Latin American Journal of Aquatic Research, 50(1): 31-38, 2022
DOI: 10.3856/vol50-issue1-fulltext-2746

*Research Article*

# Effect of sea surface temperature on the growth performance of the thread herring *Opisthonema libertate* (Günther, 1868) in the southern Gulf of California

**Francia Kesia Gemima Zamora-Sarabia**[1], **Francisco Arreguín-Sánchez**[1]
**Juan Antonio De Anda-Montañez**[2] **& Mercedes Laura Jacob-Cervantes**[3]
[1]Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas
La Paz, Baja California Sur, México
[2]Centro de Investigaciones Biológicas del Noroeste, S.C., La Paz, Baja California Sur, México
[3]Instituto Nacional de Pesca y Acuacultura, Centro Regional de Investigaciones Pesqueras y Acuícolas
Mazatlán, Sinaloa, México
Corresponding author: Francia Kesia Gemima Zamora-Sarabia (francia.zamora@hotmail.com)

**ABSTRACT.** The present study assessed the effect of sea surface temperature (SST) on the individual growth performance of the thread herring *Opisthonema libertate* in the southern Gulf of California. For the period from 1988 to 2017, based on monthly length-frequency information, the von Bertalanffy equation's growth parameters ($L_\infty$, $K$, and $t_0$) were estimated annually. Annual values of the growth performance index $\Phi'$ were inversely related to the SST ($P < 0.05$). The values of $K$ and $L_\infty$ corresponding to the modal value of the distribution of $\Phi'$ were taken as representative of the species, and the temperature change pattern function over time was incorporated as a forcing of the growth coefficient, $K$, in the growth model. Thus, it was possible to represent the yearly effect of SST on growth performance. These estimates are considered of great interest for future research because they directly influence the variability in allocating the number of individuals at different ages.

**Keywords:** *Opisthonema libertate*; age structure; length frequency; growth performance; growth coefficient; thermal variability; small pelagics

## INTRODUCTION

The *Opisthonema* genus consists of three species (*O. libertate*, *O. mediraste*, and *O. bulleri*). The *Opisthonema* complex is commonly known as the crinuda sardine because it has a filamentous extension of the last dorsal fin radius colloquially called "crina" (Berry & Barret 1963). The crinuda sardine is a coastal-pelagic species that forms dense shoals, inhabits tropical and subtropical waters, and is geographically distributed from Santa Rosalillita, Baja California in the Pacific Ocean, within the Gulf of California (GC) to Punta Sal and Punta Picos in Peru (Lluch-Belda et al. 1995).

The small pelagic fishery in the southern Gulf of California (SGC) mainly focuses on catching thread herring, with *O. libertate* being the most abundant species in landings, historically contributing accounting for approximately 50% of the landings; thread herring is important in this region due to its catch volumes and its economic contribution (Jacob-Cervantes 2010). However, thread herring is a resource that fluctuates in catches because its abundance and availability are closely related to environmental variability. Several authors have documented that during "El Niño" events, the catches of crinuda sardines tend to decrease (Vallarta-Zárate 2012, Vallarta-Zárate & Jacob-Cervantes 2014, DOF 2018).

The GC is a subtropical sea between the Baja California Peninsula and the coasts of Sonora and Sinaloa, connected to the open ocean at its southern end and surrounded mostly by elevated topography (Badan-Dangon et al. 1991, Lluch-Cota et al. 2007). The GC is located in a temperate-tropical transitional zone, which gives it atmospheric, oceanographic, and ecological characteristics that make it an area rich in species diversity (Lluch-Cota 2000). The movements of equa-

---

Corresponding editor: Federico Cortés

torial belt winds strongly influence the exchange of heat and gases near the sea surface level. In summer, the winds blow from south to north and northwest in winter (Douglas et al. 1993). The elevated topography on both coasts causes this behavior of the winds (Parés-Sierra et al. 2003).

Some physical properties of oceans impact marine life, such as the great thermal fluctuations in the epipelagic zone of the water column, where the constant exchange of heat and gases between the ocean and the atmosphere results in variations in water temperature. One of the physical properties of the marine environment essential for biological processes (metabolism and growth) is the water temperature because it controls the speed at which these processes are carried out (Lalli & Parsons 1997).

Organismal growth denotes a measurable change in size as an age function that occurs through the assimilation of food; fish obtain energy from food, and that energy is used for growth, reproduction, or activity; however, various external factors may affect fish growth, such as food, temperature, and habitat (Von Bertalanffy 1938). Similarly, the individual growth of a fish is one of the factors in population dynamics that defines the biomass gain and contributes to changes in the abundance of the resource; and, therefore, in the annual catches fisheries (Pauly & David 1981).

