Latin American Journal of Aquatic Research, 52(5): 713-726, 2024
DOI: 10.3856/vol52-issue5-fulltext-3201

Research Article

Estimation of age, growth, and length at first maturity of the round herring *Etrumeus acuminatus* (Gilbert, 1890) on the western coast of Baja California Sur, Mexico

Ricardo Javier Flores-Anaya[1], Casimiro Quiñonez-Velázquez[1]
Dana Isela Arizmendi-Rodríguez[2] & Xchel Gabriel Moreno-Sánchez[1]
[1]Centro Interdisciplinario de Ciencias Marinas, Instituto Politécnico Nacional
La Paz, B.C.S., México
[2]Centro Regional de Investigación Pesquera, Guaymas, Instituto Mexicano de
Investigación en Pesca y Acuacultura Sustentables, Guaymas, Sonora, México
Corresponding author: Ricardo Javier Flores-Anaya (rfloresa1705@alumno.ipn.mx)

ABSTRACT. In Mexico, the round herring *Etrumeus acuminatus* is caught along with other small pelagic fishes of the Western Baja California Sur coast (WBCSC) and Gulf of California. This species has a discontinuous distribution on the eastern margin of the Pacific Ocean, and its population structure and dynamics are unknown. In this study, we evaluated the direct determination of age using otoliths, estimated length at first sexual maturity (L_{50}), and individual growth parameter determination of round herrings caught off the WBCSC. A total of 731 specimens were collected through monthly biological sampling from 2012 to 2022. Age-length data were obtained from 617 otoliths. The growth was isometric (b = 3); however, the differences in the length-weight relationship were significant between sexes (F = 7621, P < 0.05). Up to seven age groups were identified (0 ± 6). The L_{50} and individual growth parameters were estimated using a multimodel approach. The Lysack (1979), White et al. (2002), Brouwer & Griffiths (2005), and logistic models showed statistically solid support for L_{50} estimation in both sexes. The von Bertalanffy model provided the best fit for the data to describe individual growth in both sexes. Significant differences between sexes were detected in the L_{50} estimates (P < 0.05). However, the differences in growth parameters between sexes were not statistically significant (P > 0.05).

Keywords: *Etrumeus acuminatus*; age; multimodel approach; L_{50}, allometry; individual growth

INTRODUCTION

The round herring *Etrumeus acuminatus* Gilbert, 1890 is a clupeiform fish from the family Dussumieriidae that inhabits the eastern coast of the Pacific Ocean, from Monterey Bay (California, USA) to Cabo San Lucas (Baja California Sur) and the Gulf of California, Mexico, and from Ecuador to Chile (Lluch-Belda et al. 1996, DiBattista et al. 2012, Randall & DiBattista 2012). There are no records of its presence south of the Mexican Pacific coast or Central America.

Round herrings are caught along with sardines, mackerel, and anchovies by purse seine boats in Mexico. This fishery resource (small pelagic fishes) occupies the first place in terms of capture volume, representing 35% on average of total fish catches (mean = 1.5 million tons) (CONAPESCA 2022). The main characteristics defining this group of species are that they form schools, consume plankton, are preyed upon by upper trophic levels, present an extensive anti-tropical distribution, are associated with the current systems with the most significant productivity such as the California Current and Humboldt Current (Félix-Uraga et al. 2005, Cárdenas-Quintana et al. 2015), and present large abundance fluctuations associated with large-scale changes in sea surface temperature (Chávez et al. 2003).

Associate Editor: Patricio Arana

There are two fishing and industrial processing (meal and oil) areas for the round herring *E. acuminatus* off the Mexican Pacific coast: one to the north of the Western Baja California Sur coast (WBCSC) and the other one in the central Gulf of California (Fig. 1). In these two areas, the importance of this species is marginal (2%) compared with the total small pelagic fish resource (DOF 2021). However, Mexico occupies the second place worldwide, after Japan, in terms of round herring catches (https://www.fao.org/fishery/statistics-query/en/capture/capture_quantity). In addition, other species of the genus are also caught in the Gulf of Suez and the coast of Egypt in the Mediterranean Sea (Farrag et al. 2014).

The WBCSC habitat is characterized by relatively cold, low-salinity waters associated with the California Current. During La Niña years, these cold hydrological conditions occur in the spring and summer and can extend into the fall and winter. In the summer and fall, warmer, saltier waters of subtropical origin have been observed intruding over the continental slope and shelf. These intrusions may be linked to a countercurrent flowing toward the North Pole, especially during El Niño years (Durazo et al. 2005, Zaitsev et al. 2014). At the end of the fall, upwellings driven by northwestern winds occur off the eastern margin of the Gulf of California, cooling the coastal waters in Sonora and Sinaloa. By the end of the spring, the wind direction shifts to flow from the southwest, leading to an increase in sea surface temperature (Martínez-Zavala et al. 2007).

The little information on the biology of the round herring *E. acuminatus* has come from fisheries analysis of small pelagic fishes in the Gulf of California. In this zone, two recruitment periods per year have been identified, with greater recruitment during the second semester of the year, an ample reproductive period from fall to spring, with maximum spawning in January, and a sexual proportion (female:male) of 1.0:0.5 to 1.0:1.3 (Cisneros-Mata et al. 1991, 1997, Martínez-Zavala et al. 2007). Recently, in March 2014, an anomalously warm year, round herrings were identified using mtDNA sequences of eggs and larvae inside the Cabo Pulmo National Park, an area south of the western Gulf of California (Ahern et al. 2018).

Also, in the Gulf of California, growth parameters of the round herring have been estimated using indirect methods based on lengths, adjusting the von Bertalanffy model to the data trend (Cisneros-Mata et al. 1991, 1997). No information on this species' population structure and dynamics has been reported for the WBCSC. Knowing growth parameters and reproductive aspects is essential to evaluate fish population dynamics, especially for populations potentially with wide distribution and structured by stocks. In Mexico, the von Bertalanffy model has been used *a priori* to describe growth in small pelagic fishes and the logistic model has been used to estimate length at first sexual maturity (L_{50}) (Carmona & Alexandres 1994, Gluyas-Millán 1994, Alvarado-Castillo & Félix-Uraga 1996). However, these models might not necessarily be the most adequate or the best fit for the data (Jacob-Cervantes & Aguirre-Villaseñor 2014, Ruiz-Domínguez & Quiñonez-Velázquez 2018, Payan-Alejo et al. 2020). Moreau (1987) stated that changes in life history, fishing pressure, and sampling could influence the results of growth parameter estimates, and therefore, more than one model should be evaluated, and the best model should be selected using mathematical tools (Burnham & Anderson 2004, Katsanevakis 2006). Information theory (Akaike's information criterion) is used with the multimodel approach to select the best model (Salgado-Cruz et al. 2020). This type of approach is based on the parsimony principle of a set of candidate models, selecting the "best" model, taking into consideration the relationship between the number of parameters and data adjustment (Aragon-Noriega 2014, Ruiz-Domínguez & Quiñonez-Velázquez 2018).

In this study, we focus on allometry, the direct determination of age, and use a multimodel approach to estimate L_{50} and estimate individual growth parameters of the round herring *E. acuminatus* off the WBCSC based on the number of growth marks on otoliths.

