ACTA ICHTHYOLOGICA ET PISCATORIA (2017) 47 (4): 411–415 DOI: 10.3750/AIEP/02239

LENGTH–WEIGHT RELATIONS OF FISHES INHABITING A HYPERHALINE COASTAL LAGOON IN YUCATAN, MEXICO

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Vega-Cendejas M.E., Peralta-Meixueiro M.A., Hernández de Santillana M. 2017. Length–weight relations of fishes inhabiting a hyperhaline coastal lagoon in Yucatan, Mexico. Acta Ichthyol. Piscat. 47 (4): 411–415.

Abstract. Length–weight relations (LWR) were estimated for 45 fish species (27 families) from a tropical hyperhaline coastal lagoon and a protected biosphere reserve located in Yucatan Peninsula. The following species were studied: *Elops saurus* Linnaeus, 1766; *Anchoa mitchilli* (Valenciennes, 1848); *Harengula jaguana* Poey, 1865; *Ariopsis felis* (Linnaeus, 1766); *Synodus foetens* (Linnaeus, 1766); *Opsanus beta* (Goode et Bean, 1880); *Mugil trichodon* Poey, 1875; *Menidia colei* Hubbs, 1936; *Menidia peninsulae* (Goode et Bean, 1879); *Atherinomorus stipes* (Müller et Troschel, 1848); *Strongylura notata* (Poey, 1860); *Chriodorus atherinoides* Goode et Bean, 1882; *Hyporhamphus meeki* Banford et Collette, 1993; *Fundulus grandissimus* Hubbs, 1936; *Lucania parva* (Baird et Girard, 1855); *Poecilia velifera* (Regan, 1914); *Cyprinodon artifrons* Hubbs, 1936; *Floridichthys polyommus* Hubbs, 1936; *Jordanella pulchra* (Hubbs, 1936); *Syngnathus makaxi* Herald et Dawson, 1972; *Prionotus tribulus* Cuvier, 1829; *Trachinotus falcatus* (Linnaeus, 1758); *Lutjanus griseus* (Linnaeus, 1758); *Diapterus auratus* Ranzani, 1842; *Diapterus rhombeus* (Cuvier, 1829); *Eucinostomus argenteus* Baird et Girard, 1855; *Eucinostomus gula* (Quoy et Gaimard, 1824); *Eucinostomus harengulus* Goode et Bean, 1879; *Eugerres plumieri* (Cuvier, 1830); *Gerres cinereus* (Walbaum, 1792); *Orthopristis chrysoptera* (Linnaeus, 1766); *Archosargus rhomboidalis* (Linnaeus, 1758); *Lagodon rhomboides* (Linnaeus, 1766); *Bairdiella chrysoura* (Lacepède, 1802); *Cynoscion nebulosus* (Cuvier, 1830); *Cynoscion arenarius* Ginsburg, 1930; *Micropogonias undulatus* (Linnaeus, 1766); *Menticirrhus littoralis* (Holbrook, 1847); *Menticirrhus americanus* (Linnaeus, 1758); *Menticirrhus saxatilis* (Bloch et Schneider, 1801); *Mayaheros urophthalmus* (Günther, 1862); *Gobiosoma robustum* Ginsburg, 1933; *Sphyraena barracuda* (Edwards, 1771); *Achirus lineatus* (Linnaeus, 1758); *Sphoeroides testudineus* (Linnaeus, 1758). A total of 31 011 specimens were collected using a beach seine and a trawl net from October 2004 through November 2005, and from August 2007 through October 2008. Dominant species were *Floridichthys polyommus*, *Cyprinodon artifrons*, *Menidia colei*, and *Sphoeroides testudineus*. Results indicated a negative (19 species) and positive (26 species) allometric growth. The present paper provides the first published LWRs estimations for *Syngnathus makaxi* and *Eucinostomus harengulus*, and a new maximum length record for *Hyporhamphus meeki* (20.9 cm standard length).

