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Lenght-weight relationships of fish species inhabiting the unprotected Yucatan costal Corridor, Mexico

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Abstract. Length-weight relationships (LWR) were estimated for 44 fish species collected from the unprotected Yucatan coastal Corridor. The sample was composed of species represented by 23 families: Urotrygonidae [*Urobatis jamaicensis* (Cuvier, 1816)], Albulidae [*Albula vulpes* (Linnaeus, 1758)]; Elopidae [*Elops saurus* Linnaeus, 1766], Engraulidae [*Anchoa hepsetus* (Linnaeus, 1758), *Anchoa lamprotaenia* Hildebrand, 1943, *Anchoa lyolepis* (Evermann & Marsh, 1900), *Anchoa mitchilli* (Valenciennes, 1848)]; Dorosomatidae [*Harengula jaguana* Poey, 1865, *Opisthonema oglinum* (Lesueur, 1818)]; Ariidae [*Ariopsis felis* (Linnaeus, 1766), *Bagre marinus* (Mitchill, 1815)]; Synodontidae [*Synodus foetens* (Linnaeus, 1766)]; Batrachoididae [*Opsanus beta* (Goode & Bean, 1880)]; Mugilidae [*Mugil curema* Valenciennes, 1836, *Mugil trichodon* Poey, 1875]; Belonidae

[*Strongylura notata* (Poey, 1860), *Strongylura timucu* (Walbaum, 1792)]; Hemiramphidae [*Chriodorus atherinoides* Goode & Bean, 1882, *Hyporhamphus unifasciatus* (Ranzani, 1841)]; Carangidae [*Caranx latus* Agassiz, 1831, *Oligoplites saurus* (Bloch & Schneider, 1801), *Selene vomer* (Linnaeus, 1758), *Trachinotus carolinus* (Linnaeus, 1766), *Trachinotus falcatus* (Linnaeus, 1758), *Trachinotus goodei* Jordan & Evermann 1896]; Cynoglossidae [*Symphurus plagiusa* (Linnaeus, 1766)]; Gerreidae [*Eucinostomus argenteus* Baird & Girard, 1855, *Eucinostomus gula* (Quoy & Gaimard, 1824), *Eucinostomus harengulus* Goode & Bean, 1879]; Grammistidae [*Rypticus maculatus* Holbrook 1855]; Haemulidae [*Orthopristis chrysoptera* (Linnaeus, 1766)]; Lutjanidae [*Lutjanus griseus* (Linnaeus, 1758)]; Triglidae [*Prionotus tribulus* Cuvier, 1829]; Ephippidae [*Chaetodipterus faber* (Broussonet, 1782)]; Sciaenidae [*Bairdiella chrysoura* (Lacepède, 1802), *Cynoscion arenarius*, Ginsburg, 1930; *Menticirrhus americanus* (Linnaeus, 1758), *Menticirrhus littoralis* (Holbrook, 1847), *Menticirrhus saxatilis* (Bloch & Schneider, 1801)], Sparidae [*Archosargus rhomboidalis* (Linnaeus, 1758), *Lagodon rhomboides* (Linnaeus, 1766)]; Ostraciidae [*Acanthostracion quadricornis* (Linnaeus, 1758)]; Tetraodontidae [*Sphoeroides spengleri* (Bloch, 1785), *Sphoeroides testudineus* (Linnaeus, 1758)]. A new maximum standard length (SL) was recorded for *Anchoa lamprotaenia*. A positive allometric growth was reported in fourteen species, negative allometric growth in 26 species, and isometric growth in four species.

Keywords: nursery habitats, length-weight relationships, Yucatan Peninsula

Introduction

Length-Weight relationships (LWRs) of fishes are a key element for the study of biology, taxonomy, physiology, ecology (Vega-Cendejas et al. 2017), and for fish population dynamics (Kohler et al. 1995). They are useful to calculate the expected weight from known length of fish and vice versa (Xie et al. 2015, Kuriakose 2017), to estimate the isometric or allometric growth (Teixeira-de Mello et al. 2006), as an indicator of fatness and the relative well-being of the fish population, the standing stock biomass and comparing the ontogeny of fish population from different regions (Petrakis and Stergiou 1995). This relationship has also been used for species-specific life history comparisons between regions (Wotton 1990), and for evaluations of parasites effects (Teixeira-de Mello and Eguren 2008).

