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Estimating age and growth of roosterfish (*Nematistius pectoralis*) from otoliths

Ulianov Jakes-Cota^a, Rafael Chavéz-Arellano^a, Chugey Sepulveda^b, Scott Aalbers^b,
Sofía Ortega-García^{a,*}

^a Instituto Politécnico Nacional-Centro Interdisciplinario de Ciencias Marinas, Avenida Instituto Politécnico Nacional s/n. Colonia Playa Palo de Santa Rita, C.P. 23096 La Paz, Baja California Sur, Mexico

^b Pflieger Institute of Environmental Research, PIER, 315 Harbor Dr. S., Oceanside, California 92054, USA

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ABSTRACT

The roosterfish is a coastal pelagic species that inhabits shallow waters of the Eastern Pacific Ocean. Despite its ecological and economic importance within the region, there are few studies on its basic biology, especially those focused on age and individual growth. Therefore, the objective of this study was to estimate roosterfish age and individual growth parameters through counting growth increments of sagittal otoliths. The work focused on organisms caught off Baja California Sur, Mexico (BCS) by both the sport and artisanal fishing fleets from 2010–2017. A total of 266 organisms were sampled during the study period, ranging in size from 5.2–133 cm fork length. A model was generated to describe the relationship between otolith radius (OR) and fork length (FL) of the fish, where $FL = -43.3 + 44.59 OR$. The periodicity of otolith growth increment formation was annual, and this study found roosterfish age estimates to range from 0 to 8 years old, with most individuals ranging from 1–2 years of age. Based on the fitting of the data to three individual growth models (Gompertz, Logistic and von Bertalanffy, VBGF), the VBGF best fit the individual growth curve for roosterfish. The VBGF parameter of $L_{\infty} = 131.53$, $k = 0.35$ y $t_0 = -0.23$ supports previous studies and suggests that roosterfish are very fast growing in the first years of life.

1. Introduction

The roosterfish (*Nematistius pectoralis* Gill, 1862) is a coastal pelagic species that is well known for its elongate dorsal fin spines (Niem, 1995; Rosenblatt and Bell, 1976). This species is distributed in the Pacific Ocean, from southern California, USA, to San Lorenzo Island, Peru, including the Gulf of California and the Galapagos Islands (Love et al., 2005). Roosterfish primarily inhabit coastal waters, with juveniles often found in subtidal zones and adults distributed close to reefs and sandbars (Niem, 1995; Sepulveda et al., 2015).

Although roosterfish are caught in some artisanal commercial fisheries, they are most commonly known for their role as a gamefish in hook and line sport fishing operations (Niem, 1995; Sepulveda et al., 2015). In Mexico, the species is particularly prized by the sport industry with landings reserved solely for the recreational fleet (NOM-017-PESC-1994; DOF, 2013). Notwithstanding the lack of directed commercial fisheries along the Mexican coast, the roosterfish continues to

generate significant recreational revenue through the tourism industry, which is centered along the tip of the Baja California peninsula and into the Sea of Cortez (Southwick, 2008; Sosa-Nishizaki, 1998).

Despite the ecological and economic importance of roosterfish, few studies have been carried out on its basic biology, especially those focused on age and growth (Chávez-Arellano et al., 2019; Ortega-García et al., 2017). Accurate estimates of fish age and growth are extremely important parameters for use in stock assessments and allow us to evaluate key aspects of fish population dynamics and structure (Sparre and Venema, 1997). In addition, they are needed for understanding age structure, age at first maturity, spawning frequency, as well as individual and population responses to environmental changes (Morales-Nin, 1991).

To date, only two studies have focused on the age and individual growth of roosterfish. Ortega-García et al. (2017) analyzed daily growth increments from the sagittal otoliths of roosterfish caught in waters of the Golfo Dulce, Costa Rica and Baja California Sur, Mexico (BCS). It was

* Corresponding author at: Avenida Instituto Politécnico Nacional s/n. Colonia Playa Palo de Santa Rita C.P., 23096 La Paz, Baja California Sur, Mexico.

E-mail addresses: ujakes@ipn.mx (U. Jakes-Cota), rarellano0107@alumno.ipn.mx (R. Chavéz-Arellano), chugey@pier.org (C. Sepulveda), scott@pier.org (S. Aalbers), sortega@ipn.mx (S. Ortega-García).

