Food categories reconstruction and feeding consumption estimates for the Sciaenid *Macrodon ancylodon* (Bloch & Schneider), and the congeneric fishes *Stellifer rastrifer* (Jordan) and *Stellifer naso* (Jordan) (Pisces, Perciformes) in the Caeté Estuary, Northern Coast of Brazil

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ABSTRACT. A quantitative method to estimate fish feeding consumption and energy intake from different food categories through the reconstruction of ingested preys based on hard not digestible body structures is presented. In order to establish the equations of the functional relationships between preys weight and body structures, stomachs of 1.086 specimens of *Macrodon ancylodon* (Bloch & Schneider, 1801), *Stellifer rastrifer* (Jordan, 1889), and *Stellifer naso* (Jordan, 1889) fish species were dissected. Consequently, preys reconstruction enabled a quantitative evaluation of food categories consumption. Results indicate a marked difference in diet composition and energy requirements according to fish species ontogenetic development.

KEY WORDS. Energetic values, feeding ingestion rates.

RESUMO. Um método quantitativo para se estimar o consumo alimentar e o aporte energético das diferentes categorias alimentares é apresentado através da reconstrução das presas ingeridas com base em estruturas corporais não digeríveis. Para tal, o presente estudo estabelece, através do exame dos conteúdos estomacais de 1.086 exemplares dissecados de *Macrodon ancylodon* (Bloch & Schneider, 1801), *Stellifer rastrifer* (Jordan, 1889) e *Stellifer naso* (Jordan, 1889), as equações das relações funcionais entre o peso das presas e estruturas corporais. Com as categorias reconstruídas foi possível quantificar o alimento ingerido pelos espécimes. Os resultados indicaram que existe uma marcada diferença, tanto na composição das categorias alimentares, bem como no aporte energético acompanhando o desenvolvimento ontogênico do predador.

PALAVRAS CHAVE. Valores energéticos, taxas de consumo alimentar.

Temporal variations in the availability of feeding resources are known to be responsible for diet plasticity of tropical fishes (Knöppel 1970). The daily continuous food ingestion often characterizing tropical fishes, and reflected by relatively fast metabolic processes, hampered proper daily feeding rhythm definition (Fonteles Filho 1989, Pauly 1994). As a result, difficulties are often encountered to estimate daily food consumption and energetic contribution of each food items for a given predator. In addition, a proper identification of the preys, specially of fish larvae or juveniles, is limited by their advanced digestion state (Torno 1976).

Many studies on fishes trophic ecology include a qualitative approach of the diet through the identification of the most abundant preys present in the stomach. However, proper construction of trophic models also require data on preys abundance and biomass, as well as additional information on the way each of these food items contributes to the energetic flow within the aquatic ecosystem. Therefore, as already explained by Worthmann (1979) it appears as fundamental to first restore size and body weight of all ingested preys, to better understand their contribution in the food chain.

This study aims to first of all, estimate morphometrical relationships of *Stellifer rastrifer* (Jordan, 1889), *Stellifer naso* (Jordan, 1889) and *Macrodon ancylodon* (Bloch & Schneider, 1801) preys, to subsequently calculate average biomass and energetic values of the ingested food groups, in accordance to the development stage of the predator.

MATERIAL AND METHODS

In order to define the food groups more frequently ingested by each predator, 1.086 stomachs (469 for *Macrodon ancylodon*, 459 for *Stellifer rastrifer*, and 158 for *S. naso*) from fishes of different sizes were dissected. Once all fed items identified and gathered into taxonomic groups, the indigestible body parts such as exoskeletons, otoliths and eyes, were picked up and identified to the highest taxonomic level possible.

In parallel, preys most commonly encountered in fish stomachs were collected in the wild within the same estuary, then weighted, measured and dissected in order to assess the size of all the indigestible parts already found in the stomachs of the three predators.

Zooplanktonic organisms were measured (mm), from the head up to the caudal thorns (L_{ct}), using a micrometric magnifying glass. Length-weight relationships, were then established for five or six length classes (mm) including 100 to 200 individuals pending on the species and defined based on the fish size frequency data. Average individual body weight was estimated through the total weight (g) obtained for each length class divided by the number of weighed individuals. Results were plotted, and the regression between weight and length was estimated using the least squares method.

