Growth analysis of the Pacific sierra *Scomberomorus sierra* in Colima, México

Análisis del crecimiento de la sierra del Pacífico *Scomberomorus sierra* en Colima, México

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Resumen.- La pesca artesanal de la sierra *Scomberomorus sierra* capturada en la costa de Colima representa el 1% de la captura total. De enero 2003 a marzo 2004 se obtuvieron datos morfométricos de 972 ejemplares y otolitos de 464 especímenes que se utilizaron para analizar edad y crecimiento. Se analizó por dos métodos: análisis de frecuencia de longitud y estudio de otolitos sagittae y asterisci por lecturas directas. Ambos métodos identificaron 5 grupos de edad. Las constantes de crecimiento de la ecuación de von Bertalanffy se determinaron por los métodos Ford-Walford y Gulland y con iteraciones de ajuste, ambas técnicas presentaron un alto coeficiente de determinación, pero tuvo mejor ajuste entre valores observados y calculados, de acuerdo con la suma de cuadrados del error; los resultados fueron: L_∞ = 99,54 cm, K = 0,205, t_o = -0,060. La longitud media para cada edad fue: edad 0 (menor a uno) = 1,22 cm, edad 1 = 19,47 cm, edad 2 = 34,33 cm, edad 3 = 46,43 cm, edad 4 = 56,29 cm y edad 5 = 64,32 cm. Se compararon estos resultados con los obtenidos hace 20 años para la misma zona, aplicándose el análisis de curvas coincidentes que mostró una reducción significativa en la longitud promedio de cada edad, que podría deberse a sobreexplotación. *S. sierra* tiene un L_∞ menor en Manzanillo que en Mazatlán, debido probablemente a las diferencias climáticas, latitudinales o variaciones genéticas de las poblaciones. El índice alométrico de la relación peso-longitud fue isométrico, 3,031 y la longevidad 15 años.

Palabras clave: Distribución de frecuencia de longitud, sagittae, asterisci, von Bertalanffy, longevidad

Abstract.- The artisanal fishery of sierra *Scomberomorus sierra* along the coast of Colima represents 1% of the total catch. From January 2003 to March 2004 morphometric data of 972 organisms and otoliths of 464 specimens were obtained to determine age and growth. Growth study was carried out by two methods: length frequency analysis and study of sagittae and asterisci otoliths. Both methods identified 5 age groups. Growth parameters of von Bertalanffy's equation were determined by Ford-Walford and Gulland methods and an iteration adjustment, both techniques showed a high determination coefficient, but the second was better between observed and calculated values according to the sum of squared error; the results obtained were: L_∞ = 99.54 cm, K = 0.205, t_o = -0.060. Mean size for each age was: age 0 (less than one) = 1.22 cm, age 1 = 19.47 cm, age 2 = 34.33 cm, age 3 = 46.43 cm, age 4 = 56.29 cm and age 5 = 64.32 cm. Comparisons for this species were made with results from 20 years ago in the same area, using coincident curves test, showing a significant reduction in average length of each age; this may be caused by changes in the fishery or overexploitation, although growth parameters show the opposite trend. *S. sierra* has a lower L_∞ in Manzanillo than in Mazatlan, which could be explained by climatic, latitudinal differences or due to population's genetic variations. The allometric index from the weight-length relationship was isometric, 3.031 and longevity of 15 years.

Key words: Length frequency distribution, sagittae, asterisci, von Bertalanffy, longevity

INTRODUCTION

The Pacific sierra, *Scomberomorus sierra* Jordan & Starks, 1895 is an epipelagic neritic species which forms schools and spawns close to the coast on the continental shelf. Its entire distribution area goes from South California to Peru, including the Galapagos Islands. It feeds mainly on anchovies and sardines (Collette & Nauen 1983). Its major captures occur in Mexico, where it is captured by sport fishers and abundant enough to sustain a commercial fishery (Fischer *et al*. 1995).

Captures of the Pacific sierra in Colima, Mexico, show two marked seasonal periods due to migration: in summer they swim north and in winter they migrate south (Márquez-Millán 1972). *S. sierra* is more abundant in the coasts of Manzanillo during February and March and from September to November (Chávez 1986). *S. sierra* is commercially considered a second class species with a price to fishers from $ 3.00 to $ 4.00 USD per kilogram.