The present study aims to establish the changes in the temporal patterns of the relationship between the sea surface temperature (SST) and the growth of the crinuda sardine *O. libertate*, which is key information for determining age structure in future studies on population dynamics. Our study is based exclusively on data for *O. libertate* from the thread herring fishery that occurs in the port of Mazatlán, Sinaloa (Fig. 1), which accounts for 14% of the total sardine catch in the country (SAGARPA 2018).

## MATERIALS AND METHODS

The historical series (1988-2017) of *Opisthonema libertate* length data (standard length) and annual catches were provided by the National Institute of Fisheries and Aquaculture, through the Regional Center for Aquaculture and Fisheries Research (CRIAP, by its acronym in Spanish) based in Mazatlán, Sinaloa, which has biological fishing records for the crinuda sardine fishery in the SGC.

The standard lengths of more than 39,000 organisms were grouped in 10 mm intervals, and the frequencies were extracted for each month and year, within a global range of observed lengths, from 90 to 229 mm. The Von Bertalanffy (1938) growth equation is described as:

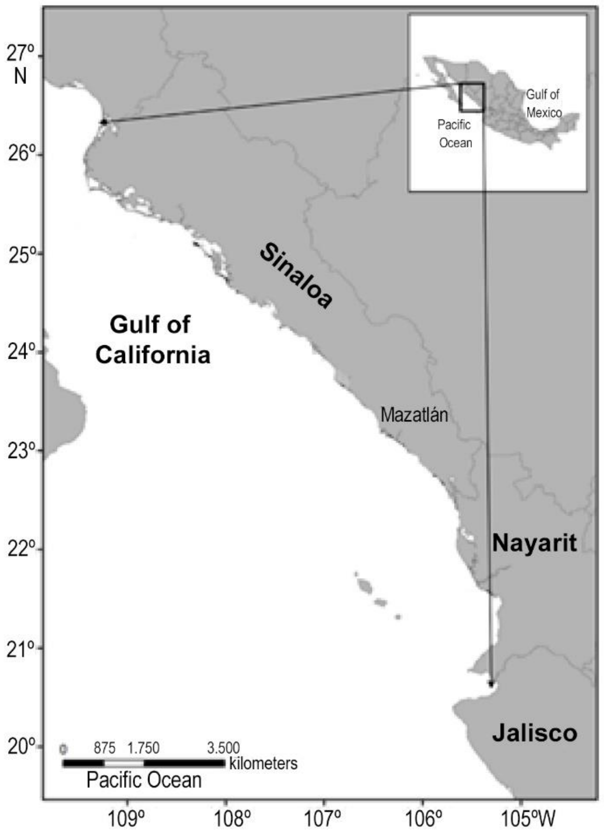

**Figure 1.** Landing port of the sardine fleet in the southern Gulf of California. Arrows indicate the limits of the fishing zone along the coastline.

$$L_t = L_\infty[1 - e^{-(K*(t-t_0))}] \quad (1)$$

where $L_t$ is the estimated standard length at a time ($t$), and $t$ represents age in years, $L_\infty$ is the maximum asymptotic length, $K$ is a growth coefficient, and $t_0$ is the age of the fish when, hypothetically, they have zero length. $L_0$ is the length when $t = 0$ and was defined as the length of the smallest juvenile recorded (Pauly 1980, Sparre & Venema 1997). For *O. libertate* we supposed $L_0 = 41$ mm (Ruiz-Domínguez & Quiñonez-Velázquez 2018). The parameter $t_0$ was estimated with the inverse von Bertalanffy equation as follows:

$$t_0 = \left({}^{1}/_{K}\right) * ln\left(1 - {}^{L_0}/_{L_\infty}\right) \quad (2)$$

The ELEFAN I (Pauly & David 1981) and NSLCA (Shepherd 1987, Pauly & Arreguín-Sánchez 1995) methods were applied to estimate the growth parameters each year using the FiSAT platform (Gayanilo et al. 1994). Generally, in the length-based methods, the value of $L_\infty$ is strongly linked to the maximum length present in the data. Given this sensitivity and the algorithms of the methods, the $K$ values were analyzed in a particular way since their magnitude has a close relationship with the life history of the species (Pauly 1980), particularly with the age of maximum longevity, $t_\lambda$, according to the empirical relationship:

$$t_\lambda \approx \frac{3}{K} + t_0 \qquad (3)$$

with the values of the growth coefficient, *K*, and the maximum asymptotic length, $L_\infty$, the growth performance index, $\varphi'$ was estimated (Pauly & Munro 1984) and described as:

$$\varphi' = Log_{10}(K) + 2\,Log_{10}(L_\infty) \qquad (4)$$

The sea surface temperature (SST) data series and its anomaly corresponded to El Niño region 3.4 (5°N-5°S, 70-120°W), used as a standard measure by the National Oceanic and Atmospheric Administration (NOAA) to identify El Niño or La Niña years in the eastern tropical Pacific Ocean (Rodríguez-Moreno et al. 2014). Its use to characterize the marine region of the SGC has been considered adequate given that there is a free exchange of water with the eastern Pacific Ocean (Álvarez-Borrego 1983).

