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Length-weight relationships of 39 continental shelf and deep-water fishes from Northwestern Gulf of México

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Abstract

Length and weight relationships (LWR) were estimated for 39 fish species from 30 families from the northwestern Gulf of Mexico. Fish specimens were sampled during four oceanographic campaigns (February and October 2016, June and September 2017) using a shrimp trawl net and benthic sled net in 20 locations at depths that ranged from 43 to 3,608 m. New maximum standard length (SL) was obtained for *Cyclothone alba*, *C. braueri*, *C. pseudopallida*, and *Lepophidium brevibarbe*. A positive allometric growth was reported in 22 species and 17 showed a negative allometric growth.

Keywords

Length and weight relationship, Gulf of Mexico, deep-water fish, *Cyclothone*, continental shelf, bathyal

Introduction

Currently, demersal fish in the northwestern Gulf of Mexico are under pressure from a growing industry that is oil exploration and extraction (Patiño-Ruiz et al. 2003). They are also affected by trawling, forming part of the discarded fauna from shrimp fishing in the area (Chávez-lópez and Morán-Silva 2019). One way to assess the scope and impact of these activities on biodiversity wise is by drawing up a list of the fish fauna in the area, as well as determining the affected life cycles, which are identified by studying the sizes of the fish specimens (Hernández-Padilla et al. 2020).

For this process, length-weight relationship (LWR) analyzes are used, which commonly focused on identifying fish stocks, growth rate of a particular species, among others (Sandoval-Huerta et al. 2015). Therefore, in the present study, it is proposed to determine the LWR of 39 dominant fish species from the northwestern region of the Gulf of Mexico in areas ranging from the continental shelf to the bathyal zone.

Materials and methods

Data collection was carried out during four oceanographic study surveys aboard the "Justo Sierra", research vessel, each trip with an approximate duration of 10 days during the months of February and October 2016, and June and September 2017 (adequate weather conditions and project logistics). The activity was carried out at 20 sampling points comprising depths between 50 to 3600 m. Two types of fishing gear were implemented depending on the depth of each site, a shrimp trawl (18.29 m long and 4.57 cm mesh size) for depths between 50 to 500 m (9 locations) and a benthic sled net (32.4 m long and 2.5 cm mesh size) for depths greater than 500 and up to 3600 m (11 locations); both nets were hauled for one mile at a constant speed of 2.7 knots.

The collected fish were labeled and immediately frozen at -20 ºC to be transferred to the laboratory facilities. All specimens were measured and weight fresh, fixed and preserved in alcohol 80%. Some organisms were deposited in the ichthyological collection (CINV-NEC) of CINVESTAV-Merida in Mexico.

We calculated the length-weight relationship using the allometric formula $W = aL^b$ where W is the weight of the fish (g), L is the SL (cm), a corresponds to the intercept, and b is the regression coefficient. The values of a and b were calculated with Statgraphics software (Centurion XV, Version 15.1.02, Copyright 1982-2006 StatPoint, Inc.) with a linear least square's regression using a logarithmic scale. With the value of the slope (b), it was established if the fish species has negative growth ($b < 3$) or positive allometric growth ($b > 3$) (Froese et al. 2011). Outliers were removed using logarithmic plots, and limits for a and b were estimated by a Student's t-test with a 95% confidence (Froese 2006).

Results

Table 1 shows the LWR analysis with the coefficient of determination r^2 for 29 species. New maximum lengths are reported for four species: *Cyclothone alba* (5.6 cm SL), *C. braueri* (4.6 cm SL), *C. pseudopallida* (4.8 cm SL), and *Lepophidium brevibarbe* (28.8 SL). All "a" values ranged between 0.0001 (*Trichiurus lepturus*) and 0.1357 (*Fowlerichthys radiosus*); and the "b" values oscillated between 1.772 (*C. braueri*) and 3.648 (*Malacocephalus occidentalis*).

Discussion

Coastal benthic ecosystems in the northwestern region of the Gulf of Mexico are being affected by shrimp trawling (Wakida-kusunoki et al. 2013). The fish that are part of the discarded fauna do not survive and this generates a strong impact on food webs and possibly generates trophic cascades (Diamond 2004; Heath et al. 2014). On the other hand, oil activity, despite not being a totally destructive activity, represents a latent danger in the ecosystem due to future hydrocarbon spills or leaks (Fisher et al. 2016), so understanding the species and cycles of life involved, provides an idea of the possible impact generated by these activities. The fish species with the greatest abundance and distribution in the area are the most affected (Chávez-López and Morán-Silva 2019), generally carnivorous species such as the flounder *Trichopsetta ventralis* and the snapper *Pristipomoides aquilonaris*; that regulate the communities of other organisms, avoiding their overpopulation (Rao 2018).