Studies on its taxonomic description have been done by Castro-Aguirre (1978), Chirichigno *et al*. (1982) and Collette & Nauen (1983). General features of its biology and fisheries are known by the studies of Márquez-Millán (1972), Chávez (1986), Espino-Barr *et al*. (1990) and Aguirre-Villaseñor *et al*. (2006), and an analysis of otolith's shape by Ramírez-Pérez *et al*. (2010).

Age determination studies are necessary to establish population structure by age groups, and to know the stock biomass increment due to their individual growth. These types of analysis allow comparative studies through time, and to determine the differences in the population structures due to environmental fluctuations and/or fishing exploitation (Espino-Barr *et al*. 2008).

Although the Pacific sierra is a commercially important species, studies on its population dynamics are limited. Age and growth studies of this species are ofwere carried out by Espino-Barr *et al*. (1990) in Manzanillo, Colima and by Aguirre-Villaseñor *et al*. (2006) in Mazatlán, Sinaloa. Therefore, this investigation provides, for the first time, data on age and growth of Pacific sierra in Manzanillo, Colima, analyzing length-frequency data and otoliths. Also, otolith asterisci analysis has never been done on this species. These results will help to establish fishery indices, and capture quotas that will help stakeholders to manage this fishing resource.

The objectives of this paper were: 1) to analyze polymodal curves in Pacific sierra's length frequency histograms, 2) determine time of growth ring formation in otoliths sagittae and asterisci, analyzing fast and slow growth borders, 3) calculate von Bertalanffy's growth constants parameters by length frequency analysis data and also those observed by Gallardo-Cabello *et al*. (2011) in the ring identification in otoliths sagittae and asterisci, 4) obtain the alometric index from the weight-length relationship, both total weight and eviscerated weight, and both asymptotic values of weight, 5) calculate *S. sierra*'s longevity and, 6) compare results obtained in the present study with those obtained by Espino-Barr *et al*. (1990) and other authors.

MATERIAL AND METHODS

From January 2003 to March 2004, individuals of *S. sierra* were obtained monthly from the commercial captures of the coastal fishery in Manzanillo, Colima, Mexico (18°40' to 19°10'N and 103°45' to 104°35'W). Total length (TL) and weight (TW) from 972 organisms were obtained directly *in situ* throughout the study period. From these, 464 were transported to the lab, where total (TL) and standard length (SL), height (He) at the base of the dorsal fin, total (TW) and eviscerated weight (EW) and sex were registered for each organism. Individuals were captured with hand lines, troll and gillnet, which helped obtain different lengths and age groups.

The length frequency distribution was analyzed with the ELEFAN program of the FISAT package (Gayanilo *et al*. 1994) to obtain the average length of the polimodal curves corresponding to each age group. This method uses a goodness of fit index called Rn on a response surface, where the maximum value indicates the best combination of growth parameters.

The time of the growth ring formation was determined, observing whether the borders had slow or fast growth rings. In every case, otoliths were observed by transparency with transmitted light; the hyaline (translucent) zone corresponds to the slow growth band and the opaque zone to the fast growth band, which is in contrast with reflected light (Blacker 1974).

The average length of each growth ring determined by the analysis of the sagittae and asterisci otoliths by Gallardo-Cabello *et al*. (2011) was utilized to obtain the parameters of von Bertalanffy´s (1938) growth equation. The observed values for sagittae were: for age 1 = 19.20 cm; age 2 = 35.14 cm; age 3 = 45.80 cm; age 4 = 56.20 cm and age 5 = 64.51 cm.

Von Bertalanffy's equation in the form of $L = L_\infty [1\text{-}e^{-K(t\text{-}t_0)}]$, was utilized, where L = length, L_∞ = asymptotic length, K = growth factor and t_0 = theoretic length at age 0.

The parameters L_∞, K and t_0 of von Bertalanffy´s (1938) equation were obtained with Ford´s (1933), Walford´s (1946) and Gulland´s methods (1964) and were adjusted by convergent iterations with Newton´s algorithm with the solver program in Excel software (Microsoft 1992). The lowest value of a sum of the squared error determined the best adjustment.

The function $W = a \cdot L^b$ was used, where W = weight, L = length, to obtain the weight-length relationship, and a t- student test proved allometry (Zar 1996). The potential function was also used to find TL vs SL and He relationships, where the trend b tends to 1, describing an isometric growth with those variables.

