Length-weight relationships of the ichthyofauna associated with the Brazilian sardine, *Sardinella brasiliensis*, on the Southeastern Brazilian Bight (22°S-29°S) between 2008 and 2010

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Abstract: In this study, estimates of length-weight relationships are presented for twenty-four species caught in association with the Brazilian sardine, *Sardinella brasiliensis*, during four acoustics surveys carried out under the Program ECOSAR (Prospecting and evaluation of biomass of the stock of Brazilian sardine on the southeast coast by acoustic methods), which was to evaluate the biomass of species that were caught. The model parameters were estimated with the nonlinear iterative method of least squares. The value of the coefficient of determination (r^2) and residual analysis were employed to verify the appropriateness of fit. The coefficient b values were tested with respect to isometry (β=3) using a $t_{\alpha 1,0.05}$ test. The values of coefficient b ranged from 2.377 to 3.538. There is a tendency for positive allometry (b) in the sampled ichythyocenose.
Keywords: *relative growth, allometric model, pelagic and demersal fishes.*

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Resumo: No presente estudo são apresentadas as estimativas das relações comprimento-peso para vinte e quatro espécies capturadas em associação com a sardinha-verdadeira (*Sardinella brasiliensis*) durante quatro cruzeiros de prospecção hidroacústica realizados no âmbito do Programa ECOSAR (Prospecção e avaliação de biomassa do estoque de sardinha-verdadeira, na costa sudeste, por métodos hidroacústicos), cujo objetivo foi permitir a avaliação das biomassas das espécies capturadas. Para estimação dos parâmetros dos modelos foi empregado o método iterativo não linear de mínimos quadrados; o valor do coeficiente de determinação (r^2) e a análise de resíduos foram empregados para verificar a adequação dos ajustes. Os valores dos coeficientes b foram testados em relação à isometria (β=3) através de teste $t_{\alpha 1,\ 0,05}$. O valor do coeficiente b variou entre 2,377 e 3,538, tendo sido constatada tendência de alometria positiva para o *b* na ictiocenose amostrada.
Palavras-chave: *crescimento relativo, alometria, peixes pelágicos e demersais.*

Introduction

The diversity of marine fish in the Southeastern and Southern Brazilian regions has traditionally been investigated through research surveys (Vazzoler & Iwai 1971, Vazzoler 1973, Yesaki et al. 1976, Rossi-Wongtschowski & Paes 1993, Rossi-Wongtschowski et al. 1995, 2008, Brasil 2006). From these records, several studies were developed concerning various aspects of the fish species. Among the studied variables, the length-weight relationship is a density-dependent parameter that provides an index of health of fish stocks (Schneider et al. 2000).

Because the prior studies related to relative growth, summarized in Huxley (1993), and focused on the growth pattern model (whether isometric or allometric) until its application in fish stock assessment (Beverton & Holt 1993, Sparre & Venema 1998, Quinn II & Deriso 1999), the length-weight relationship has been used in many studies. It is possible to mentioning fish shape and swimming patterns, biomass quantifications based on length frequency distributions, as a measure of changes in the expected individual weight for length and indicating its condition (i.e., fat accumulation and gonad development), differentiation of stocks, growth conditions, reproduction and feeding, ecological modeling, biomass calculation in acoustic surveys, and monitoring the "health" of the stocks over time.

In Brazil, several studies have estimated the parameters of the relationship between length and weight among marine fishes as Bernardes & Rossi-Wongtschowski (2000), Haimovici & Velasco (2000), Muto et al. (2000), Lessa et al. (2004), Frota et al. (2004), Vianna et al. (2004), Madureira & Rossi-Wongtschowski (2005), Giarizzo et al. (2006), Macieira & Joyeux (2008), Freire et al. (2009), Joyeux et al. (2009) and Oliveira Freitas et al. (2011).

In this study, estimates of the length-weight relationship are presented for twenty-four species that were captured in association with the Brazilian sardine, *Sardinella brasiliensis* (Steindachner, 1879), during four acoustic surveys conducted under the Program ECOSAR (Prospection and evaluation of the Brazilian sardine biomass on the southeast coast through acoustic methods).