MATERIALS AND METHODS

Sampling

The commercial small pelagic fishery off the WBCSC operates from Punta Eugenia to Bahía Magdalena (Fig. 1). The fleet is made up of six vessels of 25-28 m in length and 141-180 t of hold capacity, equipped with purse seine nets of 13-25 mm mesh size and a maximum of 10 crew members per vessel. The catches are made most frequently in the early hours of the morning and are landed in the ports Adolfo López Mateos and San Carlos, within Bahía Magdalena. Landings from this fishery have been sampled monthly since 1981. Historical records indicate that the target species of this study, *E. acuminatus*, is available to the fishery during the first half of the year, from February to September. For this study, 25 monthly samples (n = 30) were collected from 2012 to 2022. For each fish, the standard length (SL, mm), total weight (TW, g),

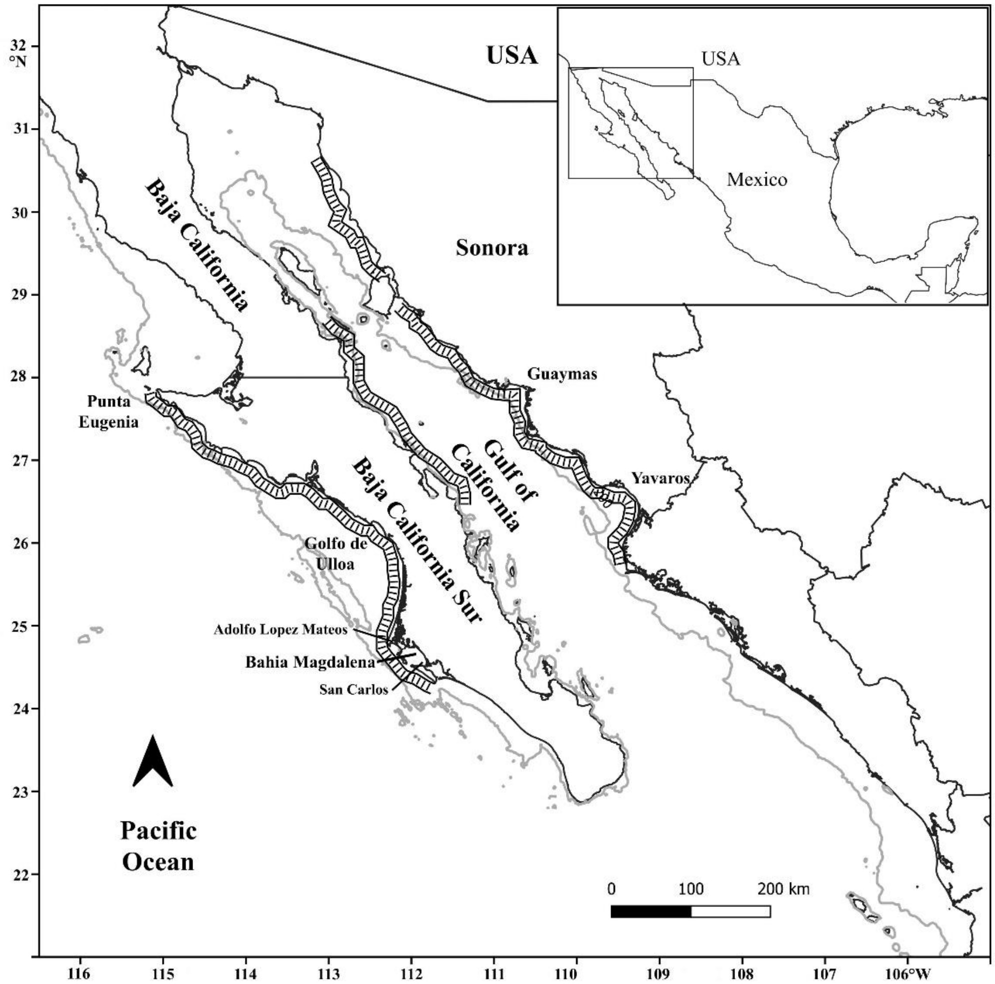

Figure 1. Western Baja California Sur coast. The hashed area shows the fishing area of the fleet landing at Bahía Magdalena, Baja California Sur, and the fleet landing at Guaymas and Yavaros, Sonora ports. The continuous gray line shows the isoline to 200 m of depth.

sex, and gonadal maturity (morphochromatic scale by Holden & Raitt 1975) were recorded, and the pair of sagittal otoliths were extracted.

Length-weight relationship

The length-weight relationship was calculated for each sex separately (males and females) and for both sexes together for the round herring *E. acuminatus* using the following equation (Sparre & Venema 1997):

$$TW = a\, SL^{b}$$

where TW is the total weight (g), SL is the standard length (mm), a is the intercept, and b is the allometric coefficient. A Student's t-test was used to identify the growth type, i.e. isometric ($b = 3$) or allometric ($b \neq 3$):

$$t = (b - 3) \times SE^{-1}$$

where SE is the standard error, with α = 5%, t =1.96, and the 95% confidence intervals of b were calculated (Zar 1999).

Age determination

The otoliths were immersed in water on a dark background, and reflected light was used to observe the growth bands' details better. To evaluate the relationship between somatic growth and that of the otolith, the radius (OR) was recorded in the posterior area of the otoliths of a subsample from the total sample. Two independent readers counted growth marks on the external otolith face twice (Campana & Thorrold 2001). One growth mark was defined as one opaque band (white area) and one hyaline band (dark area) (Quiñonez-Velázquez et al. 2002). One growth mark was formed entirely when the beginning of the next opaque band could be observed. Annual periodicity of growth marks was assumed, according to results by Farrag et al. (2014), who used the marginal increment approach to determine the formation time of one otolith annulus in *Etrumeus teres* in the Mediterranean Sea, after DiBattista et al. (2012) for *E. golanii*. The average percent error (APE, Beamish & Fournier 1981) and coefficient of variation (CV, Chang 1982) were calculated to evaluate the precision of growth mark number between readers:

$$APE_j = 100 \times \frac{1}{R} \sum_{i=1}^{R} \frac{|X_{ij}-X_j|}{X_j}$$

$$CV_j = 100 \times \sqrt{\frac{\sum_{i-l}^{R} \frac{(X_{ij}-X_j)^2}{R-1}}{X_j}}$$

where X_{ij} is the *i*th reading of the *j*th otolith, X_j is the average reading of the *j*th otolith, and *R* is the number of readings for each otolith. An APE index is obtained by averaging the APE_j for the entire sample.

Determination of length at first sexual maturity (L_{50}) (multimodel approach)

The sex and gonadal maturity state of the round herring were assigned using the morphocromatic scale proposed by Holden & Raitt (1975), which includes six maturity stages according to the color, shape, and size of the gonad. To estimate the L_{50}, mature individuals were defined as those in stages III, IV, and V (maturing, mature, and postspawning). Due to the number of mature individuals and the range in size structure, these were grouped into intervals of 5 mm SL. Chen & Paloheimo (1994) comment that for the same group of data when the class interval differs in amplitude, the estimate of L_{50} may vary. We used an interval of 5 mm; therefore, the estimate of L_{50} ranges from L_{50} -2.5 to L_{50} 2.5 mm in addition to its associated variance.

Five sigmoidal models were fitted to the cumulative relative frequency of mature organisms by 5 mm SL intervals to estimate the L_{50}: Gompertz (1825), Lysack (1979), White et al. (2002), Brouwer & Griffiths (2005), and logistic (Sparre & Venema 1997). For all models, P_{SL} is the proportion of mature individuals in each SL interval, L_{50} is the standard parameter (except for the logistic model), and the B_i parameters have different meanings in each model:

Gompertz (1825):

$$P_{SL} = e^{-e^{-B_1(SL-L_{50})}}$$

where B_1 is the rate of change.

Lysack (1979):

$$P_{SL} = \frac{1}{1+ e^{-B_1(SL-L_{50})}}$$

where B_1 is the rate of change.

White et al. (2002):

$$P_{SL} = \frac{1}{1+ e^{\left[-ln(19)\frac{SL-L_{50}}{B_1-L_{50}}\right]}}$$

where B_1 is the length at which 95% of females in the population are sexually mature.

Brouwer & Griffiths (2005):

$$P_{SL} = \frac{1}{1+ e^{-\frac{SL-L_{50}}{B_1}}}$$

where B_1 is the width of the maturity ogive.