Growth data for length and weight-length relationship were used to obtain the weight at each age. Weight growth was obtained by substituting TL and L_∞ by TW and W_∞, in the von Bertalanffy´s equation (1938). Taylor´s equation (1958, 1960) was utilized to calculate the age limit or longevity (95% of the L_∞): $A_{0.95} = \ln (1\text{-}0.95)/ K + t_0$.

A test of coincident curves was carried out to detect differences between average lengths at each age (Haddon 2001) obtained in this investigation and those reported by Espino-Barr *et al.* (1990) 20 years ago in the same area.

RESULTS

BIOMETRIC RELATIONSHIPS

The maximum value of TL was 97 cm and the minimum was 25 cm, with a difference of 72 cm (Fig. 1). Total weight varied from 140 g to 5,400 g (Table 1). Mode was lower than average, implying a data distribution with positive asymmetric trend (g_1=1.65), also with more values under the modes.

Table 1. Summary of size values of the measured variables: TL = total length, SL = standard length, He = height, TW = total weight and EW = eviscerated weight / Resumen de valores de las variables medidas: TL = longitud total, SL = longitud estándar, He = altura, TW = peso total y EW = peso eviscerado

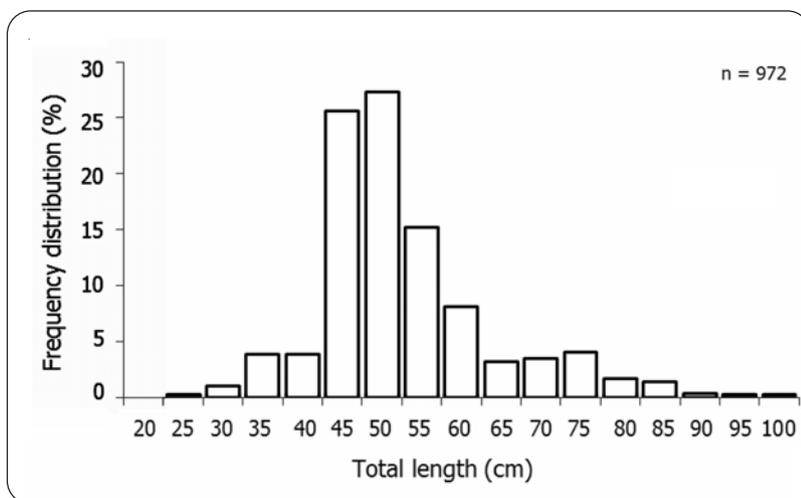|	TL (cm)	SL (cm)	He (cm)	TW (g)	EW (g)
Average	49.63	39.78	7.84	738.19	681.50
Maximum	97.00	82.30	15.50	5400.00	4916.00
Minimum	30.00	24.00	4.80	140.00	21.00
Mode	44.00	35.00	7.00	504.00	382.00
SD	11.23	9.69	1.70	638.80	585.55
n	972	464	464	972	464

Figure 1. Frequency distribution of total length of *S. sierra* / Distribución de frecuencia de longitud total de *S. sierra*

Data of the relationships between length, height and weight were highly significant, with $r^2 > 0.90$ ($P < 0.05$) (Table 2), but no differences were detected between sexes. Figure 2 shows the scatter diagram of the relation weight-length, adjusted by the potential model. The slopes of the relationships between lengths (TL, SL and He) were not statistically different to one; and those between TL and TW and EW different to three.

TIME OF GROWTH RINGS FORMATION OF THE SLOW AND FAST GROWTH BANDS

S. sierra showed that a higher percentage of sagittae and asterisci otoliths with fast growth borders occurs from July to January, while the highest percentage with slow growth bands otoliths in the borders were observed from February to June (Fig. 3) (n = 132); this means that December is the birthday month, although some individuals start their growth ring from July on and other finish in May-June.
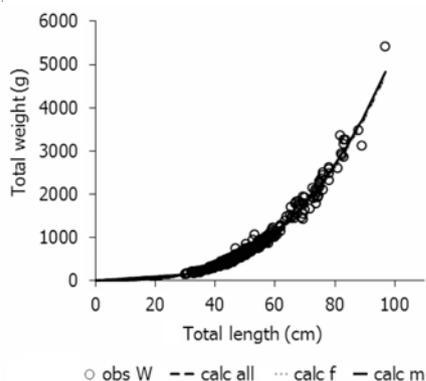