Material and Methods

The data for the present study were collected on four research cruises conducted with RV *Atlântico Sul* (FURG) during January-February 2008 (ECOSAR IV), November 2008 (ECOSAR V), September-October 2009 (ECOSAR VI) and February-March 2010 (ECOSAR VII) (Figure 1). The objective of the ECOSAR program was to assess the biomass of the species that were caught. Fish were caught using purse seine and mid-water-trawls in the Southeastern Brazilian Bight (22 °S-29 °S) at depths between 10 and 100 m. The species of the fish were identified and their nomenclature confirmed (Eschmeyer 2012). Their total length (Lt) was measured in mm (from the tip of the snout to the end of the caudal fin) as was their weight (Wt) in grams.

The data were only analyzed for those species for which more than thirty individuals were captured on the four cruises, to allow for statistical inferences. The variation in the total length of each species was subjected to descriptive analysis (Triola 2005). The length and weight data were reviewed in scatter diagrams to identify outliers and possible measurement errors. The relationships were fitted to the equation $Wt = a\ Lt^b$ (Le Cren 1951), which was calculated with the help of Minitab®. The estimates of the parameters were obtained with the nonlinear iterative method of least squares, and the coefficient of determination (r^2) and the residual analysis were employed to verify the adequacy of fit, according to Vieira (2006). To determine whether the growth was isometric ($\beta = 3$) or allometric for each species, the b coefficients were tested by a $t_{\alpha 1,0.05}$ test, considering $H_{a:}$ $b < 3$ or $b > 3$ according to the value estimated (Triola 2005).

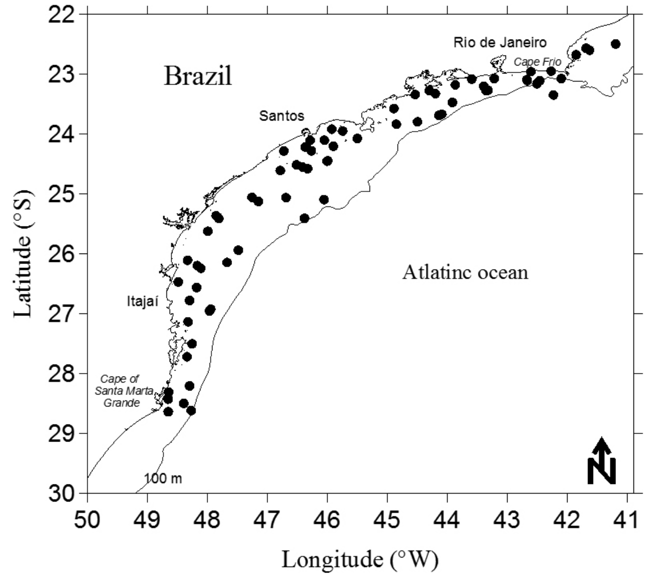

Figure 1. Fishing hauls during the surveys of the ECOSAR Program (2008-2010).

Results and Discussion

The data from 13,222 fish comprising five orders, fifteen families and twenty-five species were analyzed. Table 1 shows the species analyzed, the ranges and means of their length, the number of fishes, the parameters of the length-weight relationships, the coefficients of determination and the results of the allometric t tests. The fitted models were biologically and statistically adequate to describe the length-weight relationship for all species. A model of residual analysis is presented in Figure 2 and all assumptions (normality, randomness, homoscedasticity and independence) showed no tendency for all species. Random residuals have showed that models were adequate (Bervian et al. 2006).

The minimum and maximum values of b for the length-weight relationships were, respectively, 2.377 and 3.538, and its frequency distribution is presented in Figure 3.

It is noteworthy that b provided the best estimates for those typical small pelagic fish which were caught by the mid-water trawl and seine, such as the Clupeiformes, *Trachurus lathami* and *Chloroscombrus chrysurus*. Most of the values for the young demersal fish fell near the modeled relationships, such as *Dactylopterus volitans*, while for other species, such *as Decapterus punctatus, Anchoviella lepidentostole* and *Pomatomus saltatrix*, only a small representative range of lengths were captured.