Logistic (Sparre & Venema 1997):

$$P_{SL} = \frac{1}{1+ e^{(B_1-B_2 SL)}}$$

where B_1 and B_2 are adjustment parameters:

$$L_{50} = B_1 \times B_2^{-1}$$

The models were fitted, minimizing the negative of the logarithm of maximum likelihood assuming a normal distribution using Newton's direct search algorithm (Haddon 2011):

$$-lnLl = -\sum_{i=1}^{n} ln\left(\frac{1}{\sqrt{2\pi\sigma^2}} e^{\left(-\frac{(Li-L_{est})^2}{2\sigma^2}\right)}\right)$$

Description of growth in length (multimodel approach)

The increase in length with time was described using a multimodel approach. A set of five models presenting a curve tending to an asymptotic value was adjusted to the age-SL data:

von Bertalanffy (1938):

$$SL_t = L_\infty\left(1 - e^{-k_1(t-t_1)}\right)$$

where SL_t is the length at age *t*, L_∞ is the asymptotic length, k_1 is the annual growth coefficient, *t* is the age in years, and t_1 is the age at length 0 (t_0).

Gompertz (1825):

$$SL_t = SL_\infty\, e\left(-e^{-k_2(t-t_2)}\right)$$

where k_2 is the instantaneous growth rate at age t_2, and t_2 is the curve's inflection point.

Logistic (Ricker 1979):

$$SL_t = SL_\infty\left(1 + e^{-k_3(t-t_3)}\right)^{-1}$$

where k_3 is the instantaneous growth rate when SL tends towards 0, and t_3 is when the absolute SL growth rate begins to decrease.

Richards (1959):

$$SL_t = SL_\infty \left(1 - e^{-k_4(1-m)(t-t_4)}\right)^{\frac{1}{1-m}}$$

where k_4 is the growth rate at the inflection point, t_4 is the age at the inflection point, and m is the curve adjustment parameter.

Schnute (type 1) (1981):

$$SL_t = \left[y_1^b + \left(y_2^b - y_1^b\right)\left(\frac{1 - e(-a(t - t_5)}{1 - e(-a(t_6 - t_5)}\right)\right]^{\frac{1}{b}}$$

where y_1 is the length at age t_5, y_2 is the length at age t_6, b is the constant increase in time, a is an adjustment parameter, t_5 is the lowest age in the dataset, and t_6 is the oldest age in the dataset.

Once the model parameters were estimated, the model values were used to calculate SL_∞ and t_0 with the following arithmetic equations (Schnute 1981):

$$SL_\infty = \left[\frac{e^{at6}y_2^b - e^{at5}y_1^b}{e^{at6} - e^{at5}}\right]^{\frac{1}{b}}$$

$$t_0 = t_5 + t_6 - \frac{1}{a} ln \left|\frac{e^{at6}y_2^b - e^{at5}y_1^b}{y_2^b - y_1^b}\right|$$

The parameter estimators of the growth models were obtained using the age-length data [adding the length at the hatching of 6 mm (Moser 1996), and minimizing the negative of the logarithm of maximum likelihood assuming a normal distribution using Newton's direct search algorithm (Haddon 2011)]:

$$-lnLl = -\sum_{i=1}^{n} ln\left(\frac{1}{\sqrt{2\pi\sigma^2}} e^{\left(-\frac{(Li - L_{est})^2}{2\sigma^2}\right)}\right)$$

The 95% confidence intervals of growth parameters were estimated based on the likelihood profile calculation, assuming a χ^2 distribution with m degrees of freedom (Polacheck et al. 1993).

Selection of the best model (Akaike's information criterion)

We used Akaike's information criterion (AIC) to select the best model to describe the P_{SL}-length interval and age-length data trend of the round herring *E. acuminatus*:

$$AIC_i = 2LL + 2k$$

where LL is the likelihood value resulting from each adjusted model and k is the number of parameters in the model. The best model has the lowest AIC_i value (AIC_{min}).

AIC_i differences ($\Delta_i = AIC_i - AIC_{min}$) were estimated to classify statistical support for the evaluated models. Models with $\Delta_i \geq 10$ have no statistical support and were eliminated from the analysis; models $\Delta_i \leq 2$ have high statistical support; and models with $4 < \Delta_i < 7$ have intermediate support (Burnham & Anderson 2004). Akaike's weight (w_i) was calculated to estimate the plausibility (truthfulness) of each model given the data:

$$w_i = \frac{\exp(-0.5\Delta_i)}{\sum_{k=1}^{5} \exp(-0.5\Delta_k)}$$

where w_i is considered the weight of evidence in favor of $model_i$.

Once the best model to estimate L_{50} and growth parameters for males and females of the round herring *E. acuminatus* was selected, a comparison between sexes was performed using Kimura's likelihood test (1980).

Average values of the length at first sexual maturity ($\bar{L}_{50}$) and asymptotic length ($\bar{L}_\infty$) were estimated according to the multimodel approach. $\bar{L}_{50}$ and $\bar{L}_\infty$ are average estimates based on the model estimates multiplied by $w_i *= w_i\,(w_1 + w_2 + w_3 + w_k)^{-1}$ (Katsanevakis 2006).

RESULTS

The size frequency distribution of the round herring *E. acuminatus* ranged between 120-251 mm SL (n = 731); females measured between 125-251 mm SL and males measured between 120-230 mm SL. Females weighed between 34.6-251 g TW, and males weighed between 37.5-227.1 g TW (Fig. 2). The SL-TW relationship of females and males (Fig. 3) resulted in b values ranging between 2.99-3.04 (Table 1), values were not significantly different from 3 ($P > 0.05$), and we, therefore, concluded that the round herring presented isometric growth both sexes combined: TW = $0.2E^{-4} \times SL^{2.99}$, $R^2 = 0.92$, $b = 3$ ($t_{estimated} = 0.83$, $P > 0.05$).

A covariance analysis showed statistically significant differences in the length-sex relationship between the sexes ($F = 7621$, $P < 0.05$).

Age determination

From the total sample collected, otoliths of 617 round herrings were read for age determination. The relation between OR and SL (120-250 mm, n = 316) was described ($R^2 = 0.79$) by linear regression (Fig. 4). This significant relation demonstrates that fish growth and otolith growth are closely coupled and justifies the use of this structure for aging and growth studies. This result is consistent with the hypothesis that the growth-

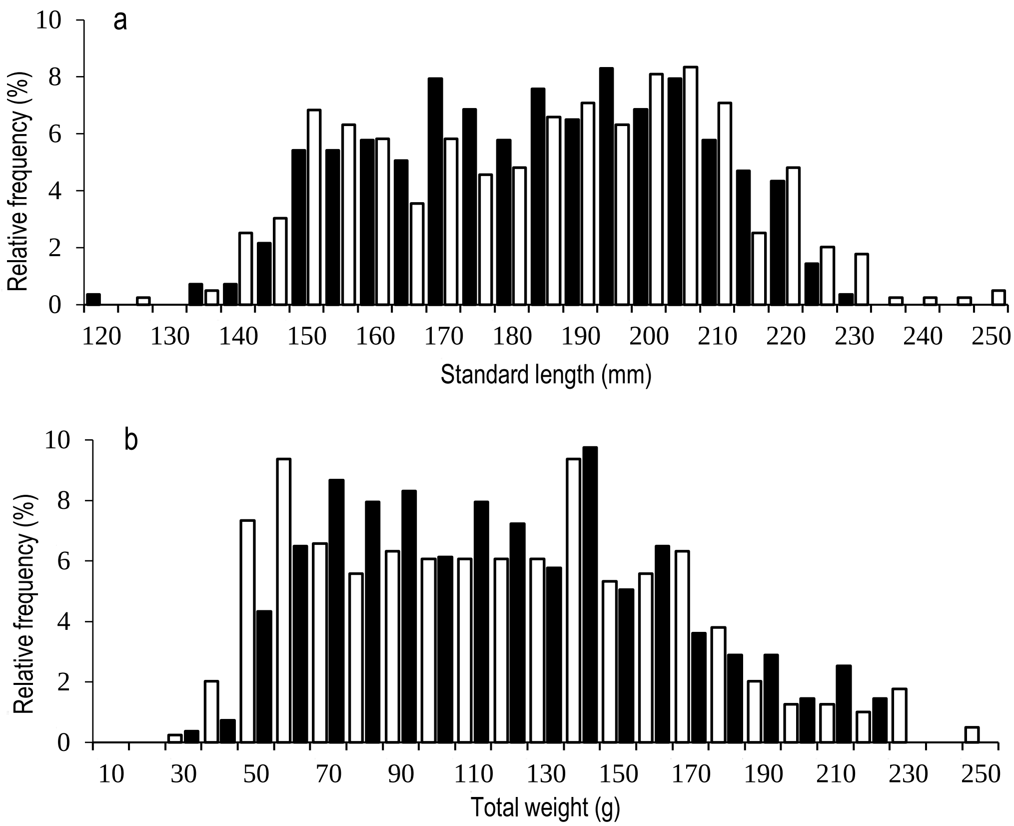

Figure 2. a) Size and b) weight structures of round herrings *Etrumeus acuminatus* caught from 2012 to 2022 off the Western Baja California Sur coast, Mexico. White bars show females and black bars show males.