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proposed that daily growth increments can be used to age organisms up to one year old (~ 66 cm fork length); however, the growth increments on roosterfish >86-cm fork length were difficult to differentiate and could not be accurately counted. Subsequently, [Chávez-Arellano et al. \(2019\)](#) estimated roosterfish age along BCS by counting growth increments from cross sections of the fourth dorsal-fin spine. However, the work was not able to validate growth increment periodicity. Despite these two studies, individual growth parameters have not yet been described for roosterfish over 1.5 years in age. Therefore, the objective of the present study was to estimate age and individual growth parameters for roosterfish (greater than 1.5 years but also including organisms less than that age) by growth increments counting on sagittal otoliths and to describe the seasonal differentiation of opaque and translucent increments.

2. Material and methods

Biological samples were collected from roosterfish landed by the sport fishing fleet in Cabo San Lucas, BCS during 3 consecutive days of each month from 2010–2017. To better represent the full-size range, smaller roosterfish were sampled in 2015 from incidental catches of the artisanal fishing fleets out of San Carlos and La Paz, BCS ([Fig. 1](#)). Additionally, two individuals measuring 5.2 and 6.9 cm fork length were sampled during zooplankton collection efforts in Bahía de La Paz, BCS in August 2014.

For each roosterfish, the fork length (FL, ± 0.1 cm) was measured with a soft tape measure and sex was recorded through macroscopic observation of the gonads. The pair of sagittal otoliths were extracted manually using saw and dissecting forceps and stored dry in plastic vials for subsequent laboratory analysis.

To assess whether the radius of the otoliths (OR) can be used as a predictor of fish length, the relationship between OR and FL was described through linear regression analysis ([Daniel and Cross, 2018](#)). Otoliths were photographed with a digital camera (Carl Zeiss brand, AxioCam MRC 5 model) adapted to a stereoscope (Carl Zeiss brand, Stemi SV11 model) and their OR was measured directly on the photographs with AxioVision software (version 4.6) ([Fig. 2](#)).

Otolith preparation closely followed the methodology described by [Ortega-García et al. \(2017\)](#). More specifically, the right otolith of each organism was embedded in transparent epoxy resin and allowed to harden for a period of 24 h. Subsequently, cross sections of 0.5 mm thick, that included the nucleus, were made with a low-speed saw (IsoMet Low Speed Saw, Buehler brand, model 11-1280-160) equipped with a diamond edge disc (Diamond Wafering Blade, Buehler brand, 15HC series).

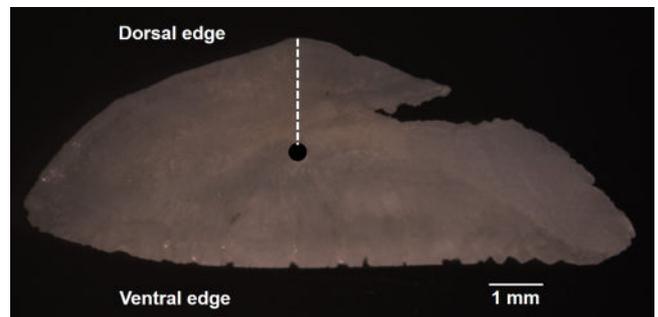


Fig. 2. Photograph of the sagittal otolith from a roosterfish (*Nematisius pectoralis*) showing the radius measurement.