Figure 2. Weight-length relation by potential model / Relación peso-longitud ajustado por el modelo potencial
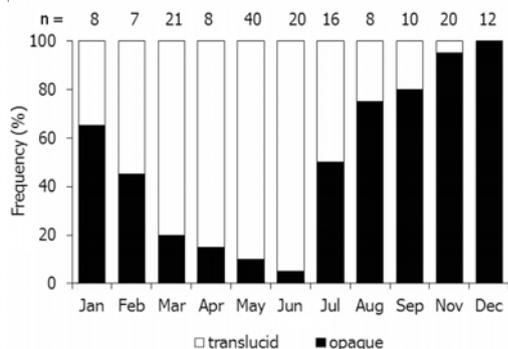

Figure 3. Monthly frequency of the slow-growth and fast-growth borders in the *S. sierra sagittae* and *asterisci* / Frecuencia mensual de los bordes de crecimiento lento y rápido en las *sagittae* y *asterisci* de *S. sierra*

Table 2. Morphometric relationships of the variables: TL = total length, SL = standard length, He = height, TW = total weight and EW = eviscerated weight / Relaciones morfométricas de las variables: TL = longitud total, SL = longitud estándar, He = altura, TW = peso total y EW = peso eviscerado

	Species	Females	Males
TL *vs* SL			
b	1.0620	1.0634	1.0615
a	0.6282	0.6247	0.6292
r^2	0.9964	0.9969	0.9955
TL *vs* He			
b	0.9408	0.9252	0.9680
a	0.1991	0.2117	0.1793
r^2	0.9481	0.9569	0.9302
TL *vs* TW			
b	3.031	3.031	3.043
a	0.005	0.005	0.004
r^2	0.986	0.989	0.981
TL *vs* EW			
b	3.056	3.017	3.056
a	0.004	0.004	0.004
r^2	0.958	0.989	0.983
n	464	225	238

ANALYSIS OF LENGTH FREQUENCY

Observed values of TL for each age ranged from 19.20 cm to 64.51 cm (Table 3), calculated with Ford-Walford and Gulland methods varied from 0.05 (at age 0) to 85.88 cm (at age 10); values were also adjusted to observed values by Solver which varied little from original values. Observed TL for each age obtained with FISAT's method showed lower values (Rn = 0.350). Growth parameters for TL were: L_∞ = 95.50 cm, K = 0.207 years^{-1} and t_0 = 0.019 (Fig. 4). The highest increment occurs during the first year of life, 17.55 cm; during the next year growth rate decreases notably, 14.57 cm from ages 1 to 2; 11.85 cm from age 2 to age 3; 9.64 cm from age 3 to age 4; 7.83 cm from age 4 to age 5 and 6.37 cm from age 5 to age 6.

ANALYSIS OF OTOLITHS

Analysis of the sagittae and asterisci otoliths allowed the identification of 5 age groups. Growth parameters obtained by Ford-Walford-Gulland methods for TL were: L_∞ = 96.82 cm; K = 0.218 years^{-1}; t_0 = -0.002. Growth parameters obtained by solver iteration process were: L_∞ = 99.54 cm; K = 0.205 years^{-1}; t_0 = -0.060. Growth from one age to the next was 18.24 cm from age 0 to age 1; 14.86 cm from age 1 to age 2; 12.10 cm from ages 2 to 3; 9.86 cm

Table 3. Observed and calculated values of total length (cm) and total and eviscerated weight (g) for each age group (years) of *S. sierra* / Valores observados y calculados de la longitud total (cm) y peso total y eviscerado (g) para cada grupo de edad (años) de *S. sierra*

Age (years)	TL (cm) sagitta	TL (cm) sagitta *	TL (cm) sagitta **	TL (cm) ***	TW (g) **	EW (g) **	TL (cm) ****
0		0.050	1.221				
1	19.20	19.005	19.470	17.55	40	35	29.73
2	35.14	34.247	34.332	32.12	226	197	49.92
3	45.80	46.503	46.436	43.97	564	497	64.01
4	56.20	56.359	56.292	53.61	1011	894	73.83
5	64.51	64.284	64.320	61.44	1514	1344	80.69
6		70.657	70.857	67.81	2030	1806	85.47
7		75.782	76.181	72.99	2528	2254	88.81
8		79.903	80.517	77.20	2990	2670	91.14
9		83.216	84.048	80.62	3406	3044	92.76
10		85.881	86.924	83.41	3771	3373	93.89

