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Length-weight relationships of the ichthyofauna from a coastal subtropical system: a tool for biomass estimates and ecosystem modelling

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Abstract: Aiming to analyse the growth pattern, to allow biomass estimates and consequently to subsidize the ecosystem modelling, the length-weight relationships (LWR) of 39 fish species from the Araçá Bay, a subtropical coastal area chosen as model for a holistic study comprising environmental, social and economic aspects have been estimated. The objective of this study was to provide LWR for the fishes from the area itself, accurately based on the life stages of fish populations present there. Particularly for *Albula vulpes*, *Trachinotus carolinus*, *T. falcatus*, *Archosargus rhomboidalis* and *Kyphosus sectatrix* these are the first records of LWR in Brazil.
Keywords: *Araçá Bay, relative growth, Huxley model, Brazil.*

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Resumo: Com o objetivo de analisar o padrão de crescimento e viabilizar estimativas de biomassas e, consequentemente, subsidiar a modelagem ecossistêmica, foram estimadas as relações comprimento-peso (RCP) de 39 espécies de peixes da baía do Araçá, uma área costeira subtropical escolhida como modelo para um estudo holístico compreendendo aspectos ambientais, sociais e econômicos. O objetivo deste estudo foi fornecer RCP para os peixes da própria área, baseadas nas estágios de vida das populações ictiícas ali presentes. Especialmente para *Albula vulpes*, *Trachinotus carolinus*, *T. falcatus*, *Archosargus rhomboidalis* e *Kyphosus sectatrix* estas são as primeiras estimativas de RCP no Brasil.
Palavras-chave: *baía do Araçá, crescimento relativo, modelo de Huxley, Brasil.*

Introduction

In the current ichthyology, it is noteworthy that biodiversity conservation and sustainability are not dissociable. Socio-ecosystem approach for fishery management is a fact (Baigun et al. 2012). In the Southwestern Atlantic Ocean comprising the Brazilian coast, there are many marine environments with different levels of impact (Lana et al. 2001, Meniconi et al. 2012), consequence of global changes in local, medium and high scales (Ray & McCormick-Ray 2014). The Araçá Bay (23°48’47,3”S 45°24’22,1”W) (Figure 1) is one of them, and it was chosen as a model for a holistic and integrated study comprising biology, ecology, oceanography, economy, sociology and policy (BIOTA FAPESP Araçá 2015).

Araçá Bay is an area of approximately 1 Km^2 subjected to daily tides, showing tidal pools, mangroves, rocky substrates, sandy beaches and the typical pelagic and benthic habitats. It shelters three beaches and two small islands. The Mãe Isabel stream flows in its north portion. In addition, it is directly affected by pollution and by the São Sebastião Port, which is close to the area. Fishermen live surrounding the bay using it and its adjacent areas for survival. Biodiversity and species richness in Araçá Bay are surprisingly high, playing an important role in the productivity of the adjacent areas (Amaral et al. 2010, 2015).

Concerning the fish population dynamics and the community structure, length-weight relationships (LWR) are one of the most useful tools in applied ichthyology and fishery management (Pauly 1984, Froese 2006). Among their several applications (Vianna et al. 2004, Macieira & Joeux 2009, Joeux et al. 2009, Silveira & Vaz-dos-Santos 2015), LWR are used to estimate fish biomass, the basis for the ecosystem modelling (Pope et al. 2006, Gasalla et al. 2007, Maury et al. 2007, Froese et al. 2008), one of the main purposes of the Araçá Bay study (BIOTA FAPESP Araçá 2015). In Brazil, these contributions have been used to estimate the biomass and to subsidize the modelling, as it is the case of demersal (Haimovici & Velasco 2000, Nascimento et al. 2012) and small pelagic ichthyofauna (Cergole & Dias Neto 2011, Vaz-dos-Santos & Rossi-Wongtschowski 2013). In order to assess the growth pattern of the fish species and to provide an essential tool

