DIET-MORPHOLOGY RELATIONSHIPS OF SOME FISH SPECIES IN THE CROSS RIVER ESTUARY, SOUTHEAST NIGERIA

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ABSTRACT: *Fish exploit the diversities of food organisms and habitats in their aquatic environments according to their structural morphology and feeding habits, hence its ecological roles and functions. Six morphological measurements and dietaries of 582 stomachs of eleven (11) species in the Cross River estuary, Nigeria, were examined from August-December, 2014 to establish interrelationship of diet and morphology. TrophLab® estimated the trophic level (TL) for each species. Dietaries reveal 3 to 11 food items on which basis species were grouped into three functional trophic guilds: omnivore (6 species), detritivore-algivore (2 species) and carnivore (3 species). Positive linear relationship was established between total length (TL) and mouth area (M_A) ($r = 0.31 - 0.96$; $p < 0.5$; $r^2 > 0.5$ in Cynoglossus senegalensis and Liza falcipinnis, $r^2 < 0.5$ for other species) except in the cichlid Ethmalosa fimbriata ($r = 0.000267$; $p = 0.9997$). Higher relationships were established in mouth area (M_A) and mouth dimensions (M_V and M_H) with trophic levels (T_{LS}) among species within same trophic guild than when non-related species were combined: detritivore ($r^2 = 1.00$), carnivore ($r^2 = 0.91$), omnivore ($r^2 = 0.4348$), and all species combined ($r^2 = 0.1414$). Cluster analysis reveal a positive trophic correlation whereby species of similar feed habits tend to exhibit similar diet-morphology traits than unrelated species. The canonical correspondence analysis reveal some level of morphological convergence in diet-morphological relationships, particularly, in traits like body depth-body height (BD/BH), mouth area and mouth area - trophic level (M_A/T_{LS}) and eye diameter (ED) among species. This study suggests trophic levels and mouth dimensions for similarly-sized samples of some species for which no information is available on their feeding habits could be estimated based on fish morphology of the species in study area.*

KEYWORDS: Food Web, *Trophlab*, Quantitative and Qualitative Trophic Connections

INTRODUCTION

Fish diet is a major topic in the area of fish biology. It forms the basis of establishing the ecological status of a given fish and determining the direction of energy flow within an ecosystem [1]. It also constitutes the basis for the development of a successful fisheries management programme on fish capture and culture [2]. Given the shift in emphasis in fisheries science, from single species management to multispecies approaches [3-4] the study of fish diet provides the most reliable method of determining the nature of biological interactions among the species [5]. Analysis of the stomach contents of fishes provides information on the niche, trophic dynamics and food webs essential for appropriate fisheries management. The study of the food and feeding habits of fish species is therefore, a subject of continuous research.

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Fish in natural habitats exploit a great diversity of food substances which vary in size and taxonomic groups using different adaptations (mouth, gill rakers, dentition and gut system). Hence food habit of fish could be related to its structural morphology in food capture and digestion [6]. Different fish species adapt to different feeding habits from larval stage to the mature-sized fish with different food items constituting the principal diet with ageing.

The food and feeding habit of fish assemblage deals with their ability to have good nutritive foods which could improve their growth within their environment. Therefore, the dietary analysis of fish in their natural habitat enhances the understanding of their growth, abundance, productivity and distribution [7] and seasonal fluxes in the type and magnitude of food available as well as the season it occurs [8].

The primary problems posed in the study of the fish feeding habits is to have the broad knowledge of the different species of prey in order to understand the quantitative and qualitative connection between fish and their food organisms [9]. Such information is lacking for the study area. This study is one a series designed to fill this gap. It adopts an ecosystem approach by quantifying feeding patterns and determining the feeding habits of the fish assemblage in the Cross River Estuary, their trophic levels and relating the diets to the morphology, in terms of mouth dimensions, trophic level and feeding guild and thus defining the ecological role of organisms within food webs for proper management of the fishery.

In the present study, the relationships between mouth dimensions and body size are presented for 11 estuarine fish species from the lower Cross River Estuary and discussed within the context of their trophic ecology.

MATERIALS AND METHODS

Study Area

The study was conducted at the Oron section of the lower Cross River estuary, southeast Nigeria (Fig. 1). The Cross River estuary is the largest estuary in the Gulf of Guinea [10] occupying a total of 54,000km^2 [11]. The whole river estuary lies approximately between longitudes 7^{o}30'E and 10^{o}00'E and latitude 4^o and 8^{o}N.

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Fig. 1. Map showing the sampling stations (inset map of Nigeria showing study area)

The climate is tropical and consists of two seasons: the wet (March to October) and dry (November to February) seasons. However, due to the effect of the hot humid moisturized air mass (as a result of the areas proximity to Guinea coast) rainfall is expected during every month of the year [12]. The estuary is characterized by brackish wetlands within which mangrove vegetation such as *Rhizophora harrisonni*, *R. mangle*, *R. racemosa*, *Avicennia africana*, the nipa palm (*Nypa fructican*) and *Laguncularia racemosa* thrives [13].

Three sampling stations were established in the study area at Oron: A: Uya Oro beach/bridge - 04^{o} 48′ 13.2″ N and 008^{o} 11′ 47.6″ E, site of log transportation and heavy anthropogenic activities; B: Museum beach - 04^{o} 49′ 37.9″ N and 008^{o} 13′ 52.9″ E; located downstream of station A and site of several outdoor recreational facilities, a petrol filling station and fishing; and C: Esuk ata nsu iyak or *Esin Ufot* - 04^{o} 49′ 08.5″ N and 008^{o} 14′ 47.3″ E; no industrial activities here apart from a government health centre, thick population, and open sewers (Fig. 1).

Sampling and Laboratory Procedures

Fish samples were purchased randomly from August to December, 2014, from selected artisanal fishers who restricted their activities to areas within and around the three sampling stations along the estuary. The fishers fished using gill net, cast net and local traps. The fish samples were transported in iced chest to the laboratory and fixed in 10% formalin solution till examined using fish identification guides [14-15].

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All fish sampled were measured to the nearest 0.1 cm total length (TL), standard length (SL) and 0.01 g total weight (TW). Eye diameter, ED (a vertical measurement of the distance or length of eye orbit), the vertical (M_V) and horizontal (M_H) mouth openings, body depth (BD), and body height, BH (a measure of vertical distance between dorsal and pelvic fins base) were taken to the nearest 0.01 mm using digital vernier calipers. Mouth dimensions were regressed against TL (either linearly or log linearly, based on the r^2 value) and the relationship between TL and mouth area (M_A) was also estimated using, $M_A = 0.25\pi (M_V M_H)$ [16].

