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Length–weight relations of 39 continental-shelf and deep-water fishes (Actinopterygii) from northwestern Gulf of México

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Abstract

Fishes from the northwestern Gulf of Mexico were surveyed 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 3608 m. Length–weight relations (LWR) were estimated for 39 fish species (in alphabetical order): *Bembrops gobioides* (Goode, 1880); *Centropristis philadelphica* (Linnaeus, 1758); *Chauliodus sloani* Bloch et Schneider, 1801; *Chlorophthalmus agassizi* Bonaparte, 1840; *Chloroscombrus chrysurus* (Linnaeus, 1766); *Citharichthys spilopterus* Günther, 1862; *Coelorinchus caelorhincus* (Risso, 1810); *Cyclopsetta chittendeni* Bean, 1895; *Cyclothone alba* Brauer, 1906; *Cyclothone braueri* Jespersen et Tåning, 1926; *Cyclothone pseudopallida* Mukhacheva, 1964; *Dibranchus atlanticus* Peters, 1876; *Epigonus pandionis* (Goode et Bean, 1881); *Fowlerichthys radiosus* (Garman, 1896); *Laemonema goodebeanorum* Meléndez et Markle, 1997; *Lagocephalus laevigatus* (Linnaeus, 1766); *Lepophidium brevibarbe* (Cuvier, 1829); *Lutjanus campechanus* (Poey, 1860); *Malacocephalus occidentalis* Goode et Bean, 1885; *Merluccius albidus* (Mitchill, 1818); *Micropogonias furnieri* (Desmarest, 1823); *Monolene sessilicauda* Goode, 1880; *Ogcocephalus declivirostris* Bradbury, 1980; *Peristedion greyae* Miller, 1967; *Porichthys plectrodon* Jordan et Gilbert, 1882; *Prionotus longispinosus* Teague, 1951; *Prionotus paralatus* Ginsburg, 1950; *Pristipomoides aquilonaris* (Goode et Bean, 1896); *Rhynchoconger flavus* (Goode et Bean, 1896); *Sardinella aurita* Valenciennes, 1847; *Saurida brasiliensis* Norman, 1935; *Sternoptyx diaphana* Hermann, 1781; *Symphurus diomedeanus* (Goode et Bean, 1885); *Synagrops bellus* (Goode et Bean, 1896); *Trachurus lathami* Nichols, 1920; *Trichiurus lepturus* Linnaeus, 1758; *Trichopsetta ventralis* (Goode et Bean, 1885); *Urophycis cirrata* (Goode et Bean, 1896); *Zalieutes mcgintyi* (Fowler, 1952). The fish species studied represented 28 families (in alphabetical order): Antennariidae, Batrachoididae, Bembropidae, Bothidae, Carangidae, Chlorophthalmidae, Congridae, Cyclopsettidae, Cynoglossidae, Dorosomatidae, Epigonidae, Gonostomatidae, Lutjanidae, Macrouridae, Merlucciidae, Moridae, Ogcocephalidae, Ophidiidae, Phycidae, Sciaenidae, Serranidae, Sternoptychidae, Stomiidae, Synagropidae, Synodontidae, Tetraodontidae Trichiuridae, Triglidae. A new maximum standard length (SL) was recorded for *Cyclothone alba*, *C. braueri*, *C. pseudopallida*, and *Lepophidium brevibarbe*. A positive allometric growth was reported in nine species, negative allometric growth in 16 species, and isometric growth in 14 species.

Keywords

bathyal, continental shelf, deep-water fish, Gulf of Mexico, length–weight relation

Introduction

Currently, demersal fishes in the northwestern Gulf of Mexico are under pressure from a growing industry focusing on 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 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 relation (LWR) analyses are used, which commonly focus on identifying fish stocks, and the growth rate of a particular species, among others (Sandoval-Huerta et al. 2015). Therefore, the presently reported study was intended 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 research vessel *RV JUSTO SIERRA*, 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 sites comprising depths between 43 and 3608 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 and 500 m (9 sites) and a benthic sled net (32.4 m long and 2.5 cm mesh size) for depths between 500 and 3608 m (11 sites); both nets were hauled for one mile at a constant speed of 2.7 knots.

