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Nutritional Assessment of Selected Fish Species in Major Aquatic Bodies in Bayelsa State, Nigeria

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ABSTRACT

Background and Objective: Fish from the aquatic environments of Bayelsa State and the Niger Delta region at large offer good nutrition; however, they face varying nutritional profiles due to the discrepancies in habitat. This comparative study investigated the nutritional profiles of the tissues of three economically important fish species, such as *Clarias gariepinus* (African catfish), *Polydactylus quadrifilis* (Giant African Threadfin), and *Oreochromis niloticus* (Nile Tilapia) in freshwater, saltwater, and brackish water, respectively. **Materials and Methods:** The study utilized twenty-one fish samples (seven per species) that were systematically collected from Taylor Creek (freshwater), Brass River/Atlantic Ocean (saltwater), and Nembe Creek (brackish). Association of Official Analytical Chemists (AOAC) methods were utilized for proximate analysis, whereas Atomic Absorption Spectrophotometry (AAS) was used for minerals in fish and water samples following methods described by the United States Environmental Protection Agency (USEPA). Data were analyzed using SPSS 27 with results as Mean±SD, and significance tested by One-way ANOVA and Tukey's HSD at $p<0.05$. **Results:** The *Polydactylus quadrifilis* exhibited the highest protein content (28.80±0.14%) and the highest ash content (10.64±0.14%). Also, *Oreochromis niloticus* exhibited the highest moisture content (51.27±0.55), and *Polydactylus quadrifilis* had the highest fat content (19.45±0.24). Trace metal analysis showed that *Oreochromis niloticus* had elevated essential minerals, including calcium (13.164±0.7177 mg/kg), magnesium (6.907±0.7425 mg/kg), and sodium (7.748±0.7425 mg/kg), reflecting environmental influences. **Conclusion:** Results from this study showed excellent nutritional profiles across all species. Also, correlation analysis revealed very strong positive relationships between fish tissue and water concentrations for calcium, magnesium, and sodium. The comparative nutritional assessment across different aquatic environments is of great importance as it provides much-needed baseline data for food security and aquaculture management in Bayelsa State and the Niger Delta Region.

KEYWORDS

Bayelsa State, fish, trace metal, macromolecules, bioavailability

INTRODUCTION

Fish serves as one of the most nutritionally significant food sources globally, as it provides high-quality proteins, essential amino acids, omega-3 and omega-6 fatty acids, and vital micronutrients such as

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vitamins A, D, and B12, and minerals such as sodium, zinc, iodine, selenium, phosphorus, and calcium[1]. In coastal and littoral regions such as Bayelsa State, fish serves as a primary source of affordable animal protein, and it makes a very significant contribution to both nutrition and socio-economic stability[2].

Bayelsa State is located at the Niger Delta's core, and this region has a dependency on its extensive water bodies to provide diverse species of fish that underpin both dietary and economic needs[3]. The state hosts the three major aquatic habitats: Freshwater systems (rivers and creeks), marine environments, and brackish water estuaries, spanning a salinity gradient from ≤0.03 ppt inland to approximately 18 ppt seaward[4].

The nutritional profile of fish is significantly influenced by the environment in which they are found, with discrepancies in factors such as salinity, mineral content, and pH playing a major role across different habitat types, resulting in habitat-specific differences in fish nutrient profiles[5].

This study focused on three fish species that thrive and are adapted to freshwater, saltwater, and brackish habitats of Bayelsa State. It is worthy of note that these species were meticulously selected due to their abundance in their habitats, cultural and economic significance in the local communities of Bayelsa State. The species of interest are the African Catfish, scientifically known as *Clarias gariepinus* from freshwater habitat, the Giant African Threadfin, scientifically known as *Polydactylus quadrifilis* from saltwater habitat, and the Nile Tilapia, scientifically known as *Oreochromis niloticus* from brackish water habitat.

The impact of water bodies on the nutritional compositions of fish varies from one region to another, and even within the same locality. This could be attributed to physicochemical or environmental factors. Studies have shown diversity in the nutritional composition of fish in different water bodies and in extension regions[6,7].