*direct method with otoliths calculated with Ford-Walford and Gulland methods (Sparre & Venema 1995).
** direct method with otoliths adjusted with solver (Microsoft 1992)
*** indirect method length frequency with FISAT (Gayanilo *et al*. 1994)
**** indirect method length frequency with FISAT (Gayanilo *et al*. 1994)
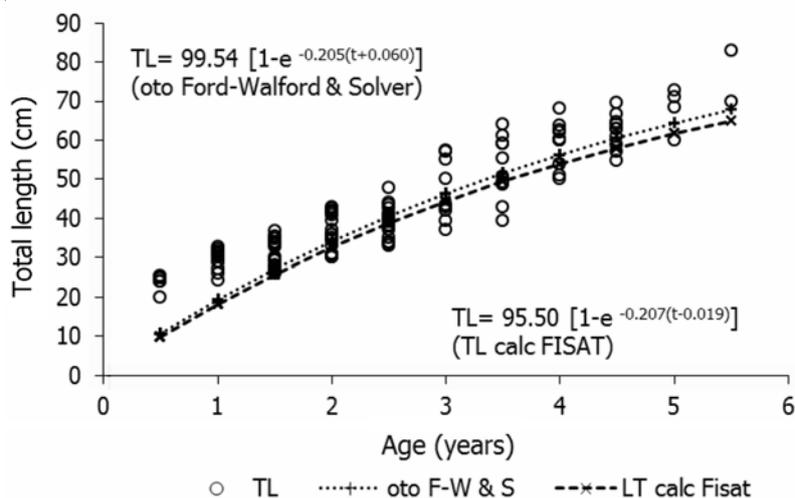

Figure. 4. Von Bertalanffy's growth curve in length for *S. sierra* by Ford-Walford with otolith readings and by length frequency with ELEFAN methods / Curva de crecimiento de von Bertalanffy's en longitud de *S. sierra*, por los métodos de Ford-Walford con lecturas directas de otolitos y por análisis de frecuencia de longitud con ELEFAN

from ages 3 to 4; 8.03 cm from ages 4 to 5 and 6.53 cm from ages 5 to 6. Figure 2 shows the growth curve of *S. sierra* according to von Bertalanffy's method.

The solver iterative process gave a better fit of the calculated equation to observed data of otoliths readings, than Ford-Walford and Gulland methods. The sum of square errors (SSE) between observed and calculated data by Ford-Walford and Gulland was 1.407, and that of the observed data and the resulting of solver process was $SSE = 1.174$.

Growth in weight

The allometric growth index value of the weight-length equation was isometric: b = 3.031 with total weight data and b = 3.056 with eviscerated specimens (Table 2). The allometric growth index b was slightly higher for eviscerated weight, because data do not come from the same organisms in all cases.

Theoretical growth in weight

Values of calculated TW and EW have a slow growth during the first years of age, starting at 40 and 35 g (Table 3, Fig. 5). After age 3 there is a very fast growth rate that starts to slow down after age 9. The calculated asymptotic total weight was $Wt_\infty = 5{,}687.38$ g and the eviscerated asymptotic weight $We_\infty = 5{,}104.49$ g.

Longevity (Age $A_{0.95}$)

S. sierra reached 95% of its infinite length L_∞ in 14.55 years.

Test of coincident curves

Statistical differences in the growth curve were found between the data reported by Espino-Barr *et al.* (1990) 20 years ago and the current results in the same area ($F_{(2,12)} = 6.45$; $P < 0.05$). Twenty years ago *S. sierra* grew faster (K = 0.36) and had higher average sizes at each age even though the asymptotic length ($L_\infty = 96.51$) was lower than parameters calculated in 2010 (Table 4).