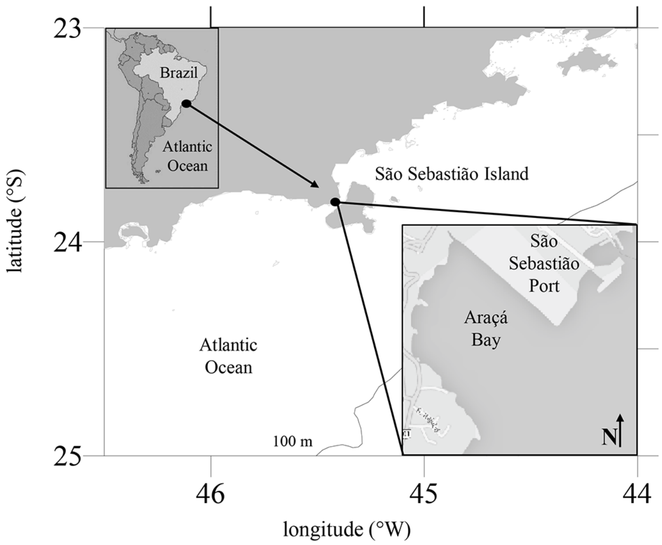

Figure 1. Map locating the Araçá Bay in the Brazilian coast, a coastal subtropical ecosystem.

to estimate the biomass with data from the area itself, the present study aimed to estimate the length-weight relationships (LWR) of the ichthyofauna in the Araçá Bay.

Material and Methods

Five samples (October 2012, March 2013, July 2013, October 2013 and January 2014) were attained by using nine different fishing gears, ensuring ontogenetic representativeness of the ichthyofauna. Fish species were identified, measured (total length, L_T, 0.1 mm) and weighed (total weight, W_T, 0.001 g). Nomenclature followed Eschmeyer (2015). Data from samples were pooled and the potential model $W_T=aL_T^b$ (Huxley 1993) was fitted through the non-linear iterative least squares method (Zar 2010). Fits were assessed through residual analysis and the coefficient of determination values, calculated as $r^2=[\Sigma(y_p-y_a)^2/\Sigma(y_o-y_a)^2]$, where y_p is the predicting weight for the individual *i*, y_a is the average weight and y_o is the observed weight for the individual *i* (Vieira 2006). Growth pattern (whether isometric or allometric in relation to the referential value 3) was verified through *t* confidence intervals (CI) of *b* estimates: every value inside the CI is statistically similar to the estimate. The proportion of young and adult fishes in the sampling was informed, thus allowing checking the life stage represented by the regressions. The young fish were those assigned as immature (never spawned) and those ones in the other phases as adults, in accordance to Brown-Peterson et al. (2011).

Results and Discussion

A total of 12,362 specimens belonging to 39 species, 21 families and 11 orders were analysed (Table 1). The allometric coefficient (*b*) varied between 2.55 and 3.97 (mean = 3.086, median = 3.096). The variation of the coefficient of determination (between 0.759 and 0.999, mean = 0.956, median = 0.978) and residual analysis ensured the acuity of regressions even in the cases in which r^2 values were reduced by the biological variability. Especially in these cases, it is important to highlight that these models represent the portion of the population and their condition in the Araçá Bay and they should be used for biomass estimates in this particular situation. Although almost all length ranges were represented in the sampling, the proportional contribution of small and young fishes (59% of species) was higher than that in adults and longer fishes (31% of species). The *Sardinella brasiliensis*, *Trachinotus* spp., *Caranx latus* and *Umbrina coroides* sampling were constituted only by young fishes, while for *Archosargus rhomboidalis*, *Menticirrhus americanus*, *Eugerres brasilianus*, *Cynoscion jamaicensis* and *Gymnothorax ocellatus* adults dominated the sampling. The remaining 10% corresponded to 3 species in which it was not possible to evaluate the life stage and one in which the proportion was exactly 1:1 (*Diapterus rhombeus*).

Isometric growth pattern was detected in 17 species, positive allometry in 16 and negative allometry in 6 species (Figure 2). While the coefficient *a* is the condition factor varying due to many factors related to the fish biology, physiology and body shape (Braga 1986, Froese 2006), the coefficient *b* represents mainly the growth pattern usually varying between 2.5 and 3.5 (Froese 2006). In *G. ocellatus* such upper limit was exceeded, and this was due both to the anguilliform body (Moyle & Cech 2004) and the narrow amplitude of lengths (Froese 2006).