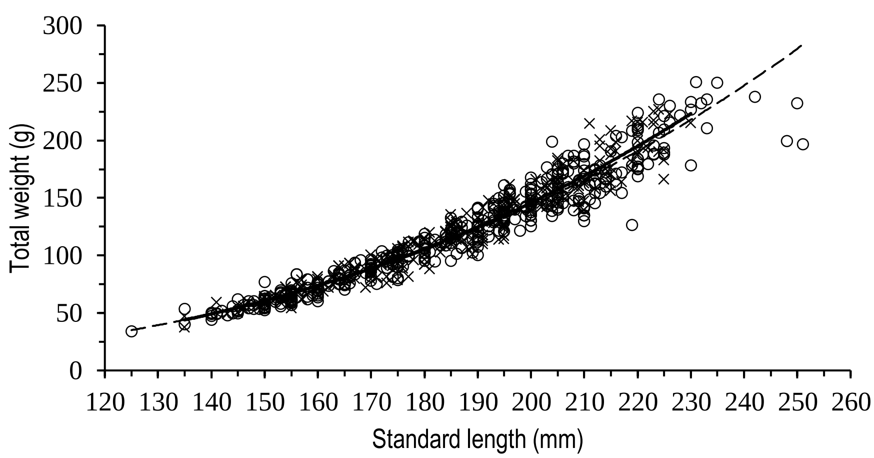

Figure 3. Length-weight relationship of round herring *Etrumeus acuminatus* by sex off the Western Baja California Sur coast. Circles black represent observed data for females, and x represents observed data for males. The dashed line shows the potential model parameterized with estimates *a* and *b* for females and the solid line for males.

mark deposition pattern is yearly (Farrag et al. 2014). There were no significant differences in reading precision between readers (APE = 8.8, CV =11.8). The age of each round herring corresponded to the average of the four readings. Up to seven groups of age were identified (0+ - 6), of which the most represented were groups ages 3 and 4 (22.5%) (Fig. 5). The 0+ age group includes organisms with an opaque band, which would be organisms less than six months old, and those round herrings with an opaque band and an incomplete

Table 1. Potential model parameter estimators used to describe growth type in females and males of the round herring *Etrumeus acuminatus* off the Western Baja California Sur coast from 2012 to 2022. Student's t-test, and the 95% confidence intervals (*CI*) for *b*.

Sex	n	*a*	*b*	*CI*	R^2	t-test	*P*
Females	395	0.00002	2.99	2.93/3.06	0.95	1.10	0.31
Males	275	0.00003	3.04	2.96/3.13	0.94	1.73	0.93

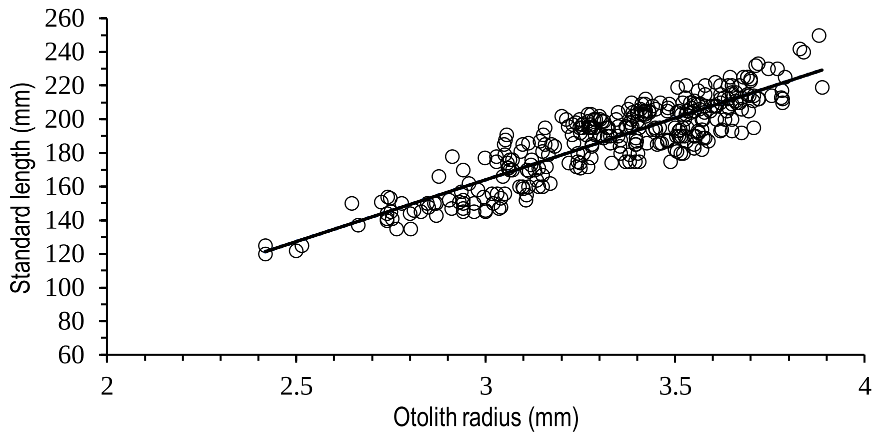

Figure 4. Otolith radius (OR)-standard length (SL) relationship of round herring *Etrumeus acuminatus,* off the Western Baja California Sur coast. SL = 73.45 × OR - 56.31, R^2 = 0.79.

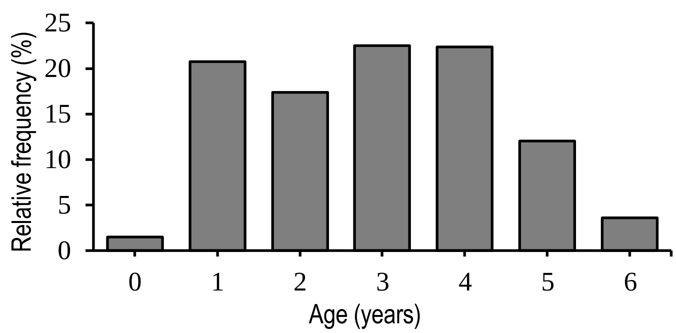

Figure 5. Age structure of round herring *Etrumeus acuminatus* off the Western Baja California Sur coast, Mexico.

hyaline band, which would be organisms more than six months and less than a year old.

Estimate of length at first sexual maturity (L_{50})

From the total sample, 395 were females, 277 were males, and 59 were undifferentiated. The sex ratio differed from a 1M:1F ratio (1.4:1, χ^2 = 20.54, P < 0.05). Of the total by sex, 249 were mature females, and 212 were mature males.

Estimates for L_{50} ranged between 174 and 185 mm SL for females and 173 and 183 mm SL for males (Table 2). The Gompertz model estimated the smallest values of L_{50} for both sexes but did not present statistical support (Table 3, $\Delta_i > 10$). The remaining models presented statistical solid support ($\Delta_i < 2$), and L_{50} estimates were identical: L_{50} = 185.07 mm SL, Δ_i = 0.00, w_i = 0.25 for females, and L_{50} = 183.15 mm SL, Δ_i = 0.00, w_i = 0.25 for males. Estimates obtained with Lysack's model were compared between sexes to evaluate differences in L_{50}, resulting in significant differences (χ^2 = 3.29, P = 0.03) (Fig. 6). The 95% confidence intervals of the Lysack model parameters were: females $183.83 \leq 185.07$ (L_{50}) ≤ 186.32 mm SL, $0.062 \leq 0.066$ (B_1) ≤ 0.070; males $182.10 \leq 183.15$ (L_{50}) ≤ 184.21 mm SL, $0.069 \leq 0.073$ (B_1) ≤ 0.078.

Estimation of growth parameters

Data for individual growth analysis were 349 females, 228 males, and 40 unidentified (n = 617). Estimations of growth parameters (Table 4) ranged between 250

Table 2. L_{50} estimates of the candidate models for females (F) and males (M) and the 95% confidence intervals (*CI*) for L_{50} of the round herring *Etrumeus acuminatus* off the Western Baja California Sur coast. L_{95}: length at which 95% of females are sexually mature, B_1: rate of change (Lysack, Gompertz) and width of the maturity ogive (Brouwer & Griffiths), B_2: adjustment parameter, -Ln (LL): logarithm of maximum likelihood.

