Length-weight relationship and condition factor of butterfish *Peprilus medius* (Peters, 1869) in the southeast Gulf of California

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Butterfish *Peprilus medius* (Peters 1869), a species in the Stromateidae family (Perciformes, Stromateoidei), are distributed in the Pacific Ocean from Mexico to Peru and the Galapagos Islands (Fischer et al. 1995). This species lives in shoals and inhabits benthopelagic habitats, including soft bottoms (sand and mud) and reef environments, to a depth of approximately 200 m (Rojas and Zapata 2006; Ulloa et al. 2007; Salas and Alvarado 2008; Anónimo 2009; Chirichigno and Cornejo 2001 in Inga et al. 2008; Herrera et al. 2010; Domínguez-Domínguez et al. 2014).

Throughout its range, the fishery of *P. medius* benefits the socioeconomic systems of fishing communities. The resource is primarily harvested by artisanal fisheries, a commercial seine fishing fleet, and as bycatch in the shrimp trawl fishery (Inga et al. 2008; Martínez-Muñoz 2012; Reyes-Lucas and Reyes-Vega 2015). There is minimal fishery regulation and population monitoring in most locations where harvest occurs. In recent years, the commercial importance of *P. medius* has grown due to its quality, low price and availability throughout the year. *P. medius* is marketed for fresh human consumption in Peru (Inga et al. 2008), Mexico (Martínez-Muñoz 2012) and Colombia (Moreira-Arcentales 2012), and

exported frozen from Peru (Inga et al. 2008). Also, *P. medius* is used as a feed component for fish aquaculture (e.g., Prado 2010, Martínez-Lagos 2003). In Mexico, *P. medius* is also used as bait, being highly important to other artisanal fisheries.

Currently, Peru is the only country that has established a research and monitoring plan to improve management of *P. medius*, so the biological knowledge of *P. medius* is scarce (Rey-Rey 2007). Due to the growing popularity of this species, information is essential to support timely decisions and effective fishery management (Torres-Lara 1991). Additionally, biological information may be useful because the species is a potential bioindicator (Sielfeld et al. 2010) of warm-anomalous environmental conditions, and it could provide information to support timely decisions for mitigation and prevention purposes for ecosystems management.

To contribute to the biological information of *P. medius*, we present unpublished estimates of the length-weight relationship (LWR) and condition factor of *P. medius* from the southeastern Gulf of California, Mexico. We also review the available information about LWR of *P. medius* along its distribution range. Variations of LWR parameters of *P. medius* and condition factor were explored for potential differences between seasons, growth stanzas and locations (Froese 2006). Results of the LWR analysis are a valuable tool to convert length observations into weight estimates, which are necessary for biomass estimates obtained from analytical models. Results are also useful in fitting the von Bertalanffy growth equation in weight and in calculating indicators of the fish's physiological condition (Jones et al. 1999, Frota et al. 2004, Froese 1998, Froese 2006). Such indicators are also crucial for determining the health of a population (Jones et al. 1999). The *b* value of LWR also can be used as indicator of body shape or condition at the time of sampling (Froese 2006).

For this study, monthly samplings on artisanal landings of *P. medius* from southeast of Gulf of California, Mexico, were conducted from December 2011 to October 2012 (2011-2012 season), and September 2014 to November 2015 (2014-2015 season). The artisanal fishery catches *P. medius* with gillnet (3-5 in. mesh size) along the coast (Figure 1). The total weight (g, *W*) and total length (cm, *L*) of individuals from a random sample of captured fish were measured. Sex and gonadal development were defined by morphochromatic inspection of gonads according to Maldonado-Amparo et al*.* (2017), in order to separate juvenile from adult organisms, with the aim of assessing potential differences in LWR parameters between sexes and different ontogenetic stages of *P. medius.*

The length-weight relationship (LWR) was calculated by using power function $W \sim a L^b$, where *a* and *b* parameters were estimated by linearization of power function as *log W = log a + (log L) b* (Ricker 1975; Froese 1998; Froese et al. 2011). Differences in intraspecific LWR can be attributed to variations in ecological factors and differences between ontogenetic stages (Froese, 2006). With this in mind, we estimated LWR separately for overall data from both sampling seasons (AS-all) and separate sampling seasons for the following groups: all sample (AS), adult males (AM, sexual mature males), adult females (AF, sexual mature females) and juveniles (J, females and males sexually immature). Additionally, a throughout review of the published literature of *P. medius* LWR parameters was conducted, in order to assess potential latitudinal variations of this species LWR.