Determination of Diet Composition and Trophic Levels

The guts were opened and the fullness condition of each stomach was determined quantitatively by the allocation of points: 0, 5, 10, 15 and 20 corresponding to empty, 25% full, 50% full, 75% full and fully distended stomachs [1]. The average gut fullness (*AGF*) was estimated as the total number of points allotted to each stomach divided by the number of specimens. The sorted contents of each stomach were classified to eight generic levels, and the individual food items were recorded and analyzed quantitatively in terms of gut repletion index (*GRI*), the number of non-empty guts divided by the total number of guts examined multiplied by 100.

The point allotted to each stomach was shared among the dietaries on the basis of their relative proportion by volume and expressed as percentage points (*PP*) of all dietaries encountered. The percentage relative frequency (*RF*) was calculated by expressing the number of each prey item in all non-empty stomach as a percentage of the total number of food items in all non-empty stomachs [1]. The overall importance of each dietary was expressed by the index of food dominance, *IFD* [17], based on the percentage points (*PP*) and percentage relative frequency (*RF*) of each food item. Dietaries with $IFD \geq 10\%$ were considered as primary dietaries; those with *IFD* of 1-9.9%, as secondary dietaries and those with $IFD < 1.0\%$ as incidental dietaries.

The trophic level (T_L) for each species (TROPH values and their standard errors, SE), was estimated from quantitative diet composition data (*IFP*) using *TrophLab*® [18] with food items categorized on the basis of trophic levels as nekton (fish bones and scales), detritus (sediments), plants (algae and sea grasses), and zoobenthos (molluscs and insects). The T_L for each species was compared to troph value estimated from the "qualitative approach" of *TrophLab*® (T_L*) using list of prey items found in the diet, and to troph value extracted from fishbase online, T_L** (www.fishbase.org). TROPH values vary between 2.0, for herbivorous/detrivorous, and 5.0, for piscivorous/carnivorous organisms [19, 20]. *TrophLab*® is a stand-alone computer application which through a random iterative process estimates the trophic level of a species based on trophic levels of its food items whose default values are extracted from fishbase [18].

The diversity of the trophic spectra of the species sampled were analyzed using PAST© version 2013 and described by the ecological biotic indices of Shannon-Weiner Diversity, *H'*, Simpson Dominance, *D*; Diversity, *1-D*; Evenness, e^H/S, and Equitability, *J*, indices and Margalef index, *d* [21]. The Bray Curtis two-way paired group cluster analysis was performed on stomach content data (*IFP*) to yield a dendrogram identifying hierarchy of association and natural grouping or clustering of dietaries [22].

RESULTS

Diet Composition

The fish assemblage examined comprised a total of 673 specimens of 11 species with a mix of immature/juvenile and adult fish, Fig. 2 (6.00 - 47.08 *cmTL*; $\overline{TL}$ = 16.56 *cmTL;* 2.71 – 2074 g;

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$\overline{TW}$ = 53.80 *gTW*). The overall stomach contents of the fish species examined reveal a high dietary complexity involving the utilization of a variety of food resources (Table 1) with the species exhibiting four functional feeding guilds (Table 2). The gut fullness for each species is shown in Fig. 3. The average gut fullness (AGF) ranges from 20% in *Labeo senegalensis* to 4.43% in *Pseudotolithus elongatus* (Table 1). Some food items (particularly crabs and bivalves) recorded very low *IFD* (< 10.0% and < 1.0%) indicating less importance to fish species (Table 1). The number of specimens with non-empty guts (% GRI) was highest for all species in Station C, located adjacent the channel opening to the sea (Fig. 3).

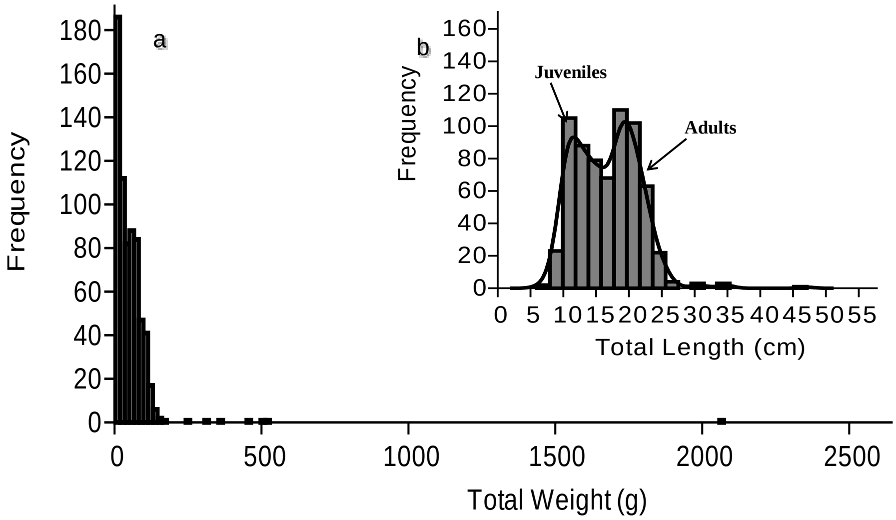

Fig. 2. Total weight (a) and length (b) profiles of fish examined for stomach contents (n = 673)

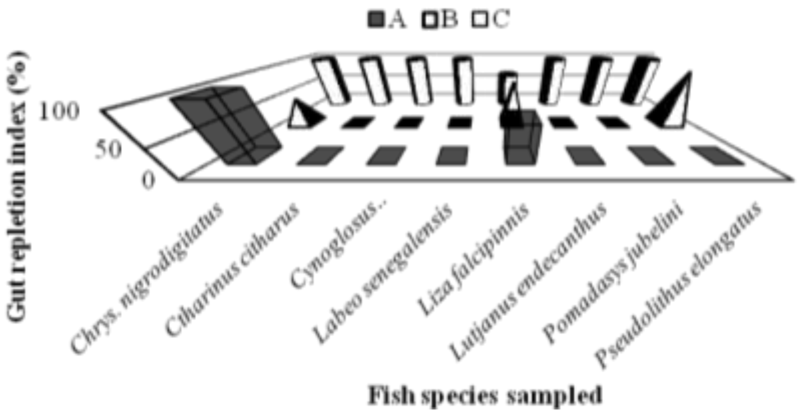

Fig. 3. Spatial distribution and relative frequency (%) of non-empty guts sampled along the Cross River Estuary, Nigeria

Diversity Indices of Diet Spectra

The dietaries of the specimens sampled comprise 3 to 11 items with diversity indices ranging from 0.1 (Oligodiverse) for *Lutjanus endecacanthus*, 0.5 (Mesodiverse) for *Pseudotolithus elongatus*, and > 0.5 (Polydiverse) for *Chrysicthys nigrodigitatus*, among others (Table 2).

