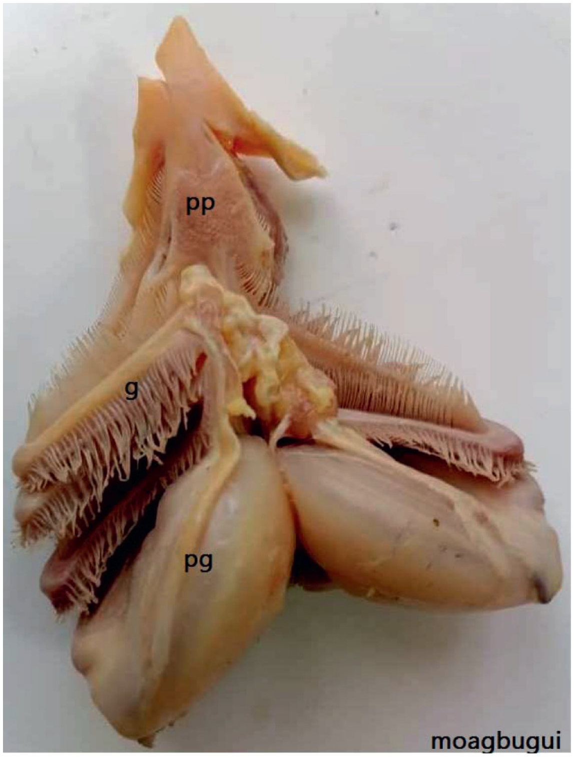

Figure 5: Gill of *H. niloticus*. pp, pharyngeal figure showing teeth; g, gills; pg, pouch of gills.

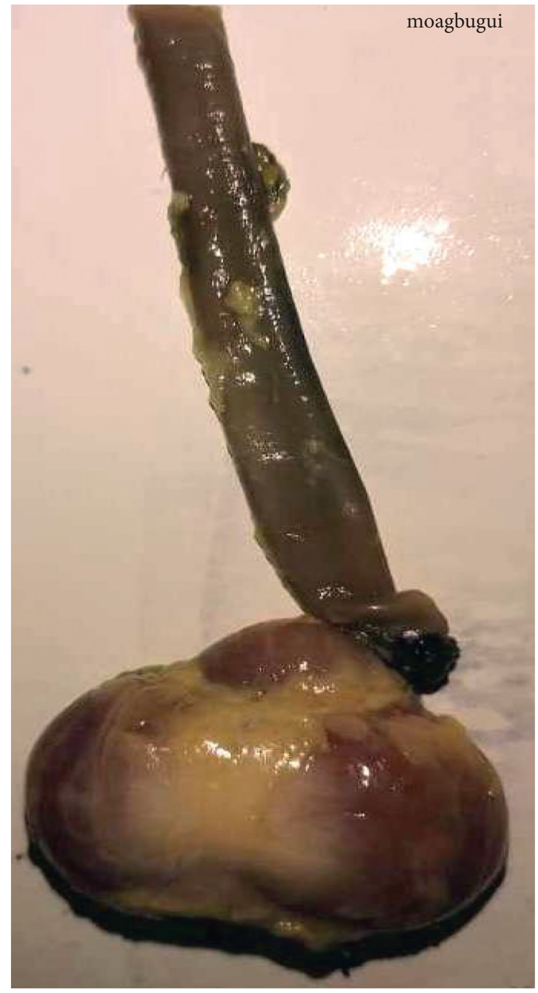

Figure 6: Gizzard-like stomach of *H. niloticus*.

The bilobed liver is large and lies over the gizzard stomach. The bile duct and pancreas lie above the gizzard, and the intestines are sheathed in fat, intestinal lining, and serosa.