The present study was an effort to determine LWRs for 44 fish species inhabiting the unprotected Yucatan Coastal Biological Corridor in the southern Gulf of Mexico (UYCBC). A biological corridor is a delimited geographic space that promotes connectivity between landscapes, ecosystems and natural or modified habitats and ensures the maintenance of biological diversity and ecological processes. It also allows genetic exchange between fragmented populations and the integration of these areas into land use planning plans. Studying these areas provides valuable information to propose new locations that require protection, as well as to identify high-priority network linkages between existing marine protected areas (Pendoley et al. 2014) and to define essential habitats for target species (Turk-Boyer et al. 2014).

Biological corridors emerge as a mechanism that attempts to give greater variability to the conservation of species found in wild areas, allowing the movement of biota from one protected area to another or between fragments of ecosystems (Moran et al. 2019). The UYCBC unites ecologically protected natural areas through areas with various productive activities and with different land use. Its importance lies in the fact that this system is unique in its habitat-species'-ecological process association and in the way in which the population that inhabits the coast uses its natural resources.

Material and Methods

The UYCBC, as part of the Mesoamerican Corridor is located in the southeastern portion of the Gulf of Mexico, which includes 350 km of littoral (Euán-Avila et al. 2014), and connects two important reserves: Celestun in the West and Ria Lagartos in the East (Palacios-Sánchez et al. 2019). This area has been recognized for having a great biodiversity, characterized by the heterogeneity of its habitats with the presence of wetlands, coastal lagoons, and petenes on its coastline. However, the UYCBC, which stretches 128 km, has been modified by various anthropogenic activities such as the construction of docks and ports, as well as by artisanal and industrial fishing, aquaculture and ecotourism (Herrera-Silveira and Morales-Ojeda 2009). Studies in this area have indicated that diversity and abundance of fishery resources increase inside protected areas. However, the surrounding unprotected areas require strategies to allow the free flow of species from one protected area to the other (Palacios-Sánchez et al. 2019)