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Morphological and Trophic Composition

Table 3 shows the trophic and morphometric data of the species, major food types/prey with respect to the highest *IFD* (%) obtained for each species and their feed habit. Measurements of mouth dimensions are also shown.

The statistical analysis of *TL* (mm) of the individuals from which measurements of mouth dimensions were taken and the estimation of the relationships between *TL* and M_A for each studied species are summarized in Table 4. The number of individuals sampled ranged from 1 (one) for *Labeo senegalensis* to 404 for *Pseudotolithus elongatus*. The r^2 values were > 0.5 for *Cynoglossus senegalensis* and < 0.5 for other species. Figures 4 and 5 provide charts of the relationship of mouth area (M_A), mouth dimensions (M_V and M_H) and maximum total lengths with trophic level (*TL*) of species indicating higher relationship between mouth dimensions and *TL*s on the bases of trophic guild (Fig. 4a, b, c.) than when all species are combined, independent of trophic relatedness (Fig. 4d). Trophic levels (*TL*) tended to increase with maximum total lengths (*TL* mm) in detrivores and omnivores (Fig. 5b, c.); the reverse was observed in carnivores (Fig. 5a). The composite sample (independent of trophic relatedness) reveal maximum total lengths contributed 0.6% to variations in trophic level (Fig. 5d).

The relationship between diet and morphology was further examined using the canonical correspondence and cluster analyses of trophic data in which the axes were linear combinations of explanatory variables (dietary and morphological variables). The cluster analysis reveals a positive trophic relationship whereby species of similar feed habits tend to be more similar in their diet/morphology traits. It clearly isolated and grouped together species with specialized feeding habits like the detritivores (such as *E. fimbriata* and *L. falcipinnis*) and carnivores (such as *S. afra* and *L. endecacanthus*) whereas generalist feeders like omnivores (such as *C. citharus, C. nigrodigitatus, P. jubelini*, and others) are dispersed through the morphological space (Fig. 6a). This is corroborated by trophic levels and guild of fish species sampled as shown in Fig. 6b.

Table 1: Index of food dominance, average gut fullness, non-empty guts and trophic levels of stomach contents of a fish assemblage along the Cross River Estuary, Nigeria

	Index of food dominance (%IFD) of species sampled										
Stomach Food Items	*Chrysichthys nigrodigitatus*	*Cynoglossus senegalensis*	*Citharinus citharus*	*Ethmalosa fimbriata*	*Labeo senegalensis*	*Liza falcipinnis*	*Lutjanus endecacanthus*	*Monodactylus sebae*	*Pomadasys jubelini*	*Pseudotolithus elongatus*	*Sphyraena afra*
PLANTS											
Plant materials	0.38	14.46	20.0	6.67	20.0	2.59		49.24		0.47	
Algae (diatoms)	1.05	16.53	15.0	19.99	4.98	23.64	2.08	9.23	20.0		
PISCES											
Fish remains	0.84	9.10			15.0	1.37	83.34		15.0	32.45	58.33
CRUSTACEA											
Crab	5.71									0.02	
Shrimp remains							2.08			51.27	20.83

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INSECTA											
Insect remains	10.23	4.12	15.0	13.32	10.0			1.53		0.13	
MOLLUSCA											
Clam	15.50	6.19									
Small sea snail	7.23	4.12							20.0		
Bivalve	3.52										
SEDIMENT											
Mud	21.54	10.33	10.0	6.67	20.0	0.76					
Sand grain	9.44	16.53	10.0	19.99	15.0	9.45	10.42	7.69	4.98	7.95	
Detritus	17.73	6.19	5.0	26.67	15.0	38.13		13.84	10.0	0.02	
WORMS											
Worm	0.10					0.76			15.0		
Unidentified items	6.63	12.39	25.0	6.67		23.28	2.08	18.46	15.0	7.67	20.83
TOTAL	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Trophic levels *TL*	2.55±0.26	2.45±0.32	2.53±0.	2.19±0.2	2.5±0.33	2.15±0.25	4.12±0.74	2.11±0.22	2.93±0.50	3.47±0.56	3.9±0.71
*TL**	3.4±0.46	2.8±0.46	2.53±0.	2.5±0.3	3.0±0.43	2.9±0.42	3.1±0.48	2.5±0.32	2.9±0.43	2.9±0.48	3.6±0.65
*TL***	3.2	3.6	2.2	2.5	2.0	2.9	4.1	3.9	3.3	4.1	4.0
AGF (%)	5.68	18.33	20.0	7.5	20	7.68	15	8.12	20	4.43	15

TL - Trophic values derived from *TrophLab*® using quantitative approach S/S – sampling stations
*TL**-Trophic values derived from *TrophLab*® using qualitative approach *n* – no. of specimens sampled
*TL*** - Trophic values extracted online from www.fishbase.org AGF = average gut fullness

The canonical correspondence analysis (Fig.7) however, reveals some level of morphological convergence in response to diet-morphology gradient, based on a measure of the similarity accounted for by the corresponding linear combinations of explanatory variables. The analysis indicate body depth-body height (BD/BH) and body depth - total length (BD/TL) are the two most important factors which account for 63.35% and 34.82% of observed variances, respectively. Ten of the species share strong dietary relationships (convergence) in body depth-body height (BD/BH), mouth area (M_A) and mouth area - trophic level (M_A/Tl) while *M. sebae* and *P. eolongatus* are better explained by their eye diameter (ED). Other ratios are probably of little importance in determining feeding habits. The distribution of the trophic levels of fishes by major habitat is shown in Figure 8.

Table 2. Ecological Indices of Index of Food Dominance (*IFD*) of Dietaries of Species Sampled in the Cross River Estuary, Nigeria

Ecological Indices of dietaries	**Species Sampled**										
	Chrysichthys nigrodigitatus	*Cynoglossus senegalensis*	*Liza falcipinnis*	*Monodactylus sebae*	*Pseudotolithus elongatus*	*Labeo senegalensis*	*Pomadasys jubelini*	*Lutjanus endecacanthus*	*Citharinus citharus*	*Ethmalosa fimbriata*	*Sphyraena afra*
No of Food items	11	10	8	6	8	7	7	5	7	7	3
Simpson's index of dominance, *D*	0.136	0.121	0.266	0.31	0.381	0.16	0.161	0.7067	0.17	0.182	0.427
Simpson's diversity, *1-D*	0.864	0.879	0.734	0.69	0.620	0.84	0.840	0.2933	0.83	0.818	0.573