For some species, such as *A. lepidentostole, Pellona harroweri, S. brasiliensis, Harengula clupeola, Priacanthus arenatus, C. chrysurus, Selene setapinnis, Scomber japonicus,* and *Chilomycterus spinosus*, the values for the coefficient b were the same as those obtained in other studies, although for other species such as *Engraulis anchoita, Chirocentrodon bleekerianus, Opisthonema oglinum, Bregmaceros atlanticus, D. volitans, P. saltatrix, T. lathami, Ctenosciaena gracilicirrhus, Thyrsitops lepidopoides, Trichiurus lepturus, Peprilus paru, Aluterus monoceros,* and *Stephanolepis hispidus*, remarkable differences from the published values were observed. Probably these differences should be caused since different surveys were performed with diverse fishing gears at different times (Magro et al. 2000, Bernardes & Rossi-Wongtschowski 2000, Muto et al. 2000, Vianna et al. 2004, Cergole et al. 2005, Madureira & Rossi-Wongtschowski 2005).

Table 1. Values of the minimum, average and maximum total length (Lt, mm); *a, b* (± confidence interval) and determination (r^2) coefficients of the length-weight relationship; and the "t" and "p" values of isometric t-test ($p < 0.05$ - significantly allometric).

Order	Family	Species		n	total length (Lt)			a	b	r^2	t	p
					minimun	average	maximun					
Clupeiformes	Engraulidae	*Anchoa tricolor*	(Spix & Agassiz 1829)	218	43	64	127	$5.4\ 10^{-6} \pm 1.1\ 10^{-6}$	3.043 ± 0.046	0.982	1.83	0.035
		Anchoviella lepidentostole	(Fowler, 1911)	35	75	89	98	$3.4\ 10^{-6} \pm 1.1\ 10^{-5}$	3.101 ± 0.705	0.758	0.29	0.387
		Engraulis anchoita	Hubbs & Marini, 1935	3621	38	86	141	$5.6\ 10^{-6} \pm 6.9\ 10^{-7}$	3.028 ± 0.026	0.930	2.08	0.019
	Pristigasteridae	*Chirocentrodon bleekerianus*	(Poey, 1867)	395	65	89	118	$6.1\ 10^{-6} \pm 2.6\ 10^{-6}$	2.978 ± 0.094	0.902	-0.47	0.320
		Pellona harroweri	(Fowler, 1917)	841	55	116	159	$1.7\ 10^{-5} \pm 5.1\ 10^{-6}$	2.881 ± 0.062	0.942	-3.78	<0.001
	Clupeidae	*Sardinella brasiliensis*	Steindachner, 1879	3108	35	155	270	$3.3\ 10^{-6} \pm 4.4\ 10^{-6}$	3.181 ± 0.025	0.995	14.34	<0.001
		Harengula clupeola	(Cuvier, 1829)	1063	65	153	192	$5.0\ 10^{-6} \pm 1.3\ 10^{-6}$	3.165 ± 0.050	0.957	6.45	<0.001
		Opisthonema oglinum	(Lesueur, 1818)	466	116	191	312	$4.5\ 10^{-5} \pm 1.3\ 10^{-5}$	2.706 ± 0.052	0.971	-11.17	<0.001