Consulting the FishBase (Froese & Pauly 2015), for *Albula vulpes*, *Trachinotus carolinus*, *T. falcatus*, *Archosargus rhomboidalis* and *Kyphosus sectatrix*, these are the first records of LWR in Brazil. In spite of the availability of LWR parameters for the other species (Froese & Pauly 2015), only Muto *et al.* (2000) studied the ichthyofauna in the same area, but outside the coastal environments. These authors used mm-g and comparisons with other studies in cm-g can be done after the conversion using the equation of Froese (2006). Muto et al. (2000) provided LWR for 57 species based on samples attained from the continental shelf adjacent to Araçá Bay between 1993 and 1997, but only 18 species (Gerreidae, Haemulidae, Sciaenidae, flounders and some others) were the same ones. In comparison to this study, differences in the LWR were found mainly for the Gerreidae family with lower *b* amounts. Such heterogeneity in the species composition and growth pattern (mainly isometry and positive allometry) ensure that Araçá Bay is a growth ground for the ichthyofauna of the area revealed by the high amounts of *b* coefficients. Only *Ctenogobius boleosoma* and *Etropus crossotus* are resident species; the others go to the Araçá Bay to feed and grow (Vaz-dos-Santos et al. 2015).

In comparison with other LWR studies of the Southwestern Atlantic, it is possible to verify that Araçá Bay is shared by the ichthyofauna from different habitats. The continental shelf is dominated by the demersal sciaenids (Vianna et al. 2004), pelagic clupeiforms and carangids (Vaz-dos-Santos & Rossi-Wongtschowski 2013). In coastal environments (mangroves, rockpools), gerreids, gobiids and *Atherinella brasiliensis* usually predominate (Macieira & Joyeux 2009, Costa et al. 2014). Differences among LWR of these studies were expected due to different fishing gears, areas and periods, especially when it is considered the space (and time) scale of the present study. In such context, aiming the biomass estimates and ecosystem modelling, the present results are the most suitable: they are from the area itself and the use of nine fishing gears reduces (almost cancelled) selectivity. Data and results are representing properly and along a cycle (year) the different development phases of fishes using the Araçá Bay.

The presence of the young-of-the-year of the Brazilian sardine, *Sardinella brasiliensis*, in the Araçá Bay is noteworthy. This is the

Table 1. Number of fishes (n), total length range, parameters and *t* confidence intervals (CI) of the potential model ($W_T = aL_T^{\,b}$), coefficient of determination, relative growth pattern (i = isometric; a = allometric; + = positive; - = negative) and percentage of individuals by life stage.

