Temporal variation, growth and natural mortality of two species of mojarras (Perciformes: Gerreidae) from a tropical coastal lagoon: La Carbonera, Yucatan, Mexico

Variación temporal, crecimiento y mortalidad natural de dos especies de mojarras (Perciformes: Gerreidae) de una laguna costera tropical: La Carbonera, Yucatán, México

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ABSTRACT

This study reports seasonal variation, growth parameters and natural mortality for *Eucinostomus gula* and *Eucinostomus argenteus* inhabiting La Carbonera, a tropical coastal lagoon on the northwestern coast of the Yucatan Peninsula, Mexico. Specimens were collected between April 2009 and March 2010. A total of 2700 organisms of *E. gula* (> 80% in rainy season) and 1577 organisms of *E. argenteus* (> 50% in dry season) were collected during the study period. Length-weight relationship (LWR) obtained was $W = 8.323E\text{-}03\ Lt^{2.92}$ in *E. argenteus* and $W = 7.314E\text{-}03\ Lt^{2.92}$ in *E. gula*. Growth parameters of von Bertalanffy growth function (VBGF) by length frequency analysis were in *E. argenteus*: L_∞ = 13.65 cm, k = 0.54 year^{-1} and t_0 = - 0.37 years; and in *E. gula*: L_∞ = 12.60 cm, k = 0.68 year^{-1} and t_0 = - 0.28 years. Additionally, estimated natural mortality in *E. gula* was 1.50 year^{-1} and in *E. argenteus* was 1.9 year^{-1}. This study presents the first estimation for both species of model parameters, growth performance index and mortality for the Yucatan Peninsula, which is relevant for the proper implementation of conservation measures for *E. gula* and *E. argenteus* in an important coastal zone of the Yucatan Peninsula.

Keywords: *Eucinostomus gula*, *Eucinostomus argenteus*, length-weight relationship, natural mortality.

RESUMEN

Se reportan la variación temporal, los parámetros de crecimiento y la mortalidad natural para *Eucinostomus gula* y *Eucinostomus argenteus* que habitan en la laguna costera tropical La Carbonera, al noroeste de la península de Yucatán, México. Los especímenes fueron recolectados entre abril de 2009 a marzo de 2010. Un total de 2 700 organismos de *E. gula* (> 80% en la estación lluviosa) y 1 577 organismos de *E. argenteus* (> 50% en la estación seca) fueron recolectados durante el período de estudio. Se determinó la relación peso-longitud (RPL) como: $P = 8.323E\text{-}03\ Lt^{2.92}$ en *E. argenteus* y $P = 7.314E\text{-}03\ Lt^{2.92}$ en *E. gula*. Para *E. argenteus,* los parámetros de crecimiento de la ecuación de crecimiento de von Bertalanffy (ECVB) fueron: L_∞ = 13.65 cm, k = 0.54 año^{-1} y t_0 = - 0.37 años; mientras que para *E. gula* fueron: L_∞ = 12.60 cm, k = 0.68 año^{-1} y t_0 = - 0.28 años. La mortalidad natural en *E. gula* fue 1.50 año^{-1} y en *E. argenteus* fue 1.9 año^{-1}. Este estudio presenta la primera estimación para ambas especies de los modelos de crecimiento, el índice del desempeño de crecimiento y la mortalidad natural para la península de Yucatán, lo que es relevante para la adecuada implementación de medidas de conservación de *E. gula* y *E. argenteus* en una valiosa zona costera de la península de Yucatán.

Palabras claves: *Eucinostomus gula*, *Eucinostomus argenteus*, relación talla-peso, mortalidad natural.

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INTRODUCTION

Juvenile fish growth is considered one of the most important factors contributing to future recruitment of adult populations within a habitat. Length and weight relationship (LWR) parameters (*a* and *b*) are necessary variables to understand the dynamics of a fish population (Pitcher & Hart, 1982), just as environmental factors are key in understanding the importance of a population in a particular habitat (Shervette *et al.* 2007) and in a particular season (Castillo-Rivera *et al.* 2002).