The relative condition factor (K_n) was estimated using the equation proposed by Le Cren (1951): $K_n = W/W_e$, where W_e is the total weight calculate by LWR for AS-all, and it was used to explore and compare groups condition within the overall sample (Froese 2006). The confidence limits (CL) of parameters (*a* and *b*) and K_n mean (by group) were estimated as parameter± [1.96*(standard error of parameter)] (Sokal and Rohlf 2009). The confidence
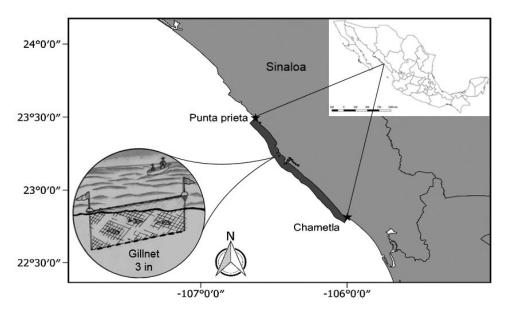
FIGURE 1.—Fishing area and fishing gear of *Peprilus medius* in the southeast Gulf of California.

limits (CL, 95%) were used to compare b with $b = 3$ to define: negative-allometric growth if b<3, isometric growth if b=3 and positive-allometric growth if b>3 (Froese 2006). K_n between groups were compared by Analysis of Variance (ANOVA) and a post-hoc Duncan test (Sokal and Rohlf 2009).

    The overall sample group (AS-all) was integrated by 922 specimens with sizes that ranged from 15 to 30 cm of L and 50 to 312 g of W (Table 1). All adjusted models of LWR explained more than 65% of variance (Table 1) and the lower determination coefficients are due a high natural variation of W in each L (Figure 2).

    Most of the upper (95%) values of the CLs for the b values were less than 3, indicating there was a negative allometric growth for all groups, except juveniles during the 2014-2015 season (Table 1, Figure 3). For all groups, the b values were higher during the 2014-2015 season (Figure 3). All b values presented an inverse trend with respect to parameter a values (Figure 3). All LWR presented a values less than 0.1.

    Available LWR of *P. medius* indicate that this species presents the three growth types (negative-allometric, isometric and positive-allometric). Our work is the first report of isometric growth (only a set of juveniles; Table 1). This variation can be the result of different ecological and biological processes, such as growth stanzas (ontogenetic stages), and intraspecific differences in gonadal development status (Schneider et al. 2000, Frota et al. 2004, Froese 2006). Most analyzed groups of *P. medius* presented negative-allometric growth (b<3) in the southeastern Gulf of California (Table 1). This indicates that large specimens change their body shape to become more elongated (Froese 2006) in our study area, indistinctly in most of the different ontogenetic stages or seasons.

    Other stromatids with negative-allometric growth reports are *P. paru* (Passos et al. 2012, Segura et al. 2012) and *P. snyderi* (Bautista-Romero et al. 2012). The positive-allometric growth was also reported for *P. simillimus* and *P. snyderi* (Rodríguez-Romero et al. 2009).

    The relative condition factor (K_n) was significantly different between groups

TABLE 1.—Length-weight relationships of *Peprilus medius*.

Category	Period	n	Interval		LWR parameters		Gt	R²	Place	Author
			LT (cm)	WT (g)	a (CL 95%)	b (CL 95%)				
All sample	D 2011 to O 2012 y S 2014 to N 2015	922	15-30	50-312	0.0261 (0.0200-0.0322)	2.7607 (2.6854-2.8360)	-A	0.8381	SE Gulf of California	This work
All sample	D 2011 to O 2012	591	16-30	50-309	0.0082 (0.0287-0.0609)	2.5775 (2.4587-2.6963)	-A	0.7443	SE Gulf of California	This work
Adult males	D 2011 to O 2012	214	17.5-26.5	61-208	0.0566 (0.0172-0.0960)	2.4910 (2.2617-2.7203)	-A	0.6536	SE Gulf of California	This work
Adult females	D 2011 to O 2012	246	17-27.5	58-309	0.0660 (0.0290-0.1030)	2.4609 (2.2767-2.6451)	-A	0.7193	SE Gulf of California	This work
Juveniles	D 2011 to O 2012	41	16-22.5	50-141	0.0463 (0.0083-0.0843)	2.5309 (2.2514-2.8104)	-A	0.8813	SE Gulf of California	This work
All sample	S 2014 to N 2015	331	15-28.8	55-312	0.0265 (0.0175-0.0355)	2.7637 (2.6551-2.8723)	-A	0.9006	SE Gulf of California	This work
Adult males	S 2014 to N 2015	174	17.2-28.7	71-270	0.0211 (0.0115-0.0307)	2.8249 (2.6785-2.9713)	-A	0.9000	SE Gulf of California	This work
Adult females	S 2014 to N 2015	143	18-28.8	73-312	0.0322 (0.0134-0.0510)	2.7161 (2.5301-2.9021)	-A	0.8679	SE Gulf of California	This work
Juveniles	S 2014 to N 2015	13	15-24.18	55-180	0.0407 (-0.0122-0.0936)	2.6386 (2.1888-3.0884)	1	0.8959	SE Gulf of California	This work
All sample	D 2009	203	5-18	NR	0.0315	2.6771	NR	0.9700	Salvador	Anonymous, 2009
All sample	O 2004 to M 2006	18	12-18.7	45-188	0.0250	3.0730 (2.6530-3.4930)	+A	0.9370	BCS, México	Rodríguez-Romero et al., 2009
All sample	J_N 2005 to J_L 2006	624	3.5-29.6	1-267	0.0080	3.0890 (3.0645-3.1135)	+A	0.8820	SE Gulf of California	Nieto-Navarro et al. 2010
All sample	1995 to 1996	541	6.5-27.5	NR	0.1024	2.2962	NR	0.8228	Colombia	Zapata-Padilla, 2011