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Evenness, e^h/S	0.661	0.6609	0.5594	0.6868	0.392	0.934	0.932	0.3752	0.907	0.87	0.8775
Equitability, *J*	0.839	0.8385	0.7206	0.7903	0.5498	0.9647	0.9636	0.3909	0.9496	0.928	0.8811
Margalef index, *d*	2.606	2.606	1.52	1.085	1.52	1.303	1.304	0.8686	1.303	1.303	0.4343
Shannon species diversity, *H'*	2.151	2.194	1.499	1.416	1.143	1.877	1.875	0.6292	1.848	1.807	0.968
Remark	PLD	PLD	PLD	PLD	MSD	PLD	PLD	OLD	PLD	PLD	MSD

OLD = Oligodiverse MSD = Mesodiverse PLD = Polydiverse

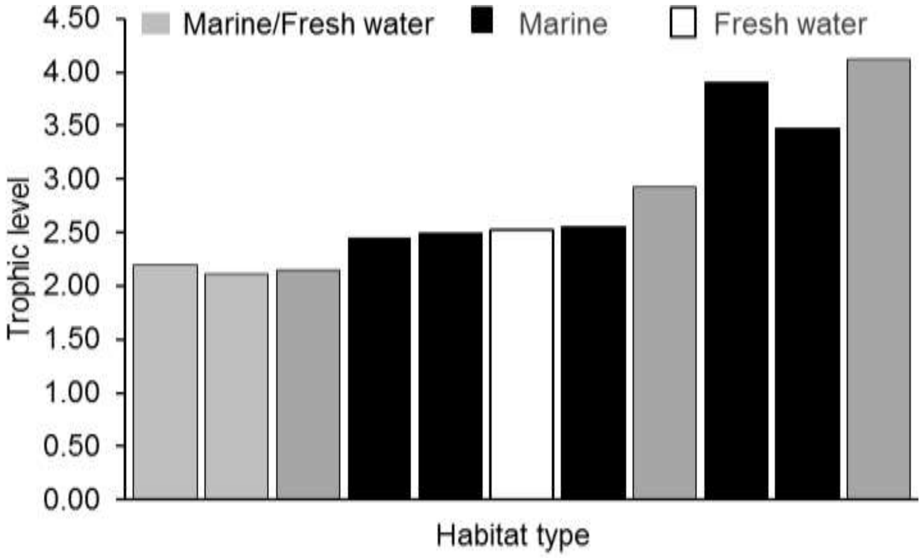

Fig. 8. The distribution of the trophic levels of fishes by major habit

DISCUSSION

A total of 673 fishes were used for this study. The highest was recorded in October (247). Examination of the gut contents of the fish assemblage revealed that the species feed mostly on diets of plant origin, vertebrates, invertebrates, and sediments. The diet components encountered during the study include algae, diatoms, fish remains, aquatic insect remains, plant materials, unidentified items, crustaceans, molluscs, worms, and mud and sand grains. Different food items were encountered for each species during the investigation. Index of food dominance enables these fishes to be categorized into: omnivore, detritivore-algivore and carnivore with number of food items ranging from 11 in *C. nigrodigitatus* to 3 in *Sphyraena afra* (Table 2).

The diet components of the species indicate availability of the particular food items during the study period. Size selection of diets by the species was not investigated during the study as was done in *Channa striatus* in Southeast Asia [23-24]. The gut repletion index of 100% (high proportion of the non-empty stomachs) among some species showed that such species are frequent feeders with higher energy requirement to sustain this level of feeding intensity [17]. This probably accounts for higher abundance of such species in the study area.

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Table 3: Information on trophic and morphometrics of some Cross River Estuary species

S/N	Names of Species/Families	*n*	*TL*	S/S	*BD*	*BH*	*ED*	*MV* Mm	*MH*	*MA*±S	*K*	Habitat	Length (L_{min})	Length (L_{max})	Major food types/prey	Food habit
1	*Lutjanus endecacanthus* Bleeker, 1863 **Lutjanidae**	1	4.12 ±0.74	C	89.01	34.19	15.36	23.45	13.95	256.96 ±0	1.64	M/F	25.02	25.02	Fish and sand grain.	Carni-vore
2	*Pseudotolithus elongatus* Bowdich,1825 **Sciaenidae**	404	3.47 ±0.56	A, B, C	15.26	31.24	8.77	14.82	11.96	1.46 ±4.55	0.95	M	7.00	26.02	Fish and shrimp	Carni-vore
3	*Sphyraena afra* Peters, 1844 **Sphyraenidae**	2	3.9 ±0.71	C	15.40	14.66	9.77	7.78	5.26	32.13 ±1.24	0.44	M	21.3	23.05	Fish and shrimp	Carni-vore
4	*Ethmalosa fimbriata* Bowdich, 1825 **Clupeidae**	2	2.19 ±0.2	A	14.43	22.67	9.29	13.43	10.35	109.51 ±0.71	1.10	M/F	15.04	16.05	Algae, aquatic insect remains, sand grains, detritus.	Detriti-vore and algivore
5	*Liza falcipinnis* (Valenciennes, 1836)	38	2.15 ±0.25	A, B, C	14.43	22.67	9.29	13.43	10.35	64.38 ±2.77	0.87	M/F	11.05	25.03	Chlorophyceae sand grain and detritus.	Detriti-vore
6	*Chrysichthys nigrodigitatus* (Lacepede, 1803) **Claroteidae**	121	2.55 ± 0.26	A, B, C	23.15	41.93	7.16	7.51	11.58	69.03 ±4.14	1.052	M	6.00	35.00	Clam, detritus, aquatic insect remains, mud.	Omni-vore
7	*Citharinus citharus* (Geoffroy Saint-Hilaire, 1809) **Citharinidae**	1	2.53 ±0.39	C	20.50	80.01	20.50	25.20	16.04	317.50 ±0	1.30	F	34.04	34.04	Chlorophyceae , aquatic insect remains, mud, sand grains,	Omni-vore
8	*Cynoglossus senegalensis* Kaup, 1858 **Cynoglossidae**	3	2.45 ±0.32	C	14.64	61.63	5.72	6.84	11.99	66.69 ±0	0.314	M	31.00	47.08	Chlorophyceae mud, sand grain, plant material, fish.	Omni-vore
9	*Labeo senegalensis* Valenciennes, 1842 **Cyprinidae**	1	2.5 ±0.33	C	33.52	64.25	13.91	18.88	13.82	204.96 ±0	1.05	M	35.04	35.04	Fish, aquatic insect, mud, detritus, sand grain, plant material.	Omni-vore
10	*Monodactylus sebae* Cuvier, 1829 **Monodactylidae**	8	2.11 ±0.22	A, B, C	26.75	62.23	14.61	11.46	11.50	1.06 ±0.83	3.63	M/F	13.05	15.09	Plant material, Chlorophyceae and detritus.	Omni-vore
11	*Pomadasys jubelini* (Cuvier, 1830) **Haemulidae**	1	2.93 ±0.50	C	32.43	67.75	16.67	17.21	18.57	251.03 ±0	1.32	M/F	30.00	30.00	Algae, fish, small sea snail, detritus and worm.	Omni-vore

TL - Trophic values derived from *TrophLab*® using quantitative approach S/S – sampling stations
n- number of specimens sampled F – freshwater M - Marine

The species in the present study revealed trophic flexibility and heterotrophic behaviour. The ecological advantage of this is that it enables the fish species to switch from one category of food to another in response to fluctuations in their abundance. Another advantage is the ability

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of the species to utilize many different food objects effectively. Some of the factors responsible for changes in feeding habits of fish include age, size of fish, sex, season, water temperature, habitat and competition [25]. Morphological changes in the feeding apparatus of the fish as a result of age may also lead to change in feeding habit [26].