Model	Sex	L_{50}	*CI*	L_{95}	B_1	B_2	-Ln (LL)
Gompertz	F	174.46	172.99/175.94		0.045		-4.740
Lysack	F	185.07	183.83/186.32		0.066		-17.253
White et al.	F	185.07	184.24/185.89	229.838			-17.253
Brouwer & Griffiths	F	185.07	184.20/185.94		15.203		-17.253
Logistic	F	185.07	185.07/185.07		12.173	0.066	-17.253
Gompertz	M	173.64	172.55/174.73		0.050		-10.224
Lysack	M	183.13	182.10/184.21		0.073		-19.190
White et al.	M	183.15	182.46/183.83	223.409			-19.196
Brouwer & Griffiths	M	183.15	182.41/183.88		13.672		-19.196
Logistic	M	183.15	183.15/183.15		13.396	0.073	-19.196

Table 3. Akaike's information criterion (AIC), AIC differences (Δ_i), and AIC weight (w_i) of the candidate models to estimate L_{50} in females (F) and males (M) of round herring *Etrumeus acuminatus* off the Western Baja California Sur Coast.

Model	Sex	AIC	Δ_i	w_i
Gompertz	F	-5.479	25.026	0.000
Lysack	F	-30.505	0.000	0.250
White et al.	F	-30.505	0.000	0.250
Brouwer & Griffiths	F	-30.505	0.000	0.250
Logistic	F	-30.505	0.000	0.250
Gompertz	M	-16.449	17.944	0.000
Lysack	M	-34.380	0.013	0.250
White et al.	M	-34.393	0.000	0.250
Brouwer & Griffiths	M	-34.393	0.000	0.250
Logistic	M	-34.393	0.000	0.250

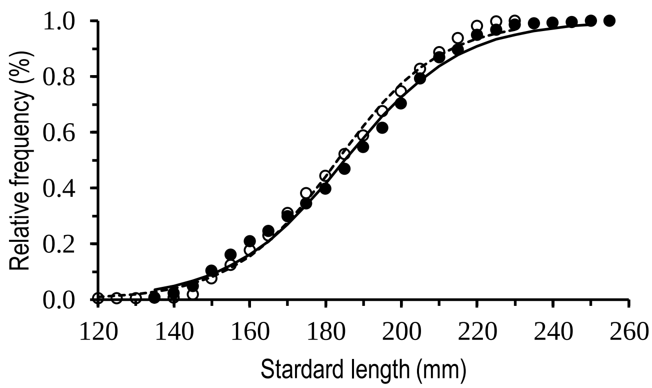

Figure 6. Scatterplot of the proportion of mature female and male by length intervals and Lysack model curves for estimating the L_{50} parameter of round herring off the Western Baja California Sur coast, Mexico. Females: solid lines and filled circles; males: dashed lines and empty circles.

and 287 SL_∞, 0.165-0.332 annual K, and -3.492-0.030 yr^{-1} t_0 for females, and 220-257 mm SL_∞, 0.216-0.403 annual K, and -2.730-(-0.168) yr^{-1} t_0 for males. From the five evaluated candidate models to describe the age-length data trend, the von Bertalanffy, Richards, and Schnute (type 1) models showed high statistical support ($\Delta_i \leq 2$); the von Bertalanffy model was the best model for both sexes (Table 5). The Gompertz and logistic models did not have statistical support ($\Delta_i > 10$). The evaluation of growth parameters of the best von

Table 4. Growth parameters of the candidate models adjusted to age-length data for each sex of the round herring *Etrumeus acuminatus* off the Western Baja California Sur coast. F: females, M: males, SL_∞: asymptotic length, *K:* annual growth coefficient, t_0: age at length 0, y_1: minimum age, y_2: maximum age, *a*: relative growth rate, *b*: inherent growth rate constant, *m*: dimensionless parameter.

Model	Sex	SL_∞	*K*	t_0	y_1	y_2	*a*	*b*	*m*	-ln(LL)
von Bertalanffy	F	287.31	0.165	-3.439						1960.20
Gompertz	F	268.69	0.248	-1.147						1963.20
Logistic	F	257.93	0.332	0.030						1965.82
Richards	F	287.27	0.167	-3.492					0.01	1960.20
Schnute (type 1)	F	250.32	0.165	-3.438	92.59	189.20	0.17	1.03		1960.20
von Bertalanffy	M	257.34	0.230	-2.730						1361.97
Gompertz	M	246.86	0.317	-1.113						1364.47
Logistic	M	240.50	0.403	-0.168						1366.76
Richards	M	257.34	0.216	-2.463					-0.06	1361.97
Schnute (type 1)	M	220.68	0.230	-2.730	89.78	196.45	0.23	1.03		1361.97

Table 5. Akaike's information criterion (AIC), AIC differences (Δ_i), and AIC weight (w_i) of the candidate models to estimate growth parameters of candidate models adjusted to age-length data for each sex of round herring *Etrumeus acuminatus* off the Western Baja California Sur coast.

Model	Sex	AIC	Δ_i	w_i
von Bertalanffy	F	3926	0.00	0.580
Gompertz	F	3932	6.00	0.000
Logistic	F	3938	11.24	0.000
Richards	F	3928	2.00	0.210
Schnute (type 1)	F	3928	2.00	0.210
von Bertalanffy	M	2730	0.00	0.580
Gompertz	M	2735	5.01	0.000
Logistic	M	2740	9.59	0.000
Richards	M	2732	2.00	0.210
Schnute (type 1)	M	2732	2.00	0.210

Bertalanffy model between sexes did not show significant differences (χ^2 = 1.98, P = 0.11) (Fig. 7). The 95% confidence intervals of the von Bertalanffy model for both sexes were 289.18 ≤ 290.16 (SL_∞) ≤ 291.13 mm, 0.1561 ≤ 0.1569 (*K*) ≤ 0.1577, -3.668 ≤ -3.631 (t_0) ≤ -3.594.

DISCUSSION

Length at first sexual maturity (L_{50})

There are currently no studies involving length at first sexual maturity L_{50} of the round herring *E. acuminatus* off the WBCSC. This information is essential for the demographic analysis that serves as a reference for resource management through minimum catch sizes or periods of closure to fishing (Jacob-Cervantes & Aguirre-Villaseñor 2014).

The logistic model has been commonly used to estimate L_{50} in small pelagic fish (Gluyas-Millán 1994, Sparre & Venema 1997, Martínez-Zavala et al. 2007, García-Alberto 2010). However, it is not necessarily the best model to describe the data trend. Since the parameter estimators depend on the fit of the model used. The statistical criteria, i.e. AIC, allows us to select the "best model" given the data set. Nevertheless, when there is no clear "winning model, w_i > 90%", the best estimates of the model parameters are derived from weighted averages of the parameter values across the model, a procedure known as model averaging. Jacob-Cervantes & Aguirre-Villaseñor (2014) used this approach in estimating L_{50} for Pacific thread herring (*Ophistonema libertate*) females; three of the candidate models showed statistical solid support ($\Delta_i \leq 2$), which led to estimating a model averaging.

In the present study, four models of the five candidates evaluated presented statistically solid support. We used multimodel inference to deliver a model-averaged estimate of L_{50} in females and males of the round herring *E. acuminatus*. The Gompertz model did not fit well (Δ_i > 10) for either sex. Generally, models with high statistical support resemble a logistic function but differ in how the B_i parameter controls the ogive width. The Gompertz model fits an asymmetric distribution and reaches its lower asymptote more quickly, resulting in an earlier inflection point (L_{50}) than logistic models (Jacob-Cervantes & Aguirre-Villaseñor 2014).

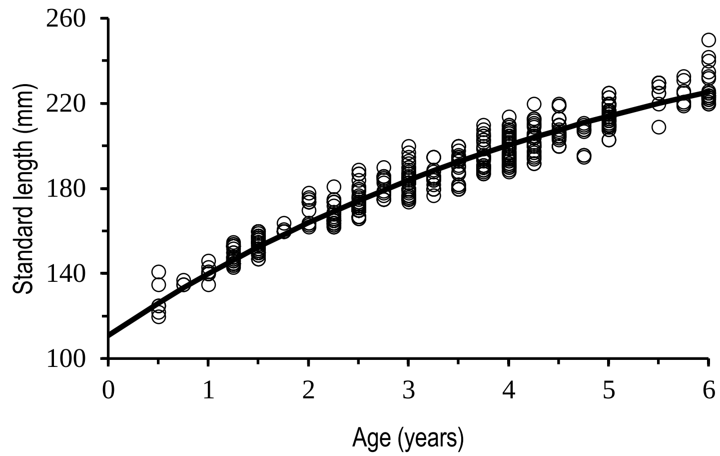

Figure 7. Age-length data for combined sexes and von Bertalanffy model curve for the round herring *Etrumeus acuminatus* off the Western Baja California Sur coast.