The Gerreidae family, colloquially known as *mojarras*, is a marine-euryhaline species (Godefroid *et al.* 2001) widely distributed in tropical and subtropical latitudes, constituting an abundant resource of commercial importance in Mexican coastal lagoons (Ordóñez-López & García-Hernández, 2005). The silver mojarra, *Eucinostomus argenteus*, and the jenny mojarra, *Eucinostomus gula*, are the most abundant species in coastal lagoons influenced by freshwater seeps in the northwestern Yucatan peninsula (Vega-Cendejas *et al*. 2012). Although both species are not fished in the northwestern Yucatan peninsula, they are considered important for fisheries along other coastal areas of the Gulf of Mexico, the Caribbean, and the Atlantic (Kerschner *et al.* 1985).

The Yucatan peninsula has numerous coastal lagoons, whose structure and function are modified by wastewater discharge, groundwater pumping, and land use changes. La Carbonera coastal lagoon is a transitional environment between karst land and a marine habitat with highly environmental variability over short time scales. This lagoonal system is important for local fisheries and as bird habitat (e.g. rose flamingos *Phoenicopterus ruber*).

The aim of this study was to estimate the natural mortality and present the seasonal variation, length-weight relationship (LWR), and growth parameters of *E. gula* and *E. argenteus* from La Carbonera lagoon in the northwestern Yucatan Peninsula.

MATERIALS AND METHODS

Study area: La Carbonera coastal lagoon lies on the northwestern Yucatan peninsula, Mexico (21° 13’ – 21° 14' N; 89 °52' – 89° 54' W; Fig. 1) (Bonilla-Gómez *et al*. 2012). It is connected to the sea by a channel formed in 1988 by Hurricane Gilbert and is fringed with *Rhizophora mangle* stands and a sand barrier. The lagoon is shallow (average annual depth ~0.5 m) and covers an area of ~16.5 km^2. It is a very low karstic biogenic marine littoral (Batllori-Sampedro *et al.* 2006). Freshwater input is restricted to underground seeps and rainfall. There is a *cenote* (sinkhole) in the southern part of the lagoon, in a patch of mangroves. There are three climatic seasons in the area and a karstic substratum through the system with three types of sediments: sandy, rocky bed, and muddy (Lankford, 1977).