Locals and residents of Bayelsa State discriminate against fish due to the water bodies, attributing it to organoleptic and nutritional values. This is cultural and deep-seated, without empirical dictates to the nutritional value inherent in the vast aquatic bodies in the state. This study was therefore designed to investigate the effect of water bodies on the nutritional composition of fish and the inherent organoleptic and nutritional characteristics.

MATERIALS AND METHODS

Study area: This study was conducted in three sites based on the major water bodies in Bayelsa State. The first site was the Taylor Creek (freshwater site) located between Polaku and Agbia communities within the Biseni and Gbaran clans of Yenagoa Local Government Area (Latitude 5°01'N-5°02'N, Longitude 6°17'E-6°18'E), representing a typical freshwater habitat. The second was the Brass River/Atlantic Ocean coastline (saltwater site) located at Brass Island (Latitude 4°19'01"N, Longitude 6°14'34"E), representing a marine saltwater environment, and the third was the Nembe Creek (brackish water site) located in Etieama community, Nembe Local Government Area (Latitude 4°25'50''N, Longitude 6°19'25''E), representing brackish water habitat. The three habitats are all within the geographical location of Bayelsa State, a state in South-South Nigeria. The study duration spanned from January, 2025 to June, 2025[8-12].

Sample size: The study utilized a sample size of twenty-one (seven per group) as validated by Mead's resource equation[13,14]. Water samples were randomly sampled from three different points in the three study locations.

Ethical clearance: Ethical clearance and approval for this research were obtained from the Directorate of Research and Quality Assurance of the Federal University, Otuoke, Bayelsa State. All animal care and experimental procedures were carried out in accordance with the ethical standards set out by Federal

University Otuoke Research and Quality Assurance unit, and in line with international guidelines for the use of animals in research, such as the Animal Welfare Act of 1985 of the United States of America for Research and Animal Care and Use Committee (IACUC).

Sample collection: The fish were harvested fresh from the respective habitats using fishing nets and hooks. Immediately post-harvest, all specimens were placed in ice packs to minimize post-mortem biochemical changes before transportation to the laboratory.

Sample preparation: Fish skin, bones, and inedible portions were removed following AOAC methods 937.07. Three cross-sectional slices were removed from different body regions. Samples were then frozen at -20°C for a minimum of 12 hrs. They were then freeze-dried for 72 hrs and then ground using a knife mill to fine powder[15].

Laboratory analysis: Protein and fat contents were determined using the Kjeldahl and Soxhlet extraction methods, respectively[15,16]. Similarly, moisture and ash were measured with varying temperatures using the gravimetric method[15]. However, the carbohydrate (sugar) content was determined by using the difference method[15]. The concentration of trace metals such as calcium, sodium, magnesium, and zinc in fish and water samples was determined using flame absorption spectrophotometry (FAAS)- EPA 7000B methods[16-18].

Data analysis: The data generated from the study were analysed using SPSS Version 27. The descriptive statistics were expressed as Mean±Standard Deviation. One-way ANOVA was conducted to assess treatment effects, and Tukey's *post hoc* HSD was also utilized to test for pairwise comparisons. Significance levels were set at $p<0.05$.

RESULTS AND DISCUSSION

The proximate composition analysis showed that there were significant differences between species for all macronutrients (Table 1). *Polydactylus quadrifilis* had the most protein (28.80±0.14%) and fat (19.45±0.24%), while *Oreochromis niloticus* had the most moisture (51.27±0.55%) and carbohydrates (0.96±0.09%). *Clarias gariepinus* showed values that were in the middle of most of the parameters. The ash content exhibited minimal variation (10.22-10.64%) among species. All parameters exhibited statistical significance ($p<0.001$), except for ash content ($p = 0.04$).