Four major and distinct layers make up the gut of *H. niloticus* which is typical of higher vertebrate animals. The oesophagus composed of four conspicuous layers from the inside to the outside: mucosa, submucosa, inner circular layer and outer longitudinal layer of muscularis, and serosa (Figure 8(a)). The mucosa showed large numbers of the esophageal folds of the lumen of the oesophagus giving oval-shaped appearance in all sections. These oval folds were thick and elongated and had few gastric glands. The serosa is distinct, and these longitudinal folds may lead to an increase in the capacity of the organ for distension during food transportation [22]. The stomach of *H. niloticus* (Figure 8(b)) showed dense regions of the gastric gland revealing gastric cells within stratified epithelial cells. The mucosa of the stomach consists of surface and gastric epithelium. The surface epithelium is made up of a single layer of columnar epithelial cells, and the gastric epithelium consists of gastric glands. The lamina propria, in the form of a connective tissue network, lies between the gastric glands. The muscularis consists of an outer longitudinal and an inner thick circular muscle layer. The columnar epithelium was filled with lamina propria and mucus-secreting cells. The mucous secreted by these cells may be attributed to the lack of salivary glands in fishes; however, reports revealed that mucin is secreted by the esophageal epithelium which is probably a compensation [23, 24]. Furthermore, the mucin and mucus secretions are important for the formation of a continuous sheet along the entire wall of the oesophagus, lubrication of food particles, ionic absorption, and protection of the esophageal mucosa against mechanical damage and bacterial invasion, while mucous secretions participate in enzymatic digestion of the ingested food and facilitate its transformation into chime [25, 26].

The pyloric ceca (Figure 8(c)) had a dense muscularis, the mucosa had flat epithelium filled with cells, and gastric pits and mucus glands were not visible. The absence of glands and pits with visible macrovilli in the pyloric ceca reveals that this organ is not essential for digestion. Its location between the stomach and the intestine could be primarily to store food and slow down the passage of food into the intestine, providing enzymes and digestive abilities for food. Carnivorous fish species are known to have short intestine, hence the presence of other organs to assist in digestion. The stomach is composed of numerous longitudinal folds, gastric glands, gastric pits, columnar striated epithelium, lamina propria, and microvilli making the function of the stomach specialized. These findings are in agreement with those of [27, 28]. In this study, it was observed that the stomach muscularis possesses a circular layer

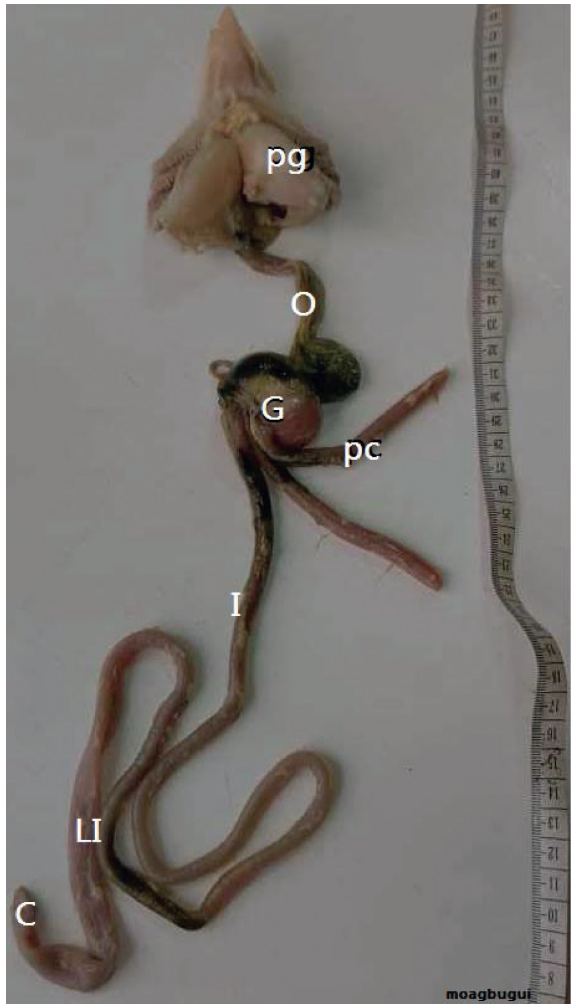

Figure 7: The detached GIT of *H. niloticus*. pg, pouch of gills; O, oesophagus; G, gizzard-like stomach; pc, pyloric ceca; I, intestine; LI, large intestine, C, cloaca.