Keywords: Ría Lagartos Lagoon, L–W relation, hyperhaline ecosystem

Length–weight relations (LWR) are the key element in the research of biology, taxonomy, and ecology—the fisheries sciences, estimating the biomass of fish species from length observations. LWRs have been useful in determining fish weight based on its length (Xie et al. 2015), for development of fish population dynamics models (Kohler et al. 1995), in comparisons of fish species life histories between regions (Froese and Pauly 2017), ontogenetic allometric changes and estimations of isometric or allometric growth (Teixeira de Mello et al. 2006) in order to determine how the distribution of energy relates to axial growth or to biomass (Teixeira de Mello et al. 2009), and for evaluations of parasites effects (Teixeira-de Mello and Eguren 2008). These estimations may differ between species of different regions, and among locations for the same species (Velázquez-Velázquez et al 2009). LWRs concerning fishes inhabiting protected tropical areas of south-eastern Mexico are very scarce (Vega-Cendejas et al. 1997). Thus, the aim of this study was to estimate the LWRs for 31 011 specimens belonging

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to 45 fish species (representing 27 families) that inhabit a tropical coastal hyperhaline lagoon of Ría Lagartos, a Biosphere Reserve located in Yucatan Peninsula. The following species were studied: *Elops saurus* Linnaeus, 1766; *Anchoa mitchilli* (Valenciennes, 1848); *Harengula jaguana* Poey, 1865; *Ariopsis felis* (Linnaeus, 1766); *Synodus foetens* (Linnaeus, 1766); *Opsanus beta* (Goode et Bean, 1880); *Mugil trichodon* Poey, 1875; *Menidia colei* Hubbs, 1936; *Menidia peninsulae* (Goode et Bean, 1879); *Atherinomorus stipes* (Müller et Troschel, 1848); *Strongylura notata* (Poey, 1860); Chriodorus atherinoides Goode et Bean, 1882; *Hyporhamphus meeki* Banford et Collette, 1993; *Fundulus grandissimus* Hubbs, 1936; *Lucania parva* (Baird et Girard, 1855); *Poecilia velifera* (Regan, 1914); *Cyprinodon artifrons* Hubbs, 1936; *Floridichthys polyommus* Hubbs, 1936; *Jordanella pulchra* (Hubbs, 1936); *Syngnathus makaxi* Herald et Dawson, 1972; *Prionotus tribulus* Cuvier, 1829; *Trachinotus falcatus* (Linnaeus, 1758); *Lutjanus griseus* (Linnaeus, 1758); *Diapterus auratus* Ranzani, 1842; *Diapterus rhombeus* (Cuvier, 1829); *Eucinostomus argenteus* Baird et Girard, 1855; *Eucinostomus gula* (Quoy et Gaimard, 1824); *Eucinostomus harengulus* Goode et Bean, 1879; *Eugerres plumieri* (Cuvier, 1830); *Gerres cinereus* (Walbaum, 1792); *Orthopristis chrysoptera* (Linnaeus, 1766); *Archosargus rhomboidalis* (Linnaeus, 1758); *Lagodon rhomboides* (Linnaeus, 1766); *Bairdiella chrysoura* (Lacepède, 1802); *Cynoscion nebulosus* (Cuvier, 1830); *Cynoscion arenarius* Ginsburg, 1930; *Micropogonias undulatus* (Linnaeus, 1766); *Menticirrhus littoralis* (Holbrook, 1847); *Menticirrhus americanus* (Linnaeus, 1758); *Menticirrhus saxatilis* (Bloch et Schneider, 1801); *Mayaheros urophthalmus* (Günther, 1862); *Gobiosoma robustum* Ginsburg, 1933; *Sphyraena barracuda* (Edwards, 1771); *Achirus lineatus* (Linnaeus, 1758); *Sphoeroides testudineus* (Linnaeus, 1758). The majority of the collected specimens were juveniles, which may be explained by the critical nursery function of the lagoon, as well as fish species with high tolerant ranges to salinity (>50) and low oxygen levels (2.0 mg · L^{-1}) such as *Floridichthys polyommus* and *Cyprinodon artifrons* (see Vega-Cendejas and Hernandez de Santillana 2004, Peralta-Meixuero and Vega-Cendejas 2011).

Ría Lagartos Lagoon is located on the north-eastern coast of Yucatan Peninsula, Mexico (21°26′–21°38′N, 87°30′–88°15′W). It is a long (80 km), wide (25 m to 3.5 km) coastal system, and has been considered a Biosphere Reserve for being a breeding and nesting area of pink flamingo *Phoenicopterus ruber* (see Vega-Cendejas and Hernández de Santillana (2004).