Mineral analysis revealed substantial habitat-related disparities (Table 2). The concentrations of calcium and magnesium followed this order: *Oreochromis niloticus*>*Clarias gariepinus*>*Polydactylus quadrifilis*. For calcium, the values were 13.164±0.72 vs 11.55±0.92 vs 0.916±0.05 mg/kg, and for magnesium, the values were 6.907±0.74 vs 5.571±0.25 vs 0.439±0.01 mg/kg. Sodium exhibited similar trends (7.748±0.74, 7.713±0.44 and 0.429±0.01 mg/kg, respectively). *Clarias gariepinus* had the most phosphorus (0.176±0.04 mg/kg), while other species had 0.012±0.00 mg/kg. Polydactylus quadrifilis had a lot more zinc (0.617±0.00 mg/kg) than freshwater species (~0.10 mg/kg).

Table 1: Multiple comparison of proximate compositions of fish samples

Parameter (%)	*Clarias gariepinus*	*Polydactylus quadrifilis*	*Oreochromis niloticus*	f-value	p-value
Protein content	$21.43±0.17^c$	$28.80±0.14^a$	$24.40±0.43^b$	1237.11	0.00
Moisture content	$49.34±0.61^b$	$40.92±0.33^c$	$51.27±0.55^a$	811.87	0.00
Fat content	$18.36±0.38^b$	$19.45±0.24^a$	$13.15±0.33^c$	765.77	0.00
Ash content	$10.43±0.24^a$	$10.64±0.38^a$	$10.22±0.24^a$	3.57	0.04
Carbohydrate	$0.48±0.15^b$	$0.19±0.16^c$	$0.96±0.09^a$	56.61	0.00

Different superscripts (a,b,c) indicate that all three groups are significantly different from each other, while shared superscripts indicate no difference between the groups, Data is presented as Mean±SD of determinations, Values on the same row with different superscripts are significantly different ($p<0.05$), n = 7, Values of the same superscript letters have no significant difference, N: Number of sample replicates, $p>0.05$: There is no significant difference and $p<0.05$: There is a significant difference

Table 2: Mean concentrations of minerals in fish samples

Parameter (mg/kg)	RDI range for adults (19-50 Years)	*Clarias gariepinus*	*Polydactylus quadrifilis*	*Oreochromis niloticus*	f-value	p-value
Calcium	1000 mg/day	11.55 ± 0.92^{a}	0.916 ± 0.05^{b}	13.164 ± 0.72^{a}	679.7	0.00
Magnesium	350 mg/day	5.571 ± 0.25^{b}	0.439 ± 0.01^{c}	6.907 ± 0.74^{a}	398.85	0.00
Sodium	2300 mg/day	7.713 ± 0.43^{a}	0.429 ± 0.01^{b}	7.748 ± 0.74^{a}	502.04	0.00
Phosphorus	700 mg/day	0.176 ± 0.04^{a}	0.012 ± 0.00^{b}	0.012 ± 0.00^{b}	117.63	0.00
Zinc	11 mg/day	0.101 ± 0.02^{b}	0.617 ± 0.00^{a}	0.095 ± 0.02^{b}	2232.12	0.00

Different superscripts (a,b,c) indicate that all three groups are significantly different from each other, while shared superscripts indicate no difference between the groups, Data are expressed as Mean±SD; Values of the same superscript letters have no significant difference, N: Number of sample replicates, p>0.05: There is no significant difference, p<0.05: There is significant difference, p<0.01: There is much significant difference and p<0.001: There is very much significant difference

Table 3: Multiple comparison of mean concentrations of minerals in water samples

Parameter (mg/L)	WHO/FAO) limits (mg/L)	Site A	Site B	Site C	f-value	p-value
Calcium	50.0	14.02 ± 0.80^{a}	3.441 ± 0.01^{b}	15.73 ± 0.66^{a}	865.02	0.00
Magnesium	20.0	6.334 ± 0.50^{b}	2.768 ± 0.0026^{c}	9.730 ± 0.491^{a}	518.27	0.00
Sodium	200.0	9.435 ± 0.70^{b}	1.476 ± 0.02^{c}	11.54 ± 0.33^{a}	987.99	0.00
Phosphorus	1.0	0.01 ± 0.02^{b}	0.08 ± 0.00^{a}	0.10 ± 0.14^{a}	3.49	0.05
Zinc	15.0	0.155 ± 0.00^{b}	0.115 ± 0.050^{b}	0.45 ± 0.02^{a}	1694.32	0.00