Gadiformes	Bregamcerotidae	*Bregmaceros atlanticus*	Goode & Bean, 1886	117	26	41	60	$7.8\ 10^{-7} \pm 2.3\ 10^{-6}$	3.508 ± 0.140	0.955	7.16	<0.001
Scorpaeniformes	Dactylopteridae	*Dactylopterus volitans*	(Linnaeus, 1758)	1875	68	102	281	$8.7\ 10^{-6} \pm 4.6\ 10^{-7}$	3.036 ± 0.010	0.963	7.09	<0.001
Perciformes	Priacanthidae	*Priacanthus arenatus*	Cuvier, 1829	51	74	97	129	$3.9\ 10^{-5} \pm 2.0\ 10^{-5}$	2.803 ± 0.107	0.980	-3.68	<0.001
	Pomatomidae	*Pomatomus saltatrix*	(Linnaeus, 1766)	34	281	387	420	$7.6\ 10^{-5} \pm 1.5\ 10^{-4}$	2.645 ± 0.329	0.953	-2.20	0.018
	Carangidae	*Chloroscombrus chrysurus*	(Linnaeus, 1766)	658	110	201	372	$2.9\ 10^{-5} \pm 5.4\ 10^{-6}$	2.786 ± 0.034	0.985	-12.39	<0.001
		Decapterus punctatus	(Cuvier, 1829)	106	181	207	243	$5.0\ 10^{-6} \pm 4.8\ 10^{-5}$	3.122 ± 0.207	0.896	1.17	0.123
		Oligoplites saliens	(Bloch, 1793)	393	149	256	635	$3.2\ 10^{-6} \pm 6.0\ 10^{-7}$	3.119 ± 0.031	0.992	7.59	<0.001
		Selene setapinnis	(Mitchill, 1815)	66	33	232	442	$1.9.\ 10^{-5} \pm 1.5\ 10^{-5}$	2.915 ± 0.137	0.996	-1.24	0.110
		Trachurus lathami	Nichols, 1920	1801	27	148	208	$9.1\ 10^{-6} \pm 1.8\ 10^{-6}$	3.018 ± 0.038	0.991	0.95	0.171
	Sciaenidae	*Ctenosciaena gracilicirrhus*	(Metzelaar, 1919)	79	90	129	183	$4.3\ 10^{-6} \pm 0.2\ 10^{-5}$	3.229 ± 0.104	0.980	4.40	<0.001
	Gempylidae	*Thyrsitops lepidopoides*	(Cuvier, 1832)	205	60	177	360	$2.9\ 10^{-6} \pm 1.5\ 10^{-6}$	3.108 ± 0.088	0.978	2.42	0.008
	Trichiuridae	*Trichiurus lepturus*	Linnaeus, 1758	580	104	657	1510	$3.6\ 10^{-7} \pm 2.4\ 10^{-7}$	3.068 ± 0.095	0.892	1.40	0.080
	Scombridae	*Scomber japonicus*	Houttuyn, 1782	274	72	228	310	$3.9\ 10^{-6} \pm 8.7\ 10^{-6}$	3.129 ± 0.037	0.990	6.82	<0.001
	Stromateidae	*Peprilus paru*	(Linnaeus, 1758)	97	92	210	304	$1.2\ 10^{-5} \pm 1.0\ 10^{-5}$	3.059 ± 0.150	0.988	0.77	0.221
Tetraodontiformes	Monacanthidae	*Aluterus monoceros*	(Linnaeus, 1758)	64	136	202	254	$6.5\ 10^{-7} \pm 4.3\ 10^{-7}$	3.538 ± 0.185	0.959	5.80	<0.001
		Stephanolepis hispidus	(Linnaeus, 1766)	90	24	50	173	$3.9\ 10^{-4} \pm 2.7\ 10^{-4}$	2.378 ± 0.138	0.974	-8.92	<0.001
	Diodontidae	*Chilomycterus spinosus*	(Linnaeus, 1758)	93	40	64	140	$1.4\ 10^{-3} \pm 6.4\ 10^{-4}$	2.377 ± 0.091	0.924	-13.66	<0.001