In the case of crustacean decapods, the indigestible structures included eyes and carapace. Relations between carapace length (L_{car}) and ocular peduncle (Lp_{eye}) of 48 individuals of *Acetes americanus* Ortmann, 1893, and between carapace length (L_{car}) and eye diameter (D_{eye}) of 128 individuals of *Xiphopenaeus kroyeri* (Heller, 1862) were established. In the case of the crustacean *Uca* sp., the relationship was established between body weight (g) and carapace width W_{car} (mm) of the individuals. Obtention of these relationships enabled subsequent plotting of preys body structure size *vs* preys weight and definition of mathematical equations for the obtained regressions

Collection of otoliths from preyed fishes and subsequent study of their shape in relation to preys size enabled to define mathematical equations between these two parameters. Hence sagitta width W_{otol} (mm) was plotted *vs* preys standard length (mm) (L_s) or preys weight, and respective linear or exponential regressions were calculated.

Mathematical functions between preys body parts were given as linear regressions, obtained after logarithmic transformations in the case of exponential relationships. Once the mathematical relations established, body weights of various length classes of each food categories were reconstructed. Average consumption of all three studied predators was assessed through the sum of weights of all feeding categories per defined length class. Additionally, lengths at first maturation as defined by CAMARGO & ISAAC (in press) enabled dividing the predators into three ontogenic groups, namely the younger, pre-adult and adult groups. Predators energetic intake (Kcal) for each food category, and expressed per gram of predator, was calculated based on the energetic contents of the preys (Kcal/gram of preys), as available in the literature.

RESULTS

Diet composition of the three predator species varies along the ontogeny. While young individuals feed more exclusively on zooplanktonic organisms such as *Pseudodiaptomus marshi* Wright, 1936 and *Acartia lilljerborgii* Giesbrecht, 1889 copepods, pre-adults also include in their diet invertebrates like *Acetes americanus*, *Xiphopenaeus kroyeri*, and *Uca* sp. Other hand, adults can also feed on young fishes like *Cathorops arenatus* (Valenciennes, 1840), *Macrodon ancylodon*, and *Stellifer rastrifer*, hence demonstrating a cannibalism behavior (Figs 1-3).

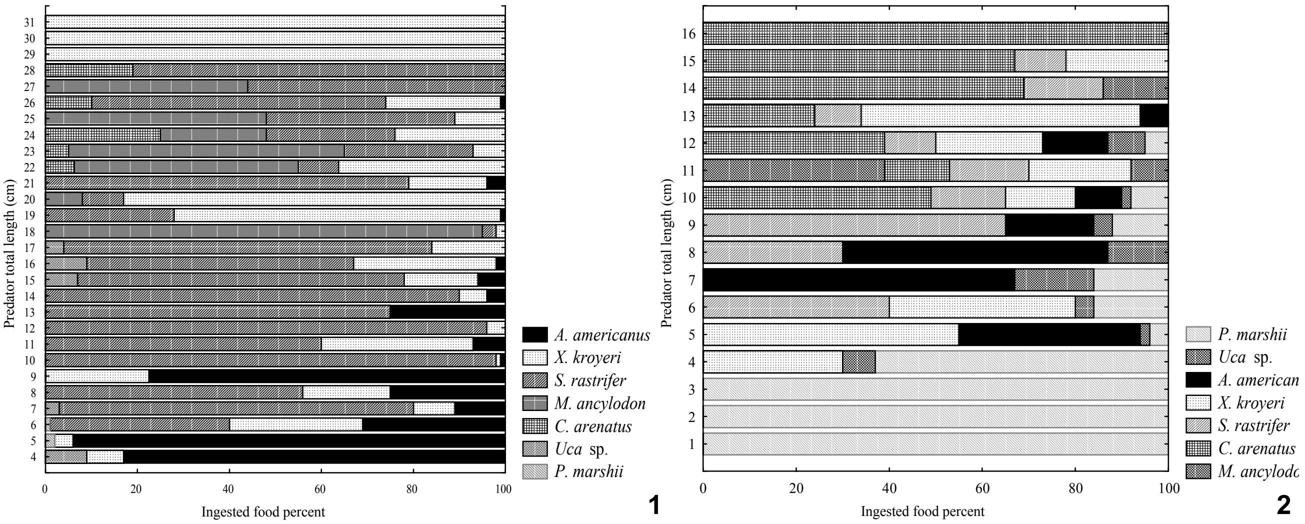
Fresh body weight of the preys, obtained through mathematical equations themselves issued from body structure relationships, is presented in table I.

