Length-Weight Relationship of Marine Fishes from Southern Brazil

M. Haimovici and G. Velasco

Abstract

The relationship between length (L) and weight (W) was estimated for 80 species belonging to 50 families of marine fishes from the shelf and upper slope of southern Brazil (lat. 28°S - 34°S). Sample sizes (n) for different species ranged from 11 to 14 741 specimens collected from commercial landings and research surveys. The fit of the equations ($W=aL^b$) with **a** and **b** parameters estimated from regular and functional regression (of log-transformed weight and length data) as well as from a non-linear iterative process using the quasi-Newton algorithm were compared. The non-linear method gave the most accurate estimates in terms of residual sum of squares. Differences were less than 2.3% for $n>500$ compared with predictive regressions and 1.5% compared with functional regressions. No difference was observed between both predictive and functional regressions. Determination coefficients (r^2) increased with sample size, and the highest r^2 were obtained for $50<n<500$, decreasing slightly for larger samples due to seasonal changes in the condition of the fishes.

Introduction

Length-weight relationships are required in population dynamics and fisheries stock assessment (Gulland 1983). Until the early 1960s, length-weight relationships were calculated mostly using log-transformed mean weights of fishes in different length classes (Nomura 1962). In the following decade, scientific pocket calculators and mainframe computers made it easy to use data on individual fishes and to compare statistically linear "predictive" regressions through covariance analysis. As log transformations introduce a negative bias in the estimate of the weights of large specimens, Ricker (1973, 1975) recommended the use of "functional" regression. While accepted by few statisticians, it was widely used by fishery scientists in the 1970s. Statistical packages for mainframes (1980s) and powerful personal computers and programs (1990s) made it easy to estimate non-linear relationships without transformations. While there is no doubt that the non-linear fitting approach combined with least squares or maximum likelihood statistics are a powerful tool to describe and compare length-weight relationships (Kimura 1980; Saila et al. 1988; Cerrato 1990), each of these approaches has advantages and drawbacks in real life situations.

The shelf and upper slope along Rio Grande do Sul (28°-34°S) (Fig. 1) is among the most productive marine regions of Brazil. During the

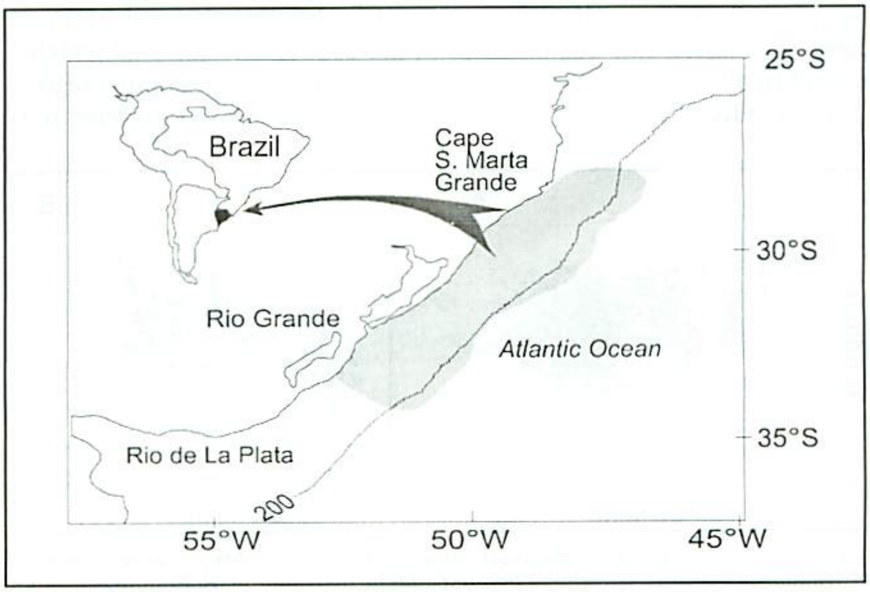

Fig. 1. Map showing the southern Brazil shelf and upper slope. Shaded area indicates where the sample fishes were caught.

1975-1994 period, annual landings ranged between 58 000 and 91 800 t and over 85% of these landings were composed of bony fishes (Haimovici et al. 1997). Over the last two decades, a regular sampling program of the industrial fisheries landings in Rio Grande and several surveys with bottom and mid-water trawls provided length and weight data of most of the demersal and small pelagic bony fishes from southern Brazil (Haimovici 1987; Haimovici et al. 1996; Castello 1997). The first objective of this paper is to estimate their length-weight relationships; the second is to compare the fit of the predictive, functional and non-linear regression models.