Table 4. Relationship of mouth area (M_A) with total length (*TL*) and trophic level (*TL*) of fish species sampled along the Cross River Estuary, Nigeria

S/N	Trophic Guild/Names of species	*TL* and M_A Relationship
1	Carnivore: *Pseudotolithus elongatus* Sciaenidae	Log M_A = 1.1261 + 0.84787 Log TL; r = 0.66122; r^2 = 0.43722, p = 3.95E-52, n = 404
2	**All Carnivores (3 spp)**: *L. endecacanthus*, *P. elongatus* and *S. afra* combined	Log M_A = 1.0857 + 0.88669 Log TL r = 0.63609; r^2 = 0.40461, p = 1.55E-47, n = 407 $T_L = 3.4391\ M_A^{0.0336}$; r^2 = 0.9914, n=3
3	Detritivore: *Ethmalosa fimbriata* Cichlidae	Log M_A = 0.000843 + 2.0356 Log TL r = 0.000267; r^2 = 0.0000000712, p = 0.99966, n = 5
4	Detritivore: *Liza falcipinnis* Mugilidae	Log M_A = 1.5311 + 0.15364 Log TL r = 0.7758; r^2 = 0.60187, p = 0.000000011, n = 38
5	**All Detritivores (2 spp)**: *E. fimbriata* and *L. falcipinnis* combined	Log M_A = 1.6752 + 0.023128Log TL r = 0.72226; r^2 = 0.52166, p = 0.0000000457, n = 40 $T_L = 2.5305 M_A^{-0.035}$: r^2 = 1, n=2
6	Omnivore: *Chrysichthys nigrodigitatus* Claroteidae	Log M_A = 0.65268 + 1.0472Log TL r = 0.34175; r^2 = 0.11679; p = 0.000000338, n = 121
7	Omnivore: *Cynoglussus senegalensis* Cynoglossidae	Log M_A = 1.91 – 3.08 Log TL r = 0.96; r^2 = 0.92, n = 3
8	Omnivore: *Monodactylus sebae* Monodactylidae	Log M_A = 2.0932 – 0.16306 Log TL r = 0.38954; r^2 = 0.15174, p = 0.34014, n = 8
9	**All Omnivores (6 spp)**: *C. nigrodigitatus*, *C. citharus*, *C. senegalensis* *L. senegalensis***,** *M. sebae* and *P. jubelini*	Log M_A = 0.53967 + 1.1847 Log TL r = 0.31083; r^2 = 0.096616, p = 0.0000017, n = 135 $T_L = 2.1041 M_A^{0.0412}$; r^2 = 0.7001, n = 6
10	**All Eleven Species combined** (Carnivore, Detritivore, Omnivore)	Log M_A = 0.58476 + 1.3053Log TL; r = 0.32293; r^2 = 0.10428, p = 6.40E-18, n = 582 $T_L = 2.6744 M_A^{0.0057}$; r^2 = 0.0023, n =11
11	M_V = 0.4648TL, r^2 = - 0.616; M_H = 0.407TL, r^2 = - 0.543; M_A = 4.3072TL, r^2 = 0.0607	

The gut of *Labeo coubie* was described dominated by plant tissues (68.7% occurrence) indicating the fish is capable of digesting plant matter; suggesting it is herbivorous [27]. Similar observations (80.65% plant materials) were reported for *Labeo senegalensis* [28]; while another study observed worms (whole worm, worm part, and nematode) were the single most prominent food group suggesting the fish could be a benthic detrivore or herbivore [27]. Our study suggests a possibility that the species of 35.04 cm TL in Cross River estuary is an omnivore feeding almost evenly on plant materials, fish parts and sediments. Only one sample was examined in this study. Similar low occurrences of the species were observed in unpublished data on the study area.

Pseudotolithus elongatus are the most successful commercially important fish in both marine and estuarine environments [29]. The estuarine sciaenidae are dominated by *P. elongatus*, *P.*

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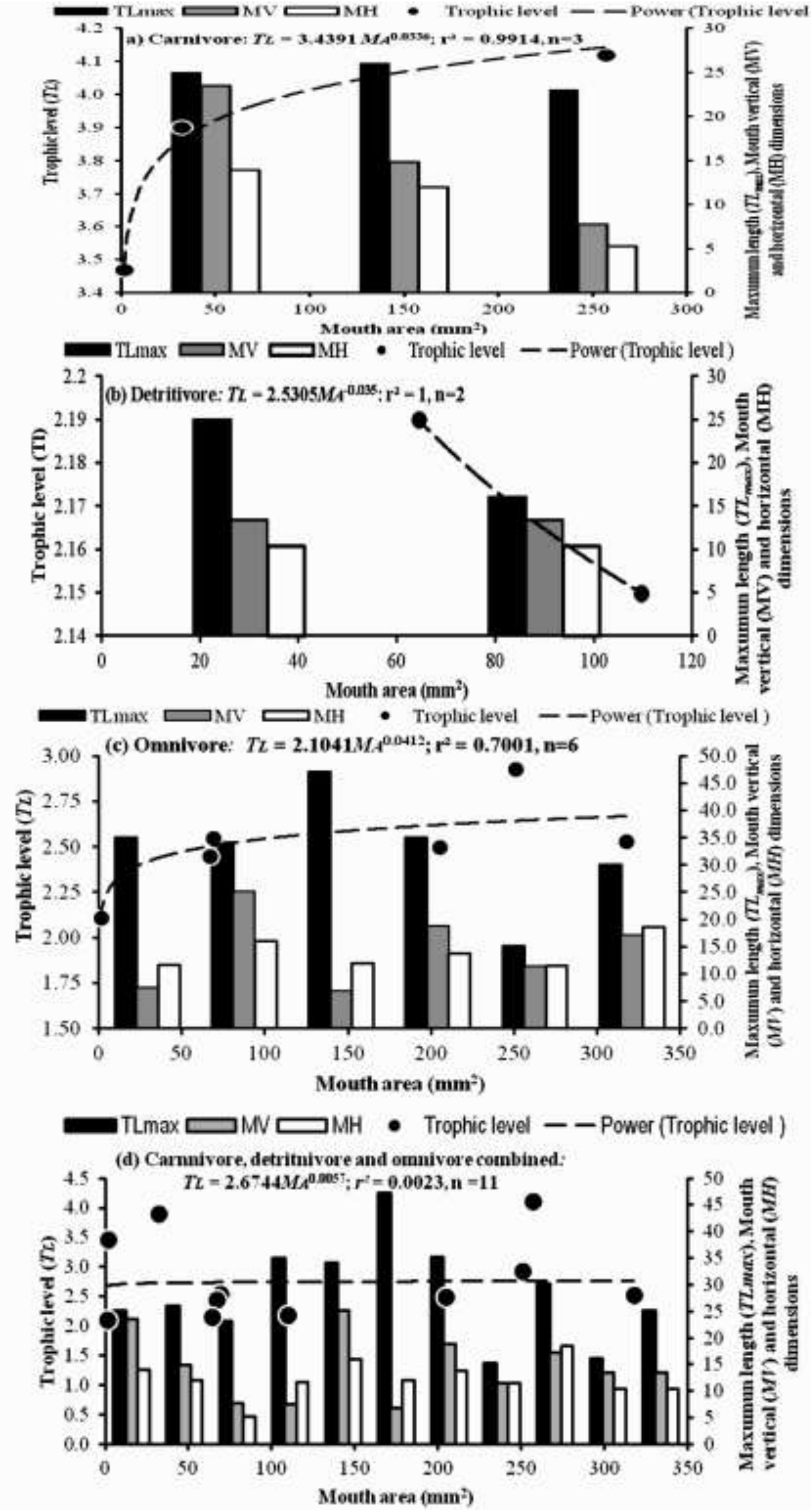