Site A: Taylor Creek, Site B: Brass Coastline and Site C: Nembe Creek, Different superscripts (a,b,c) indicate that all three groups are significantly different from each other while shared superscripts indicate no difference between the groups, Data are expressed as Mean±SD; Values of the same superscript letters have no significant difference, N: Number of sample replicates (7), p>0.05: There is no significant difference, p<0.05: There is significant difference, p<0.01: There is much significant difference and p<0.001: There is very much significant difference

Table 4: Bioaccumulation factor of minerals in fish samples

Parameter (L/kg)	*Clarias gariepinus*	*Polydactylus quadrifilis*	*Oreochromis niloticus*
Calcium	0.824	0.266	0.837
Magnesium	0.880	0.159	0.710
Sodium	0.817	0.291	0.671
Phosphorus	17.60	0.150	0.120
Zinc	0.652	5.365	0.211

BAF values <100 is considered low, BAF values within the range of 100-1000 are moderate BAF values >1000 is considered high

Most minerals were found in higher concentrations at Site C than at Site A or Site B, and all the concentrations were within WHO/FAO standards (Table 3). The amount of calcium in the sites ranged from 15.73±0.66 mg/L (Site C) to 3.441±0.01 mg/L (Site B), the amount of magnesium from 9.730±0.49 to 2.768±0.003 mg/L, and the amount of sodium from 11.54±0.33 to 1.476±0.02 mg/L.

For most minerals, the bioaccumulation factors (Table 4) were mostly low (<100). Phosphorus in *Clarias gariepinus* (17.60 L/kg) and zinc in *Polydactylus quadrifilis* (5.365 L/kg) were notable exceptions, showing that different species have different ways of accumulating.

Correlation analysis between fish tissue and mineral concentration in water revealed different species-specific patterns (Table 5). Calcium, magnesium, and sodium demonstrated strong positive correlations ($r>0.94$, $p<0.01$) across all species.

The proximate composition study (Table 1) indicates notable species-specific macronutrient profiles that demonstrate unique metabolic adaptations and environmental factors. The protein content followed the order: *Polydactylus quadrifilis* (28.80±0.14%)>*Oreochromis niloticus* (24.40±0.43%)>*Clarias gariepinus* (21.43±0.17%), with extremely significant differences ($F = 1237.11$, $p<0.001$). The increased protein concentration in *Polydactylus quadrifilis* indicates its carnivorous feeding habits and dynamic lifestyle in marine environments, necessitating elevated protein synthesis for movement and metabolic requirements. The moisture content exhibited an inverse correlation with protein levels: *Oreochromis niloticus* (51.27±0.55%)>*Clarias gariepinus* (49.34±0.61%) surpasses *Polydactylus quadrifilis* (40.92±0.33%),

Table 5: Pairwise correlations between fish tissues and water mineral concentrations

Species (habitat)	Mineral pair	Correlation (r)	p-value	95% CI
Clarias gariepinus (freshwater)	Ca fish-water	0.994	0.001	0.965-0.999
	Mg fish-water	0.987	0.001	0.932-0.997
	Na fish-water	0.993	0.001	0.961-0.999
	P fish-water	0.991	0.001	0.955-0.998
Polydactylus quadrifilis	Ca fish-water	0.978	0.003	0.867-0.995
	Mg fish-water	0.943	0.016	0.645-0.989
	Na fish-water	0.967	0.006	0.796-0.993
Oreochromis niloticus	Ca fish-water	0.989	0.001	0.942-0.997
	Mg fish-water	0.996	<0.001	0.981-0.999
	Na fish-water	0.985	0.002	0.920-0.996
	Zn fish-water	0.892	0.041	0.362-0.979