The periodicity of the SST was analyzed through the function "periods" (González-Rodríguez et al. 2015), which is capable of identifying the different significant cyclical components in the time series studied in terms of amplitude, phase, and period; including them in a final model of the anomaly, allowing the SST to be estimated each year. The model was adjusted by multiple regression:

$$X_e = \alpha + \beta t + \sum_{i=1}^{m}(a_i * Cos(2\pi p_i^{-1} t) + b_i * Sen(2\pi p_i^{-1} t)) \qquad (5)$$

where α and β are the linear regression coefficients when a linear trend is assumed; otherwise, both parameters are equal to zero, $a_i$: amplitude, $b_i$: phase, $p_i$: period, and $t$ is the time series. Trends in the patterns of temperature change and the index $\varphi'$expressing growth performance were analyzed to test the hypothesis of the SST effect on growth. According to Pauly et al. (1996), $\varphi'$ shows a normal distribution and represents the variability in the growth performance of one species. Thus, the distribution mode was assumed as the growth performance mean value, with corresponding growth parameters values so that the effect of SST on $\varphi'$ was expressed within the variability in the set of the estimators of $\varphi'$ per year. Therefore, the growth parameters values corresponding to the modal estimator $\varphi'$ will represent the average growth curve, incorporating the variation associated with the temperature pattern as a forcing effect on the growth speed (parameter *K*), considering favorable temperatures or unfavorable effects based on accelerating or not accelerating the metabolic processes. Thus, the growth curve incorporating the effect of SST was expressed as:

$$L_t = L_\infty * \left[1 - \exp\left(-(X_e * K) * (t - t_0)\right)\right] \qquad (6)$$

where $X_e$ represents the model of the SST pattern of change.

## RESULTS

The von Bertalanffy equation growth parameters' annual estimation, $L_\infty$ and *K*, using ELEFAN I and NSLCA methods is shown (Table 1).

The annual values of the *K* parameter are shown in Figure 2. According to the literature (Gallardo-Cabello et al. 1993, Ruiz-Domínguez & Quiñones-Velázquez 2018, Payán-Alejo et al. 2020), the maximum ages present in commercial catches vary between 4 and 8 years and, consequently, according to Equation 2, not have expected values of $K > 0.8$. Given the consistent biologically expected values, the analysis continued with the parameters resulting from the ELEFAN I method.

The distribution of the values of $\varphi'$ (Fig. 3) showed a modal value of $\varphi' = 4.52$, to which values of $K = 0.65$ and $L_\infty = 224$ mm corresponded. The $t_0$ value was estimated considering these values, and the smallest juveniles' length was reported in the literature, resulting in a value of $t_0 = -0.311$.

Analyzing the SST time series with growth performance ($\varphi'$), a statistically significant inverse relationship was found ($r^2 = 0.23$, $P < 0.05$). To have a better appreciation of the behavior, we used a 3-year moving average to smooth out the SST and Phi prime data, this allowed us to highlight that in years with warmer temperatures, the growth of the thread herring slowed, and the opposite occurred for those years where the SST was lower than the annual average (Fig. 4).

Once the relationship between SST and $\varphi'$ was established, the SST data were analyzed in detail with the function "Periods." Three main harmonic components were identified in the time series, and the periods, amplitudes, and phases were determined for each component (Table 2). The results indicate that the first harmonic found had a period of 12 years and was the period with the largest amplitude, therefore was the most influential period in the time series, followed by cyclical components of 5 and 26 years, with lower amplitude than the first, this indicates the importance of those periods in the index. These estimations allow us to make predictions outside the observed values and thus predict whether thermal fluctuations may affect sardine growth.