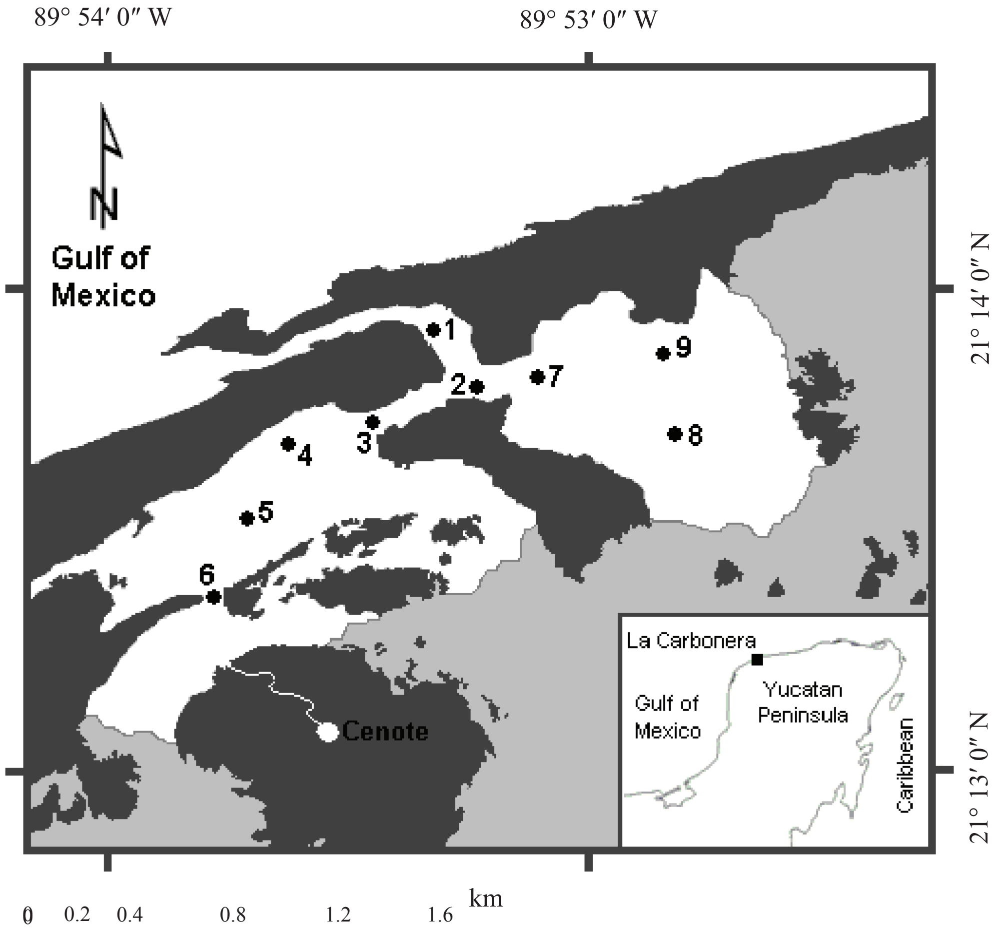

Fig. 1. Map of La Carbonera coastal lagoon with the sampling stations and the “cenote” (sinkhole). The line indicates the maximum level in the rainy season, the light black zone is the wetland, and the black spots are patches of mangroves

Fig. 1. Mapa de la laguna costera La Carbonera con las estaciones de muestreos y el cenote. La línea indica el nivel máximo en la estación lluviosa, la zona sombreada es el humedal y las zonas negras son parches de manglares

Sampling and environmental data: Sampling simultaneously including fish and environmental variables was performed monthly between April 2009 and March 2010 in nine sampling stations distributed along the lagoon (nine replications per month). Water temperature (ºC) and salinity were recorded in each sampling station (measured at 30 cm depth) with a Yellow Springs Instrument (YSI), model 556 MPS.

Specimens were caught monthly with a beach seine net (40 m long x 1 m depth x 1.27 cm stretch mesh size; Mexican government permit No. DOPA/04031/310510.1940). The sampling area was 400 m^2 (40 m width per 10 m long of dragging) with one sample per station taking 2 minutes to drag; the net was cast once at each site for each month. All sites were sampled within a 6 h period during high tide and on the same day. Collected specimens were euthanized in an ice slurry, preserved in formaldehyde (4%) and transported to the laboratory, where they were measured (± 0.1 mm total length: *Lt*) and weighed (± 0.01 g total weight: *W*).

Collected fish and environmental data were classified to analyze seasonal variations under three climatic seasons: dry (D: March-June), rainy (R: July-October), and northerly winds (locally known as *nortes*) (NW: November-February) according to Bonilla-Gómez *et al*. (2012). April 2010 was not included in this analysis. A total of 99 measurements were performed (9 repetitions per 11 months sampled). Total abundance (Nind m^{-2}) was determined in all climatic seasons. ANOVA was used to show statistical differences in the environment and abundance data between climatic seasons.

Length-weight relationship and growth: LWR was estimated using the equation: $W = a\,Lt^b$ (Sparre & Venema, 1995), where *W* represents weight (g), *Lt* is total length (cm), parameter *a* is a constant and *b* is the slope of the model. To determine parameters *a* and *b*, a regression analysis was conducted of the log-converted total weight and total length. The 95% confidence intervals for *b* (CI 95%) and the correlation coefficient (r^2) were calculated to determine whether the hypothetical isometric value (3) fell between these intervals (Froese, 2006). This analysis included all fish data from April 2010 with a total of 108 measurements (9 repetitions per 12 months sampled).

Parameters of the von Bertalanffy growth function (VBGF) were determined through the ELEFAN-I software included in the package FAO-ICLARM Fish Stock Assessment Tools (FiSAT II) (Gayanilo *et al*. 2005), using length frequency distribution with class intervals of 1.0 cm of total length. VBGF is expressed as follows: $Lt = L_\infty [1 - exp^{-k(t-t0)}]$, where *Lt* is the length at age *t*, L_∞ is asymptotic length, *k* is the growth rate (cm $year^{-1}$) and t_0 is the hypothetical age of fish at length zero.

In order to assess the variability of *k* taking into account the uncertainty in the estimation of asymptotic length, estimated values of maximum length and its 95% confidence interval from the routine Maximum Length Estimate included in FiSAT II (Gayanilo *et al.* 2005) were used to obtain a range of possible values for *k*. The hypothetic age at which the fish length is zero (t_0) was calculated separately using Pauly's empirical formula (1979). The growth performance index (*f'*) used was the one proposed by Munro and Pauly (1983).