The sampling of the fish specimens was conducted bimonthly from October 2004 through November 2005, and from August 2007 through October 2008, using a beach seine (15-m long, 2.0-m high, and 2.5-cm mesh size), and a trawl net (3.5-m long, 0.33-cm mesh size). Depending on the season, the number of sampling stations along the lagoon ranged from 10 to 31, because during the dry season the level of the water decreased drastically and was is not possible to operate the fishing gear.

Collected fishes were euthanized in an ice slurry, then preserved in formalin (10%), and transported to the laboratory where they were identified, measured for standard length (SL) (± 0.1 mm precision), and weighed with an electronic scale (± 0.01 g precision). A representative sample of each species was deposited and catalogued in the Ichthyology Collection of the Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional (CINVESTAV), Merida (CINVNEC) with the reference number YUC-PEC.084.0999.

Parameters (*a* and *b*) of the LWR were estimated (using Statgraphics software; version 5.1) with a linear least squares regression using a log–log scale

$$W = aL^b$$

where W is the weight of the fish [g], L is the standard length (SL) [cm], a is the intercept, and b is the regression coefficient (indicating isometric growth when equal to 3). Based on the slope (b) of the relation between weight and length, one can check whether the growth of a fish is negative ($b < 3$), or positive allometric ($b > 3$) (Froese et al. 2011). Outliers were detected and eliminated using log–log plots and 95% confidence limits for b (CI 95% for b) were estimated by a Student's t-test (Froese 2006). Comparisons of maximum sizes recorded in previous studies were made using the records reported in FishBase (Froese and Pauly 2017). Scientific names of the fishes were verified following Eschmeyer et al. (2017).

A total of 31 011 specimens were collected and they belonged to 45 species and represented 27 families. The ocellated killifish, *Floridichthys polyommus*, was the most abundant fish species (6886 specimens), followed by Yucatan pupfish, *Cyprinodon artifrons*, and golden silverside, *Menidia colei* (5868 and 4439, individuals respectively) (Table 1). The coefficient of determination (r^2) ranged from 0.837 in *Lucania parva* to 0.993 in *Eugerres plumieri*. The parameter b ranged from 2.582 in *Menticirrhus americanus* to 3.518 in *Harengula jaguana*. The value of b for *H. jaguana* is like the one reported for this species at Celestun Lagoon (3550) (Vega-Cendejas et al. 2012). Differences in b values among areas could be attributed to species morphology and environmental factors such as temperature, salinity, food (quantity, quality and size), sex, health, and developmental stage (Sparre and Venema 1992).

This study provides the first LWR estimation for *Syngnathus makaxi* and *Eucinostomus harengulus* (Table 1). We also present a new maximum length (L_{max}) record for *Hyporhamphus meeki* (20.9 cm SL). Results provided in this study are of importance for the management and functional knowledge of the hyperhaline ecosystems, which using ECOPATH modelling and trophic knowledge

* Statistical Graphics System Corporation, Rockville, Maryland, USA 2000.

Table 1

Length–weight relations for 45 species in the hyperhaline Ría Lagartos lagoon, Yucatan, Mexico