Sampling of the fish specimens was realized for three years (October 2001 to April 2004) in 24 localities of the UYPCBC using a trawl net (3.5 m long, 0.33 cm mesh). Collected fish were euthanized in ice slurry, preserved (alcohol 70%), and transported to the laboratory where they were identified using specialized references (Carpenter 2002a; Carpenter 2002b; McEachran and Fechhelm 1998 and 2005, among others), measured for standard length (SL) (±0.1 cm precision), and weighed (±0.01 g precision). A representative sample of each species was deposited and catalogued in the Ichthyology Collection of CINVESTAV-Merida (CINV-NEC), reference number YUC-PEC.084.0999. Data were collected from 44 species which represents 23 families (Table 1), including *Urobatis jamaicensis* (Cuvier, 1816) [Urotrygonidae]; *Albula vulpes* (Linnaeus, 1758) [Albulidae]; *Elops saurus* Linnaeus, 1766 [Elopidae]; *Anchoa hepsetus* (Linnaeus, 1758), *Anchoa lamprotaenia* Hildebrand, 1943, *Anchoa lyolepis* (Evermann & Marsh, 1900), *Anchoa mitchilli* (Valenciennes, 1848) [Engraulidae]; *Harengula jaguana* Poey, 1865, *Opisthonema oglinum* (Lesueur, 1818) [Dorosomatidae]; *Ariopsis felis* (Linnaeus, 1766), *Bagre marinus* (Mitchill, 1815) [Ariidae]; *Synodus foetens* (Linnaeus, 1766) [Synodontidae]; *Opsanus beta* (Goode & Bean, 1880) [Batrachoididae]; *Mugil curema* Valenciennes, 1836, *Mugil trichodon* Poey, 1875 [Mugilidae]; *Strongylura notata* (Poey, 1860), *Strongylura timucu* (Walbaum, 1792) [Belonidae]; *Chriodorus atherinoides* Goode & Bean, 1882, *Hyporhamphus unifasciatus* (Ranzani, 1841) [Hemiramphidae]; *Caranx latus* Agassiz, 1831, *Oligoplites saurus* (Bloch & Schneider, 1801), *Selene vomer* (Linnaeus, 1758), *Trachinotus carolinus* (Linnaeus, 1766), *Trachinotus falcatus* (Linnaeus, 1758), *Trachinotus goodei* Jordan & Evermann 1896 [Carangidae]; *Symphurus plagiusa* (Linnaeus, 1766) [Cynoglossidae]; *Eucinostomus argenteus* Baird & Girard, 1855, *Eucinostomus gula* (Quoy & Gaimard, 1824), *Eucinostomus harengulus* Goode & Bean, 1879 [Gerreidae]; *Rypticus maculatus* Holbrook 1855 [Grammistidae]; *Orthopristis chrysoptera* (Linnaeus, 1766) [Haemulidae]; *Lutjanus griseus* (Linnaeus, 1758) [Lutjanidae]; *Prionotus tribulus* Cuvier, 1829 [Triglidae]; *Chaetodipterus faber* (Broussonet, 1782) [Ephippidae]; *Bairdiella chrysoura* (Lacepède, 1802), *Cynoscion arenarius* Ginsburg, 1930, *Menticirrhus littoralis* (Holbrook, 1847), *Menticirrhus americanus* (Linnaeus, 1758), *Menticirrhus saxatilis* (Bloch & Schneider, 1801)

[Sciaenidae]; *Archosargus rhomboidalis* (Linnaeus, 1758), *Lagodon rhomboides* (Linnaeus, 1766) [Sparidae]; *Acanthostracion quadricornis* (Linnaeus, 1758) [Ostraciidae]; *Sphoeroides spengleri* (Bloch, 1785), *Sphoeroides testudineus* (Linnaeus, 1758) [Tetraodontidae].

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 standard length (cm), a was the intercept and b was 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 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) 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).

Results

The descriptive statistics and the estimated LWR parameters for 44 species are summarized in Table 1. All LWR estimates were statistically significant (P<0.05). New maximum lengths are reported for one specie *Anchoa lamprotaenia* (12.2 cm SL). The scaled herring *Harengula jaguana* was the most abundant fish species (3,769specimens), followed by broad-striped anchovy *Anchoa hepsetus* (3,559 specimens). However, even though the three years of sampling, a lower number of specimens was obtained (10-12 specimens) for some of the species (*Urobatis jamaicensis, Bagre marinus,Mugil curema, Strongylura timucu, Selene vomer, Rypticus maculatus, Prionotus tribulus, Chaetodipterus faber*), due to their low abundance and occurrence in these coastal ecosystems. Estimates of *a* and *b* for the length-weight relationships, the coefficient of determination r^2 and 95% confidence limits for *b* are given in Table 1. A negative allometric growth was recorded in 26 species, a positive allometric growth in 14 species and isometric growth in four species.

Discussion

The coefficient of determination (r^2) ranged from 0.891 (*A. quadricornis*) to 0.997 (*P. tribulus*). The exponent *b* presented a mean value of 2.977 (SE: 0.30), with values ranging from 2.166 estimated for *Elops saurus* to 3.985 for *Hyporhamphus unifasciatus*. The lower values may be since for most of the specimens analyzed were juveniles (<32.0 cm SL) due to their type of habitat (wetlands, petenes, swamps), while for *H. unifasciatus* it is attributed to its maturity stage.