Mortality: Total instantaneous mortality rate (*Z*), with a 95% confidence interval, was determined by the length-converted catch curve (Pauly, 1983; 1990), which, in the absence of exploitation in the area of study, is equivalent to the instantaneous natural mortality rate (*M*). Additionally, an independent estimate of *M* was obtained using the empirical equation proposed by Pauly (1980).

RESULTS

Mean temperature found during this study (n = 99 measurements) was 28.6 ± 1.6ºC (83.48ºF) and varied significantly with the different climatic seasons (ANOVA, F = 11.98, $P < 0.05$). Higher mean values were found during the rainy season. On the other hand, mean salinity was 35.1 ± 5.4 with a significant seasonal variation (ANOVA, F = 6.25 $P < 0.05$). Lower mean values were obtained when north winds prevailed (Fig 2).

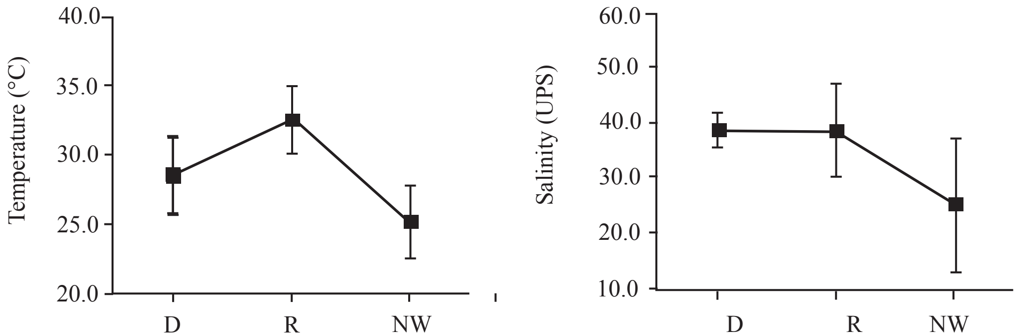

Fig. 2. Mean environmental variables (± standard deviation) in the different climatic seasons in La Carbonera lagoon, Yucatan, Mexico

Fig. 2. Variables ambientales promedio (± desviación estándar) en las diferentes temporadas climáticas en la laguna La Carbonera, Yucatán, México

From the total specimens collected during this study, 1 577 organisms of *E. argenteus* were most abundant (> 50%) during the dry season. On the other hand, in the sample of 2 700 organisms of *E. gula*, a higher abundance (> 80%) occurred during the rainy season (Fig. 3). However, abundance for both species was not statistically different (ANOVA, F = 1.70, $P > 0.05$) between climatic seasons.

The estimated parameters of LWR in *E. argenteus* were: a = 8.323E-03 and b = 2.92, while in *E. gula* were: a = 7.314E-03 and b = 2.92 (Table 1). Exponent b in the combined LWRs was not statistically different from the isometric value (*E. argenteus*: *t-test* = -0.2145, $P > 0.05$; *E. gula*: *t-test* = - 0.2316, $P > 0.05$) (Fig. 4). However, parameter a showed differences between climatic seasons, given it was significantly higher during the dry season for *E. argenteus* and during the northerly winds season for *E. gula*. The values found for the coefficient of determination (r^2) were > 0.95 in the three climatic seasons in both species (Table 1).

The estimated equations of the VBGF for total length were: $Lt = 13.65\ [1 - exp^{-0.54\ (t - 0.370)}]$ and $Lt = 12.60\ [1 - exp^{-0.68\ (t - 0.283)}]$ for *E. argenteus* and *E. gula*, respectively. In addition, the monthly variation of the growth curve was estimated based on the length frequency data on both species (Fig. 5 and 6), and the growth performance index (f') estimated