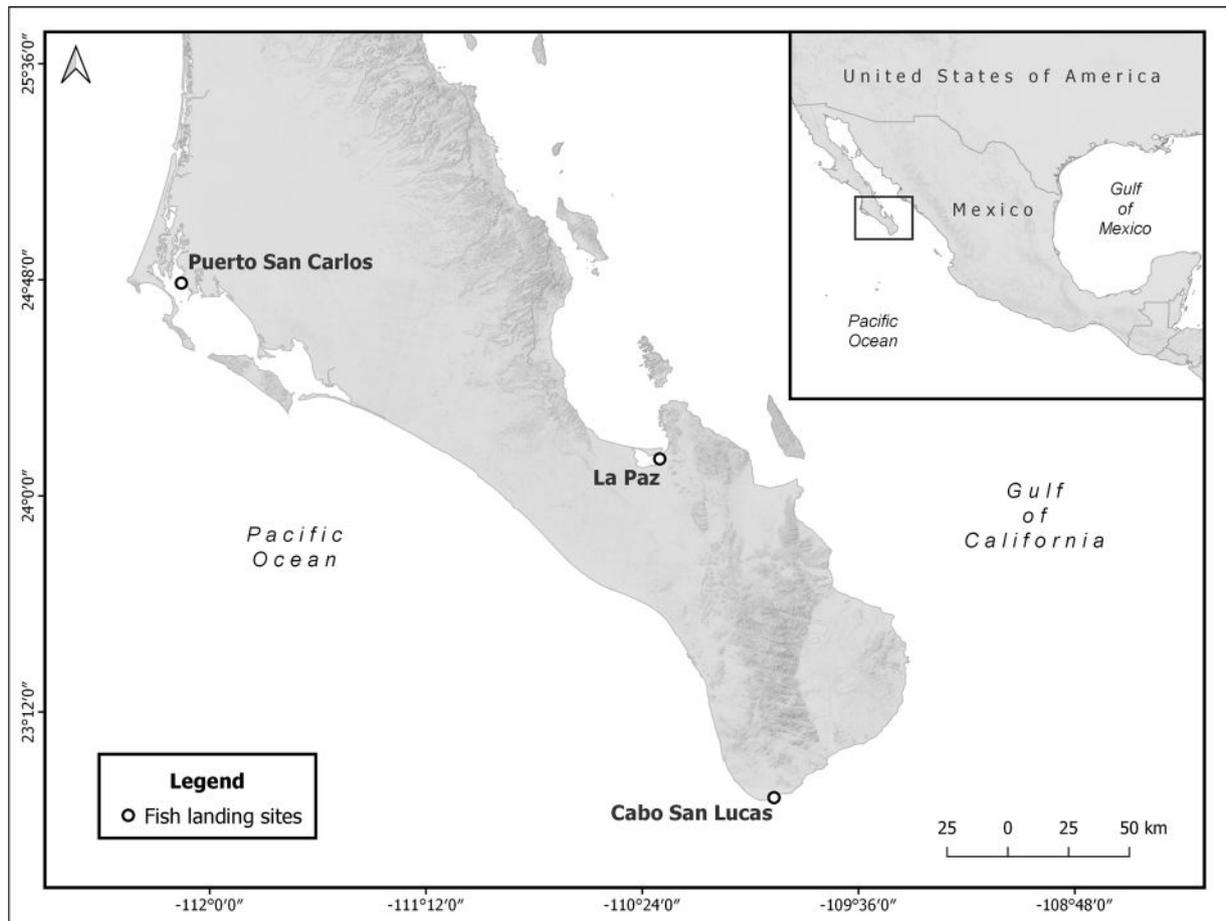


Fig. 1. Geographical location of the roosterfish (*Nematisius pectoralis*) collection sites along Baja California Sur, Mexico.

Cross sections were mounted on histological slides with Cytoseal mounting medium (Thermo Fisher Scientific, Waltham, MA) and allowed to dry for 24 h. To make the growth increments more visible and facilitate counting, the cross sections were polished by hand with water and a series of micrometric sandpaper of decreasing grain size (15 to 3 μm , Diamond Lapping Film disc, Buehler brand). For finishing, cross sections were polished with micro polish (0.3 μm , MicroPolish alumina, Buehler brand) and micrometric sandpaper (0.3 μm , MicroCloth micrometric sandpaper, Buehler brand).

The growth increments contained in the cross sections of the otoliths were counted independently by two readers using a stereoscope with transmitted light on a dark background without prior knowledge of fish length and weight. An opaque increment followed by a translucent increment was considered an annulus (pl. annuli) (Fig. 3). Under transmitted light, the nucleus and opaque increments appear as dark rings and the translucent increments appear as light rings. The precision in the growth increments counting between both readers was evaluated using the coefficient of variation (CV) (Chang, 1982). Additionally, the age of the two smallest organisms (5.2 and 6.9 cm FL) was estimated based on the counting of daily growth increments according to the methodology described by Ortega-García et al. (2017).