Order	Family	Species		n	Total lenght (mm)			*a*	±	CI	*b*	±	CI	r^2	growth pattern	% of life stage	
					minimun	average	maximum									youngs	adults
Albuliformes	Albulidae	*Albula vulpes*	(Linnaeus, 1758)	60	32	78	210	$6.571.10^{-6}$	±	$2,201.10^{-6}$	3,05	±	0,063	0,984	i	78	22
Anguiliformes	Muraenidae	*Gymnothorax ocellatus*	Agassiz, 1831	38	332	402	522	$4.169.10^{-9}$	±	$0,100.10^{-10}$	3,97	±	0,419	0,933	a+	16	84
Clupeiformes	Engraulidae	*Anchoa tricolor*	(Spix & Agassiz, 1829)	111	35	73	103	$7.670.10^{-6}$	±	$4,756.10^{-6}$	2,99	±	0,142	0,931	i	71	29
	Clupeidae	*Harengula clupeola*	(Cuvier, 1829)	654	39	74	212	$6.331.10^{-6}$	±	$7,854.10^{-7}$	3,12	±	0,025	0,983	a+	97	3
		Sardinella brasiliensis	(Steindachner, 1879)	538	43	78	116	$1.306.10^{-6}$	±	$3,929.10^{-7}$	3,41	±	0,057	0,990	a+	100	---
Aulopiformes	Synodontidae	*Synodus foetens*	(Linnaeus, 1766)	77	56	169	238	$2.990.10^{-6}$	±	$2,191.10^{-6}$	3,13	±	0,137	0,990	i	66	34
Mugiliformes	Mugilidae	*Mugil curema*	Valenciennes, 1836	1272	25	129	452	$1.672.10^{-5}$	±	$3,335.10^{-6}$	2,90	±	0,033	0,986	a-	73	27
Atheriniformes	Atherinopsidae	*Atherinella brasiliensis*	(Quoy & Gaimard, 1825)	1760	22	89	151	$4.542.10^{-6}$	±	$3,923.10^{-7}$	3,10	±	0,021	0,986	a+	42	58
Beloniformes	Hemiramphidae	*Hyporhamphus unifasciatus*	(Ranzani, 1841)	63	116	199	322	$2.562.10^{-7}$	±	$1,999.10^{-7}$	3,45	±	0,099	0,959	a+	34	66
Scorpaeniformes	Triglidae	*Prionotus punctatus*	(Bloch, 1793)	155	22	104	220	$1.394.10^{-5}$	±	$2,568.10^{-6}$	2,98	±	0,034	0,986	i	64	36
Perciformes	Centropomidae	*Centropomus parallelus*	Poey, 1860	24	200	318	403	$1.307.10^{-4}$	±	$2,610.10^{-4}$	2,55	±	0,342	0,896	a-	---	---
	Serranidae	*Diplectrum radiale*	(Quoy & Gaimard, 1824)	110	55	148	246	$2.645.10^{-6}$	±	$1,189.10^{-6}$	3,32	±	0,089	0,978	a+	49	51
	Carangidae	*Caranx latus*	Agassiz, 1831	37	59	171	225	$3.765.10^{-5}$	±	$4,056.10^{-5}$	2,82	±	0,208	0,956	i	100	---
		Chloroscombrus chrysurus	(Linnaeus, 1766)	50	38	118	210	$2.070.10^{-5}$	±	$1,166.10^{-5}$	2,85	±	0,108	0,999	a-	57	43
		Oligoplites saurus	(Bloch & Schneider, 1801)	211	20	54	254	$3.194.10^{-6}$	±	$3,943.10^{-7}$	3,17	±	0,022	0,999	a+	94	6
		Trachinotus carolinus	(Linnaeus, 1766)	91	18	34	62	$1.488.10^{-5}$	±	$6,755.10^{-6}$	2,99	±	0,112	0,999	i	94	6
		Trachinotus falcatus	(Linnaeus, 1758)	115	18	37	65	$3.511.10^{-5}$	±	$1,347.10^{-5}$	2,87	±	0,100	0,865	a-	100	---
		Trachinotus goodei	Jordan & Evermann, 1896	31	62	97	125	$1.139.10^{-5}$	±	$1,634.10^{-5}$	3,01	±	0,294	0,968	i	100	---
	Lutjanidae	*Lutjanus analis*	(Cuvier, 1828)	31	39	203	410	$1.296.10^{-5}$	±	$7,750.10^{-6}$	3,01	±	0,101	0,999	i	64	36
		Lutjanus synagris	(Linnaeus, 1758)	38	54	120	316	$3.779.10^{-5}$	±	$1,054.10^{-5}$	2,81	±	0,049	0,999	a-	77	23