Family	Species	*n*	SL [cm]	Weight [g]	L_m [cm]		L_{max} [cm]			*a*	*b*	SE of *b*	95%CI of *b*	r^2	REM
					SL_m	TL_m	SL_{max}	FL_{max}	TL_{max}						
Elopidae	*Elops saurus*	148	2.5–26.7	0.10–180.00	32.5				100.0	0.016	2.773	0.046	2.682–2.863	0.961	
Engraulidae	*Anchoa mitchilli*	1313	1.0–5.5	0.01–1.30	4.0		10.0			0.007	3.037	0.026	2.980–3.087	0.907	
Clupeidae	*Harengula jaguana*	757	1.7–10.7	0.03–22.90	8.0				21.2	0.006	3.518	0.016	3.486–3.549	0.982	
Ariidae	*Ariopsis felis*	231	1.4–35.3	0.70–431.20	12.3				70.0	0.020	2.847	0.029	2.790–2.903	0.975	
Synodontidae	*Synodus foetens*	68	2.0–25.3	0.04–168.40	19.0			48.3		0.003	3.322	0.038	3.247–3.396	0.991	
Batrachoididae	*Opsanus beta*	30	2.5–20.0	0.30–254.60	7.6				30.0	0.018	3.151	0.055	3.043–3.258	0.991	G
Mugilidae	*Mugil trichodon*	79	1.4–21.3	0.04–182.10	16.0				46.0	0.023	2.945	0.060	2.827–3.062	0.968	G
Atherinopsidae	*Menidia colei*	4439	0.1–3.7	0.01–0.50	—	—	5.8			0.011	3.000	0.017	2.966–3.033	0.879	
	Menidia peninsulae	53	1.6–3.7	0.04–0.50	—	—	18.3			0.014	2.747	0.117	2.517–2.976	0.914	F
Atherinidae	*Atherinomorus stipes*	139	1.4–4.4	0.04–1.30	6.0		12.5			0.012	3.136	0.055	3.028–3.243	0.959	G
Belonidae	*Strongylura notata*	261	1.2–40.5	0.01–153.30		22.6			61.0	0.001	3.031	0.022	2.987–3.074	0.986	
Hemiramphidae	*Chriodorus atherinoides*	28	11.4–18.7	11.40–66.30	—	—			26.0	0.004	3.210	0.208	2.802–3.617	0.900	
	Hyporhamphus meeki	79	8.0–20.9	1.30–33.40	—	—	18.0			0.003	3.009	0.143	2.728–3.289	0.852	M, F
Fundulidae	*Fundulus grandissimus*	54	2.7–14.8	0.30–38.70		4.9			21.8	0.010	3.243	0.088	3.070–3.514	0.962	F
	Lucania parva	363	0.1–4.5	0.01–3.30		2.5			5.0	0.023	2.797	0.064	2.671–2.922	0.837	
Poeciliidae	*Poecilia velifera*	89	1.4–5.2	0.10–6.40	3.4				15.0	0.022	3.302	0.059	3.186–3.417	0.972	F
Cyprinodontidae	*Cyprinodon artifrons*	5868	0.1–5.7	0.01–18.40	2.4				6.0	0.025	3.336	0.015	3.306–3.365	0.891	F
	Floridichthys polyommus	6886	0.1–9.1	0.01–27.90	—	—	11.6			0.041	2.885	0.011	2.863–2.906	0.909	
	Jordanella pulchra	759	0.6–3.0	0.01–0.80	—	—			4.0	0.028	2.979	0.023	2.933–3.024	0.953	
Syngnathidae	*Syngnathus makaxi*	146	1.0–8.7	0.01–0.50	5.3		7.0			0.0008	2.834	0.099	2.639–3.028	0.850	F
Triglidae	*Prionotus tribulus*	41	1.4–8.5	0.20–17.10	—	—			35.0	0.040	2.785	0.102	2.585–2.984	0.950	F
Carangidae	*Trachinotus falcatus*	159	1.2–13.8	0.10–84.90	54.0			122.0		0.040	2.887	0.022	2.843–2.930	0.990	G
Lutjanidae	*Lutjanus griseus*	54	4.0–18.2	1.30–80.60	32.0				89.0	0.040	2.793	0.059	2.677–2.908	0.977	
Gerreidae	*Diapterus auratus*	185	1.7–11.5	0.10–45.10	12.0				34.0	0.016	3.250	0.031	3.189–3.310	0.983	
	Diapterus rhombeus	50	2.2–8.7	0.30–13.70	13.0				40.0	0.019	3.046	0.056	2.936–3.155	0.983	
	Eucinostomus argenteus	1477	0.7–9.1	0.01–19.20	12.0				21.0	0.017	3.139	0.015	3.109–3.168	0.967	
	Eucinostomus gula	1733	0.9–8.3	0.01–15.60	11.0				23.0	0.021	3.134	0.011	3.112–3.155	0.975	
	Eucinostomus harengulus	223	1.4–8.3	0.04–13.80	12.0				15.0	0.017	3.177	0.024	3.129–3.224	0.987	F
	Eugerres plumieri	53	3.2–10.5	0.70–34.10	17.0				40.0	0.016	3.251	0.037	3.178–3.323	0.993	
	Gerres cinereus	20	4.8–11.6	2.70–42.70	16.4				41.0	0.034	2.916	0.108	2.704–3.127	0.975	
Haemulidae	*Orthopristis chrysoptera*	102	2.5–20.6	0.30–143.00		20.0			46.0	0.041	2.695	0.101	2.497–2.892	0.876	
Sparidae	*Archosargus rhomboidalis*	45	3.8–10.5	1.60–40.50	8.0				33.0	0.020	3.220	0.082	3.059–3.380	0.972	
	Lagodon rhomboides	853	1.3–11.8	0.10–49.40	13.1				40.0	0.029	3.009	0.023	2.963–3.054	0.957	

Table continues on next page.