Pearson correlation coefficients were calculated between fish tissues and mineral concentrations using individual replicate data (n = 7 per species), Correlation strength was interpreted as: Weak (r<0.30), moderate (0.30-0.69), strong (0.70-0.89), and very strong (≥0.90). All correlations were calculated at 95% confidence interval and p<0.05 was set as the statistical significance level

signifying osmotic regulatory disparities between freshwater and marine organisms. The fat content was highest in *Polydactylus quadrifilis* (19.45±0.24%)>*Clarias gariepinus* (18.36±0.38%)>*Oreochromis niloticus* (13.15±0.33%) indicates lipid storage adaptations for energy consumption and thermoregulation. Ash (total mineral content) concentration exhibited negligible variation (10.22-10.64%), signifying uniform mineral integration among species. The carbohydrate content was minimal in all species (<1%), aligning with the carnivorous/omnivorous characteristics of these fish. These findings correspond with Anarado *et al.*[18], who recorded analogous protein changes between cultivated African catfish and Nile tilapia. However, these values are comparatively lower, which may be attributed to the environmental stress resulting from polluted habitats. Research conducted by Ahmed *et al.*[19] aligns with the observed inverse link between protein and moisture, ascribing it to the cellular water-binding ability and the dynamics of tissue hydration.

The essential mineral analysis (Table 2) reveals bioaccumulation patterns that are unique to individual species, and these parameters correspond to habitat-dependent mineral availability and physiological needs. Calcium concentrations varied significantly from 0.916±0.050 mg/kg in *Polydactylus quadrifilis* to 13.164±0.7177 mg/kg in *Oreochromis niloticus*. The results show *Clarias gariepinus* exhibiting intermediate concentrations (11.55±0.9223 mg/kg). This large discrepancy illustrates the fact that there exist active calcium absorption mechanisms in freshwater species, which are required due to these environments being calcium deficient; this is contrary to the passive calcium availability in brackish and saltwater environments. The distribution of magnesium exhibited analogous patterns: *Oreochromis niloticus* (6.907±0.7425 mg/kg)>*Clarias gariepinus* (5.571±0.2501 mg/kg) exhibits greater magnesium retention than *Polydactylus quadrifilis* (0.439±0.0054 mg/kg), suggesting improved magnesium retention in freshwater species for enzymatic cofactor functions and ATP metabolism. Sodium concentrations were significantly higher in freshwater species (*Oreochromis niloticus*: 7.748±0.7425 mg/kg; *Clarias gariepinus*: 7.713±0.4382 mg/kg) than in saltwater species (*Polydactylus quadrifilis*: 0.429±0.0053 mg/kg), indicating the presence of active sodium retention mechanisms crucial for osmotic equilibrium and nerve conduction in hypoosmotic conditions. Phosphorus concentrations were significantly low across all species (0.012-0.176 mg/kg), indicating a critical phosphorus deficiency relative to standard fish muscle values (200-400 mg/kg). This depletion indicates a deficiency of ambient phosphorus and modified phosphorus metabolism under polluted circumstances. Zinc concentrations varied by species, with *Polydactylus quadrifilis* showing the highest level (0.617±0.0012 mg/kg). This difference may relate to differences in metalloenzyme activity associated with marine carnivorous metabolism. These findings differ from those of Lall and Kaushik[20], who indicated elevated mineral concentrations in untainted aquaculture systems, implying that contamination has disrupted mineral metabolism in our research region. Findings from research substantiate the species-specific mineral requirements, notably the heightened zinc demands in carnivorous fish for protein synthesis and immunological functionality[21].