Materials and Methods

Lengths were measured from the most anterior part of the head (with the mouth closed) to the farthest tip of the caudal fin (total length or LT), or to the midpoint of the caudal fin (fork length or LF). Smaller species were measured in millimeters. Larger species were measured to the lower centimeter and recorded adding 5 mm. Total weight (W) was recorded to the nearest gram or nearest ten grams depending on the size of the fish. Sample size (n) depended on species size ranges and availability. Except in a few cases, n was more than 30 individuals.

The parameters of the length-weight equation ($W = a L^b$) were calculated in three different ways: (i) from $\log_{10}$ - transformed weight and length with a and b estimated by ordinary least squares linear regression (Zar 1984); (ii) from geometric mean linear (also called "functional") regression of $\log_{10}$-transformed weight and length (Ricker 1973, 1975); and (iii) with a non-linear iterative procedure.

Two statistical softwares were initially used to perform the iterative non-linear fitting procedure: the non-linear estimation module of Statistica® 5.1 (Stat. Soft. Inc 1996) and the "*solver*" routine in Excel 97® (Microsoft 1997). Both use the quasi-Newton algorithm to minimize the residual sum of squares (RSS) of the observed minus predicted weights at length. The first yielded parameter estimates that converged for a wide range of seed values and step sizes. The second is more "user friendly" but seed values and step size choices affected the calculation. Residual sum of squares using Statistica were on average 4.8% lower for the 93 data sets (and 1.1% lower for data sets with $n>500$) than those of Excel. The residual sum of squares for linear regression was calculated in an Excel worksheet.

Weights that differed by more than 20% of the expected weights in a preliminary predictive regression analysis were considered outliers and excluded from the calculations. More than one length-weight relationship was calculated for species where the plots of the residuals against length showed possible changes in the relationship during growth (see example in Fig. 2).

Family and genera nomenclature followed the classification proposed by Eschmeyer (1998).

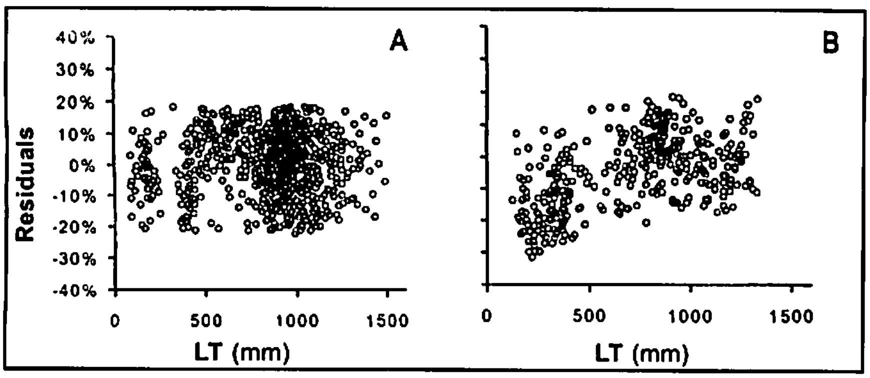

Fig. 2. Plots of residuals of observed minus estimated weights (%) at each length. A: **Trichiurus lepturus** ***showing a homoscedastic distribution; B:*** **Pogonias cromis** ***showing a trend during growth for a single length-weight relationship (formerly two different relationships were calculated).***

Results

The parameters of the length-weight relationship are estimated for 93 data sets corresponding to 80 species from 50 families. Sample sizes range from 11 to 14 741, with a mean of 569. The smallest samples corresponded to infrequent species from the upper slope and the largest samples to the most important species in the commercial landings in Rio Grande.

The **LT**, **LF** and **W** ranges, sample sizes, estimates of a and b and the correlation coefficients from non-linear regression are presented in Table 1.

The quotients between RSS of predictive and non-linear regression are calculated and plotted against sample size (Fig. 3A). The RSS of the predictive regression is always higher or equal to the corresponding RSS of non-linear regression. Mean difference is 8.3% but ranges from over two-fold for $n<30$ to less than 2.3% for $n>500$.

The quotients between RSS of functional and non-linear regression are also plotted against sample size (Fig. 3B). The same tendency as in the previous case was observed. Functional RSS are on average 8.4% higher than those of the non-linear regression and decrease steadily with sample size to 1.5% for $n>500$.