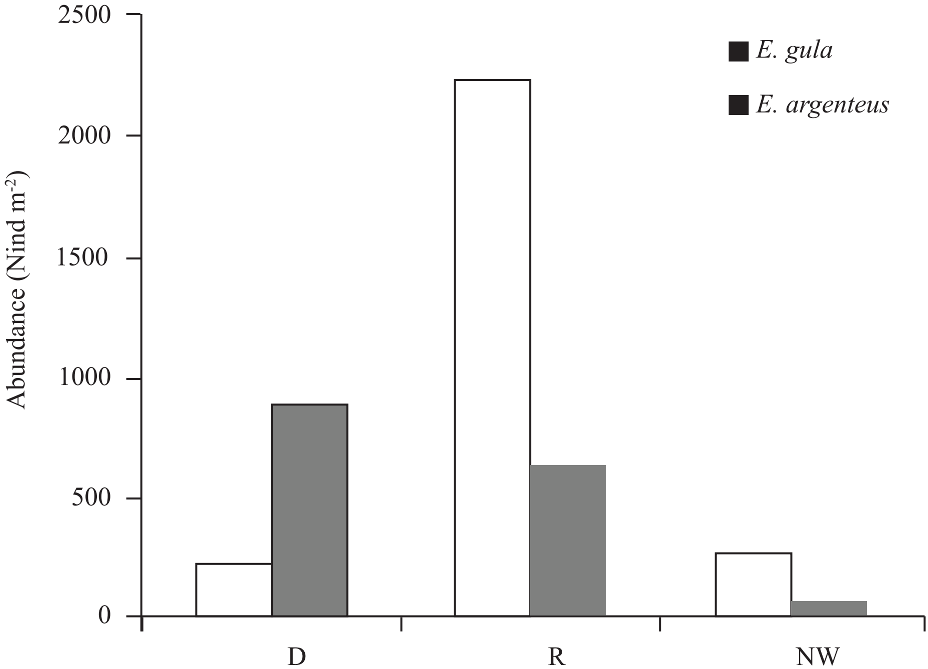

Fig. 3. Abundance (Ind/m^2) of *E. gula* and *E. argenteus* in the different climatic seasons in La Carbonera lagoon, Yucatan, Mexico

Fig. 3. Abundancia (Ind/m^2) de *E. gula* y *E. argenteus* en las diferentes temporadas climáticas en la laguna La Carbonera, Yucatán, México

was approximately 2.03 for *E. gula* and 2.00 for *E. argenteus* (Table 2).

The total instantaneous mortality rate (*Z*) estimated by the length-converted catch curve in *E. gula* was 2.20 years^{-1} (1.50 – 2.90; 95% confidence interval); however, in *E. argenteus* it was 1.75 years^{-1} (0.07 – 3.43; 95% confidence interval). In contrast, the instantaneous natural mortality rate (*M*) in *E. gula* was 1.50 years^{-1} and in *E. argenteus* was 1.79 years^{-1} in relation to the average temperature of the sampling period (28.6ºC).

DISCUSSION

It is interesting to find a marked impact of salinity and temperature on abundance throughout the study; when lower values were found, both species studied decreased. However, higher temperatures were found during the rainy season and higher salinity during the dry season, when *E. gula* and *E. argenteus* respectively occurred most abundantly. Similar results were found by Arceo-Carranza & Vega-Cendejas (2009) with the same species in another coastal lagoon of Yucatan. However, Pacheco *et al*. (2010) suggest that environmental conditions are important determinants of spatial distribution and size of *E. argenteus* during the dry season in the north zone of the Colombian Caribbean Sea, with temperature and depth as variables that better predict the spatial distribution of

Table 1. Descriptive statistics and estimated parameters of length-weight relationships per season (dry, rainy and NW = north winds) and total of *E. gula* and *E. argenteus* en La Carbonera lagoon, Yucatan, Mexico
Cuadro 1. Estadística descriptiva y parámetros estimados de la relación talla-peso por temporada (secas, lluvias y NW = nortes) y total de *E. gula* y *E. argenteus* en la laguna La Carbonera, Yucatán, México