Once the model was parameterized, the "periods" function was incorporated into the Von Bertalanffy growth equation. The annual growth curves estimated

**Table 1.** Maximum asymptotic length ($L_\infty$) and growth coefficient ($K$) estimate from the von Bertalanffy equation by ELEFAN I and NSLCA. $\varphi'$: *g*rowth performance index. *Not used, considered biologically inconsistent.

| | ELEFAN I | | | NSLCA | | |
|---|---|---|---|---|---|---|
| | $L_\infty$ (mm) | $K$ (years) | $\varphi'$ | $L_\infty$ (mm) | $K$ (years) | $\varphi'$ |
| 1988 | 226 | 0.4 | 4.3 | 214 | 0.26 | 4.1 |
| 1989 | 234 | 0.66 | 4.6 | 200 | 0.17 | 3.8 |
| 1990 | 227 | 0.55 | 4.5 | 202 | 0.1 | 3.6 |
| 1991 | 211 | 1.34* | 4.8 | 213 | 0.14 | 3.8 |
| 1992 | 234 | 0.33 | 4.3 | 202 | 0.23 | 4 |
| 1993 | 233 | 0.90* | 4.7 | 223 | 0.2 | 4 |
| 1994 | 229 | 1.01* | 4.7 | 217 | 0.35 | 4.2 |
| 1995 | 240 | 0.46 | 4.4 | 236 | 1.73 | 5 |
| 1996 | 219 | 0.58 | 4.4 | 219 | 0.18 | 3.9 |
| 1997 | 217 | 0.46 | 4.3 | 200 | 1.57 | 4.8 |
| 1998 | 218 | 0.82 | 4.6 | 211 | 0.17 | 3.9 |
| 1999 | 211 | 0.83 | 4.6 | 210 | 0.17 | 3.9 |
| 2000 | 236 | 0.6 | 4.5 | 235 | 0.31 | 4.2 |
| 2001 | 231 | 0.69 | 4.6 | 214 | 0.77 | 4.6 |
| 2002 | 220 | 0.4 | 4.3 | 190 | 1.56 | 4.8 |
| 2003 | 223 | 0.54 | 4.4 | 205 | 0.3 | 4.1 |
| 2004 | 211 | 0.6 | 4.4 | 211 | 0.17 | 3.9 |
| 2005 | 219 | 0.81 | 4.6 | 201 | 0.42 | 4.2 |
| 2006 | 205 | 0.57 | 4.4 | 214 | 0.77 | 4.5 |
| 2007 | 236 | 0.68 | 4.6 | 235 | 0.88 | 4.7 |
| 2008 | 229 | 1.10* | 4.7 | 210 | 0.23 | 4 |
| 2009 | 214 | 1.08* | 4.7 | 210 | 0.58 | 4.41 |
| 2010 | 235 | 0.88 | 4.7 | 203 | 0.16 | 3.8 |
| 2011 | 212 | 0.78 | 4.5 | 212 | 1.5 | 4.8 |
| 2012 | 232 | 1.20* | 4.8 | 204 | 0.21 | 3.94 |
| 2013 | 234 | 0.62 | 4.5 | 218 | 0.29 | 4.1 |
| 2014 | 230 | 0.58 | 4.5 | 232 | 0.14 | 3.9 |
| 2015 | 231 | 0.79 | 4.6 | 202 | 0.5 | 4.3 |
| 2016 | 236 | 0.73 | 4.6 | 213 | 0.46 | 4.3 |
| 2017 | 200 | 0.67 | 4.4 | 202 | 0.54 | 4.3 |

considering SST showed considerable variability in growth by age group, with the first stages of life (0-3 years) being the most affected (Fig. 5). Furthermore, Figure 5 shows that the higher the temperature, the lower the growth and vice versa.

## DISCUSSION

There are three ways to estimate growth parameters according to available biological information: periodic marks on bone structures (scales, otoliths), tag-recapture data, and length-frequency data (Pauly & David 1981). The last method has gained popularity over the years because the other two age-based methods (scales or otoliths and tag-recapture) pose more problems during their application, especially in tropical fish. Due to seasonal changes in their habitat, the bone structures' periodic marks are more tenuous than those in temperate water fish (Gulland & Rosenberg 1992), as is the case of the crinuda sardine *Opisthonema libertate* in the SGC.

The growth parameters of the crinuda sardine *O. libertate* have been estimated by direct methods (scales or otolith reading) and indirect methods (length frequencies). Table 3 shows the values obtained in the present study and by other authors applying different