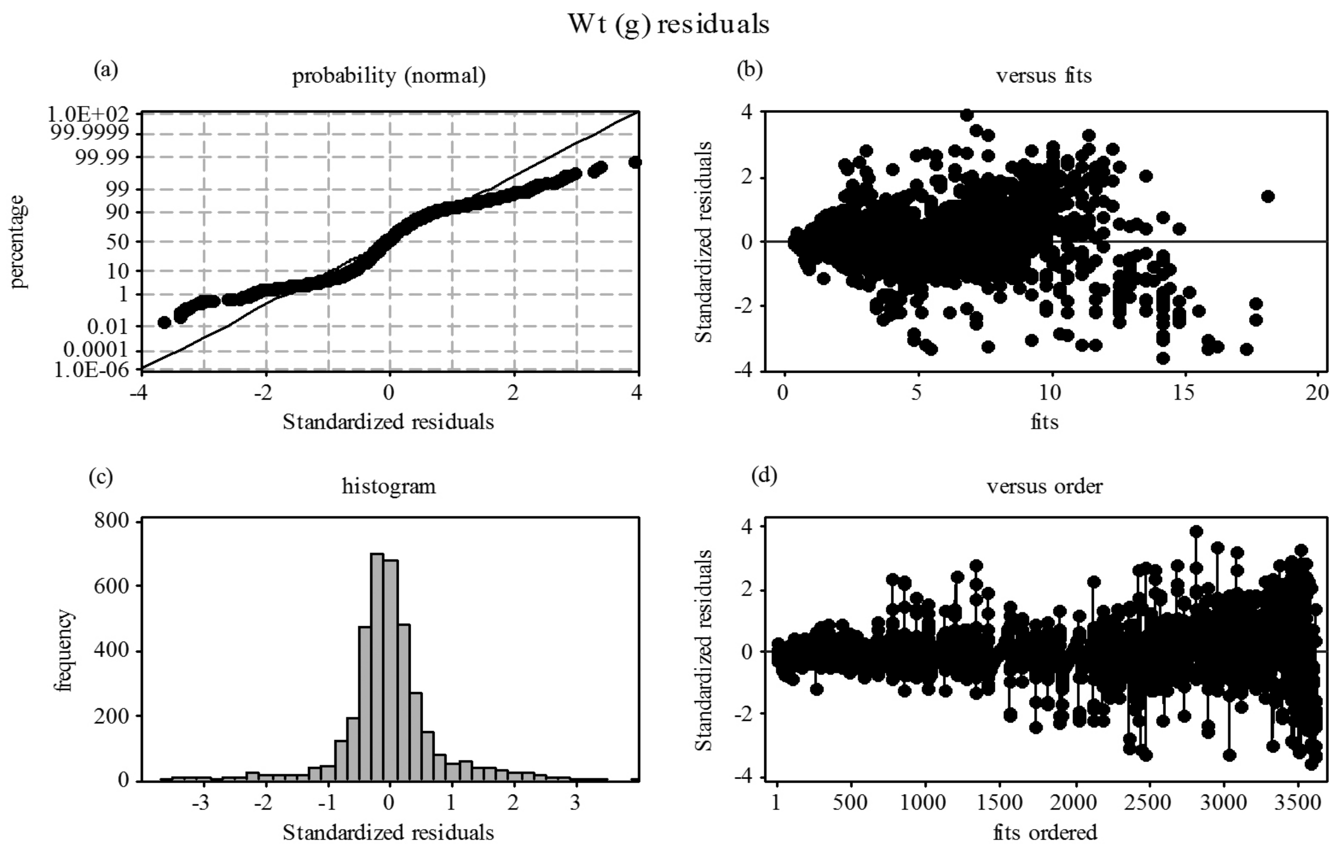

Figure 2. Model based on *Engraulis anchoita* data of the residual analysis applied to fit the length-weight relationships. The graphics allow checks of the assumptions of (a) normality, (b) randomness, (c) homoscedasticity and (d) independence of the data.

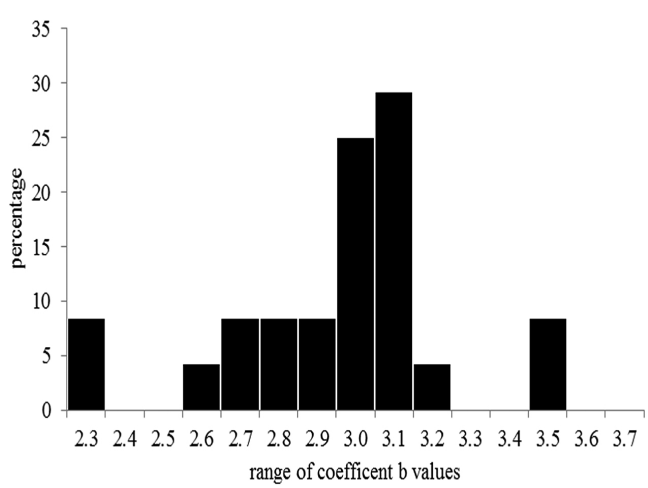

Figure 3. Frequency distribution values of the coefficient b obtained for the length-weight relationships of 25 species.

The magnitude of b represents the fish growth pattern, whether the growth is proportionally greater for length or weight (Quinn II & Deriso 1999), and is therefore related to their body shape (Pough et al. 2008). Thus, fish in pelagic ecosystem usually have small and slender shapes, which show a proportionately greater increase in length than in weight over time, rather than rounded shapes. Besides, allometric coefficient depicts better relative growth of fishes (Braga 1986).

In this study, the b values varied within the expected range (Froese 2006): the most common values were between 3.0 and 3.1, the range that included 50% of the species. The distribution of b values was asymmetrical, with more species having values above 3.0 than below this value; eleven species showed positive allometry ($b > 3$, $p < 0.05$), seven showed negative allometry ($b < 3$, $p < 0.05$), and seven showed isometric growth ($b = 3$, $p > 0.05$) (Table 1).

Unless some length-weight parameters represent only some life stages, the results are the most current estimates for the species recorded in the Southeastern Brazilian Bight and may be used as a tool in future studies aimed at monitoring the populations.

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