Species	Data	N	Total length (cm)		Total weight (g)		Regression parameters					
			Min	Max	Min	Max	*a*	*b*	SE (*b*)	CI 95% (*a*)	CI 95%(*b*)	r^2
E. argenteus	**Dry**	876	1.70	12.00	0.08	18.47	1.198E-02	2.839	0.014	1.1E-03–1.2E-03	2.812-2.868	0.9889
	Rainy	637	2.06	11.80	0.12	19.08	9.345E-03	2.990	0.021	9.1E-03-9.5E-03	2.949-3.031	0.9852
	NW	64	3.50	11.00	0.57	15.07	9.436E-03	2.917	0.057	8.9E-03-9.8E-03	2.804-3.030	0.9885
	Total	1 577	1.70	12.00	0.08	19.08	8.323E-03	2.922	0.011	8.2E-03-8.4E-03	2.899-2.944	0.9774
E. gula	**Dry**	218	2.70	12.33	0.26	28.90	4.440E-03	3.038	0.033	4.2E-03-4.6E-03	2.973-3.102	0.9875
	Rainy	2 222	1.76	10.70	0.04	19.30	9.362E-03	2.884	0.011	9.3E-03-9.4E-03	2.863-2.906	0.9842
	NW	260	3.20	9.00	0.43	8.35	1.152E-02	2.990	0.043	1.1E-03–1.2E-03	2.905-3.076	0.9738
	Total	2 700	1.76	12.33	0.04	28.90	7.314E-03	2.921	0.010	7.2E-03-7.4E-03	2.902-2.941	0.9686

N, number of specimens considered in the analysis; *a*, scaling constant; *b*, slope; CI, confidence intervals; r^2, coefficient of determination.

this species. Despite the environmental variability of this region, La Carbonera coastal lagoon provides a favorable habitat for *E. gula* and *E. argenteus*, irrespective of the shallowness by season (Bonilla-Gómez *et al.* 2011). Therefore, salinity and temperature prompted a shift in abundances by season, especially when north winds prevailed. A similar trend is reported for both studied species in another coastal system (Arceo-Carranza *et al.* 2013).

Growth parameters for *E. gula* and *E. argenteus* showed the exponent *b* around 2.92, indicating a preference for isometric relationships. Similar results were found by Vega-Cendejas *et al.* (2012) in another coastal lagoon in the northwestern Yucatan peninsula. In addition, the LWR exponent remains close to isometric growth, showing that those species have a proportional volume growth. This isometric growth could be attributed to food availability,

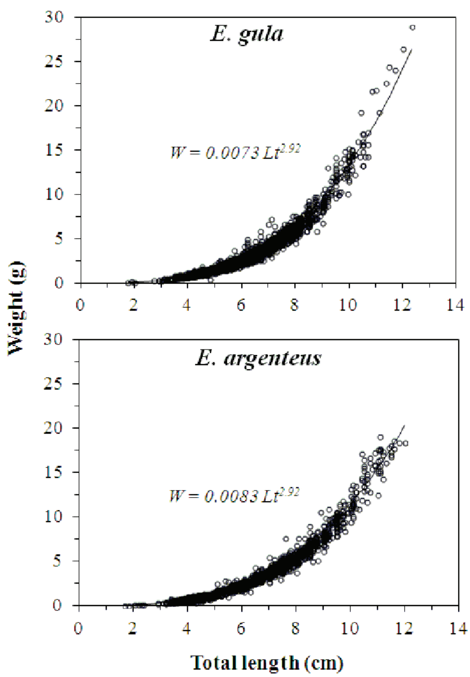

Fig. 4. Length-weight relationship (above) and log-log plot (below) of *E. gula* and *E. argenteus* in La Carbonera lagoon, Yucatan, Mexico
Fig. 4. Relación peso-longitud (arriba) y logarítmica (abajo) de *E. gula* y *E. argenteus* en la laguna La Carbonera, Yucatán, México

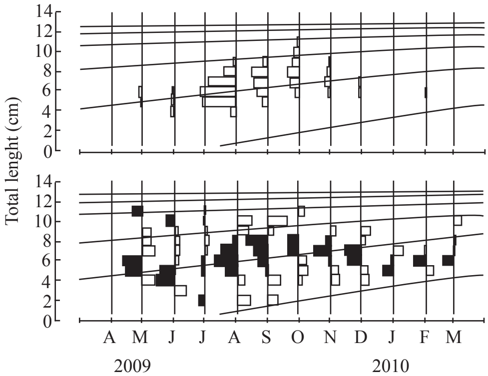

Fig. 5. Temporal variation of the growth curve based on length frequency data (above) and restructured length frequency data (below) computed in ELEFAN-I of *E. gula* from La Carbonera lagoon, Yucatan, Mexico