The collected fishes were labeled and immediately frozen at –20°C. They were subsequently transferred to the laboratory, where they were identified using specialized references (Carpenter 2002a, 2002b; McEachran and Fechhelm 2005). Individual weight and standard length (SL) were determined for all specimens and supplemented with the relevant site information, such as the coordinates, and depth. All specimens were measured and weighed fresh, fixed, and preserved in 80% ethyl alcohol. Some fish individuals were deposited in the ichthyological collection (CINV-NEC) of CINVESTAV-Merida in Mexico. The following 39 species, representing 28 families were investigated (Table 1), including *Rhynchoconger flavus* (Goode et Bean, 1896) [Congridae]; *Sardinella aurita* Valenciennes, 1847 [Dorosomatidae]; *Cyclothone alba* Brauer, 1906, *Cyclothone braueri* Jespersen et Tåning, 1926, *Cyclothone pseudopallida* Mukhacheva, 1964 [Gonostomatidae]; *Sternoptyx diaphana* Hermann, 1781 [Sternoptychidae]; *Chauliodus sloani* Bloch et Schneider, 1801 [Stomiidae]; *Saurida brasiliensis* Norman, 1935 [Synodontidae]; *Chlorophthalmus agassizi* Bonaparte, 1840 [Chlorophthalmidae]; *Coelorinchus caelorhincus* (Risso, 1810), *Malacocephalus occidentalis* Goode et Bean, 1885 [Macrouridae]; *Laemonema goodebeanorum* Meléndez et Markle, 1997 [Moridae]; *Merluccius albidus* (Mitchill, 1818) [Merlucciidae]; *Urophycis cirrata* (Goode et Bean, 1896) [Phycidae]; *Lepophidium brevibarbe* (Cuvier, 1829) [Ophidiidae]; *Porichthys plectrodon* Jordan et Gilbert, 1882 [Batrachoididae]; *Chloroscombrus chrysurus* (Linnaeus, 1766), *Trachurus lathami* Nichols, 1920 [Carangidae]; *Citharichthys spilopterus* Günther, 1862, *Cyclopsetta chittendeni* Bean, 1895 [Cyclopsettidae]; *Monolene sessilicauda* Goode, 1880, *Trichopsetta ventralis* (Goode et Bean, 1885) [Bothidae]; *Symphurus diomedeanus* (Goode et Bean, 1885) [Cynoglossidae]; *Trichiurus lepturus* Linnaeus, 1758 [Trichiuridae]; *Bembrops gobioides* (Goode, 1880) [Bembropidae]; *Synagrops bellus* (Goode et Bean, 1896) [Synagropidae]; *Epigonus pandionis* (Goode et Bean, 1881) [Epigonidae]; *Centropristis philadelphica* (Linnaeus, 1758) [Serranidae]; *Lutjanus campechanus* (Poey, 1860), *Pristipomoides aquilonaris* (Goode et Bean, 1896) [Lutjanidae]; *Prionotus longispinosus* Teague, 1951, *Prionotus paralatus* Ginsburg, 1950, *Peristedion greyae* Miller, 1967 [Triglidae]; *Micropogonias furnieri* (Desmarest, 1823) [Sciaenidae]; *Fowlerichthys radiosus* (Garman, 1896) [Antennariidae]; *Dibranchus atlanticus* Peters, 1876, *Ogcocephalus declivirostris* Bradbury, 1980, *Zalieutes mcgintyi* (Fowler, 1952) [Ogcocephalidae]; and *Lagocephalus laevigatus* (Linnaeus, 1766) [Tetraodontidae].

We calculated the length–weight relation using the allometric formula

$$W = aL^b$$

where W is the weight of the fish [g], L is the standard length [cm], a is the intercept and b is the allometric coefficient/slope. 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 squares 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 ($b > 3$) and $b = 3$, indicating isometric growth (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). For comparison, information on the maximum length (L_{max}) and the length at first maturity (L_m) is taken from FishBase and other references, with the respective length type being indexed (TL= total length, FL= Fork length). This study provides LWR that had not yet been reported for 11 species representing four different families. In some cases, when the number of specimens and/or the range of sizes was very narrow to estimate the *a*

Table 1. Length–weight relations for 39 fish species caught in northwestern Gulf of México.