Functional versus predictive regression RSS quotients are plotted (Fig. 3C). For some data sets, predictive regressions yield lower RSS and for others the functional regressions do. Absolute differences are on average 3.8% and 1.6% for

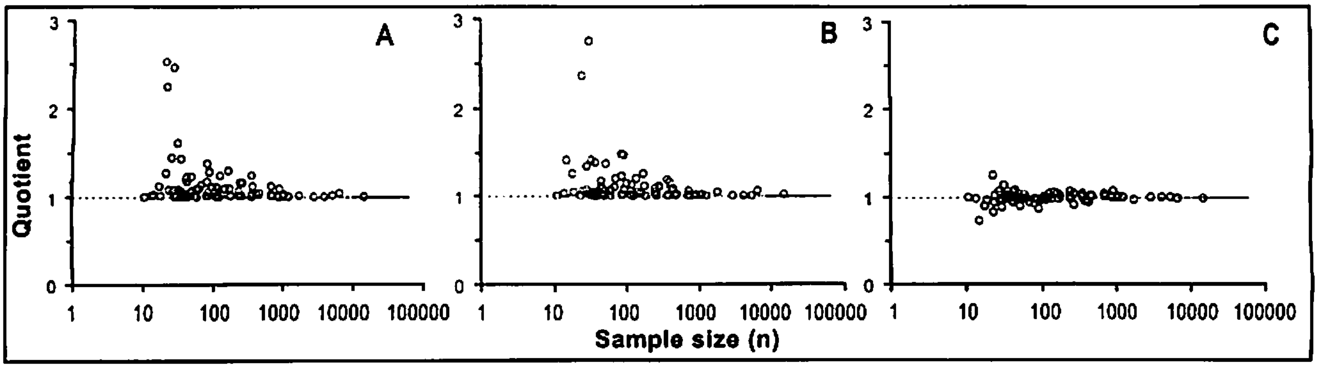

Fig. 3. Ratios between residual sum of squares (RSS) of different fitting methods of length-weight relationships against sample sizes: A: predictive/non-linear; B: functional/non-linear; C: predictive/functional.

Table 1. Length-weight relationship of 80 species of fish from southern Brazil (n-sample size; LF-fork length; LT-total length; a, b - regression coefficients, r^2-determination coefficient).