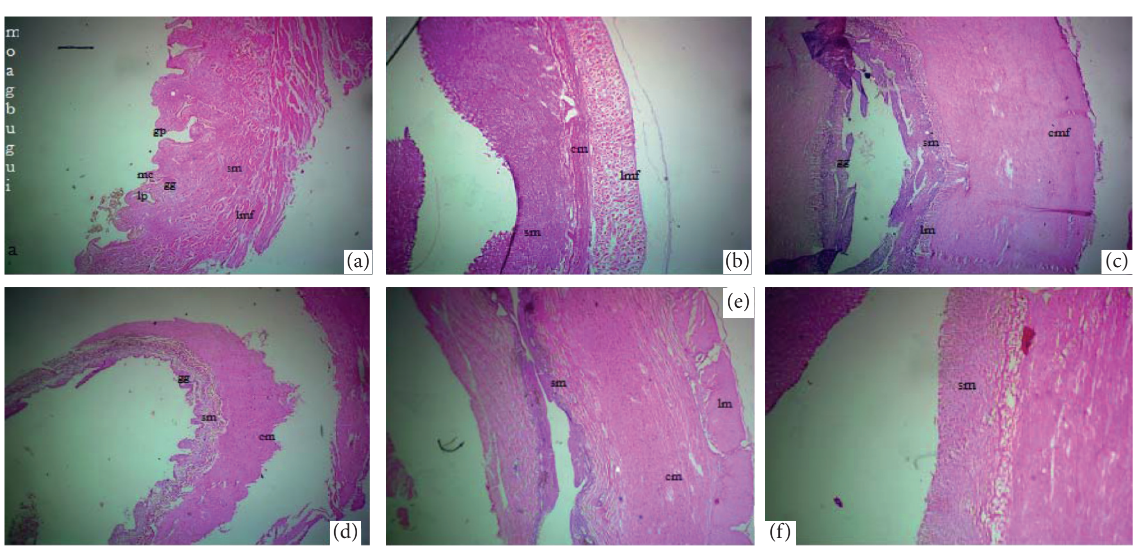

Figure 8: Histology of the gastrointestinal tract of *H. niloticus*: (a) oesophagus; (b) stomach; (c) pyloric ceca; (d) small intestine; (e) large intestine; (f) cloaca. gg, gastric gland; sm, submucosa; gp, gastric pits; lp, lamina propria; mc, mucus cells; cmf, circular muscle fibre; lmf, longitudinal muscle fibre.

that is thicker than the longitudinal layer, which is consistent with the findings of [22, 26, 29]. The small intestine, which is the anterior section of the intestine, showed numerously mucus glands; the mucosa revealed longitudinal folds of finger-like projections (villi), with a prominent columnar epithelium; and the macro- and microvilli possess cells that line the entire length of the intestine. The provision for excess mucus gland aids lubrication and easy passage of food materials, protecting the mucosal epithelium from mechanical or chemical injuries arising from interactions with digestive tract contents or enzymes, and the presence of absorptive cells helps in the absorption of valuable nutritive substances. The villi help to absorb nutrients from the food eaten and then shuttle the nutrients into the bloodstream of every species [30–32]. The posterior region which is the large intestine shows gastric pits and glands, the mucosal folds are numerous, and the presence of large villi is prominent. The columnar epithelium is distinct. The large intestine has a thick and dense circular muscle, the submucosa has very reduced gastric glands and gastric pits, the columnar epithelium and lamina propria are short (Figure 8(e)). The cloaca is packed with dense circular muscle and a reduced submucosa (Figure 8(f)). The cloaca is a region for reserving waste before it is passed off the gut. The cloaca has strong muscle for appropriate contraction to propel defecation.

Total weight and standard length of the 125 specimens of *H. niloticus* examined were within the ranges of 219–3417 g (2148.06 ± 715.93) and 21.0–98.0 cm (56.96 ± 13.08), respectively Table 1.

The *Heterotis* species are available all year round in large numbers. In this study, it was noticed that size was related to sex (Table 1). Using the mean and standard deviation, it was seen that female *Heterotis* species were larger than the males with a significant difference. A *t*-test was used to compare sex to size (length and weight). The result of the *t*-test of length and weight of females was 0.6, while for males 0.1 was obtained. Females are possibly larger than males because of the tendency to acquire food in preparation for reproductive capacity, hence the need for extra capacity and the ability of the anatomy and body structure to accommodate reproductive organs. Furthermore, females could grow larger because they possibly eat more for extra energy during spawning, hatching, and care of young ones. The sexual abundance (1 : 1.5) in favor of the females in the Lower Niger River may be influenced by variable factors including food availability, short lifespan, rapid growth, and conducive environment. Variety of fish species in addition to other macro- and microinvertebrates is available all year round in the river, thus enabling rapid growth and high recruitment. The active survivors prey on the rich variety of food available in the river; they grow very fast and become recruited into the fishery.