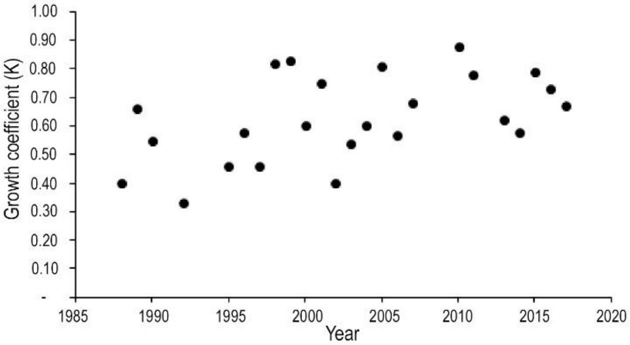

**Figure 2.** Annual values of the growth coefficient *K*, estimated using ELEFAN I.

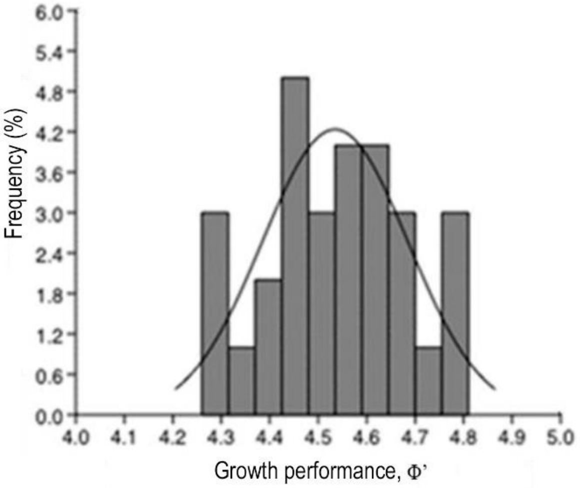

**Figure 3.** Growth performance distribution estimated using Battacharya's method. Gray bars represent Phi's frequency, and the solid black line is the normal distribution of Phi prime.

**Table 2.** Values of the function "periods" parameters.

| Variable | Period ($p_i$) | Amplitude ($a_i$) | Phase ($b_i$) |
|---|---|---|---|
| Temperature | 12 | 0.2813 | 0.0693 |
| | 5 | -0.2354 | 0.0763 |
| | 26 | -0.1702 | -0.0572 |
| Anomaly | 12 | 0.4315 | 0.1063 |
| | 5 | -0.3610 | 0.1171 |
| | 26 | -0.2611 | -0.0877 |

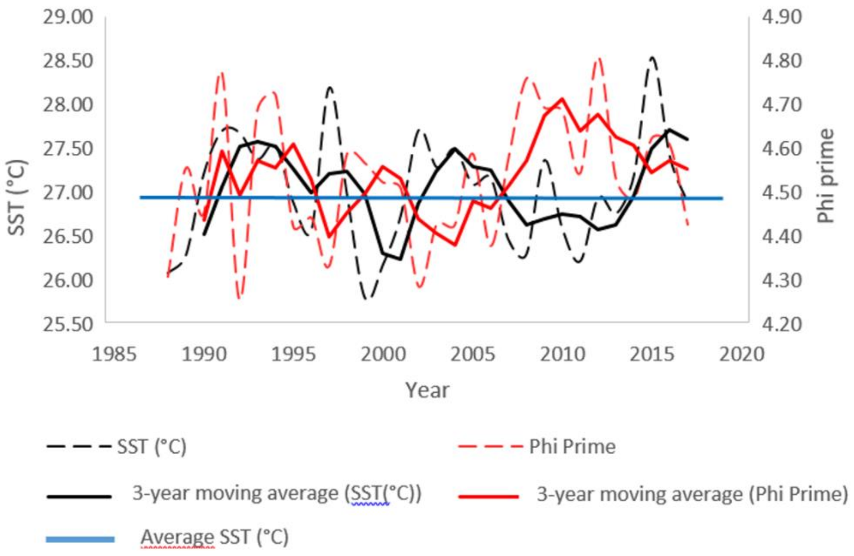

**Figure 4.** Relationship between sea surface temperature (SST) and growth performance (Phi prime) of *Opisthonema libertate* in the southern Gulf of California. Dashed lines show observed SST and Phi prime values (black and red colors, respectively). Solid lines show moving averages (3 years) of SST and Phi prime (black and red colors, respectively). The blue solid line represents the average SST in the period studied.

**Table 3.** Values of von Bertalanffy growth equation parameters estimated for *Opisthonema libertate* by direct and indirect methods. $L_\infty$: maximum asymptotic length, *K*: growth coefficient, $t_0$: age of the fish when, hypothetically, they have zero length, and $\varphi'$: growth performance index.

| Authors | $L_\infty$ (mm) | *K* | $t_0$ | $\varphi'$ | Method |
|---|---|---|---|---|---|
| Carmona & Alexandres (1994) | 194.0 | 0.812 | -0.015 | 4.49 | Otolith reading |
| Lizárraga & García-Franco (1994) | 257.8 | 0.678 | -0.031 | 4.65 | Length frequency |
| Martínez-Zavala et al. (2000) | 250.0 | 0.650 | -0.247 | 4.61 | Length frequency |
| Martínez-Zavala et al. (2006) | 219.8 | 0.590 | -0.283 | 4.45 | Length frequency |
| | 221.0 | 0.560 | -0.299 | | |
| Ruiz-Domínguez & Quiñonez-Velázquez (2018) | 186.3 | 1.410 | -0.020 | 4.44 | Otolith reading |
| Present study | 224.0 | 0.650 | -0.311 | 4.69 | Length frequency |

methods. All estimates fall within the $\varphi'$ distribution (Fig. 3).