Fig. 4: Relationship of mouth area and mouth dimensions with trophic level of species sampled based on trophic guilds: (a) carnivores (b) detritivores (c) omnivores and (d) species of different trophic guilds sampled combined

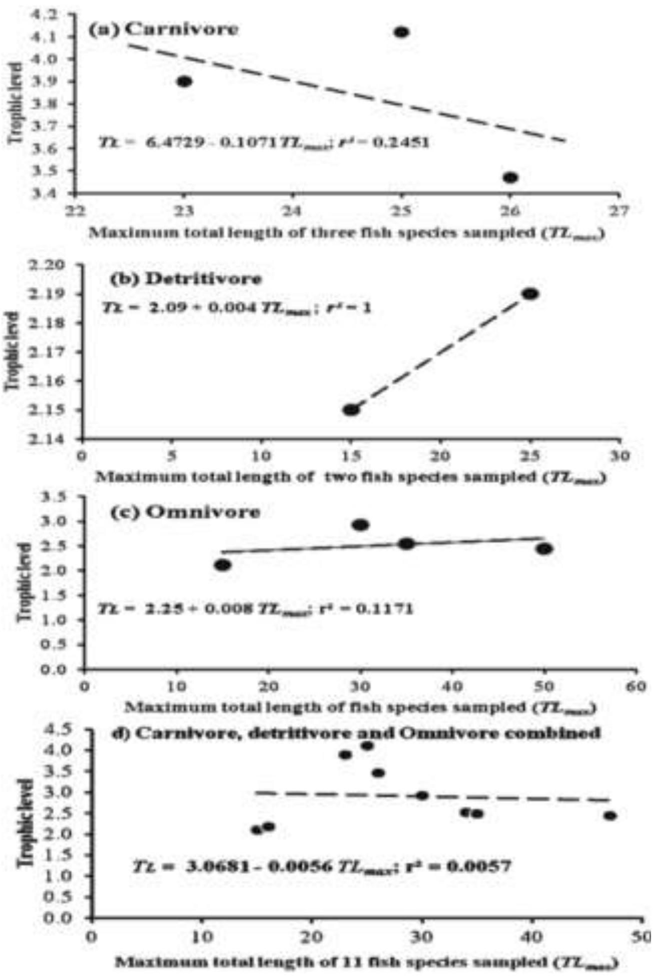

Fig. 5: Relationship of maximum total lengths with trophic levels of fish species sampled based on trophic guilds

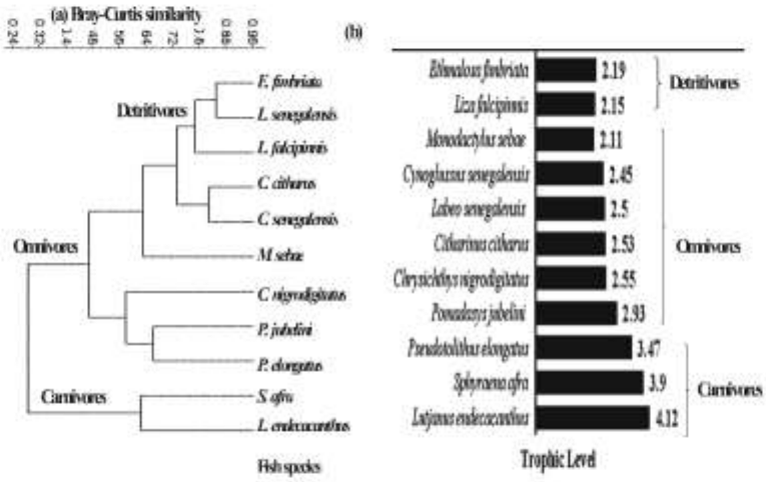

Fig. 6: Diet-morphological relationship and trophic guilds of a fish community in Cross River estuary, Nigeria showing (a) paired group cluster analysis of species in relation to dietaries and (b) trophic levels and guild of fish species sampled

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P. senegalensis and *P. typus* [30]. The dominance of shrimps in the gut of *P. elongatus* in this study agrees with the observations that invertebrates (such as Penaeid shrimps, mantis shrimps, *Macrobrachium spp*, Hermit crabs), small fish and crabs are the major food faunae in Bonny River, southeast Nigeria [31, 32]. Similar observations were made with slight variations [33-35]. The feeding habit of *P. elongatus* was described as omnivorous tending towards piscivory and benthic; and exhibiting ontogenic variations in food items with regards to fish size and age [36]. The dominance of fish and shrimps in the diet of *P. elongatus* in our study indicate the estuarine population most of which are juvenile (7.00 - 26.02 *cm TL*) exhibit carnivorous tendencies in the Cross River estuary (Table 3).