On the other hand, the species that are located at depths greater than 500 m, are specimens characterized by low abundances and with little information about their populations and growth rates (Danovaro et al. 2017), so the analysis of their biological information is considered relevant. The deep-sea species reported in this study are carnivorous, located in the vertical gradients of the continental slope and the bathyal zone, examples of some of them are *Epigonus pandionis*, *Merluccius albidus*, *Chauliodus sloani*, *Chlorophthalmus agassizi*, among others (Ramírez et al. 2019). Furthermore, we highlight an amplitude in its maximum length reported by the literature corresponding to *C. alba* from 2.9 to 5.6 cm SL, *C. braueri* from 3.8 to 4.6 cm SL, *C. pseudopallida* from 4.6 to 4.8 cm SL (Harold 2015) and *Lepophidium brevibarbe* from 27.3 to 28.8 cm SL. In addition, we consider that these species are the ones that are possibly being most affected during extraction maneuvers and hydrocarbon leaks in the depths (Fisher et al. 2016). The genus *Cyclothone* corresponds to the most abundant resource in these deep zones (Olivar et al. 2017), and is perhaps the main food source that generates stability in populations, so its impact would generate a disparity in the deep marine ecosystem.

LWR studies in the northern Gulf of Mexico are very scarce. In these studies, the species analysed include *Chloroscombrus chrysurus* and *Citharichthys spilopterus* (Dawson 1965; Galindo-Cortes et al. 2015) and a single deep-sea species *Urophycis cirrata* (Matlock et al. 1988). Most of the species mentioned in these investigations are associated with shallow coastal areas. In the present study, LWR information is provided on ecologically important species found at depths greater than 500 m, including records of both juvenile and sexually matured organisms. With this information, the reports of these species in the area were completed, as well as the delivery of new biological information on the deep-sea ecosystem, which is a poorly studied region located in the north of the Gulf of Mexico, and where samples are difficult to obtain (Blomberg and Montagna 2014). Likewise, we recorded species of *Micropogonias furnieri* and *Citharichthys spilopterus* that did not reach sexual maturity and were captured by shrimp trawls of the same dimensions as the fishing boats, so it is possible that both species are showing a decrease in their populations.

The slope (b) that was estimated in this study was between the expected range of 2.5 to 3.5 (Froese 2006), except for five species, *C. braueri*, *C. alba*, *Chloroscombrus chrysurus* and *Dibranchus atlanticus* that were found below the value (1.77-2.43), and *Malacocephalus occidentalis* which is above those values (3.64). However, this may be due to the low number of specimens analyzed for some of these species (Carlander 1997) or can be attributed to the combination of one or more of the following factors: habitat, area/season effect, gonad maturity stages, sex, stomach fullness, health condition, population and differences within species and preservation techniques (Tesch 1971; Froese 2006; Bautista-Romero et al. 2012). Finally, a total of 17 and 22 species showed a positive and a negative allometric grow, respectively. However, the information presented with the species *Cyclothone braueri*, *Chloroscombrus chrysurus* and *Trachurus lathami*, should be taken with caution due to the reduced number of organisms and their high values of the “a” intercept.

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Conflict of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Technical Statements

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author contribution

We use a Contributor roles Taxonomy by Credit, using the following 14 roles:

Ariel Adriano Chi Espinola: Conceptualization, Formal Analysis, Investigation, Methodology, Visualization, Writing - original draft preparation, Writing - review and editing

María Eugenia Vega Cendejas: Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Visualization, Writing - original draft preparation, Writing - review and editing

Jovita Mirella Hernández de Santillana: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing - original draft preparation

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Table 1. Length-weight relationships for 39 fish species caught in the Perdido Fold Belt (Northwest Gulf of México) during four oceanographic surveys carried out in two years (2016-2017) covering 20 locations using shrimp trawl and benthic sled net. n = number of individuals, SL = standard length, weight (g); equation parameters, "*a*" (intercept) and "*b*" (slope); SE = standard error of parameter *b;* 95% CI = 95 % confidence limits for both equation parameters; r^2 = coefficient of determination; Species in bold = new maximum length data greater than previously recorded (Froese & Pauly, 2022). Species collected ≥500 m depth. Species in bold with a maximum length greater than previously recorded (Froese & Pauly 2022). For comparison reasons, information on maximum length (Lmax) and length at first maturity (Lm) are taken from the electronic databank "FishBase", with the respective length type being indexed (TL= total length, FL= Fork length).