	Gerreidae	*Diapterus rhombeus*	(Cuvier, 1829)	1038	14	124	258	$3.999.10^{-6}$	±	$5,887.10^{-7}$	3,27	±	0,033	0,971	a+	50	50
		Eucinostomus argenteus	Baird & Girard, 1855	2552	17	76	189	$1.049.10^{-5}$	±	$2,157.10^{-6}$	3,03	±	0,045	0,982	i	60	40
		Eucinostomus gula	(Quoy & Gaimard, 1824)	163	73	137	205	$6.515.10^{-6}$	±	$3,159.10^{-6}$	3,16	±	0,093	0,967	a+	51	49
		Eucinostomus melanopterus	(Bleeker, 1863)	87	28	174	230	$1.177.10^{-5}$	±	$1,392.10^{-5}$	3,02	±	0,231	0,951	i	36	64
		Eugerres brasilianus	(Cuvier, 1830)	35	152	194	269	$8.614.10^{-6}$	±	$1,016.10^{-5}$	3,10	±	0,226	0,991	i	11	89
	Haemulidae	*Haemulon steindachneri*	(Jordan & Gilbert, 1882)	56	99	154	258	$1.573.10^{-5}$	±	$8,818.10^{-6}$	2,99	±	0,105	0,968	i	71	29
		Orthopristis ruber	(Cuvier, 1830)	256	54	84	148	$1.953.10^{-5}$	±	$5,317.10^{-6}$	2,94	±	0,058	0,978	i	70	30
		Haemulopsis corvinaeformis	(Steindachner, 1868)	1477	46	120	178	$8.432.10^{-6}$	±	$1,177.10^{-6}$	3,11	±	0,028	0,973	a+	34	66
	Sparidae	*Archosargus rhomboidalis*	(Linnaeus, 1758)	46	16	135	191	$9.168.10^{-6}$	±	$5,438.10^{-6}$	3,14	±	0,120	0,999	a+	---	100
	Sciaenidae	*Ctenosciaena gracilicirrhus*	(Metzelaar, 1919)	187	42	107	145	$3.765.10^{-6}$	±	$1,973.10^{-6}$	3,26	±	0,104	0,892	a+	59	41
		Cynoscion jamaicensis	(Vaillant & Bocourt, 1883)	109	124	192	269	$6.382.10^{-6}$	±	$6,343.10^{-6}$	3,13	±	0,188	0,829	i	14	86
		Menticirrhus americanus	(Linnaeus, 1758)	61	28	234	425	$5.671.10^{-6}$	±	$5,201.10^{-6}$	3,13	±	0,156	0,984	i	5	95
		Umbrina coroides	Cuvier, 1830	38	70	111	185	$1.871.10^{-6}$	±	$1,418.10^{-6}$	3,38	±	0,145	0,999	a+	100	---
	Gobiidae	*Ctenogobius boleosoma*	(Jordan & Gilbert, 1882)	145	20	39	55	$1.706.10^{-5}$	±	$1,384.10^{-5}$	2,81	±	0,213	0,860	i	---	---
	Kyphosidae	*Kyphosus sectatrix*	(Linnaeus, 1758)	30	23	237	462	$5.829.10^{-6}$	±	$5,522.10^{-6}$	3,20	±	0,156	0,993	a+	---	---
Pleuronectiformes	Paralichthyidae	*Citharichthys spilopterus*	Günther, 1862	101	40	112	199	$2.704.10^{-6}$	±	$7,936.10^{-7}$	3,26	±	0,061	0,969	a+	63	37
		Etropus crossotus	Jordan & Gilbert, 1882	387	30	89	143	$2.907.10^{-6}$	±	$7,864.10^{-7}$	3,28	±	0,054	0,759	a+	28	72
		Syacium papillosum	(Linnaeus, 1758)	38	52	112	155	$1.104.10^{-5}$	±	$1,216.10^{-6}$	3,01	±	0,216	0,972	i	79	21
Tetraodontiformes	Tetraodontidae	*Sphoeroides greeleyi*	Gilbert, 1900	90	43	87	174	$1.126.10^{-4}$	±	$5,921.10^{-5}$	2,64	±	0,109	0,869	a-	46	54

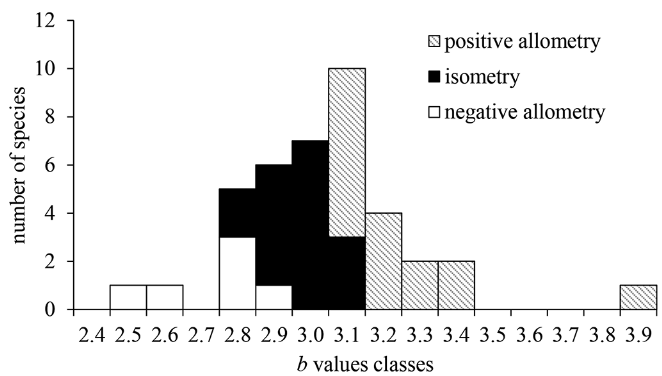

Figure 2. Frequency distribution of *b* values for 39 species caught in the Araçá Bay, a coastal subtropical ecosystem.

most important fishery resource in Brazil (MPA 2011), spawning along the continental shelf (Matsuura 1998). The displacement to a coastal ecosystem indicates the importance of Araçá Bay to the recruitment of the species.

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