A previous study carried out in Ría Lagartos, Yucatan report a b = 2.773 for *Elops saurus*,which may be due to a larger sample size (148) (Vega-Cendejas et al., 2017). The LWRs parameters of *Rypticus maculatus*, Grammistidae and *Anchoa lamprotaenia*, Engraulidae are herein published for the first time in both the scientific literature and databases, such as FishBase (Froese & Pauly 2023) (Table 1). A new maximum length was recorded for *A. lamprotaenia* (12.2 cm SL). Overall,LWRs were highly significant for all species ($P < 0.001$). Changes in *b* respond mostly to species morphology and environmental factors such as temperature, salinity, food (quantity, quality and size), sex, health and developmental stage (Sparre 1992). In the case of *Sphoerides testudineus a* (0.055) and *b* (2.880) were very similar to those previously reported in a hyperhaline coastal lagoon located near this unprotected coastal region (Vega-Cendejas et al. 2017).

Conclusions

The results provided in this study can be very useful for the management of coastal ecosystems, including wetlands, which is required to maintain their diversity due to the increase in human activity in this unprotected coastal region (tourism, fisheries, habitat degradation). Additionally, this information is very useful for the development of trophic models using ECOPATH, which are of significative value to make predictions about the conservation status of this critical habitat for fishery and ecologically important species that use the ecosystem in the juvenile stage.

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Table 1. Length-weight relationships for 44 species of the unprotected Yucatan coastal region. Yucatan, Mexico