The length-weight relationship (LWR) of *Heterotis niloticus* obtained in the study for the whole population (both males and females) revealed a correlation coefficient (r) of 0.83 as shown in Table 2.

The value obtained for b was 0.53 for the whole population, 0.41 for males, and 0.26 for females. This result shows that *H. niloticus* exhibits a negative allometric growth

Table 1: Summary of length and weight parameters of *H. niloticus*.

Males	Length (cm)	Weight (g)	Females	Length (cm)	Weight (g)
Min	21	246	Min	25	219
Max	77	2952	Max	98	3417
Total	2400	96663	Total	4443	172555
Average	53.33333	2148.067	Average	56.96154	2212.244
SD	10.91788	715.9376	SD	13.08105	707.1197
N	36		N	53	
Df	35		Df	52	

Table 2: Linear relationship of morphometric parameters of *Heterotis niloticus*.

Population		a	b	R^2	r
LWR					
Whole population		1.645	0.532	0.683	0.83
Males		1.891	0.041	0.693	0.83
Females		1.745	0.263	0.663	0.83
Length-girth relationship (LGR)					
Whole population		0.995	−0.236	0.661	0.77
Males		0.921	−0.341	0.633	0.78
Females		01.11	0.256	0.692	0.69
Condition factor (K)					
Whole population	1.51				
Males	1.87				
Females	2.14				

($b < 3.0$) meaning that the length increases much more with body weight. This finding is in line with those of [33, 34, 35]. The length-girth relationship of *H. niloticus* showed a strong and positive correlation coefficient (r) of 0.77. The mean condition factor K was 1.51 (t-test, $P > 0.05$), which indicates that the *Heterotis* are in good condition in the river. Many factors could determine the productivity of a river; availability of food, proper management policies, pollution, turbidity, and indiscriminate dredging could affect the condition and production of the river. Moreover, heavy bodied fishes such as the *Heterotis* species are noted to have higher condition factors than those with flattened bodies [36]. It is also reported that *H. niloticus* can thrive well in polluted and turbid waters, hence its ability to maintain a condition factor >1 [37, 38]. Out of the 125 specimens obtained, 36 were males while 53 were females with a ratio of 1 : 1.5, and the remaining 36 were unsexed. All of these specimens were examined for variety of food items; 69 had empty stomachs while 56 had food items in their stomachs. The percentage composition of food items obtained from *H. niloticus* from November 2019 to October 2020 is shown in Table 3.

The dominant food items found were copepods (33.48%) and shrimps (16.74%) by %FO. Other food items of low importance were mollusc, plant parts, sand, and detritus: 14.16%, 12.02%, 3.43, and 14.59%, respectively (Table 3). The food item with the most relevance was copepod with a percentage of 34.45%.

The food items obtained in this study from the stomachs of *H. niloticus* show a dominance of arthropods and crustaceans in addition to detritus materials, suggesting frequent

Table 3: Percentage composition of various food items consumed by *Heterotis niloticus*.

Food items	%NO	%FO	%W	IRI	%IRI
Copepods	35.42	33.48	43.71	0.34	34.45
Shrimps	18.75	16.74	14.22	0.18	17.74
Mollusc	7.64	14.16	16.85	0.11	10.90
Plant parts	8.33	12.02	6.74	0.10	10.18
Sand	5.56	3.43	2.69	0.04	4.49
Fish	7.64	5.58	10.01	0.07	6.61
Detritus	16.67	14.59	5.79	0.16	15.63
Total	100	100.00	100.00	1.00	100

NO: numerical method, FO: frequency of occurrence method, *W*: gravimetric method, IRI: index of relative importance. Food items with %IRI >3 are regarded as primary and >0.1 to <3 are secondary, whereas those with % IRI <0.1 are considered as incidental food items.