Our estimates of L_{50} are 185 mm SL for females and 183 mm SL for males. Compared to other species of the genus *Etrumeus*, the values obtained in the present study are higher than those reported by Sanders et al. (1984) for *E. teres* in the Gulf of Suez (163.6 mm SL for females and 161.7 mm SL for males), and by Osman et al. (2011) off the coast of Egypt in the Mediterranean Sea (138 mm SL for males and 135 mm SL for females). These differences are probably due to variations in species growth rates, environmental conditions, latitudinal differences, model selection, sample size, or data structure (Farrag et al. 2014).

Age determination

Clear growth bands were observed in all analyzed otoliths of the round herring *E. acuminatus*; band differentiation improved after submerging the otoliths in water. Up to seven growth marks were recorded, corresponding to 0+ to 6 years old. The mean length by age group increased with age; it was more significant for the first three age groups (30 mm per year) and decreased after this point (14 mm per year). The 0+ and 6 age groups were less abundant (2%), and the ages 3 and 4 groups were more abundant (27% each).

The first growth marks were easily identifiable during the otolith reading process. In contrast, marks near the otolith edge were harder to discern due to their proximity and decreased growth bandwidth. This situation occurred more frequently in age groups 5 and 6. Landa & Piñeiro (2000) and Lucena & O'Brien (2001) reported that this situation is common in numerous species, as growth rates decrease significantly in adult individuals. However, growth marks are still being deposited on the otolith edge.

Before this study, there were no reports on round herring *E. acuminatus* age using otoliths. Studies of age and growth have been carried out for *E. teres* (Farrag et al. 2014), with a reported maximum age of 5 years and best-represented age groups of 2 and 3 years of age (both 64%), which is like what was found in the present study. Yilmaz & Hossucu (2003) and Mehanna & El-Gammal (2005) reported a maximum age of three years for *E. teres* in the Red Sea. Chen et al. (1992) also reported on the age of juvenile round herring *E. teres* in the Gulf of Mexico.

Individual growth

The round herring *E. acuminatus* showed accelerated growth during the first year of life, with sizes ranging from 125 to 135 mm SL, representing 60% of L_∞. The growth rate during the first year of life coincides with what has been reported for *E. teres* in the Mediterranean Sea and Red Sea (Mehanna & El-Gammal 2005, Farrag et al. 2014). It also coincides with what has been found for other small pelagic fish, such as the Pacific sardine *Sardinops sagax* and the thread herring *Opisthonema* spp. (Alvarado-Castillo & Félix-Uraga 1996, Ruiz-Dominguez & Quiñonez-Velázquez 2018), which shares the WBCSC habitat with the round herring. Growth gradually decreased as it reached the asymptotic phase. A decrease in growth rate after the first year of life could be associated with the beginning of maturity, frequently producing a discontinuity in the growth curve (Beverton & Holt 1957).

Previous reports on individual growth of the round herring *E. acuminatus* correspond to size-frequency data using the von Bertalanffy model. The common practice when describing fish growth is to adopt the von

Table 6. Several authors estimated the von Bertalanffy model's growth parameters (L_∞, K, t_0) for *Etrumeus teres* and *E. acuminatus* at different locations. Gulf of Suez 1; Red Sea 2; Egypt 2; Gulf of California 3; Gulf of Antalya, Mediterranean Sea, Izmir, Turkey 4; Gulf of Suez 5; Mediterranean Sea, Egypt, 6; Western Baja California Sur Coast. *Based on length frequencies. TL: total length, ST: standard length.

Author(s)	Study area	Sex	Length	L_∞ (mm)	K (yr^{-1})	t_0 (yr)	Species
Sanders et al. (1984)	1	Both	TL	268	0.805	0.549	*E. teres*
Cisneros-Mata et al. (1990)*	2	Both	SL	230.5	0.86	-0.11	*E. acuminatus*
El-Sayed (1996)	1	Both	TL	297	1	-0.159	*E. teres*
Cisneros-Mata et al. (1997)*	2	Both	SL	246.0	0.80	-0.112	*E. acuminatus*
Martínez-Zavala et al. (2000)*	2	Both	SL	249.5	0.55	-0.29	*E. acuminatus*
Yilmaz & Hossucu (2003)	3	Males	SL	299	0.28	-1.22	*E. teres*
		Females	SL	415	0.13	-2.19	
		Both	SL	337.7	0.20	-1.63	
Mehanna & El-Gammal (2005)	4	Both	TL	269.7	0.59	-0.4	*E. teres*
Farrag et al. (2014)	5	Males	TL	317.1	0.214	-0.77	*E. teres*
		Females	TL	290.7	0.246	-0.68	
		Both	TL	302.6	0.225	-0.74	
Present study	6	Males	SL	257.4	0.23	-2.73	*E. acuminatus*
		Females	SL	287.3	0.16	-3.43	
		Both	SL	290.1	0.15	-3.63	

Bertalanffy model *a priori*; however, in several cases, this growth model does not adequately describe the data trend, as numerous species seem to follow different growth trajectories (Katsanevakis & Maravelias 2008). In the present study, the individual growth of the round herring was approached using a multimodel approach and AIC to select the best model. The advantage of using the AIC lies in that the models can be ranked hierarchically according to the data fit and according to Akaike's differences and obtain an average value of the parameters shared by models with $\Delta_i \leq 2$ (Burnham & Anderson 2004). Ricker (1979) stated that fish growth varies during the different life stages due to discontinuity in development, maturity, changes in behavior, or habitat, which could result in two stocks of the same species being evaluated with different growth models.

In the present study, the models that best fit the age-SL data for both sexes of the round herring *E. acuminatus* were, in order, von Bertalanffy, Richards, and Schnute (type 1). The growth parameter estimates were similar to those found for *E. teres* in the Gulf of Suez, Red Sea, and Mediterranean Sea (L_∞= 268 mm TL, K = 0.8, t_0 = 0.54) by Sanders et al. (1984); by Cisneros-Mata et al. (1991) in the Gulf of California, Mexico (L_∞ = 231 mm SL, K = 0.86); and by Mehanna & El-Gammal (2005) in the Gulf of Suez and the Red Sea (L_∞= 269 mm TL, K = 0.59, t_0 = -0.4). The values found here were lower than those reported by El-Sayed (1996), Yilmaz & Hossucu (2003), and Farrag et al. (2014) for *E. teres*. Differences could be attributed to the analyzed size interval, the number of age groups, and the environmental characteristics of the study areas (Table 6).

CONCLUSIONS

In conclusion, we provide information on age, L_{50}, and individual growth parameters of the round herring *E. acuminatus* distributed in the WBCSC, as well as population structure and dynamics.

The multimodel inference has proven helpful in calculating a model averaging mean L_{50} and describing individual growth in small pelagic fish.

Determination of L_{50} and estimation of growth parameters may differ between sexes and between areas due to latitudinal differences, model selection, sample size, or data structure.

The round herring presented an age structure of 0+ to 6-year-olds; the best-represented age groups were 3- and 4-year-olds. According to the multimodel approach, Lysack (1979), White et al. (2002) Brouwer & Griffiths (2005) and logistic models yielded adequate L_{50} estimates. The best models to describe individual growth were, in order, the von Bertalanffy, Richards, and Schnute (type 1) models.

Credit author contribution

R.J. Flores-Anaya: methodology, software, data curation, formal analysis, writing-original draft; C. Quiñonez-Velázquez: conceptualization, validation, investigation, resources, writing-review, editing, funding acquisition; D.I. Arizmendi-Rodríguez: data curation, writing-review editing; X.G. Moreno-Sánchez: data curation, writing-review and editing. All authors have read and accepted the published version of the manuscript.