However, Table 3 shows high values of the growth parameter, *K*, obtained from the otolith reading. In the first case, it is an estimate based on a small number of otoliths, where most of them correspond to individuals of two years or less, causing a dominance of large increases in the initial part of the curve when adjusting the model to the data, presenting a possible bias in the estimation of *K*.

In the other case, estimates by Ruiz-Domínguez & Quiñonez-Velázquez (2018) includes data from larval stages causing, in terms of adjustment, the same effect as in the previous case, an overestimation of *K*. In addition, physiologically, the von Bertalanffy model does not describe the growth of the larval stages.

In fishing ecology, fish growth can be measured through the change in body length, which is an important element because through this information, characteristics of the life history of an organism, including maturity rates, longevity, and mortality, can be determined (Froese & Pauly 2000). Metabolism involves two opposite processes (catabolism and anabolism), the balance of which leads to growth in fish (Von Bertalanffy 1938). This balance can be affected by various physical factors in the environment. In the present study, an inverse relationship was found between the sea surface temperature and the growth performance of the crinuda sardine *O. libertate*. The results suggest that temperature affects metabolism and consequently growth, which coincides with that reported by other authors in various fish species (i.e. Pauly 1980, Williams et al. 2007, Gislason et al. 2010). Also, the present study results showed that thermal fluctuations make more variable the growth of organisms organisms of the *O. libertate* in the first stages of life

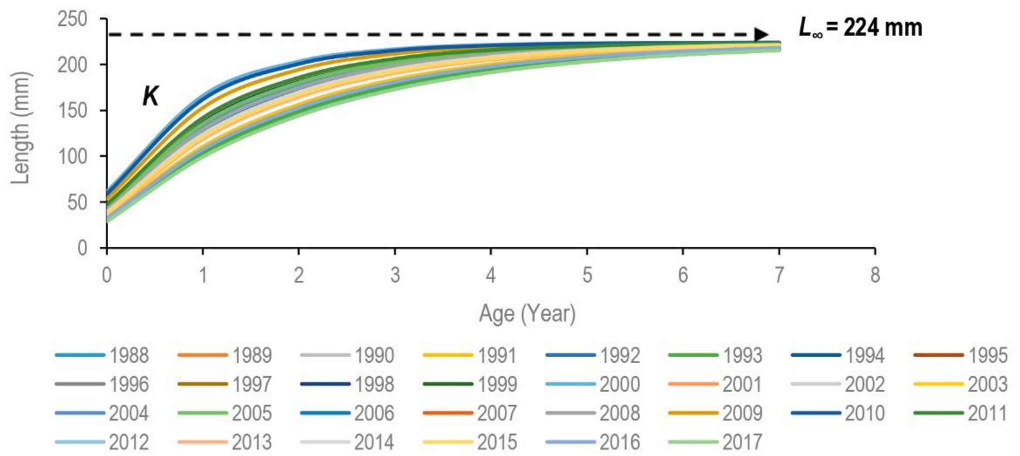

**Figure 5.** Annual growth curves of *Opisthonema libertate* considering the forcing of the sea surface temperature on the growth coefficient, *K* (1988-2017). The pattern shown is that the lower the temperature, the better the growth. $L_\infty$: maximum asymptotic length.

(0-3 years) (Fig. 5). A possible explanation for this phenomenon can be the theory posed by several authors (Hjort 1914, Beverton & Holt 1957, Cushing 1996), which say that the fishes have a critical period in the first stages of life because they are more vulnerable to environmental factors, this can affect their growth even the survivor rate.

In the specific case of the crinuda sardine *O. libertate* in the SGC, Vallarta-Zárate (2012) notes that the years that presented the greatest abundance of this resource were those with relatively low temperatures with the SST ranging between 25 and 26°C, linked to upwelling and turbulence index; which does not fully coincide with the individual growth performance estimated in the present study, which was observed at temperatures around 26.5°C (Fig. 4).