J_N, June; J_L, July; D, December; O, October; S, September; N, November; M, March; n, data number; LT, total length; WT, total weight; LWR, length-weight relationship; a, intercept; b, slope; GT, growth type; I, isometric growth; -A, negative allometric growth; +A, positive allometric growth; CL, confidence limit; R^2, coefficient of determination; SE, southwest; BCS, Baja California Sur state; NR, data not reported.
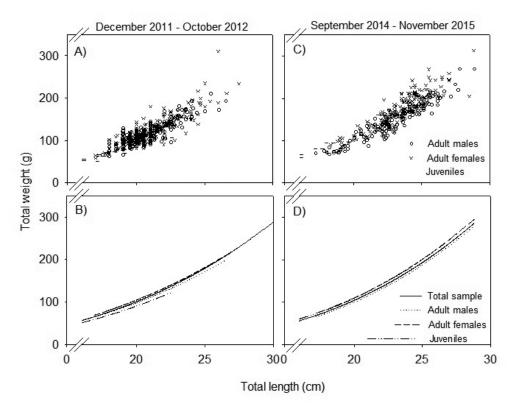
FIGURE 2.—Observed data and LWR regression fit for December 2011 – October 2012 (A and B, respectively) and for September 2014 – November 2015 (C and D, respectively).

$(F_{(3,921)})=16.8536$, P<0.001). The general trend was that *P. medius* had better condition in 2014-2015 season with respect to 2011-2012 season in the southeastern of Gulf of California (Figure 3). The major difference in condition factor was between juveniles, followed by the differences between adult females. The condition factor of adult males was similar between seasons (Figure 3). Changes in fish condition can be the result of good versus poor feeding success, disease or reproduction (Helfman et al. 2009). Juveniles do not invest energy in reproduction; therefore, they could enhance notably their condition in favorable ecological context. Meanwhile adults use part of their energy in gonadic development, thus possibly their condition improvement is minor (as in females) or not significant (as in males).

Reproductive activity was also more intense during 2014-2015 season. Most specimens' gonads were mature or in partial spawning phase (71.71%), and only 4.18% were immature, 10.93% in development, 4.5% post-spawning and 8.68% in resting phase. Conversely, in 2011-2012 season, the gonads were predominantly immature (45.53%) or in development process (47.86%), and a minor percentage presented as mature or partial spawning appearance (6.61%).

According to the Oceanic Niño Index (NOAA 2018), warm oceanic environmental conditions occurred during the 2014-2015 season, which is consistent with the higher K_n and b values and more intense reproductive activity observed in that season. Conversely, during 2011-2012 season the Pacific Ocean was slightly cooler-than-normal. This suggests
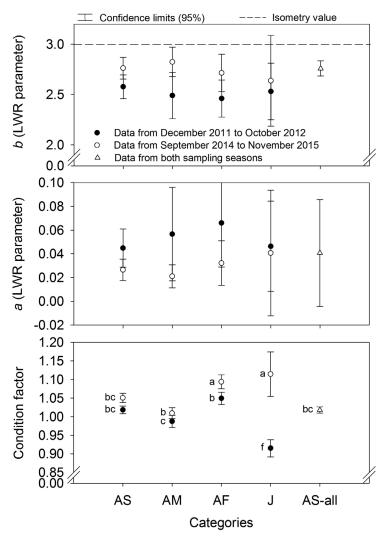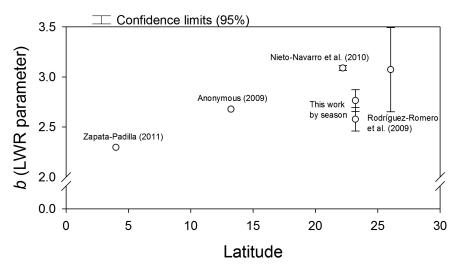
FIGURE 3.—Estimation and confidence interval of Length-weight relationships parameters and relative condition factor of *Peprilus medius.*

that warm-anomalous environmental phenomenons are favorable for *P. medius*, and in consequence, the population could enhance its condition and its reproductive activity. Additionally, it has been reported that *P. medius* can also change its distribution patterns during warm periods, and can be found outside its typical distribution range (Sielfeld et al. 2010).

The *b* values presented positive latitudinal arrangement being higher at subtropical areas with respect to tropical zones (Figure 4). This suggests that Bergmann's rule could occur in *P. medius* if higher *b* values are considered as indicators of better condition, based on the similar trends between b values and K_n (Figure 3). The Bergmann's rule postulates that body mass increases towards higher latitudes (Meiri 2011). To strengthen this idea it is necessary to assess *b* coefficient in more places over the entire latitudinal distribution range of *P. medius*.

FIGURE 4.—Latitudinal variation of previously published data and results of this study for values of the *b* parameter in the LWR of *Peprilus medius.*

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