Specie	***n***	**SL (cm)**	**Weight (g)**	**a**	**CI 95% a**	**b**	**CI 95% b**	**Growth type**	R^2	**Referenc data**	
										L_m **(cm)**	L_{max} **(cm)**
Urobatis jamaicensis	10	12.5-29.9	22.0-239.9	0.010	0.002-.0.053	2.988	2.474-3.501	-A	0.980	$20.0_{TL,1}$	76.0_{TL}
Albula vulpes NT	13	3.2-13.1	0.3-32.8	0.008	0.006-0.010	3.229	3.085-3.373	+A	0.996	21.0_{FL}	104.0_{TL}
Elops saurus	20	12.7-31.5	24.1-196.5	0.104	0.015-0.725	2.166	1.568-2.764	-A	0.878	32.5_{SL}	100.0_{TL}
Anchoa hepsetus	3559	3.4-6.7	0.4-2.4	0.019	0.018-0.020	2.508	2.475-2.542	-A	0.861	$4.3_{TL,2}$	15.3_{TL}
Anchoa lamprotaenia	360	**2.9-12.2**	0.12-34.5	0.005	0.005-0.006	3.315	3.278-3.352	+A	0.989	$5.0_{SL,3}$	12.0_{TL}
Anchoa lyolepis	39	3.9-6.3	0.5-2.2	0.006	0.004-.012	3.171	2.802-3.540	+A	0.904	$8.2_{SL,\mathbf{28}}$	12.0_{TL}
Anchoa mitchilli	1232	2.3-6.1	0.1-2.4	0.009	0.009-0.010	2.999	2.944-3.055	-A	0.905	$4.0_{SL,4}$	10.0_{TL}
Harengula jaguana	3769	2.1-12.8	0.1-36.3	0.008	0.007-0.008	3.381	3.366-3.397	+A	0.979	$8.0_{SL,5}$	21.2_{TL}
Opisthonema oglinum	92	3.8-17.1	0.8-86.2	0.011	0.009-.012	3.122	3.020-3.224	+A	0.976	11.5_{FL}	38.0_{TL}
Ariopsis felis	1388	4.0-26.3	0.9-240.7	0.016	0.015-0.017	2.948	2.924-2.972	-A	0.977	$15.0_{SL,6}$	70.0_{TL}
Bagre marinus	12	7.2-15.3	5.0-50.2	0.013	0.004-0.037	3.071	2.640-3.503	I	0.952	$32.8_{FL,8}$	$100_{TL,7}$
Synodus foetens	52	3.9-41.4	0.4-166.0	0.016	0.011-0.022	2.751	2.620-2.882	-A	0.974	19.0_{SL}	53.8_{TL}
Opsanus beta	23	4.5-10.4	1.9-24.8	0.012	0.007-0.019	3.301	3.032-3.571	+A	0.972	7.6_{SL}	$32.4_{SL,9}$
Mugil curema	10	2.0-23.9	0.1-153.4	0.013	0.007-0.024	3.086	2.834-3.339	I	0.994	$16.4_{TL,10}$	91.0_{TL}
Mugil trichodon	20	2.1-15.3	0.1-64.6	0.013	0.009-0.018	3.180	3.034-3.326	+A	0.991	16.0_{FL}	46.0_{TL}
Strongylura notata	104	24.0-46.0	23.7-124.8	0.009	0.005-0.015	2.524	2.364-2.683	-A	0.909	22.6_{TL}	61.0_{TL}
Strongylura timucu	10	7.2-36.5	0.3-72.0	0.0009	0.00002-0.054	3.090	1.918-4.261	I	0.993	-	61.0_{TL}
Chriodorus atherinoides	36	3.8-17.8	0.2-40.2	0.003	0.002-.008	3.312	2.971-3.652	+A	0.933	-	26.0_{TL}
Hyporhamphus unifasciatus	173	5.0-25.5	0.4-86.7	0.0002	0.0002-0.0003	3.985	3.887-4.084	+A	0.971	$18.5_{FL,\mathbf{28}}$	30.0_{TL}
Caranx latus	14	7.0-14.9	7.5-82.0	0.012	0.006-0.024	3.233	2.934-3.533	+A	0.981	37.0_{FL}	101.0_{FL}
Oligoplites saurus	28	2.2-23.8	0.1-145.3	0.017	0.014-0.021	2.735	2.639-2.830	-A	0.993	$19.8_{SL,11}$	$42.5_{SL,13}$
Selene vomer	11	2.3-9.2	0.4-23.4	0.049	0.031-0.079	2.700	2.374-3.025	-A	0.982	24.1_{TL29}	48.3_{TL}
Trachinotus carolinus	123	1.5-9.5	0.5-20.7	0.032	0.029+-0.035	2.861	2.804-2.917	-A	0.988	$25.0_{FL,12}$	64.0_{TL}
Trachinotus falcatus	491	2.0-14.5	0.4-104.1	0.045	0.042-0.049	2.850	2.800-2.900	-A	0.963	48.6_{FL}	122.0_{TL}
Trachinotus goodei	34	2.8-16.9	0.8-119.4	0.029	0.021-0.041	2.927	2.778-3.078	-A	0.983	$26.0_{TL,12}$	50.0_{TL}
Symphurus plagiusa	14	7.5-14.4	3.6-28.7	0.011	0.004-0.032	2.899	2.478-3.321	-A	0.971	10.1_{TL}	21.0_{TL}
Eucinostomus argenteus	347	2.0-14.5	0.2-45.1	0.022	0.020-0.024	3.006	2.954-3.058	I	0.975	$12.0_{TL,14}$	21.2_{TL}
Eucinostomus gula	388	2.6-9.1	0.4-20.7	0.016	0.015-0.018	3.219	3.161-3.277	+A	0.970	$9.0_{FL,14}$	25.5_{TL}
Eucinostomus harengulus	19	5.5-8.2	3.0-12.5	0.015	0.005-0.049	3.153	2.547-3.759	+A	0.905	12.0_{SL}	15.0_{SL}
Rypticus maculatus	10	6.4-8.9	5.2-13.6	0.019	0.002-0.168	2.984	1.969-3.999	-A	0.965	8.9_{16}	24.0_{TL15}
Orthopristis chrysoptera	15	4.2-20.5	1.5-158.7	0.032	0.017-0.061	2.844	2.601-3.086	-A	0.992	20.0_{SL}	46.0_{FL}
Lutjanus griseus	42	4.8-18.5	2.9-128.4	0.034	0.025-0.045	2.891	2.766-3.015	-A	0.984	$18.0_{SL,17}$	89.0_{TL}
Prionotus tribulus	10	2.6-14.3	0.6-61.6	0.032	0.020-0.053	2.885	2.668-3.101	-A	0.997	$8.4_{TL,18}$	35.0_{TL}
Chaetodipterus faber	10	2.8-7.4	1.5-23.8	0.074	0.048-0.113	2.917	2.650-3.185	-A	0.989	$9.9_{TL,19}$	91.0_{TL}
Bairdiella chrysoura	114	3.3-17.7	0.7-111.2	0.021	0.018-0.024	2.966	2.909-3.022	-A	0.990	$9.1_{SL,20}$	30.0_{TL}
Cynoscion arenarius	64	2.6-20.9	0.3-109.3	0.018	0.015-0.021	2.914	2.853-2.976	-A	0.994	$14.0_{SL,21}$	63.5_{TL}
Menticirrhus littoralis	69	2.6-15.7	0.2-63.2	0.014	0.012-0.017	2.943	2.856-3.031	-A	0.984	$19.8_{TL,23}$	$60.0_{SL,22}$
Menticirrhus americanus	104	2.4-14.8	0.2-57.3	0.010	0.009-0.012	3.149	3.093-3.206	+A	0.992	$15.0_{TL,24}$	$60.0_{TL,25}$
Menticirrhus saxatilis	57	2.5-19.0	0.4-102.2	0.014	0.012-0.017	2.997	2.908-3.086	-A	0.986	25.6_{TL}	46.0_{TL}
Archosargus rhomboidalis	139	2.7-21.0	0.5-327.0	0.023	0.021-0.024	3.148	3.116-3.179	+A	0.996	8.0_{SL}	33.0_{TL}
Lagodon rhomboides	230	4.7-13.0	2.6-62.4	0.041	0.032-0.052	2.846	2.740-2.953	-A	0.929	$8.0_{SL,26}$	40.0_{TL}
Acanthostracion quadricornis	16	12.9-21.7	79.9-283.6	0.221	0.049-1.004	2.313	1.771-2.855	-A	0.891	19.8_{TL}	55.0_{TL}
Sphoeroides spengleri	19	3.8-6.3	1.7-6.9	0.052	0.031-0.087	2.619	2.294-2.944	-A	0.954	$18.8_{SL,28}$	30.0_{TL}
Sphoeroides testudineus	110	2.3-20.0	3.8-378.7	0.055	0.039-0.077	2.880	2.753-3.008	-A	0.925	$10.0_{TL,27}$	38.8_{TL}