For each of the three preyed species, namely: *Stellifer rastrifer*, *Macrodon ancylodon* and *Cathorops arenatus*, linear equations between otolith width and individual standard length, and exponential equations between body weight and otolith width or standard length were established. It is important to note that otoliths, known as body growth indicators, present an exponential relationship with fish body weight up to the juvenile stage, after which parameters of the equation change. Therefore, as in this case predators consume exclusively young organisms, equations were only defined for young preys.

Once preys weight reconstructed, food consumptions (per gram of body weight) were defined by predator group class of 1 cm. In the case of juveniles Macrodon ancylodon (Lt ≤ 21 cm) consumption rate ranged from 0.002g of prey/g of predator to 0.800g of prey/g of predator. For specimens of Lt ≥ 21 cm, consumption rate was comprised between 0.001 g of prey/g of predator and 0.400 g of prey/g of predator. Results indicate that *M. ancylodon* of a total length comprised between 4 and 6 cm fed preferentially on juvenile decapods of Sergestidae (*Acetes americanus*) and Penaeidae (*Xiphopenaeus kroyeri*). *Acartia lilljeborgii* and *Pseudodiaptomus marshi* were the more common copepods consumed by the three predators; however due their small size they represented a relatively small proportion of the overall stomach contents. Above 6 cm standard length, diet of the younger specimens was complemented by fish juveniles, principally *Stellifer rastrifer* and *Macrodon ancylodon* and to a lower extends *Cathorops arenatus* (Fig. 1).

In the case of juveniles *Stellifer rastrifer* of length ranging between 1 and 10 cm, results indicate a consumption rate comprised between 0.001 g of prey/g of predator to 0.085 g of prey/g of predator. For bigger individuals up to 16 cm of length, the rate ranged between 0.007 g of prey/g of predator and 0.075 g of prey/g of predator. Juveniles of 1 to 3 cm of total length fed mainly on zooplankton, and especially on copepods such as *Pseudodiaptomus marshi*. At 4 cm of total length, this diet was complemented by juveniles of crustacean decapods like *Acetes, Xiphopenaeus* and *Uca* sp. At last, diet of bigger individuals (i.e. ≥ 6 cm standard length) also included fish juveniles, mainly *Stellifer rastrifer* and *Cathorops arenatus* species (Fig. 2).

Rates of average consumption for *Stellifer naso* ranged from 0.001 g of prey/g of predator to 0.013 g of prey/g of predator for individuals measuring from 4 to 10 cm standard length, and from 0.003 g of prey/g of predator to 0.034 g of prey/g of predator for bigger individuals of 11 to 16 cm of standard



Figures 1-2. Percentage of food categories in ingested by length class of (1) *Macrodon ancylodon* and (2) *Stellifer rastrifer*.

Table I. Mathematical relatinships established for various body structures of the main food resources of *M. ancylodon, S. rastrifer*, and *S. naso.*

Feeding Category	Species	Equation	Range (mm)	n	R^2
Zooplankton	*Pseudodiaptomus marshii*	Weight = $7x10^{-5} *L_{ct}^{3.47}$	0.89-1.27	750	0.96
	Acartia lilljerborgi	Weight = $4.4x10^{-5}*L_{ct}^{3.85}$	0.82-1.16	860	0.95
Crustaceans Decapods	*Acetes americanus*	Lcar = $-0.128+3.537LP_{eye}$ Weight = $0.01*CP_{eye}^{4.64}$	0.65-1.65	48	0.98 0.82
	Xiphopenaeus kroyeri	Lcar = $3.15+5.340*D_{eye}$ Weight = $5x10^{-4} *L_{car}^{3.10}$	0.61-2.21 4-16	128 140	0.85 0.97
	Uca sp.	Weight = $3x10^{-4}*W_{Car}^{3.17}$	7-19	27	0.98
Fishes	*Cathorops arenatus*	Ls = $-12.17+24.94W_{otol}$ Weight = $9x10^{-6}*L_s^{2.86}$	1.6-3.2 27-70	47 47	0.96 0.98
	Stellifer rastrifer	Ls = $-8.24+26.02W_{otol}$ Weight = $9.1x10^{-3}*L_s^{3.04}$	1.34-3.40 2.1-8.2	48	0.96 0.97
	Macrodon ancylodon	Ls = $5.23+27.8*W_{otol}$ Weight = $4x10^{-6}*L_s^{3.25}$	0.6-2.2 28-78	43	0.98 0.98

(L_{ct}) Length up to the caudal thorns; (LP_{eye}) ocular peduncle length; (D_{eye}) eye diameter; (W_{Car}) carapace width; (W_{otol}) otoliths width; (L_s) standard length.

length. Specimens of 4 cm fed mainly on copepods like *Pseudodiaptomus marshii* and *Acartia lilljerborgi*, while individuals of standard length ^{3} 5 cm also eat decapods and barnacles larvae. Larger individuals showed preferences for crustacean decapods of *Uca* sp. and *Acetes americanus*, and to a lower extend for juveniles of *Cathorops arenatus* (Fig. 3).