Both processes, however, are reflected in the behavior of the observed trends in the catches of small pelagic fishes, wherein fishing seasons that continued after a year in which the "El Niño" phenomenon occurred, they tended to decrease (Vallarta-Zárate 2012, Vallarta-Zárate & Jacob-Cervantes 2014, DOF 2018), coinciding with relatively low growth performance. The results obtained from the growth estimation, the variability explained by the effect of temperature, and the direct association with fishing yields denotes the importance of their consideration in the biomass availability assessment for each fishing season.

## ACKNOWLEDGMENTS

The authors thank Maz Sardina S.A. of CV for the raw sardine samples, the Small Pelagic Program of the Regional Fisheries Research Center of Mazatlan of INAPESCA-SAGARPA for providing the base data to carry out this study, the National Council of Science and Technology (CONACyT) for the grant awarded to postgraduate studies, and Harold Castillo-Navarro for his support in the development of the period function. Francisco Arreguín-Sánchez appreciates the support through the EDI and COFFA programs of the National Polytechnic Institute and the partial support of the SIP-20201413 Project.

## REFERENCES

Álvarez-Borrego, S. 1983. Gulf of California. In: Ketchum, B.H. (Ed.). Estuaries and enclosed seas. Elsevier, Amsterdam, pp. 427-449.

Badán-Dangon, A., Dorman, C.E., Merrifield, M.A. & Winant, C. 1991. The lower atmosphere over the Gulf of California. Journal of Geophysical Research, 96: 16877-16896.

Berry, D.H. & Barrett, I. 1963. Análisis de las branquiespinas y denominación del arenque de hebra *Opisthonema*. Inter-American Tropical Tuna Commission, 7: 137-190.

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

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

Cushing, D.H. 1996. Towards a science of recruitment in fish populations. International Ecology Institute, Oldendorf.

Diario Oficial de la Federación (DOF). 2018. Acuerdo por el que se da a conocer la actualización de la Carta Nacional. Diario Oficial de la Federación, Ciudad de México.

Douglas, M.W., Maddox, R.A., Howard, K. & Reyes, S. 1993. The Mexican monsoon. Journal of Climate, 6: 1665-1677.

Froese, R. & Pauly, D. 2000. Fish base 2000: concepts, design and data sources. ICLARM, Manila.

Gallardo-Cabello, M., Laguarda-Figueras, A. & Corrales-Urrea, R. 1993. Análisis de la edad, crecimiento y mortalidad natural de la sardina crinuda *Opisthonema libertate* (Gunther, 1868) de las aguas del sur del Golfo de California. Ciencia Pesquera, 9: 137-146.

Gayanilo Jr., F.C., Sparre, P. & Pauly, D. 1994. The FAO-ICLARM stock assessment tools (FiSAT) user's guide. FAO, Rome.

Gislason, H., Daan, N., Rice, J.C. & Pope, J.G. 2010. Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries, 11: 149-158.

González-Rodríguez, E., Villalobos, H., Gómez-Muñoz, V.M. & Ramos-Rodríguez, A. 2015. Computational method for extracting and modeling periodicities in time series. Open Journal Systems, 5: 604-617.

Gulland, J.A. & Rosenberg, A.A. 1992. Examen de los métodos que se basan en la talla para evaluar las poblaciones de peces. FAO Documento Técnico de Pesca N°323. FAO, Rome.

Hjort, J**.** 1914. Fluctuations in the great fisheries of northern Europe. Rapports et Procès-Verbaux des Réunions du Conseil Permanent International Pour L'Exploration de la Mer, 20: 8-228.

Jacob-Cervantes, M. 2010. La pesquería de peces pelágicos menores en el sur del golfo de California. Análisis de la temporada de pesca 2008. Ciencia Pesquera, 18: 47-58.

Lalli, C. & Parsons, T.R. 1997. Biological oceanography: an introduction. Elsevier, Amsterdam.

Lizárraga, R. & García-Franco, W. 1994. Avances de la investigación de la sardina crinuda *Opisthonema libertate* (Günter, 1866) de las costas de Sinaloa, Nayarit y Jalisco durante 1992. Resúmenes del taller del comité técnico de pelágicos menores "Evaluación de los efectos del cambio climático global en las pesquerías de pelágicos menores". SEPESCA, Ensenada, B.C.

Lluch-Belda, D., Arvisu, J., Baumgartner, T., Cota, A., Cotero, C.E., García, W., et al. 1995. Situación actual de la pesquería de sardina y anchoveta. Libro conmemorativo de XXV Aniversario del Instituto Nacional de la Pesca, SEPESCA, Ensenada, B.C.

Lluch-Cota S. 2000. Coastal upwelling in the eastern Gulf of California. Oceanologica Acta, 23: 731-740.