Family	Species	n	Length type	Length (mm)		Total weight (g)		Non-linear regression		
				min.	max.	min.	max.	a	b	r^2
Clupeidae	*Brevoortia pectinata*	874	LF	70	365	6	943	8.795E-06	3.1215	0.965
Engraulidae	*Anchoa marinii*	28	LT	35	115	0.2	8	1.760E-06	3.2232	0.981
Engraulidae	*Engraulis anchoita*	375	LT	59	150	1	22	4.776E-06	3.0503	0.974
Engraulidae	*Lycengraulis grossidens*	45	LT	33	191	0.2	55	1.122E-06	3.3572	0.991
Muraenidae	*Gymnothorax conspersus*	18	LT	610	1 083	220	1 373	1.956E-07	3.2536	0.964
Congridae	*Conger orbignyanus*	366	LT	405	1 200	67	2 450	8.394E-08	3.4100	0.975
Argentinidae	*Argentina striata*	67	LT	69	221	2	65	7.618E-06	2.9629	0.990
Sternoptychidae	*Maurolicus muelleri*	42	LT	39	53	0.4	1	1.799E-07	3.9601	0.919
Ariidae	*Genidens genidens*	36	LT	125	332	15	327	4.494E-06	3.1062	0.989
Ariidae	*Netuma barba*	116	LT	68	700	3	4 090	5.503E-06	3.1243	0.983
Synodontidae	*Synodus foetens*	30	LT	138	470	10	640	8.344E-06	2.9511	0.978
Chlorophthalmidae	*Chlorophthalmus agassizi*	23	LT	133	164	11	30	8.714E-09	4.3060	0.922
Chlorophthalmidae	*Parasudis ortruculenta*	33	LT	191	250	38	102	1.665E-06	3.2388	0.919
Myctophidae	*Diaphus dumerilli*	19	LT	64	98	2	6	5.945E-06	3.0173	0.934
Polymixiidae	*Polymixia lowei*	367	LT	73	294	6	430	1.184E-05	3.0339	0.985
Gadidae	*Urophycis brasiliensis*	252	LT	87	586	3	1 805	2.480E-06	3.2054	0.981
Gadidae	*Urophycis cirrata* Adult.	902	LT	252	665	102	2 830	9.569E-07	3.3566	0.981
Gadidae	*Urophycis cirrata* Juv.	88	LT	124	250	13	122	8.405E-06	2.9753	0.972
Merlucciidae	*Merluccius hubbsi*	711	LT	202	755	55	2 775	1.366E-05	2.8737	0.974
Macrouridae	*Coelorhinchus coelorhynchus*	15	LT	232	295	39	74	5.788E-04	2.0700	0.461
Macrouridae	*Malacocephalus occidentalis*	37	LT	152	455	4	300	2.139E-08	3.8155	0.977
Ophidiidae	*Genypterus brasiliensis*	133	LT	297	1 090	94	9 800	5.251E-08	3.7059	0.979
Ophidiidae	*Raneya fluminensis*	25	LT	172	300	22	185	4.502E-08	3.8693	0.979
Batrachoididae	*Porichthys porosissimus*	275	LT	55	334	1	429	1.805E-06	3.3253	0.988
Lophiidae	*Lophius gastrophysus*	48	LT	234	740	215	6 320	1.221E-05	3.0359	0.979
Atherinidae	*Atherinella brasiliensis*	37	LT	27	155	0.1	29	1.524E-06	3.3324	0.991
Atherinidae	*Odonthestes argentinensis*	53	LT	28	421	0.1	449	4.113E-06	3.0675	0.990
Zeidae	*Zenopsis conchifer*	170	LT	90	568	10	2 100	1.420E-05	2.9549	0.987
Grammicolepididae	*Xenolepidichthys dalgleishi*	37	LT	80	175	9	96	3.158E-05	2.8901	0.974
Caproidae	*Antigonia capros*	111	LT	41	205	3	305	3.550E-05	2.9797	0.990
Centriscidae	*Macrorhamphosus scolopax*	30	LT	92	143	5	18	1.223E-05	2.8486	0.962
Scorpaenidae	*Helicolenus lahillei*	739	LF	157	449	59	1 779	6.407E-06	3.1641	0.968
Scorpaenidae	*Helicolenus lahillei*	1 021	LT	74	452	6	1 779	4.581E-06	3.2132	0.978
Triglidae	*Prionotus nudigula*	389	LT	96	253	9	185	1.172E-05	2.9904	0.971
Triglidae	*Prionotus punctatus*	1 076	LT	66	430	4	1 090	3.240E-06	3.2374	0.967
Peristediidae	*Peristedion gracile*	45	LT	105	190	8	43	1.351E-05	2.8431	0.966
Polyprionidae	*Polyprion americanus*	86	LF	435	1 100	1 200	22 700	1.745E-05	3.0025	0.980
Polyprionidae	*Polyprion americanus*	101	LT	438	1 130	1 200	24 100	2.804E-05	2.9210	0.977
Serranidae	*Diplectrun formosum*	11	LT	145	196	39	121	1.438E-06	3.4327	0.939
Serranidae	*Diplectrun radiale*	14	LT	137	240	35	214	1.631E-05	2.9760	0.933
Serranidae	*Dules auriga*	71	LT	77	172	6	91	2.715E-05	2.9115	0.964
Serranidae	*Epinephelus niveatus*	38	LT	108	1 090	24	21 200	2.535E-05	2.9266	0.986
Acropomatidae	*Synagrops bellus*	51	LT	125	242	22	141	7.308E-06	3.0601	0.985
Acropomatidae	*Synagrops spinosus*	61	LT	77	142	5	30	1.385E-05	2.9427	0.971