Based on the conversion factors mentioned in the literature for the most common fed items, the different categories were transformed into energy units (Kcal) (Tab. II).

Based on the performed calculations presented in table II, the relative energetic intake for each prey and by predator was estimated (Tab. III).

The main energetic intake in the diet was due to fishes, whose size increases concomitantly with predators size.

DISCUSSION

The main energy flow in the Caeté Estuary was found to be of benthic origin (Wolff *et al.* 2000). The present results

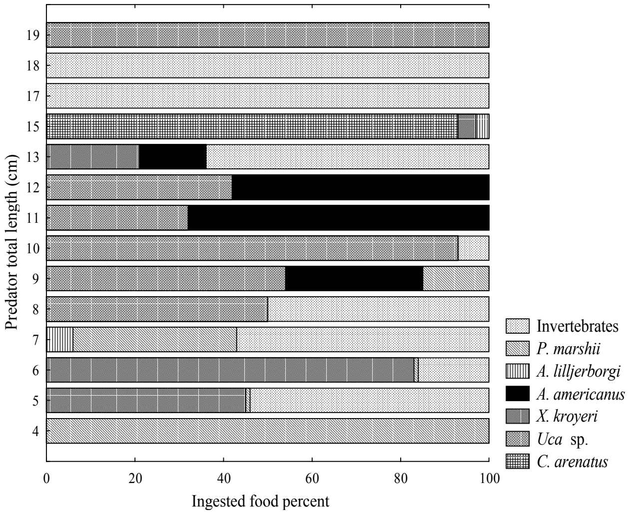


Figure 3. Percentage food categories ingested by length class of *Stellifer naso*.

Table II. Caloric values (kcal) for food categories per fresh weight unit (g), as indicated in the litterature.

Feeding Categories	Fresh Weight (Kcal/g)	Source for Calculation
Peneidae	1.09	Thayer *et al.* (1973)
Fishes	1.54	Whitfield & Blader (1980)
Acartia tonsa	0.79	Honjo & Roman (1978) Butler & Dam (1994)
Pseudodiaptomus marshi	0.83	Uye & Kaname (1994)
Uca sp.	0.45	Golley (1961)

Table III. Energetic contribution (Kcal) of each food categories expressed per body weight unit (g) of predator.

Feeding Categories	Predator Kcal/g		
	M. ancylodon	*S. rastrifer*	*S. naso*
Fishes	0.031-1.170	0.031-0.072	0.005-0.054
Acetes-Xiphopenaus	0.011-0.087	0.001-0.092	0.002-0.008
Uca sp.	0.005-0.007	0.001-0.002	0.0001-0.018
Pseudodiaptomus-Acartia	0.004-0.008	0.001-0.002	0.001-0.004

indicate that demersal preys constitute the main feeding resources for the three fish species studied. However, it was showed clear difference in the qualitative composition of the diet between individuals of different sizes but belonging to a same species. This variation was related to predators digestive structures efficiency as a function of individual age, and to preys availability within the estuary. Based on the energetic input from planktonic preys, it can be hypothesized that juveniles have a higher feeding frequency in order to compensate for the relatively low supply in energy provided by their diet. On the other hand, the adults, who feed on bigger preys, would present a lower feeding frequency. The relatively high frequency of fishes and shrimps in predators stomachs, could be explained by the relatively high energetic value of these preys. The present results support Weatherley (1972) finding, who reported higher metabolic rates for young fishes when compared to the adults, hence suggesting bigger feeding requirements of the formers.

The reconstruction of preys size and weight for several groups of vertebrate has already been applied to different aquatic environments as in Hansel *et al.* (1988), and Prenda & Granado-Lorencio (1992). This methodology, pursued in details, can provide accurate information on the energy requirements of an individual all along its ontogeny, but also on the relationships between preys and predators.

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