Family	Specie	n	SL range (cm)	Weight range (g)	Lm (cm)	Lmax (cm)	a	95% CI a	b	95% CI b	r^2
Congridae	*Rhynchoconger flavus* (Goode & Bean 1896)	35	14.2-42.7	4.4-133.0		150.0_{TL}	0.0012	0.001-0.003	3.055	2.817-3.293	0.954
Clupeidae	*Sardinella aurita* Velenciennes 1847	51	7.0-19.3	4.1-99.3	12.0_{TL}	41.0_{TL}	0.0124	0.007-0.022	3.024	2.831-3.216	0.953
Gonostomatidae	***Cyclothone alba**** Brauer 1906	75	1.3-5.6	0.02-0.42	1.56_{SL2}	2.9_{SL}	0.0076	0.007-0.009	2.309	2.168-2.449	0.936
	Cyclothone braueri* Jespersen & Tåning, 1926	22	1.4-4.6	0.02-0.23	$2.0_{SL,2}$	3.8_{SL}	0.0149	0.013-0.018	1.772	1.641-1.904	0.975
	Cyclothone pseudopallida* Mukhacheva, 1964	71	1.5-4.8	0.02-0.51	$1.75_{SL,2}$	4.6_{SL}	0.0076	0.006-0.009	2.518	2.333-2.703	0.914
Sternoptychidae	*Sternoptyx diaphana** Hermann, 1781	26	1.2-4.5	0.09-4.21		5.5_{SL}	0.0503	0.041-0.062	2.892	2.671-3.114	0.968
Stomiidae	*Chauliodus sloani** Bloch & Schneider, 1801	25	4.5-19.2	0.09-17.03	$15.1_{SL,3}$	35.0_{SL}	0.0012	0.001-0.002	3.181	2.919-3.442	0.965
Synodontidae	*Saurida brasiliensis* Norman 1935	203	3.1-9.7	0.3-8.8	$8.0_{SL,1}$	25.0_{TL}	0.0171	0.015-0.020	2.708	2.632-2.783	0.961
Chlorophthalmidae	*Chlorophthalmus agassizi**Bonaparte 1840	74	11.4-19.5	13.7-100.0	$11.5_{TL,4}$	40.0_{TL}	0.0038	0.002-0.006	3.401	3.222-3.579	0.952
Macrouridae	*Coelorinchus caelorhincus**(Risso 1810	27	13.0-30.0	5.2-112.0	$17.2_{TL,5}$	48.0_{TL}	0.0006	0.0003-0.0013	3.509	3.271-3.749	0.973
	*Malacocephalus occidentalis** Goode & Bean, 1885	15	27.0-38.5	49.3-162.8		45.0_{TL}	0.0003	0.00002-0.003	3.648	2.936-4.359	0.904
Moridae	*Laemonema goodebeanorum** Meléndez C. & Markle, 1997	15	7.5-27.3	2.4-191.5		30.3_{SL}	0.0023	0.001-0.004	3.379	3.104-3.655	0.982
Merlucciidae	*Merluccius albidus** (Mitchill, 1818)	40	27.3-40.9	212.8-699.7	$23.0_{SL,6}$	$70.0_{TL,6}$	0.0373	0.022-0.064	2.627	2.471-2.782	0.968
	Urophycis cirrata (Goode & Bean, 1896)	23	20.4-43.5	86.4-770.7		66.0_{TL}	0.0162	0.008-0.033	2.864	2.659-3.069	0.976
Ophidiidae	***Lepophidium brevibarbe*** (Cuvier, 1829)	26	11.3-28.8	4.6-117.1	$10.1_{TL,7}$	27.3_{SL}	0.0017	0.001-0.003	3.313	3.151-3.475	0.987
Batrachoididae	*Porichthys plectrodon* Jordan & Gilbert, 1882	217	4.2-18.3	1.2-93.3	$8.0_{FL,8}$	29.0_{TL}	0.0182	0.015-.0.022	2.856	2.771-2.941	0.953
Carangidae	*Chloroscombrus chrysurus* (Linnaeus, 1766)	40	11.6-16.3	31.5-68.4	11.2_{FL}	65.0_{TL}	0.1047	0.073-0.150	2.324	2.184-2.464	0.967