Declaration of competing interest

The authors have no conflicts of interest to declare.

ACKNOWLEDGMENTS

The Instituto Politécnico Nacional (IPN) granted this study's financing. So many people obtained biological samples that it would be difficult to mention them all. The boat crews and processing plant personnel offered assistance for biological sampling at the time of landing. We thank everyone involved. We also thank our colleague E. Alvarez-Trasviña for assisting us with the map edition. RJFA thanks the Consejo Nacional de Humanidades, Ciencia y Tecnología (CONAHCyT) for a postgraduate scholarship. CQV, DIAR and XGMS are Sistema Nacional de Investigadores (SNI-CONAHCyT) members. CQV is a fellow of EDI-IPN and COFAA-IPN. Finally, we thank four anonymous reviewers for critically reviewing this manuscript. Their comments contributed significantly to the final version of the manuscript.

REFERENCES

Ahern, A.L.M., Gómez-Gutiérrez, J., Aburto-Oropeza, O., Saldierna-Martínez, R.J., Johnson, A.F., Harada, A.E., et al. 2018. DNA sequencing of fish eggs and larvae reveals high species diversity and seasonal changes in spawning activity in the southeastern Gulf of California. Marine Ecology Progress Series, 592: 159-179. doi: 10.3354/meps12446

Alvarado-Castillo, R.M. & Félix-Uraga, R. 1996. Edad y crecimiento de la sardina monterrey *Sardinops caeruleus* (Pisces: Clupeidae) en Isla de Cedros, Baja California, México, durante 1985 y 1986. Boletín de Investigaciones Marinas y Costeras, 25: 77-86.

Aragon-Noriega, E.A. 2014. Modeling the individual growth of the gulf corvina, *Cynoscion othonopterus* (Pisces: Sciaenidae), using a multimodel approach. Ciencias Marinas, 40: 149-161. doi: 10.7773/cm.v40i2.2410

Beamish, R.J. & Fournier, D.A. 1981. A method for comparing the precision of a set of age determinations. Canadian Journal of Fisheries and Aquatic Sciences, 38: 982-983. doi: 10.1139/f81-132

Beverton, R.J.H. & Holt, S.J. 1957. On the dynamics of exploited fish populations. Chapman and Hall, London.

Brouwer, S.L. & Griffiths, M.H. 2005. Reproductive biology of carpenter seabream (*Argyrozona argyrozona*) (Pisces: Sparidae) in a marine protected area. Fishery Bulletin, 103: 258-269.

Burnham, K.P. & Anderson, D.R. 2004. Model selection and multimodel inference: a practical information-theoretic approach. Springer Science and Business Media, New York.

Campana, S.E. & Thorrold, S.R. 2001. Otoliths, increments, and elements: ¿keys to a comprehensive understanding of fish populations? Canadian Journal of Fisheries and Aquatic Sciences, 58: 30-38. doi: 10.1139/cjfas-58-1-30

Cárdenas-Quintana, G., Franco-Meléndez, M., Salcedo-Rodríguez, J., Ulloa-Espejo, D. & Pellón-Farfán, J. 2015. La sardina peruana, *Sardinops sagax*: análisis histórico de la pesquería (1978-2005). Ciencias Marinas, 41: 203-216. doi: 10.7773/cm.v41i3.2466

Carmona, R. & Alexandres, F. 1994. Determinación del crecimiento de *Opisthonema libertate* (Clupeiformes: Clupeidae) mediante lectura de otolitos. Revista de Biología Tropical, 42: 233-238.

Chang, W.Y. 1982. A statistical method for evaluating the reproducibility of age determination. Canadian Journal of Fisheries and Aquatic Sciences, 39: 1208-1210.

Chavez, F.P., Ryan, J., Lluch-Cota, S.E. & Niquen, M. 2003. From anchovies to sardines and back: multidecadal change in the Pacific Ocean. Science, 299: 217-221. doi: 10.1126/science.1075880

Chen, Y. & Paloheimo, J.E. 1994. Estimating fish length and age at 50% maturity using a logistic-type model. Aquatic Sciences, 56: 206-219.

Chen, W., Govoni, J.J. & Warlen, S.M. 1992. Comparison of feeding and growth of larval round herring *Etrumeus teres* and gulf menhaden *Brevoortia patronus*. Fishery Bulletin, 90: 183-189.

Cisneros, M.A., Estrada, J. & Montemayor, G. 1990. Growth, mortality, and recruitment of exploited small pelagic fishes in the Gulf of California, Mexico. Fishbyte, 8: 15-17.

Cisneros-Mata, M.A., Nevárez-Martínez, M.O., Montemayor-López, G., Santos-Molina, J.P. & Morales-Azpeitia, R. 1991. Pesquería de sardina en el Golfo de California 1988/1989-1989/1990. Documento interno. SEPESCA, Instituto Nacional de Pesca, CRIP Guaymas, Sonora.

Cisneros-Mata, M.A., Nevárez-Martínez, M.O., Martínez-Zavala, M.A., Anguiano-Carrazco, M.L., Santos-

Molina, J.P., Godínez-Cota A.R., et al. 1997. Diagnosis de la pesquería de pelágicos menores del Golfo de California de 1991/1992-1995/1996. Documento interno. SEPESCA, Instituto Nacional de Pesca, CRIP Guaymas, Sonora.

Comisión Nacional de Acuacultura y Pesca (CONAPESCA). 2022. Anuario estadístico de acuacultura y pesca 2020. CONAPESCA, Ciudad de México.

Diario Oficial de la Federación (DOF). 2021. Norma Oficial Mexicana NOM-003-SAG/PESC2020, para regular el aprovechamiento de las especies de peces pelágicos menores con embarcaciones de cerco, en aguas de jurisdicción federal del Océano Pacífico, incluyendo el Golfo de California. Diario Oficial de la Federación, Ciudad de México. 24 de diciembre de 2021, pp. 1-2.

Dibattista, J.D., Randall, J.E. & Bowen, B.W. 2012. Review of the round herrings of the genus *Etrumeus* (Clupeidae: Dussumieriinae) of Africa, with descriptions of two new species. Cybium, 36: 447-460.

Durazo, R., Gaxiola-Castro, G., Lavaniegos, B., Castro-Valdez, R., Gómez-Valdés, J. & Da Mascarenhas Jr., A. 2005. Oceanographic conditions west of the Baja California coast, 2002-2003: A weak El Niño and subarctic water enhancement. Ciencias Marinas, 31: 537-552. doi: 10.7773/cm.v31i3.43.

El-Sayed, A. 1996. Biological and ecological studies on purse-seine fisheries in the Gulf of Suez. Ph.D. Dissertation, Suez Canal University, Ismailia.

Farrag, M.M S., Osman, A.G.M., Akel, E.S.H.K. & Moustafa, M.A. 2014. Catch and effort of night purse seine with emphasis to age and growth of Lessepsian (*Etrumeus teres*) (De Kay, 1842), Mediterranean Sea, Egypt. Egyptian Journal of Aquatic Research, 40: 181-190. doi: 10.1016/j.ejar.2014.06.003

Félix-Uraga, R., Gómez-Muñoz, V.M., Quiñonez-Velázquez, C., Melo-Barrera, F.N., Hill, K.T. & García-Franco, W. 2005. Pacific sardine (*Sardinops sagax*) stock discrimination off the west coast of Baja California and southern California using otolith morphometry. California Cooperative Oceanic Fisheries Investigations Report, 46: 113.

Food and Agriculture Organization (FAO). 2021. Global capture production quantity (1950-2020). [https://www.fao.org/fishery/statistics-query/en/capture/capture_quantity]. Reviewed: December 04, 2024.

García-Alberto, G. 2010. Reproducción de la sardina del Pacífico (*Sardinops sagax*) (Jenyns, 1842) en la región sur de la corriente de California. Tesis de Maestría, Instituto Politécnico Nacional, La Paz.