Sickle fin fish, *L. falcipinnis* are demersal and chiefly marine, coastal [14] or brackish water. The presence of plant materials in their diet presumes the species to be algivore or herbivore; while presence of organic matter and sand grains in reasonable number presumes the species to be both detritus and benthic feeder; presence of invertebrates (carnivore), while feeding on fish fry is an indication of its piscivorous ability [37]. Grey mullets are essentially herbivorous [1]; though they feed on algae and diatoms, consuming zooplanktons as well. *Liza subviridis* (green back grey mullet) fry feed principally on planktons and are believed to prefer diatoms and epiphytic Cyanophyceae [38]. However, mullet species were observed to feed predominantly on detritus, algae and sediments [39]. Consequently, *L. falcipinnis* was described as a "detritivore – algivore – deposit feeder" and *L. grandisquamis* as a "detritivore" [40]. *L. falcipinnis* in our study agrees with above description as "detritivore – algivore – deposit feeder" exhibiting strong preference for algae, sand grain and detritus. It was also noted that mullet species (*Mugil cephalus*) exhibit high feeding intensity which might be a reflection of the abundance of requisite food resources [41].

Mean condition factor was highest for *Monodactylus sebae* (3.6) and lowest for *Cynoglossus senegalensis* (0.31). Low body condition values (range: 0.28 - 0.36) were also reported for *C. senegalensis* [42] which may be attributed to its negative growth pattern. This species is omnivorous and piscivore-invertivorous off the coast of Cross River estuary, Nigeria, feeding on algae and plant matter, with the inclusion of sand and mud items suggesting the fish feeds close to the bottom using its inferior and/or ventral mouth location [42]. However, the (3) samples examined in this estuary exhibit omnivorous feeding habit (Tables 1, 3) probably due to shifts in food preferences along with availability.

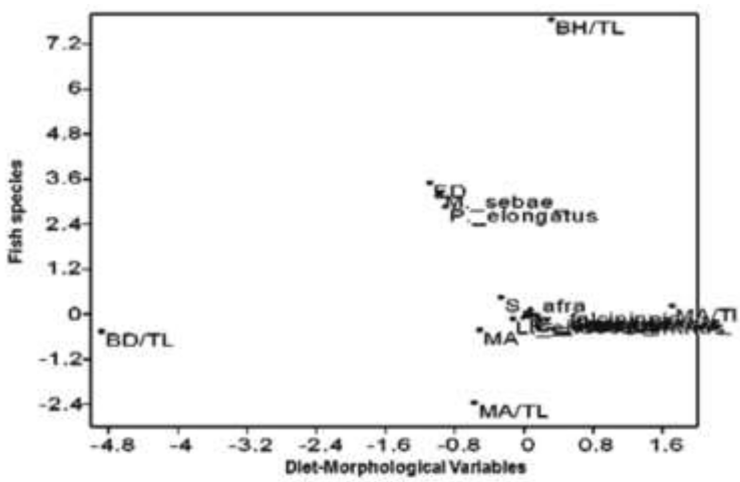

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Fig. 7. The canonical correspondence analysis of diet-morphology of a fish community in Cross River estuary, Nigeria, showing morphological convergence of fish species sampled irrespective of feeding habit

The estuarine catfish, *C. nigrodigitatus* in Lagos lagoon, southwest Nigeria, feed mainly on bivalves (84% mainly *Aloides*) and gastropod (mainly *Nerita* sp. 14%) [35], while mollusc, insects, cladocera, copepods, ostracods and mysids constituted the major dietaries of this species in the Lekki Lagoon, southwest Nigeria [43]. The species was described as omnivorous in Cross River estuary [44], feeding on a wide variety of benthic food organisms and materials, with a significant amount of plankton, fish and shrimps. The presence of pieces of large fish in their stomachs portrays the species as a top predator in the estuary. In another study, juveniles of *C. nigrodigitatus* were described as omnivorous, consuming diatoms (14%) while adults were planktotrophic, consuming diatoms (23%) and chlorophyceae, 33% [45]. Over 100 specimens of this species were examined in this study ranging from juveniles to adults (6.00-35.00 *cm TL*) and all exhibited omnivorous feeding habit. *E. fimbriata* is reported [46] to feed mostly on diets of plant origin: algae, diatoms, plant materials and also on fish eggs, fish scales, mud/sand particles, detritus and unidentified food items. Similar observations were made in this study which describes this species as detritivore – algivore.

The relationships between total length *TL*, trophic level, *TL* and mouth dimensions as determined by M_A, M_H and M_V were estimated for 11 estuarine fish species of the Cross River estuary, excluding landed samples caught offshore/outside the delineated sampling areas. The different types of fishing gears applied gave a fair representation of the assemblage with one to 400 individuals sampled per species. Further studies should enlarge the spatial coverage and actively engage more gears. Fish abundance is affected by season, hence less abundance of some species sampled. Generally, the fish samples as expected were of juvenile sizes, since the estuary is a nursery ground for several species [47]. This is the first record of a report between TL, *TL*, and mouth dimensions in fish assemblage of the area. Similar studies have been reported for the Mediterranean [16] and Colombian Caribbean [48] fish species. To improve on this study it would be needful to scrutinize unpublished theses data and other gray literature, particularly quantitative size-based changes in diets. However, our results suggest that trophic level increases with size for a given species or trophic guild (Fig. 4, Table 3). The trophic levels estimated here should be viewed in relation to the fish sizes sampled. The detection of relationships between diet and morphology is much enhanced when species are grouped on basis of trophic guild (Fig. 4a-c) or phylogeny [49] than when such is disregarded (Fig. 4d).

This study presents a power relationship describing trophic level (*TL*) as a function of mouth area (M_A), explaining about 70 to 100% of fish *TL* variation (Fig. 3). The significant power relationship ($r^2 > 0.9$) between M_A and trophic level (Table 4, Fig. 3), indicates a phenotype-environment relationship [50] between the resources utilized and the morphological traits used to exploit such resources [16]. Several other authors however, reported linear relationship between *TL* and M_A for several marine species [16, 51-53]. This study also shows a positive linear relationship exists between trophic level (*TL*) and maximum body size or total length, *TL* (i.e., trophic level increases with an increase in species' size), with the latter accounting for 11% (in omnivores) to 25% (in carnivores) of the variance in trophic level (Fig. 4). Some studies reported that fish size explained about 20% [54] to 30% [54] variation in fish trophic level variation. However, in this study a weak positive linear relationship of 0.6% variation was obtained (Fig.4d); pooled fish maximum lengths independent of trophic relatedness were used for the comparison. The samples examined consisted juveniles, sub- adults and adults (L_{min} = 6.00 - 35.04 cm TL; L_{max} = 15.09 - 47.08 cm TL), with intra-species size-based variations in

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trophic levels. Hence, application of this result should be limited to similarly-sized species for which no information is available on their feeding habits.