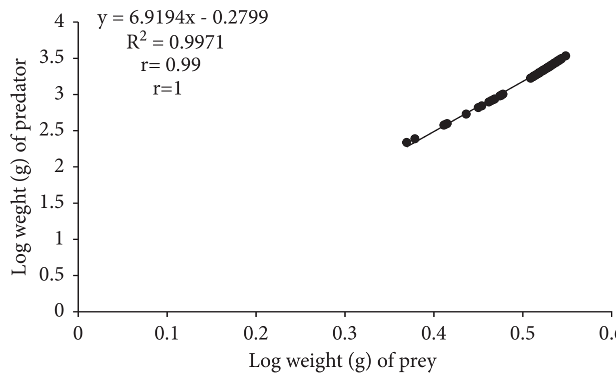

Figure 9: Relationship between prey body weight and total weight of *Heterotis niloticus*.

bottom feeding on benthic invertebrates as shown in Table 3. It is evident that *H. niloticus* was strictly a planktonic microphage. Larger fish had some whole fish or sometimes fish flesh in their stomach. The presence of plant remains and sand could be due to the probability that while grazing on other benthic organisms it scraped, quickly pulled out, or nipped off plants along with their substrate. Hence, the variation of food items, which include sand, detritus, fish, copepods, shrimps, and mollusc, makes it possible to conclude that *H. niloticus* is an omnivore. From the shape of the mouth and the arrangement of the gills, it could be concluded that filter-feeding habit is made possible by the possession and arrangement of fine gill rakers and gill filaments as seen in Figures 4 and 5. Although the species had earlier been described as more of a plankton feeder [11, 39], this study has shown that *H. niloticus* is an omnivore with arthropods and crustaceans being the significant food items in its diet with the capability of filtering planktons and other food substances in water. Similar findings proving that *H. niloticus* is an omnivore were reported by [34, 39–41]. The nature of the gut, possession of a gizzard (food grinder), and long gut length (extended absorption) of the intestine are important features that show omnivorous feeding. The gizzard serves as an organ of digestion. Fluid and digested matter were preset in the gizzard with no grains or seeds as in the case of birds. The gut length recorded in this study (mean of 77.32 cm) and the relative gut length (RGL) of 1.08 suggest a long gut transit time for the food of this fish. According to Biswas [16], fish can be classified as herbivorous (RLG >1), carnivorous (RLG <1), or omnivorous (RLG =, >, or <1). With regard to the RGL, the result obtained in this study shows that *H. niloticus* is a herbivore, but the food items discovered do not show that. Following the theory of Ward-Campbell and Beamish [42] which is supported by [43–46], it is generally accepted that RGL< 1 indicates carnivorous diet, and RGL < 3 > 1 indicates omnivorous, whereas values of RGL ˃3 indicate diet based on plant material or detritus. This theory is an added proof that *H. niloticus* is an omnivore.

In this study, the prey-predator relationship of *H. niloticus* revealed that fish weight was more related to prey size as shown in Figures 9 and 10.

A linear and positive relationship between the predator body weight and prey body weight of *H. niloticus* was observed. Larger prey was obtained as the fish size (weight) increased. A perfect relationship between the weight of *H. niloticus* and its prey was obtained. This shows that as the fish gets bigger, larger sizes of meals were preferred to smaller ones; hence, size of fish is associated with feeding capacity. Similar findings relating feeding capacity to size were reported by [47–52].

Heterotis niloticus possesses a single ovary located on the right side. Color of ovary is amber or ovary pink at the quiescent/immature stage, deep pink in mature stages, and yellow to orange in mature and running stages. The ovary is elongated and larger at the anterior part and thinner at the posterior end towards the cloaca, laterally compressed, and has 51–82 ± 68 lamellar folds. *H. niloticus* showed variation in gonadosomatic index (GSI) which was greatly induced by season and size of fish. Monthly averages of GSI were recorded in the rainy season with its peak in the months of May to September and then a decrease till November. No gravid females were found in November till early February, which confirms that the spawning period begins as the flood plains rise in the rainy season. The African bonytongue has relatively large eggs (2.3 mm–3.00 mm) and moderate fecundity (2100–32000 eggs) (Table 4). The size of *H. niloticus* in the Lower Niger River at first maturity was not calculated in this study because the size of sample collected is small (<500).

The number and size of eggs were dependent on the size of fish. The weight in relation to its length was a determinant for ovarian weight and oocyte count available to a species. Mature fishes represented gonad stages of 2–5. Mature fishes were recorded from fish with sizes of 368 g–2000 g. The smallest mature fish observed has a TL of 31 cm, SL of 21 cm, and *W* of 368 g, with the length of the gonad being 5.3 cm and weight being 5 g. Fecundity was obtained only for 19 fecund female specimens.

Six stages of gonad development were found in *H. niloticus* during the sample period in both males and female fishes: the immature, quiescent, maturing, mature, running, and spent stages (Table 5).