Table 4. Growth curves comparison between years: data taken obtained from Espino-Barr *et al.* (1990) and results from this study, from the same area / Comparación de las curvas de crecimiento entre años: datos tomados de Espino-Barr *et al.* (1990) y los de este trabajo, de la misma zona de estudio

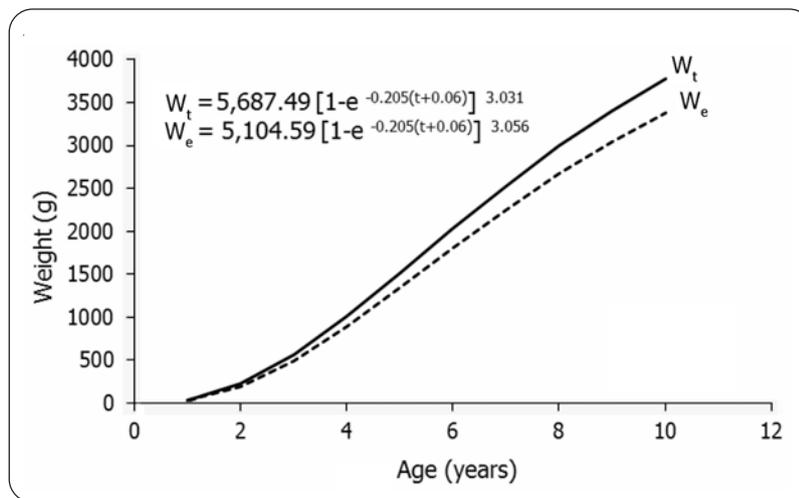| Year	L_∞ (cm)	K	T_0	SC	d.f.
1990	96.51	0.360	-0.023	33.541	7
2010	99.54	0.205	-0.060	1.357	4
	$F_{(2,12)} = 6.45$	$P < 0.05$			

Figure 5. Von Bertalanffy's growth curve in total and eviscerated weight for *S. sierra* / Curva de crecimiento de von Bertalanffy en peso total y eviscerado de *S. sierra*

DISCUSSION

Each year a band of fast and slow growth are deposited on the otoliths sagittae and asterisci, validating the use of this structure to estimate age of *S. sierra* and its growth. This has also been found in other tropical species, where scales are not present (Gallardo-Cabello *et al*. 2006, 2007, 2011, Espino-Barr *et al*. 2006, 2008), allowing a good assessment of ageing, not always possible with scales.

The values obtained with the length frequency analysis were similar (although underestimated) to those found by the identification of growth rings in the sagittae and asterisci, which render age determination of *S. sierra* valid with both methods, and supporting each other (Joseph 1962). The differences emerged because of different methods utilized, a direct and an indirect approach.

Espino-Barr *et al*. (1990) also used the ELEFAN program (Gayanilo *et al*. 1994) for age determination of *S. sierra* obtaining the data listed in Table 3. The values of the von Bertalanffy growth equation were: $L_\infty = 96.51$ cm; $K = 0.36$ years^{-1}, $t_0 = -0.023$ (Table 5). Even though the L_∞ value was not very different from the one obtained in this study, $K = 0.36$ expresses a much faster growth, therefore the populations of *S. sierra* studied by Espino-Barr *et al*. (1990) reached its larger lengths faster, that is, at a lower age. This may be due to natural fluctuations in the environmental parameters in the past 20 years, which can cause changes in the food availability, affecting growth and recruitment. Overfishing can also cause size reduction

for each age group (Macías-Zamora 1992, Ibáñez-Aguirre & Álvarez-Hernández 1998), although it seems this is not the case. Capture of sierra in Manzanillo has declined sharply since 1980, when 330 tons were fished (8.85% of the total artisanal fisheries) compared to 15.6 tons (3.1% of the total artisanal fisheries) in 2007. This reduction in the fishery has to be studied from the fishing effort point of view, to find a verifiable explanation.

Aguirre-Villaseñor *et al*. (2006) obtained for *S. sierra* in the coast of Mazatlán, Sinaloa, values of $L_\infty = 108.30$ cm, and $K = 0.15$ years^{-1} (Table 5). Compared to the obtained values, our L_∞ was lower (95.50 cm) and K higher (0.207), which is explained by the fact that K index value is inversely proportional to L_∞. Similarly when the sea temperature rises, so does the index value K (25ºC in Mazatlán and 27ºC in Manzanillo), in accordance with Taylor (1958, 1960) who states that the K index has a directly proportional relationship to the temperature.