continued

Table 1. continued

Malacanthidae	*Lopholatilus villarii*	708	LF	323	1 022	430	17 500	2.492E-06	3.2734	0.983
Malacanthidae	*Lopholatilus villarii*	699	LT	265	1 054	200	17 500	2.910E-06	3.2340	0.978
Pomatomidae	*Pomatomus saltatrix* Adult.	1 771	LT	251	676	143	2 705	1.712E-05	2.8990	0.982
Pomatomidae	*Pomatomus saltatrix* Juv.	275	LT	86	250	5	149	6.796E-06	3.0500	0.986
Carangidae	*Trachurus lathami*	123	LT	109	225	8	91	6.626E-07	3.4664	0.979
Haemulidae	*Orthopristis ruber*	28	LT	145	275	44	310	8.030E-05	2.6859	0.945
Sparidae	*Pagrus pagrus*	177	LF	96	406	16	1 553	3.864E-05	2.9144	0.980
Sparidae	*Pagrus pagrus*	2 896	LT	106	605	16	3 630	1.802E-05	2.9766	0.971
Sciaenidae	*Ctenosciena gracilicirrhus*	424	LT	82	197	8	104	1.378E-05	3.0022	0.947
Sciaenidae	*Cynoscion guatucupa*	6 598	LT	58	575	3	1 810	3.533E-05	2.7752	0.976
Sciaenidae	*Cynoscion jamaicensis*	1 254	LT	140	329	25	470	5.191E-06	3.1476	0.964
Sciaenidae	*Macrodon ancylodon*	5 405	LT	63	460	2	1 080	1.633E-06	3.3014	0.974
Sciaenidae	*Menticirrhus americanus*	388	LT	94	474	6	1 417	3.886E-06	3.1950	0.984
Sciaenidae	*Menticirrhus litoralis*	245	LT	100	475	8	1 155	2.281E-06	3.2463	0.980
Sciaenidae	*Micropogonias fumieri*	4 082	LT	135	736	25	4 555	1.143E-05	2.9960	0.978
Sciaenidae	*Paralonchurus brasiliensis*	487	LT	68	237	2	143	3.680E-07	3.6264	0.962
Sciaenidae	*Pogonias cromis* Adult.	256	LT	520	1 335	1 400	31 700	8.985E-06	3.0404	0.972
Sciaenidae	*Pogonias cromis* Juv.	139	LT	127	500	26	1 560	2.347E-05	2.8985	0.983
Sciaenidae	*Umbrina canosai*	14 741	LT	93	533	10	2 451	1.480E-05	2.9957	0.965
Mullidae	*Mullus argentinae*	155	LT	120	225	22	183	8.657E-07	3.5334	0.967
Cheilodactylidae	*Cheilodacthylus bergi*	42	LT	215	378	122	575	9.952E-06	3.0147	0.979
Mugilidae	*Mugil platanus*	117	LF	283	507	283	1 613	1.970E-05	2.9168	0.951
Mugilidae	*Mugil platanus*	126	LT	240	554	116	1 613	1.110E-05	2.9627	0.962
Percophidae	*Bemprops heterurus*	23	LT	113	240	6	78	1.441E-05	2.8326	0.988
Percophidae	*Percophis brasilianus*	247	LT	242	680	46	1 240	4.146E-06	2.9964	0.969
Pinguipedidae	*Pseudopercis numida*	44	LF	510	995	1 535	14 100	2.685E-06	3.2408	0.983
Pinguipedidae	*Pseudopercis numida*	33	LT	530	1 035	1 535	14 100	1.620E-06	3.2945	0.987
Uranoscopidae	*Astroscopus sexspinosus*	39	LT	212	463	172	2 191	1.115E-05	3.0961	0.961
Gempylidae	*Thyrsitops lepidopoides*	53	LT	150	382	15	301	9.787E-06	2.9054	0.961
Trichiuridae	*Benthodesmus elongatus*	46	LT	273	760	3	76	4.258E-08	3.2207	0.989
Trichiuridae	*Evoxymetopon taeniatus*	24	LT	199	905	5	590	3.049E-06	2.8013	0.984
Trichiuridae	*Lepidopus caudatus*	34	LT	175	785	3	450	1.072E-07	3.3253	0.983
Trichiuridae	*Trichiurus lepturus*	915	LT	89	1 500	0.1	2 410	2.141E-08	3.4770	0.978
Scombridae	*Scomber japonicus*	111	LT	173	419	38	779	7.300E-07	3.4496	0.985
Ariommatidae	*Ariomma bondi*	59	LT	62	187	3	73	1.238E-05	2.9800	0.983
Stromateidae	*Peprilus paru* Adult.	274	LF	136	278	85	670	1.753E-04	2.6912	0.982
Stromateidae	*Peprilus paru* Adult.	245	LT	165	360	85	745	1.712E-04	2.5892	0.979
Stromateidae	*Peprilus paru* Juv.	41	LF	54	105	4	43	6.572E-06	3.3542	0.983
Stromateidae	*Peprilus paru* Juv.	37	LT	50	130	2	43	8.627E-06	3.1652	0.990
Stromateidae	*Stromateus brasiliensis*	91	LF	154	352	53	1 040	3.104E-06	3.3385	0.955
Stromateidae	*Stromateus brasiliensis*	84	LT	173	395	53	1 040	1.391E-06	3.4048	0.955
Bothidae	*Etropus longimanus*	31	LT	85	155	5	24	6.999E-05	2.5240	0.924
Pleuronectidae	*Oncopterus darwini*	39	LT	103	287	14	264	6.889E-06	3.0893	0.978
Paralichthyidae	*Paralichthys isosceles*	475	LT	98	362	6	542	5.010E-07	3.5194	0.953
Paralichthyidae	*Paralichthys orbignyanus*	439	LT	116	840	13	7 005	6.889E-06	3.0768	0.986
Paralichthyidae	*Paralichthys patagonicus*	182	LT	178	600	55	2 100	4.617E-06	3.1201	0.991
Paralichthyidae	*Verecundum rasile*	61	LT	127	363	12	478	4.723E-07	3.5127	0.987
Cynoglossidae	*Symphurus jenynsi*	30	LT	113	258	8	147	2.783E-07	3.6103	0.965
Tetraodontidae	*Sphoeroides pachygaster*	43	LT	265	429	390	1 701	1.185E-04	2.7129	0.898