Table 1 cont.

Family	Species	n	SL [cm]	Weight [g]	L_m [cm] SL_m	TL_m	L_{max} [cm] SL_{max}	FL_{max}	TL_{max}	a	b	SE of b	95%CI of b	r^2	REM
Sciaenidae	*Bairdiella chrysoura*	30	1.5–15.5	0.10–76.20	9.3				30.0	0.020	2.962	0.042	2.879–3.044	0.983	
	Cynoscion nebulosus	105	2.4–21.3	0.20–119.40		24.8			100.0	0.015	2.946	0.028	2.891–3.000	0.987	G
	Cynoscion arenarius	1077	3.1–11.6	0.50–24.60		14.0			63.5	0.014	3.017	0.015	2.987–3.046	0.971	G
	Micropogonias undulatus	28	2.3–6.0	0.10–2.80		17.3			55.0	0.007	3.306	0.182	2.949–3.662	0.926	
	Menticirrhus littoralis	25	3.0–8.3	0.50–6.60		19.8	60.0			0.020	2.760	0.066	2.630–2.889	0.986	
	Menticirrhus americanus	160	2.5–14.9	0.30–49.90		15.0	60.0			0.031	2.582	0.040	2.503–2.660	0.962	G
	Menticirrhus saxatilis	185	1.7–13.0	0.10–20.90		25.6			46.0	0.026	2.697	0.056	2.587–2.806	0.925	G
Cichlidae	*Mayaheros urophthalmus*	148	2.5–26.7	0.10–180.00	7.5				39.4	0.034	3.045	0.030	2.986–3.103	0.995	
Gobiidae	*Gobiosoma robustum*	27	1.5–3.5	0.10–1.20	2.7				5.0	0.015	3.310	0.030	3.251–3.368	0.932	G
Sphyraenidae	*Sphyraena barracuda*	32	6.5–32.5	1.50–261.90	58.0		230.0			0.004	3.245	0.015	3.215–3.274	0.986	G
Achiridae	*Achirus lineatus*	375	1.5–9.3	0.10–27.60	11.1				33.1	0.022	3.265	0.032	3.202–3.327	0.963	
Tetraodontidae	*Sphoeroides testudineus*	2034	1.1–21.3	0.80–390.60	10.8				38.8	0.124	2.600	0.044	2.513–2.686	0.963	

n = number of individuals, SL = standard length, L_m = length at maturity (SL_m = standard length, TL_m = total length), L_{max} = reported maximum length (SL_{max} = standard length, FL_{max} = fork length, TL_{max} = total length, a = intercept, b = slope, SE of b = standard error of b, CI = confidence limits; r^2 = coefficient of determination; REM = remarks, M = species with a maximum length greater than previously recorded (Froese and Pauly 2017), F = first LWR report published, G = length–weight relation information available in FishBase but not for Mexico.

and population dynamics of the fish species, will allow evaluating the functionality of these unique ecosystems, with respects to its ecological dynamics.

ACKNOWLEDGEMENTS

The authors would like to thank to the Consejo Nacional de Ciencia y Tecnología, Mexico–Sistema de Investigación Regional "Justo Sierra" (CONACYT–SISIERRA), which provided part of the financial support of this study and to René H. Kantún Palma, Director of the Ría Lagartos Biosphere Reserve for his help during the study. This study was also partly financed by a CONACYT doctoral scholarship granted to Miguel A. Peralta Meixuero. We are also very grateful to Alex Acosta, Victor Castillo, Grisel Díaz, Mónica Herrera, Judith Mazún, Ericka Canul, Oscar Navarrete, and Domingo Blanqueto, for field technical assistance and to Daniel Arceo for his laboratory support. We also thank the Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Mexico (CINVESTAV), for infrastructure support.

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Received: 21 April 2017
Accepted: 5 October 2017
Published electronically: 31 December 2017