The decline in rainfall which correlated to reduction and absence of gravid females suggests the end of spawning periods. The changes in GSI revealed that *H. niloticus* has specific periods for maturation of ovaries, spawning, and breeding times. *H. niloticus* is thus observed to be

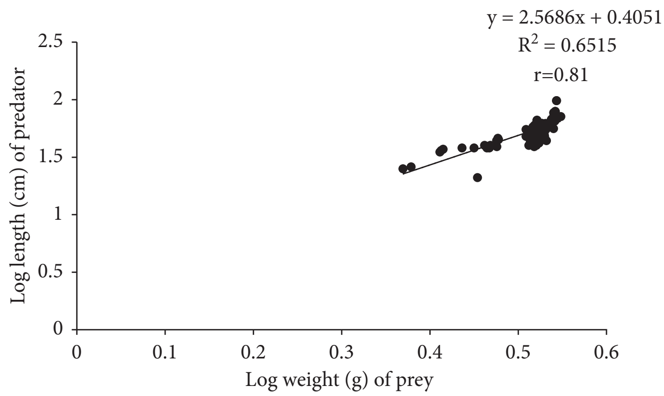

FIGURE 10: Relationship between prey body weight and total length of *Heterotis niloticus*.

TABLE 4: Summary of gonadosomatic index (GSI) of *Heterotis niloticus*.

Parameters	Males	Females
Sample size (*n*)	36	53
Total length (cm)	515.00	4139.00
Mean ± SD	57.22 ± 7	59.13 ± 11.0
Total weight (g)	20635.00	166456.00
Mean ± SD	2292.78 ± 566.58	2377 ± 515.3
Mean gonad weight (g)	26.89 ± 8.0	23.90 ± 7.52
Gonadosomatic index (GSI)	1.29 ± 1.22	1.00 ± 1.56
Fecundity (*n*)	Nil	21548 ± 6065.33 (19)

TABLE 5: Stages of gonad developments observed in *H. niloticus*.

Gonad stage	Macroscopic character	
	Testis	Ovaries
(I) Immature	Not encountered	Not encountered
(II) Quiescent	Testis were small and opaque in color	The quiescent stage had ovaries that were translucent and pinkish in color, oocytes were not visible to the naked eye, and blood vessels were seen on the surface of ovaries
(III) Maturing	The males had small milt that was milky in color	The maturing stage had ovaries that were creamy in color; oocytes could be visible though not well developed
(IV) Mature	The mature stage had larger milt that could be released with some pressure	There were creamy colored eggs with visible oocytes that could be counted. Blood vessels were very visible
(V) Running	Milt could be released with little pressure	Eggs could be released with little pressure
(VI) Spent	Not encountered	Not encountered

moderately fecund ((2100–32000 eggs) when compared to fish species like the African mudfish (*Protopterus annectens*) and the grunt (*Pomadasys jubelini*) [2, 53]. These results are in conformity with the findings of [19]. This study reveals an overlap in the ranges of average sizes in relation to maturity stages. This could be because *H. niloticus* does not depend on length alone but also weight of the fish and other contributing factors such as availability of food, water quality, climate changes, and neural responses [54–58].

4. Conclusion

Heterotis niloticus is an omnivorous macrophage detritor, consuming a wide variety of bottom-dwelling food items. The anatomy of the mouth and gut along with its histology is modified to accommodate the feeding habits. *H. niloticus* has a single ovary which rests on the right side of the fish; it is reproductively active as the flood plains rise and peaks at the peak of the rains, being a moderately fecund fish. The high fecundity is complemented with peaks of GSI observed during the months of September, October, and November, which reveals spawning periods. Hence, the aforementioned attributes of the African bonytongue make it a suitable candidate for culture.

Abbreviations

H. niloticus: *Heterotis niloticus*
GIT: Gastrointestinal tract
N: Sample size
Df: Degree of freedom.

Data Availability

The data used to support the findings of this study are included in the article.

Ethical Approval

Not applicable.

Consent

Not applicable.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

Authors' Contributions

Dr. M. O. A. is the principal researcher and was responsible for sample collection, analyses, and manuscript writing. Mr. F. E. A. participated in handling field and laboratory procedures. Dr. H. O. E. contributed to histological preparations and analyses of processes. All authors read and approved the manuscript.

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