Lluch-Cota, S.E., Aragón-Noriega, E.A., Arreguín-Sánchez, F., Aurioles-Gamboa, D., Bautista-Romero, J.J., Brusca, R.C., et al. 2007. The Gulf of California: review of ecosystem status and sustainability challenges. Programa de Oceanografía, 73: 1-26.

Martínez-Zavala, M.A., Cisneros-Mata, M.A., Anguiano-Carrazco, M.L., Santos-Molina, J.P., Godínez-Cota, A.R., Nevárez-Martínez, M.O. & Montemayor-López, G. 2000. Diagnosis de la pesquería de pelágicos menores del golfo de California de 1996/97 y 1997/98. SEMARNAP - Instituto Nacional de la Pesca - Centro Regional de Investigación Pesquera, Guaymas.

Martínez-Zavala, M.A., Nevárez-Martínez, M.O., Anguiano-Carrazco, M.L., Santos-Molina, J.P. & Godínez-Cota, A.R. 2006. Diagnosis de la pesquería de pelágicos menores en el Golfo de California, temporadas de pesca 1998/99 a 2002/03. SAGARPA - Instituto Nacional de la Pesca - Centro Regional de Investigación Pesquera, Guaymas.

Parés-Sierra, A., Mascarenhas, A., Marinone, S.G. & Castro, R. 2003. Temporal and spatial variation of the surface winds in the Gulf of California. Geophysical Research Letters, 30: 451-454.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. Journal du Conseil, 39: 175-192.

Pauly, D. & Arreguín-Sánchez F. 1995. Improving Shepherd's length composition analysis (SLCA) method for growth parameter estimations. Naga: the ICLARM Quarterly, 18: 31-33.

Pauly, D. & David, N. 1981. ELEFAN I, a BASIC program for the objective extraction of growth parameters from length-frequency data. Meeresforschung, 28: 205-211.

Pauly, D. & Munro, J.L. 1984. Once more on the comparison of growth in fish and invertebrates. World Fish Center, 2: 1-21.

Pauly, D., Moreau, J. & Gayanilo Jr., F.C. 1996. A new method for comparing the growth performance of fishes, applied to wild and farmed tilapias, In: Pullin, R.S.V., Lazard, J., Legendre, M., Amon-Kothias, J.B. & Pauly, D. (Eds.). The Third International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings, 41: 433-441.

Payán-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.

Rodríguez-Moreno, V.M., Ruíz-Corral, J.A., Medina-García, G., Padilla-Ramírez, J.S. & Kretzschmar, T.G. 2014. Efecto de la condición ENSO en la frecuencia e intensidad de los eventos de lluvia en la península de

Baja California (1998-2012). Revista Mexicana de Ciencias Agrícolas, 10: 1923-1937.

Ruiz-Domínguez, M. & Quiñonez-Velázquez, C. 2018. Edad, crecimiento y mortalidad de *Opisthonema libertate* en las costas del noroeste de México. Ciencias Marinas, 44: 235-250.

Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA). 2018. Anuario estadístico de acuacultura y pesca 2018. SAGARPA, Ciudad de México.

Shepherd, J.G. 1987. A weakly parametric method for estimating growth parameters from length composition data, In: Pauly, D. & Morgan, G.R. (Eds.). Length-based methods in fisheries research. ICLARM Conference Proceedings, 13: 113-119.

Sparre, P. & Venema, S.C. 1997. Introduction to tropical fish stock assessment. Part I. Manual. FAO fisheries technical paper, 306. FAO, Rome.

*Received: March 30, 2021; Accepted: August 12, 2021*

Vallarta-Zárate, J.R.F. 2012. Distribución y abundancia de la sardina crinuda (*Opisthonema* spp.) en el sur del golfo de California asociada a la variabilidad ambiental durante el periodo 1996-2010. Tesis de Maestría, Universidad Nacional Autónoma de México, Ciudad de México.

Vallarta-Zárate, J.R.F. & Jacob-Cervantes, M.L. 2014. La pesquería de sardina crinuda (*Opisthonema* spp.) del sur del golfo de California y su relación con la variabilidad ambiental. In: Flores-Campaña, L.M. (Ed.). Sinaloa ante el cambio climático global. Universidad Autónoma de Sinaloa, Sinaloa, pp. 185-203.

Von Bertalanffy, L. 1938. A quantitative theory of organic growth (inquiries on growth laws II). Human Biology, 10: 181-213.

Williams, A.J., Mapstone, B.D. & Davies, C.R. 2007. Spatial patterns in cohort-specific mortality of red throat emperor, *Lethrinus miniatus*, on the Great Barrier Reef. Fisheries Research, 84: 328-337.