Fig. 5. Variación temporal de la curva de crecimiento basada en datos de frecuencias de longitudes (arriba) y en datos de frecuencia de longitud reestructurada computada en ELEFAN-I para *E. gula* en la laguna La Carbonera, Yucatán, México

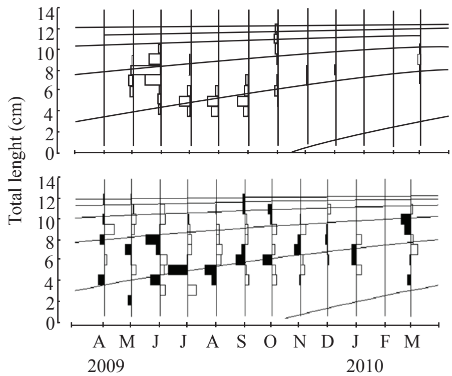

Fig. 6. Temporal variation of the growth curve based on length frequency data (above) and restructured length frequency data (below) computed in ELEFAN-I of *E. argenteus* from La Carbonera lagoon, Yucatan, Mexico

Fig. 6. Variación temporal de la curva de crecimiento basada en datos de frecuencias de longitudes (arriba) y en datos de frecuencia de longitud reestructurada computada en ELEFAN-I para *E. argenteus* en la laguna La Carbonera, Yucatán, México

Table 2. Growth parameters of VBGF and growth performance index (ϕ') for *E. gula* and *E. argenteus* from La Carbonera lagoon, Yucatan, Mexico

Cuadro 2. Parámetros de crecimiento de la ECVB y el índice del desempeño del crecimiento (ϕ') para *E. gula* y *E. argenteus* en la laguna La Carbonera, Yucatán, México

Species	**N**	L_∞ **(cm)**	***k*** **(cm year^{-1})**	t_0 **(year)**	ϕ'
E. argenteus	1 577	13.65	0.54	-0.370	2.00
E. gula	2 700	12.60	0.68	-0.283	2.03

L_∞, asymptotic length; *k*, growth constant; t_0, hypothetical age at which the fish length is zero.

low density, and productivity characterizing the study area, with productivity being in its highest during the rainy season (Herrera, 1988).

VBGF parameters for both species have not been previously reported in the Yucatan peninsula. According to the results of the growth performance index (*f’* = 2.03), both species on the coast of the Yucatan peninsula have a lower growth rate compared to the one reported by García & Duarte (2006) on the Caribbean coast of Colombia (*E. gula*, *f’* = 2.16; *E. argenteus*, *f’* = 2.39). This could be related to the uncertainty associated with the growth rate (*k*) estimates by the length frequency analysis. Pauly (1979) and Sparre & Venema (1995) determine that the coefficient of variation of *f’* should not exceed 4% for growth patterns to be considered statistically similar.

This study presents the first estimates of mortality for *E. gula* and *E. argenteus* in the Yucatan Peninsula. Estimates of total mortality by the length-converted catch curve (Pauly, 1983) are equivalent to the natural mortality rate ($Z = M$) due to the absence of fishing of this species in the study area. Differences in natural mortality can be attributed to latitudinal dissimilarities according to Bravo *et al.* (2009), who reported that variations of these parameters could be due to growth differences associated to species present at different latitudes.

CONCLUSIONS

Abundance was the lowest in *E. argenteus* and *E. gula* when salinities and temperature occurred with the lowest values, especially during the northerly winds season. The LWR in *E. argenteus* and *E. gula* showed an isometric growth. Growth parameters of the VBGF in *E. argenteus* were: L_∞ = 13.65 cm, k = 0.54 year^{-1} and t_0 = - 0.37 years, while in *E. gula* were: L_∞ = 12.60 cm, k = 0.68 year^{-1} and t_0 = - 0.28 years. The natural mortality in *E. gula* was 1.50 years^{-1} and in *E. argenteus* was 1.9 years^{-1}. The information provided in this study on the basic parameters of the population dynamics of *E. gula* and *E. argenteus* represents fundamental knowledge of both species to implement the measures and strategies for their management and conservation in an important coastal area of the Yucatan peninsula.

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