n= number of individuals, SL = standard length, TL = total length, *a* = intercept (equation parameter), *b* = slope (allometry coefficient), 95% CI = 95% confidence limits (for both equation parameters), R^2 = coefficient of determination, Lm = size at first maturity, Lmax = maximum length. 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= Yáñez-Arancibia and Amezcua 1979, 2 = Munroe et al. 2015a, 3 = Munroe et al. 2015b, 4 = Vega-Cendejas et al. 2017, 5 = Munroe et al. 2019, 6 = Betancur 2015, 7 = Chao et al. 2015, 8 = Caballero-Chávez 2013, 9 = Collette et al. 2019, 10 = Yago-Bruno 2020, 11 = Duque-Nivia et al. 1995, 12 = Alvarez-Lajonchere 2012, 13 = Ospina-Arango et al. 2008, 14 = Mexicano-Cíntora 1999, 15 = Anderson et al. 2015, 16 = Bullock and Smith 1991, 17 = Allen 1985, 18= Hoff 1992, 19=Soeth 2018, 20= Grammer 2009, 21= Nemeth et al. 2006, 22= Chao et al. 2020a, 23=Aloisio and Nelson 2004, 24=Chao et al. 2020b, 25= McEachran and Fechhelm 2005, 26=Russell et al. 2014, 27=Shao et al. 2014, 28=Bouchon-Navaro et al. 2006; 29=Becerra 2013.