Species	Depth [m]	*n*	SL [cm]	Weight [g]	*a*	95% CI *a*	*b*	95% CI *b*	Growt type	R^2	Reference data	
											L_m [cm]	L_{max} [cm]
Rhynchoconger flavus		35	14.2–42.7	4.4–133.0	0.0012	0.001–0.003	3.055	2.817–3.293	I	0.954	—	150.0_{TL}
Sardinella aurita		51	7.0–19.3	4.1–99.3	0.0124	0.007–0.022	3.024	2.831–3.216	I	0.953	12.0_{TL}	41.0_{TL}
Cyclothone alba	≥500	75	1.3–5.6	0.02–0.42	0.0076	0.007–0.009	2.309	2.168–2.449	–A	0.936	$1.56_{SL,2}$	2.9_{SL}
Cyclothone braueri	≥500	22	1.4–4.6	0.02–0.23	0.0045	0.002–0.005	3.000	—	I	0.975	$2.0_{SL,2}$	3.8_{SL}
Cyclothone pseudopallida	≥500	71	1.5–4.8	0.02–0.51	0.0076	0.006–0.009	2.518	2.333–2.703	–A	0.914	$1.75_{SL,2}$	4.6_{SL}
Sternoptyx diaphana	≥500	26	1.2–4.5	0.09–4.21	0.0503	0.041–0.062	2.892	2.671–3.114	I	0.968	—	5.5_{SL}
Chauliodus sloani	≥500	25	4.5–19.2	0.09–17.03	0.0012	0.001–0.002	3.181	2.919–3.442	+A	0.965	$15.1_{SL,3}$	35.0_{SL}
Saurida brasiliensis		203	3.1–9.7	0.3–8.8	0.0171	0.015–0.020	2.708	2.632–2.783	–A	0.961	$8.0_{SL,1}$	25.0_{TL}
Chlorophthalmus agassizi	≥500	74	11.4–19.5	13.7–100.0	0.0038	0.002–0.006	3.401	3.222–3.579	+A	0.952	$11.5_{TL,4}$	40.0_{TL}
Coelorinchus caelorhincus	≥500	27	13.0–30.0	5.2–112.0	0.0006	0.0003–0.0013	3.509	3.271–3.749	+A	0.973	$17.2_{TL,5}$	48.0_{TL}
Malacocephalus occidentalis	≥500	15	27.0–38.5	49.3–162.8	0.0003	0.0002–0.0003	3.648	2.936–4.359	+A	0.904	—	45.0_{TL}
Laemonema goodebeanorum	≥500	15	7.5–27.3	2.4–191.5	0.0023	0.001–0.004	3.379	3.104–3.655	+A	0.982	—	30.3_{SL}
Merluccius albidus	≥500	40	27.3–40.9	212.8–699.7	0.0373	0.022–0.064	2.627	2.471–2.782	–A	0.968	$23.0_{SL,6}$	$70.0_{TL,6}$
Urophycis cirrata		23	20.4–43.5	86.4–770.7	0.0162	0.008–0.033	2.864	2.659–3.069	I	0.976	—	66.0_{TL}
Lepophidium brevibarbe		26	11.3–28.8	4.6–117.1	0.0017	0.001–0.003	3.313	3.151–3.475	+A	0.987	$10.1_{TL,7}$	27.3_{SL}
Porichthys plectrodon		217	4.2–18.3	1.2–93.3	0.0182	0.015–0.022	2.856	2.771–2.941	–A	0.953	$8.0_{FL,8}$	29.0_{TL}
Chloroscombrus chrysurus		40	11.6–16.3	31.5–68.4	0.0182	0.017–0.018	3.000	—	I	0.967	11.2_{FL}	65.0_{TL}
Trachurus lathami		32	10.4–17.9	18.8–77.6	0.0443	0.026–0.076	2.598	2.394–2.802	–A	0.957	11.4_{TL}	40.0_{TL}
Citharichthys spilopterus		70	6.4–11.9	5.2–27.8	0.0283	0.021–0.038	2.763	2.632–2.894	–A	0.963	$12.0_{SL,9}$	21.0_{TL}