M_A exhibited an exponential relationship with body size for *Sarda chiliensis* Cuvier [55]. In this study, fish size (*TL*) does not determine mouth area; contributing 6% to its variations. However, a linear relationship was established between mouth dimensions, M_V and M_H, and fish size, with fish size explaining about 54 - 62% variations in mouth dimensions (Table 3). The T_L values estimated in this study fall within values predicted for each species in Fishbase (Table 3), indicating a high level of reliability.

The M_A is an integrative index of mouth morphology and diet pattern. The M_A values of the 11 fish species were characterized by highly diversified mouth morphology ranging from 1.01 to 317.50 mm^2 (Table 3). Such indicates diversification of food resources consumed and of competence and natural fitness for resource competition, exploring prey of diverse morphology and sizes in accordance with the foraging ability of the species. Large M_A dimensions allow consumption of large, profitable prey items (such as fishes, cephalopods and large decapods [52, 56] and attainment of higher trophic levels [57]. It is established [49] that mouth area and teeth size, both show a strong association with diets of fish and shellfish. For example, among the carnivorous species (Table 3), *L. endecacanthus* with a larger mouth (M_A = 257 mm^2) and extensible jaws, fed on larger-sized prey fishes (T_L = 4.12 ± 0.74) while *P. elongatus* with a small mouth (M_A = 1.5 mm^2), fed on shrimps and small fishes (T_L = 3.47 ± 0.56). Similar trend could be observed among the detritivores like *E. fimbriata* with a larger M_A (109.51) exhibiting invertivorous diet (aquatic insects) while *L. falcipinnis* concentrated on detritus and algae, though both share similar trophic levels. Some deviations were also observed. Though *C. citharus* had the highest mouth area among studied omnivores it had similar trophic level (2.5) and consumed similar prey items, primarily zoobenthos like *C. nigrodigitatus* with an M_A 21.7% the size of the former (Table 3, Fig. 4). The M_A of marine fishes increases faster with length for carnivorous than omnivorous fishes [16] as illustrated in M_A-*TL* relationship in Table 4: the carnivorous species display positive slope and stronger association (40%) than omnivorous fishes (10%); some omnivores like *C. senegalensis* and *M. sebae* indicate negative slopes. The predator:prey length ratio for various fishes is established at about 4 : 1 [58, 59].

Eye position is associated with aquatic invertebrates and plankton in diet [49]. Figure 7 illustrates the importance of eye parameter (eye diameter, ED) in *M. sebae* and *P. elongatus; P. elongatus* in this study which showed preference for aquatic invertebrates like shrimps (51.27%) and fish (32%).

The 11 estuarine fish species studied can be divided, according to their feeding habits into three functional trophic groups: carnivores, detritivores and omnivores.

Carnivores (*Lutjanus endecacanthus*, *Pseudotolithus elongatus* and *Sphyraena afra*) with a preference for fish tissues and shrimp remains (3.5 < T_L < 4.1). These species were largely oligo- or mesodiverse in dietaries. They could be described as macrocarnivores consuming mainly fish (50-85%) but also shrimps (*L. endecacanthus* and *S. afra*). *P. elongatus* showed preference for shrimps (51.27%) to fish (32%). *L. endecacanthus* could be described as a specialized carnivore with strong preference for fish (83.3%); the presence of sand grains (10.42%) in its diet confirms its habitat as benthic (Table 3). Mediterranean Sea species of this group [60] recorded 3.7 < trophic level < 4.0.

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Detritivores (*Liza falcipinnis* and *Ethmalosa fimbriata*) were polydiverse in dietaries with *T*Ls between 2.15 – 2.19, and had their gut generally full of a green or brown paste comprised of detritus and algae, particularly, chlorophyceae and diatoms. In addition *E. fimbriata* further exhibited invertivorous and algivorous feeding habits with aquatic insects and diatoms, respectively, constituting major food items (*IFD* >10%).

Six species were classified as omnivores showing heterogenous and polydiverse diets. ***Omnivores*** with a preference for vegetal material (*T*L = 2.45-2.5) but also feed on other prey such as fish, aquatic insect, mud, detritus are represented by *Cynoglossus senegalensis* and *Monodactylus sebae. C. senegalensis* ingested many (31%) aquatic plants and algae (chlorophyceae) along with sediment (33%) while *M. sebae* showed tendency of an unspecialized herbivore ingesting as much as 20% sediment in a diet based on higher plants and algae (60%). This group in the Mediterranean Sea [60] recorded 2.1 < trophic level < 2.9.

Omnivores with a preference for animal materials (2.5 < *T*L < 2.9) were represented by *Chrysichthys nigrodigitatus, Labeo senegalensis, Pomadasys jubelini*, and *Citharinus citharus. C. nigrodigitatus* consumed a lot of mud and detritus while feeding primarily on zoobenthos like clam, aquatic insect remains and other molluscs. *L. senegalensis* also ingested large amounts of sediment (50%) in a diversified diet of higher plants (20%), fish parts (15%) and aquatic insects (10%). The stomach contents of *P. jubelini* revealed similar quantities each (15 - 20%) of algae, fish, detritus, and worms. *C. citharus* also ingested similar quantities each (15 - 20%) of plant materials, algae (chlorophyceae), aquatic insects and sediment. This group in the Mediterranean Sea [60] recorded 2.9 < trophic level < 3.7, indicating the presence of animal tissues of higher trophic levels in their diet. Other functional trophic groups identified for the Mediterranean Sea [60] include: pure herbivores (trophic level = 2.0-2.1) and carnivores exhibiting a preference for fish and cephalopods (4.0 < trophic level < 4.6). Fishing generally removes the largest individuals of a species, which usually have higher trophic levels.

The distribution of the trophic levels of fishes by major habitat shows the estuarine species of the Cross River comprise mainly euryhaline species naturally inhabiting both marine and fresh waters and exhibiting a wide range of trophic levels 2.1 – 4.1 (Fig. 8). Marine water species are also more common than fresh water species.

CONCLUSION

The food resources and feeding grounds of the Cross River estuary are partitioned among estuarine species to enhance their coexistence. The ecological advantage is that the wide range of dietaries and food overlaps minimizes competition for food and allows switch from one food category to another in response to fluctuations in abundance of main prey items. The interaction between morphology (mouth area) and ecology is strongest within trophic guilds indicating the ability of species to utilize many different food objects effectively and distinctly. It is hoped that the dietary list, trophic level and diet-morphology associations established in this study could be useful in applications to estuarine fish species in Nigeria and elsewhere, such as estimating trophic levels for similarly-sized species for which no information is available on their feeding habits. Three trophic groups (carnivore, detritivore and omnivore) were identified within food webs of the estuary for proper management of the fishery.

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