Gilbert, C.H. 1890. A preliminary report on the fishes collected by the steamer albatross on the Pacific coast of North America during the year 1889, with descriptions of twelve new genera and ninety-two new species. Proceedings of the United States National Museum, 13: 49-26. doi: 10.5479/si.00963801.13-797.49

Gluyas-Millán, M. 1994. Reproduction, age, and length of first maturity of Pacific mackerel *Scomber japonicus* (Houttuyn, 1872) in Vizcaino Bay. Ciencias Marinas, 20: 409-419. doi: 0.7773/cm.v20i3.967

Gompertz, B. 1825. On the nature of the function expressive of the law of human mortality. Philosophical Transactions of the Royal Society of London, 115: 513-585. doi: 10.1098/rstl.1825.0026

Haddon, M. 2011. Modelling and quantitative methods in fisheries. CRC Press, Florida.

Holden, M.J. & Raitt, D.F.S. 1975. Manual de ciencia pesquera. Parte 2. Métodos para investigar los recursos y su aplicación. Documento Técnico de Pesca. FAO, Rome.

Jacob-Cervantes, M.L. & Aguirre-Villaseñor, H. 2014. Inferencia multimodelo y selección de modelos aplicados a la determinación de L_{50} para la sardina crinuda (*Opisthonema libertate*) del sur del Golfo de California. Ciencia Pesquera, 22: 61-68.

Katsanevakis, S. 2006. Modeling fish growth: model selection, multimodel inference, and model selection uncertainty. Fisheries Research, 81: 229-235. doi: 10.1016/j.fishres.2006.07.002

Katsanevakis, S. & Maravelias, C.D. 2008. Modeling fish growth: multi-model inference as a better alternative to *a priori* using von Bertalanffy equation. Fish and Fisheries, 9: 178-187. doi: 10.1111/j.1467-2979.2008.00279.x

Kimura, D.K. 1980. Likelihood methods for the von Bertalanffy growth curve. Fishery Bulletin, 77: 765-776.

Landa, J. & Piñeiro, C. 2000. Megrim (*Lepidorhombus whiffiagonis*) growth in the north-eastern Atlantic based on back-calculation of otolith rings. ICES Journal of Marine Science, 57: 1077-1090. doi: 10.1006/jmsc.2000.0702

Lluch-Belda, D., Arvizu, J., Hernández-Vázquez, S., Lluch-Cota, D.B., Salinas-Zavala, C.A., Baumgartner, T., et al. 1996. La pesquería de sardina y anchoveta. Pesquerías Relevantes de México, 2: 419-535.

Lucena, F.M. & O'Brien, C.M. 2001. Effects of gear selectivity and different calculation methods on estimating growth parameters of bluefish, *Pomatomus saltatrix* (Pisces: Pomatomidae), from southern Brazil. Fishery Bulletin, 99: 432-432.

Lysack, W. 1979. Lake Winnipeg fish stock assessment program. Manitoba Department of Natural Resources, Manitoba.

Martínez-Zavala, M., Nevárez-Martínez, M.O., Anguiano-Carrazco, M.L., Santos-Molina, J.P. & Godínez-Cota, A.R. 2007. Captura de peces pelágicos menores en el Golfo de California, temporada de pesca 2007-2008. Ciencia Pesquera, 18: 5-18.

Mehanna, S.F. & El-Gammal, F. 2005. Stock assessment of the round herring (*Etrumeus teres*) (De Kay, 1842) in the Egyptian sector of the Red Sea. Indian Journal Fish, 52: 377-383.

Moreau, J. 1987. Mathematical and biological expression of growth in fish: recent trends and further developments. In: Robert, C. & Hall, G.E. (Eds.). Age and growth of fish. Iowa State University Press, Iowa, pp. 81-113.

Moser, H.G. 1996. The early stages of fishes in the California Current region. In: California Cooperative Oceanic Fisheries Investigations. Atlas 33. CalCOFI, California.

Osman, A.G., Akel, E.S.H., Farrag, M. & Moustafa, M.A. 2011. Reproductive biology of round herring *Etrumeus teres* (Dekay, 1842) from the Egyptian Mediterranean water at Alexandria. ISRN Zoology, 2011: 1-12. doi: 10.5402/2011/215950

Payan-Alejo, J., Jacob-Cervantes, M.L. & Rodríguez-Domínguez, G. 2020. Age and growth of thread herring *Opisthonema libertate*, in the southern Gulf of California. Latin American Journal of Aquatic Research, 48: 15-22. doi: 10.3856/vol48-issue1-fulltext-2308

Polacheck, T., Hilborn, R. & Punt, A.E. 1993. Fitting surplus production models: Comparing methods and measuring uncertainty. Canadian Journal of Fisheries and Aquatic Sciences, 50: 2597-2607. doi: 10.1139/f93-284

Quiñonez-Velázquez, C., Alvarado-Castillo, R. & Félix-Uraga, R. 2002. Relación entre el crecimiento individual y la abundancia de la población de la sardina del Pacífico, *Sardinops caeruleus* (Pisces: Clupeidae) (Girard 1856), en Isla de Cedros, Baja California, México. Revista de Biología Marina y Oceanografía, 37: 1-8. doi: 10.4067/s0718-19572002000100002

Randall, J.E. & Dibattista, J.D. 2012. *Etrumeus makiawa*, a new species of round herring (Clupeidae: Dussumierinae) from the Hawaiian Islands. Pacific Science, 66: 97-110. doi: 10.2984/66.1.6

Received: January 11, 2024; Accepted: July 9, 2024

Richards, F.J.A. 1959. A flexible growth function for empirical use. Journal of Experimental Botany, 10: 290-301. doi: 10.1093/jxb/10.2.290

Ricker, W.E. 1979. Growth rates and models. In: Hoar, W.S., Randall, D.J. & Brett, J.R. (Eds.). Fish physiology, bioenergetics, and growth. Academic Press, New York, pp. 677-743.

Ruiz-Domínguez, M. & Quiñonez-Velázquez, C. 2018. Age, growth, and mortality of *Opisthonema libertate* on the coasts of northwestern Mexico. Ciencias Marinas, 44: 235-250. doi: 10.7773/cm.v44i4.290

Salgado-Cruz, L., Quiñonez-Velázquez, C., García-Domínguez, F.A. & Pérez-Quiñonez, C.I. 2020. Detecting *Mugil curema* (Perciformes: Mugilidae) phenotypic stocks in La Paz Bay, Baja California Sur, Mexico, using geometric morphometrics of otolith shape, growth, and reproductive parameters. Revista Mexicana de Biodiversidad, 91: 1-18. doi: 10.22201/ib.20078706e.2020.91.3273

Sanders, M.J., Kedidi, S.M. & Hegazy, M.R. 1984. Stock assessment for the round herring (*Etrumeus teres*) caught by purse seine in the Gulf of Suez. FAO, Rome.

Schnute, J. 1981. A versatile growth model with statistically stable parameters. Canadian Journal of Fisheries and Aquatic Sciences, 38: 1128-1140. doi: 10.1139/f81-153

Sparre, P. & Venema, S.C. 1997. Introducción a la evaluación de recursos pesqueros tropicales. Parte 1. Manual FAO, Documento Técnico de Pesca. FAO, Rome.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Human Biology, 10: 181-213.

White, W.T., Hall, N.G. & Potter, I.C. 2002. Size and age compositions and reproductive biology of the nervous shark (*Carcharhinus cautus*) in a large subtropical embayment, including an analysis of growth during pre- and postnatal life. Marine Biology, 141: 1153-1164. doi: 10.1007/s00227-002-0914-6

Yilmaz, R. & Hoşsucu, B. 2003. Some biological parameters of round herring (*Etrumeus teres*) (De Kay, 1842) in the Gulf of Antalya (Mediterranean Sea). Ege Journal of Fisheries and Aquatic Sciences, 20: 1-8.

Zaitsev, O., Trasviña-Castro, A., Linero-Cueto, J., Gaxiola-Castro, G. & Cepeda-Morales, J. 2014. Oceanographic conditions over the continental shelf off Magdalena Bay (Mexico). Ciencias Marinas, 40: 89-112.

Zar, J.H. 1999. Biostatistical analysis. Prentice Hall, New Jersey.