Cyclopsetta chittendeni		231	4.5–28.8	1.2–371.3	0.0119	0.009–0.014	3.081	3.012–3.148	I	0.972	$14.5_{TL,9}$	$33.0_{TL,9}$
Monolene sessilicauda		36	4.9–11.8	1.1–9.6	0.0095	0.006–0.014	2.858	2.667–3.048	I	0.964	—	18.0_{TL}
Trichopsetta ventralis		873	3.6–18.0	0.5–59.6	0.0109	0.010–0.012	3.092	3.045–3.139	I	0.950	—	20.0_{TL}
Symphurus diomedeanus		21	5.0–14.7	0.9–31.0	0.0067	0.004–0.012	3.169	2.927–3.411	+A	0.975	—	22.0_{TL}
Trichiurus lepturus		17	7.4–65.3	0.1–103.3	0.0001	0.0001–0.0002	3.357	3.198–3.515	+A	0.993	30.0_{TL}	234.0_{TL}
Bembrops gobioides	≥500	21	8.8–23.4	3.9–82.6	0.0039	0.002–0.008	3.203	2.934–3.471	+A	0.970	—	30.0_{TL}
Synagrops bellus		20	6.3–20.7	4.6–166.6	0.0174	0.010–0.031	3.029	2.813–3.243	I	0.979	$13.0_{TL,13}$	$46.0_{TL,14}$
Epigonus pandionis	≥500	56	9.8–20.2	22.8–154.2	0.0358	0.022–0.058	2.809	2.633–2.984	–A	0.950	$11.2_{TL,15}$	23.5_{TL}
Centropristis philadelphica		42	9.7–23.5	23.2–289.3	0.0323	0.020–0.053	2.862	2.676–3.047	I	0.960	—	30.0_{TL}
Lutjanus campechanus		35	8.0–24.7	12.7–467.2	0.0237	0.013–0.042	3.032	2.806–3.258	I	0.958	$9.41_{FL,11}$	100.0_{TL}
Pristipomoides aquilonaris		477	3.3–20.0	1.0–197.2	0.0251	0.024–0.025	2.873	2.830–2.916	–A	0.973	—	56.0_{TL}
Prionotus longispinosus		183	3.9–24.7	1.3–307.6	0.0397	0.030–0.053	2.771	2.660–2.881	–A	0.931	$12.0_{TL,16}$	35.0_{TL}
Prionotus paralatus		180	7.8–17.5	7.5–85.2	0.0142	0.011–0.018	3.056	2.959–3.153	I	0.956	$10.0_{TL,16}$	$18.0_{SL,16}$
Peristedion greyae		123	12.8–18.4	11.9–33.4	0.0110	0.007–0.017	2.738	2.580–2.895	–A	0.907	—	23.9_{TL}
Micropogonias furnieri		26	12.0–20.2	40.4–155.5	0.0643	0.035–0.118	2.594	2.368–2.821	–A	0.959	24.3_{TL}	60.0_{SL}
Fowlerichthys radiosus		47	2.6–9.4	1.5–57.2	0.1357	0.105–0.176	2.578	2.411–2.744	–A	0.956	—	25.0_{TL10}
Dibranchus atlanticus		178	3.4–10.8	1.5–25.7	0.0696	0.059–0.083	2.434	2.351–2.517	–A	0.957	$10.9_{TL,17}$	39.4_{TL}
Ogcocephalus declivirostris		23	6.1–10.3	6.8–37.5	0.0304	0.019–0.048	3.027	2.805–3.248	I	0.975	—	16.5_{TL}
Zalieutes mcgintyi		17	3.3–7.3	1.4–10.5	0.0579	0.039–0.087	2.634	2.415–2.853	–A	0.978	—	10.0_{TL}
Lagocephalus laevigatus		30	3.9–36.0	4.2–1050.3	0.0601	0.040–0.090	2.672	2.512–2.833	–A	0.976	$24.5_{SL,12}$	100.0_{TL}