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	Trachurus lathami Nichols, 1920	32	10.4-17.9	18.8-77.6	11.4TL	40.0TL	0.0443	0.026-0.076	2.598	2.394-2.802	0.957
Paralichthyidae	*Citharichthys spilopterus* Günther, 1862	70	6.4-11.9	5.2-27.8	12.0SL,9	21.0TL	0.0283	0.021-0.038	2.763	2.632-2.894	0.963
	Cyclopsetta chittendeni Bean 1895	231	4.5-28.8	1.2-371.3	14.5TL,9	33.0TL,9	0.0119	0.009-0.014	3.081	3.012-3.148	0.972
Bothidae	*Monolene sessilicauda* Goode 1880	36	4.9-11.8	1.1-9.6		18.0TL	0.0095	0.006-0.014	2.858	2.667-3.048	0.964
	Trichopsetta ventralis (Goode & Bean, 1885)	873	3.6-18.0	0.5-59.6		20.0TL	0.0109	0.010-0.012	3.092	3.045-3.139	0.950
Cynoglossidae	*Symphurus diomedeanus* (Goode & Bean, 1885)	21	5.0-14.7	0.9-31.0		22.0TL	0.0067	0.004-0.012	3.169	2.927-3.411	0.975
Trichiuridae	*Trichiurus lepturus* Linnaeus, 1758	17	7.4-65.3	0.1-103.3	30.0TL	234.0TL	0.0001	0.0001-0.0002	3.357	3.198-3.515	0.993
Percophidae	*Bembrops gobioides** (Goode, 1880)	21	8.8-23.4	3.9-82.6		30.0TL	0.0039	0.002-0.008	3.203	2.934-3.471	0.970
Synagropidae	*Synagrops bellus* (Goode & Bean, 1896)	20	6.3-20.7	4.6-166.6	13.0TL,13	46.0TL,14	0.0174	0.010-0.031	3.029	2.813-3.243	0.979
Epigonidae	*Epigonus pandionis** (Goode & Bean, 1881)	56	9.8-20.2	22.8-154.2	11.2TL,15	23.5TL	0.0358	0.022-0.058	2.809	2.633-2.984	0.950
Serranidae	*Centropristis philadelphica* (Linnaeus, 1758)	42	9.7-23.5	23.2-289.3		30.0TL	0.0323	0.020-0.053	2.862	2.676-3.047	0.960
Lutjanidae	*Lutjanus campechanus* (Poey, 1860)	35	8.0-24.7	12.7-467.2	9.41FL,11	100.0TL	0.0237	0.013-0.042	3.032	2.806-3.258	0.958
	Pristipomoides aquilonaris (Goode & Bean, 1896)	477	3.3-20.0	1.0-197.2		56.0TL	0.0350	0.224-0.315	2.873	2.097-2.236	0.973
Triglidae	*Prionotus longispinosus* Teague, 1951	183	3.9-24.7	1.3-307.6	12.0TL,16	35.0TL	0.0397	0.030-0.053	2.771	2.660-2.881	0.931
	Prionotus paralatus Ginsburg, 1950	180	7.8-17.5	7.5-85.2	10.0TL,16	18.0SL,16	0.0142	0.011-0.018	3.056	2.959-3.153	0.956
Peristediidae	*Peristedion greyae* Miller 1967	123	12.8-18.4	11.9-33.4		23.9TL	0.0110	0.007-.017	2.738	2.580-2.895	0.907
Sciaenidae	*Micropogonias furnieri* (Desmarest, 1823)	26	12.0-20.2	40.4-155.5	24.3TL	60.0SL	0.0643	0.035-0.118	2.594	2.368-2.821	0.959
Antennariidae	*Fowlerichthys radiosus* (Garman, 1896)	47	2.6-9.4	1.5-57.2		25.0TL10	0.1357	0.105-0.176	2.578	2.411-2.744	0.956
Ogcocephalidae	*Dibranchus atlanticus* Peters, 1876	178	3.4-10.8	1.5-25.7	10.9TL,17	39.4TL	0.0696	0.059-0.083	2.434	2.351-2.517	0.957
	Ogcocephalus declivirostris Bradbury, 1980	23	6.1-10.3	6.8-37.5		16.5TL	0.0304	0.019-0.048	3.027	2.805-3.248	0.975
	Zalieutes mcgintyi (Fowler, 1952)	17	3.3-7.3	1.4-10.5		10.0TL	0.0579	0.039-0.087	2.634	2.415-2.853	0.978
Tetraodontidae	*Lagocephalus laevigatus* (Linnaeus, 1766)	30	3.9-36.0	4.2-1050.3.3	24.5SL,12	100.0TL	0.0601	0.040-0.090	2.672	2.512-2.833	0.976

Sub-index references: 1- McEachran & Fechhelm (1998), 2- Harold (2015), 3- Marks (2016), 4- Onghia et al. (2006), 5- Paramo et al. (2017a), 6- McEachran et al. (2015a), 7- Robins (2015), 8- Vianna et al. (2000), 9- Carpenter (2015), 10- McEachran et al. (2015b), 11- Kulaw et al. (2017), 12- Shao et al. (2014), 13- Vaske et al. (2009), 14- Singh-Renton et al. (2015), 15- Paramo et al. (2017b), 16- Collette et al. (2015), 17- Rees (1963).