n>500, but a Wilcoxon pairs test does not show systematic statistical differences between them ($p=0.8035$). As in the previous comparisons, differences are higher for the smaller sample sizes.

The determination coefficient (r^2) of the non-linear regressions are plotted against sample size in Fig. 4. Values of r^2 are always over 0.95 for $n>50$ and the higher determination coefficients are obtained for $50<n<500$. Slightly lower r^2 are observed for the largest samples ($n>2000$) from the year round regular sampling program of commercially important species (Haimovici 1987).

Discussion

Several factors affect the accuracy of the length-weight relationships, e.g., condition (i.e., W/L^3) of fishes caught in different seasons, sex, length ranges, sample size and fitting methods. The influence of condition and sex can be handled in two ways: (i) by using balanced samples that include specimens of both sexes and the four seasons; or (ii) estimating separate relationships. The last procedure is followed for important commercial fishes when differences are large enough to justify it. For most species and purposes, a single relationship is sufficient. In our data set, determination coefficients increase considerably with increasing sample size up to about 500 specimens and decreases slightly for larger samples (Fig. 4). This is because larger samples were gathered in year round samplings and the precision gained from the larger samples is lost due to seasonal changes in the condition of fishes.

Non-linear regressions yield more accurate estimates than linear regressions but the differences are small for large sample sizes. In fact, for data sets with over 500 specimens, RSS differences between predictive and functional regressions are small (2.3% and 1.5% on average, respectively).

It is concluded that non-linear fitting procedures should be the first choice when software are available and data are distributed uniformly along the size range. All three methods yield quite similar estimates for sample sizes greater than 500.

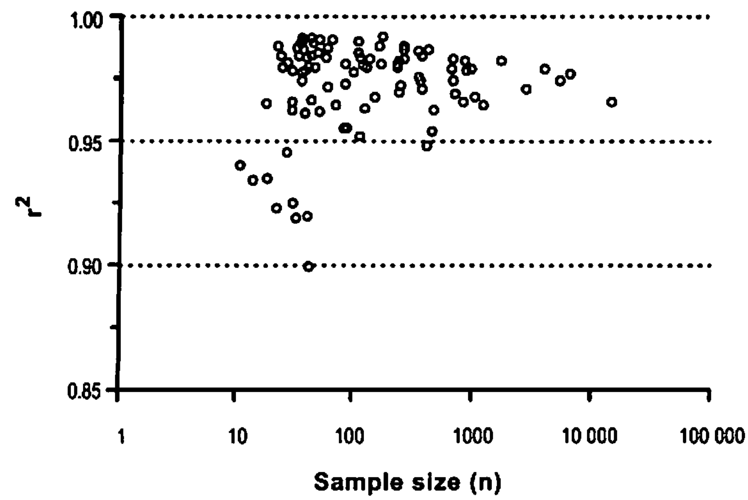

Fig. 4. Determination coefficient of 93 data sets of non-linear length-weight relationships plotted against sample size.

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M. HAIMOVICI[1] *and* G. VELASCO[2] *are from Depto. Oceanografia, FURG. Cx.P. 474, Rio Grande RS, Brazil, 96201-900 ([1]docmhm@super.furg.br;[2]pgobgvc@super.furg.br).*