n = number of individuals, SL = standard length, TL = total length, *a* = intercept (equation parameter), *b* = slope (equation parameter), 95% CI = 95% confidence limits (for both equation parameters), R^2 = coefficient of determination. Species in bold denote new maximum length. I = isometric growth, –A = negative allometric growth, +A = positive allometric growth. Isometric growth is assumed in the species with low number of specimens and/or narrow range sizes (no value for 95% CI *b*) (Froese, 2006; Hay et al. 2020). Reference data = literature data, including information covered by FishBase, Subscript references: 1= McEachran and 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 et al. 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.

and *b* parameters of the LWR, we assumed an isometric relation ($b = 3$) (Froese 2006; Hay et al. 2020) and the value of the intercept (a) will be obtained with the following formula

$$a = \frac{\sum_{i=1}^{n} \frac{W}{L^3}}{n}$$

Results

The descriptive statistics and the estimated LWR parameters for 39 species are summarized in Table 1. All LWR estimates were statistically significant ($P < 0.05$), yielding $R^2 > 0.900$. 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 the values of “*a*” ranged between 0.0001 (*Trichiurus lepturus*) and 0.1357 (*Fowlerichthys radiosus*); and the “*b*” values oscillated between 2.309 (*Cyclothone alba*) and 3.648 (*Malacocephalus occidentalis*). Positive allometric growth was reported in nine species, negative allometric growth in 16 species, and isometric growth in 14 species.

The LWR of 11 species that correspond to 10 families have not been previously reported, so it is an important contribution to their knowledge. These families and species are Congridae: *Rhynchoconger flavus*, Gonostomatidae: *Cyclothone alba*, Moridae: *Laemonema goodebeanorum*, Cyclopsettidae: *Cyclopsetta chittendeni*, Bothidae: *Monolene sessilicauda*, Cynoglossidae: *Symphurus diomedeanus*, Bembropidae: *Bembrops gobioides*, Triglidae:

Prionotus paralatus, Antennariidae: *Fowlerichthys radiosus*, and Ogcocephalidae: *Ogcocephalus declivirostris*, *Zalieutes mcgintyi*.

Discussion

The abundance of fish species associated with depths greater than 500 m, is usually low and the available information on their populations and growth rates are scarce (Danovaro et al. 2017). Therefore, any new data on their biology is important. The deep-sea species reported in this study are carnivorous, occurring in the vertical gradients of the continental slope and the bathyal zone, and were exemplified by *Epigonus pandionis*, *Merluccius albidus*, *Chauliodus sloani*, *Chlorophthalmus agassizi* (see Ramírez et al. 2019). Furthermore, we highlight an amplitude in its maximum length reported by the literature corresponding to *Cyclothone alba* from 2.9 to 5.6 cm SL, *Cyclothone braueri* from 3.8 to 4.6 cm SL, *Cyclothone 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 oil 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 have been very scarce. In these studies, the species analyzed include *Chloroscombrus chrysurus* and *Citharichthys spilopterus* (see Dawson 1965; Galindo-Cortés et al. 2015) and a single deep-sea species *Urophycis cirrata* (see Matlock et al. 1988). The majority of the species mentioned in these investigations are associated with shallow coastal areas. In the presently reported 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 *Cyclothone alba* (2.309) and *Dibranchus atlanticus* (2.434) that were found below this range of values, and for *Malacocephalus occidentalis* which is above those values (3.648). For *Cyclothone braueri* and *Chloroscombrus chrysurus* with a low number of specimens and/or with low range sizes (Carlander 1997), the LWR was calculated assuming $b = 3.0$, being the value of the intercept considered by the formula of Hay et al. (2020). These low values can be attributed also 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 nine and 16 species showed positive and negative allometric growth, respectively, while isometric growth was reported in 14 species.

Author contribution

(following Contributor Roles Taxonomy of CRediT https://credit.niso.org):

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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