Domínguez-López *et al*. (2010) reported high mitochondrial genetic diversity (mtDNA) for *S. sierra* and a highly significant divergence throughout the eastern Pacific. They found two genetically different groups: one in the northern area (Sinaloa) and the second in the central area (Oaxaca and Chiapas). We consider that our results in Manzanillo, Colima belong to the central area, because it is found under the southern limit of the California Current and very close to the latitude of the coasts of Oaxaca and Chiapas.

Table 5. Growth parameters of the von Bertalanffy equation for *Scomberomorus sierra* reported by different authors (longevity values were calculated by this research) / Parámetros de crecimiento de la ecuación de von Bertalanffy de *Scomberomorus sierra* reportados por diferentes autores (los valores de longevidad fueron calculados en este trabajo)

	Espino-Barr *et al*.	Aguirre-Villaseñor *et al*.	This paper	This paper
Year	1990	2006	2010	2010
Area	Colima	Gulf of California, Mazatlán	Central Mexican Pacific	Central Mexican Pacific
Method	TL (ELEFAN)	LF	TL (ELEFAN)	TL (otoliths)
L_∞ (cm)	96.51	108.30	95.50	99.54
K	0.360	0.150	0.207	0.205
t_0	-0.023	0.0001	0.019	-0.060
longevity (years)	8	20	14	15
fi	3.525	3.245	3.276	3.308
TºC	26.5		26.5	26.5

It is important to point out that the asynchronic spawning in distant areas can determine isolation of the stocks, and therefore the formation of genetically different populations (Shoji *et al*. 2005). Nevertheless, the spawning periods of *S. sierra* in Manzanillo show two seasons, from March to May and from August to September (Nava 2008); this is similar to the season in Sinaloa, where Aguirre-Villaseñor *et al.* (2006) reported that it occurs from July to September. The population differences may have occurred at the same time than glacial-interglacial episodes in the Pleistocene, but also can be largely related with the changes of the surface sea temperature (SST), upwelling areas and with ENSO events (Domínguez-López *et al*. 2010). Organisms utilized to study fishery dynamics come from partially biased samples, due to the catching methods; besides, these methods catch whatever fish is present, which depend on temperature of the water, currents, time of the year, fish vulnerability to fishing gears and presence of other species (predators, competitors, prey).

These periodic changes in the environment can also alter growth mechanisms in different regions, as mentioned by Ramírez-Pérez *et al*. (2010), who found three different groups of *S. sierra* in the areas of Guaymas, Mazatlan and Bahía Magdalena, based on the method of procrustes superimposition in the saggitae otolith.

According to the allometric index of the length-weight relationship, our values were similar to those found by Espino-Barr *et al*. (1990), who reported an isometric index of 3.08. *S. sierra*'s longevity calculated by Espino-Barr *et al*. (1990) of 8 years, was lower than that reported in this study (14 years). The value calculated with data from Aguirre-Villaseñor *et al*. (2006) was of 20 years old (Table 5).

There are no enough results in this study to corroborate a hypothesis that this species is an overfished resource, although catches have remarkably declined. Other analysis using growth fishery parameters must be utilized to analyze the state of health of the species in the central Mexican Pacific coast.

CONCLUSIONS

Length frequency analysis by ELEFAN method showed that the polimodal curves of the 5 growth rings observed in the otoliths sagittae and asterisci, identified age groups by direct (otoliths) and indirect methods (length frequency). The border analysis in otoliths sagittae and asterisci determined that each year a fast and slow growing band is formed, so *S. sierra*'s age determination by these hard parts is valid. The von Bertalanffy's constant values were $L_\infty = 99.54$ cm, $K = 0.205$ and $t_0 = -0.060$, and the weight-length relationship was isometric. Asymptotic total weight value was $Wt_\infty = 5,687.38$ g and eviscerated weight $We_\infty = 5,104.49$ g. *S. sierra* lives up to 14.55 years.

Twenty years ago larger sizes for each age group were obtained for *S. sierra* in Manzanillo, Colima, México, than those found in the present study, but the allometric growth index found in this study is very similar to the one reported 20 years ago in this locality. *S. sierra* reaches a smaller infinite length and a higher catabolic index in Manzanillo, Colima than in Mazatlán, Sinaloa.

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