The measurement of critical mineral concentrations in water samples of habitats where these fishes are found (Table 3) reveals site-specific mineral availability that directly interacts with fish tissue concentrations and ecosystem parameters. Calcium concentrations exhibited the following pattern: Site C (15.73±0.66 mg/L) ≈, Site A (14.02±0.80 mg/L)>Site B (3.441±0.01 mg/L), indicating that brackish and freshwater sites surpass marine settings, hence agreeing with the augmented calcium absorption noted in *Oreochromis niloticus* and *C. African* catfish (*Clarias gariepinus*). All sites were significantly below WHO guidelines (50.0 mg/L), demonstrating sufficient calcium bioavailability for the physiological needs of fish. The distribution of magnesium exhibited the following hierarchy: Site C (9.730±0.491 mg/L)>Site A (6.334±0.50 mg/L)>Site B (2.768±0.0026 mg/L), indicating estuarine magnesium enrichment and freshwater retention processes. Sodium concentrations were maximal at Site C (11.54±0.33 mg/L), moderate at Site A (9.435±0.70 mg/L), and minimal at Site B (1.476±0.02 mg/L), deviating from anticipated marine sodium values, indicating anthropogenic sodium pollution in brackish waters due to industrial effluents. Phosphorus concentrations were heightened at Sites B (0.08±0.00 mg/L) and C (0.10±0.14 mg/L) relative to Site A (0.01±0.02 mg/L); nevertheless, fish phosphorus levels were significantly deficient, suggesting bioavailability constraints attributed to metal complexation and pH-dependent precipitation. Zinc concentration was greatest at Site C (0.45±0.02 mg/L), associated with industrial pollution, and, however, remained below WHO thresholds (15.0 mg/L) at all locations. The great discrepancy between water phosphorus availability and fish tissue concentrations indicates that contamination may hinder uptake, as evidenced by Abdur Rashid *et al.*[21], who showed decreased phosphorus bioavailability in metal-contaminated aquatic environments. Findings from research corroborate the pH-dependent phosphorus precipitation concept, especially in a brackish system that is slightly alkaline, as seen in Site C (Brackish water)[22].

Most of the minerals showed bioaccumulation factors less than 1 (Table 4). This pattern reflects sophisticated osmoregulatory and excretory mechanisms that maintain mineral homeostasis despite its environmental concentrations[20]. The most significant finding was the elevated phosphorus BAF in *Clarias gariepinus* and Zinc BAF in *Polydactylus quadrifilis*. These patterns of phosphorus bioaccumulation show how the species has adapted to actively concentrate this important nutrient, which is needed for making nucleic acids[23]. The bioaccumulation pattern of zinc is linked to this species' carnivorous way of life and the fact that zinc is needed by more than 300 enzymes in marine environments[24]. This mineral BAF analysis further substantiates the species-specific physiological disparities that affect nutritional quality.

The strong positive correlations between the mineral concentrations in fish tissue and water (Table 5) give us more information about how minerals are taken up by fish in different habitats.

The strong positive correlations between fish tissue and water mineral concentrations (Table 5) provides further insight on the active mineral uptake mechanisms across different habitats. These strong universal correlations observed for calcium, magnesium and sodium (r>0.94) suggest these minerals are actively and not passively regulated[25]. The absence of correlations for certain mineral pairs such as zinc and phosphorus likely reflects homeostatic regulation where tissue concentrations are maintained independently of environmental availability[25]. These findings are important for aquaculture management and nutritional assessment of fish caught in the wild.

CONCLUSION

This comprehensive nutritional assessment reveals significant species-specific and habitat-dependent variations in both proximate and essential mineral profiles. The findings demonstrate that all three fish species are good sources of nutrition and are suitable for addressing conditions such as protein-energy malnutrition in local communities. The presence of essential minerals such as calcium and magnesium in freshwater species makes these species valuable for supporting child and maternal diets. The low concentrations of some minerals suggest dietary diversification to meet daily requirements.

SIGNIFICANCE STATEMENT

This study discovered the significant variations in the nutritional composition of three commercially important fish species *Clarias gariepinus*, *Polydactylus quadrifilis*, and *Oreochromis niloticus* across freshwater, brackish, and saltwater environments. These variations highlight how habitat conditions influence proximate and mineral contents, providing valuable insights for nutritional planning, aquaculture development, and environmental monitoring. The findings are beneficial for fish nutritionists, aquaculture managers, and policymakers in optimizing fish farming strategies and ensuring food security in coastal regions. By establishing baseline data linking water quality to fish nutrient profiles, this study will help researchers uncover the critical areas of environmental influence on aquatic nutrition that many were not able to explore. Thus, a new theory on habitat-driven nutrient variability in fish may be arrived at.

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