Otolith edge analysis was used to infer the periodicity of growth increment formation. The edge type (e.g., opaque, or translucent) of each otolith was recorded for each month throughout the year and plotted by percentage of opaque and translucent edges. The monthly percentage of opaque and translucent edges was related to mean sea surface temperature (SST) data for the study area derived from monthly satellite compositions of the MODIS-Aqua sensor using a resolution of 1.1 km (http://spg.ucsd.edu/Satellite_Projetcts/Satellite_projects.htm) from 2010 to 2017.

Length-at-age data were used to estimate the individual growth parameters of the roosterfish, for which three candidate models were used:

Von Bertalanffy growth model (von Bertalanffy, 1938):

$$FL_t = L_\infty (1 - e^{-k(t-t_0)})$$

Gompertz growth model (Gompertz, 1825):

$$FL_t = L_\infty e^{-e^{-k_2(t-t_2)}}$$

Logistic growth model (Ricker, 1975):

$$FL_t = L_\infty (1 + e^{-k_3(t-t_3)})^{-1}$$

where FL_t is the fork length (cm) at age t (years), L_∞ is the maximum average length (cm), k is the growth coefficient (years^{-1}), t_0 is the hypothetical age at length 0 (years), k_2 is the rate of the exponential decrease of the relative growth rate with age (years^{-1}), $t_2 = (\ln \lambda - \ln k_2) / k_2$, λ is the theoretical initial relative growth rate at zero age (years^{-1}),

k_3 is a relative growth parameter (years^{-1}) and t_3 is the inflection point of the sigmoidal curve.

The parameters were estimated by minimizing the negative log-likelihood (maximum likelihood method) with Newton's algorithm, assuming an additive error structure (Haddon, 2011). To select the model that best describes the individual growth of the roosterfish, the Akaike information criterion (AIC) was used (Akaike, 1973; Burnham and Anderson, 2002). The model with the lowest AIC value was selected as the best model (Haddon, 2011).

3. Results

During the study period, 266 organisms (144 females and 122 males) were sampled from the BCS region. The sex ratio was 1:1.18 males to females and did not differ significantly from a 1:1 ratio ($p > 0.05$). The highest number of individuals was sampled in June, October, and November, while the fewest were collected in March. The size range of the roosterfish sampled was from 5.2–133 cm FL, with 70 % of the total organisms between 50 and 90 cm FL (Fig. 3). Individuals greater than 100 cm FL were scarce.

The linear relationship between the radius of the otolith and the length of the fish was expressed by the following equation: $FL = -43.3 + 44.59 OR$. The relationship between both variables was significant ($r^2 = 0.95$, $p < 0.05$).

During the annual cycle, a single maximum percentage of opaque edges was observed in the months of September-October and a single

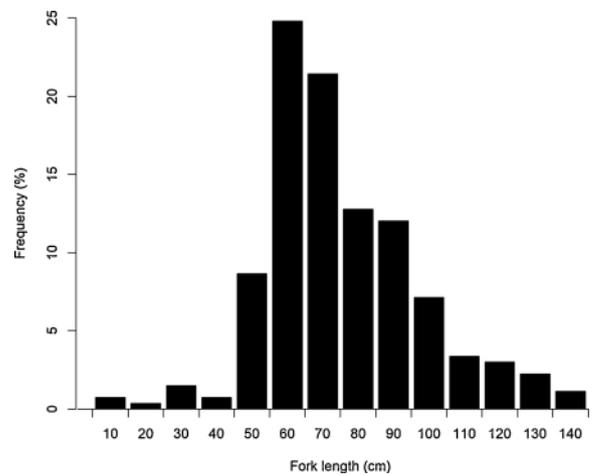


Fig. 4. Size structure of roosterfish (*Nematisius pectoralis*) sampled in Baja California Sur, Mexico from 2010-17 (n = 266).



Fig. 3. Photograph of a polished cross section from a roosterfish (*Nematisius pectoralis*) sagittal otolith showing the growth increment pattern for a 3-year-old male (78.5 cm FL). White scale bar = 1 mm; annuli (black dots).

maximum percentage of translucent edges in June (Fig. 4). There was a positive linear relationship between sea-surface temperature and the percent occurrence of opaque edges ($r^2 = 0.78$). In general, at higher sea-surface temperatures there was a larger percentage of opaque edges and at lower temperatures a higher percentage of translucent edges (Fig. 5).

Readers were able to count legible growth increments on all otolith cross sections with a low coefficient of variation ($CV = 5.67$). Based on consistent growth increments counts among readers, the age of sampled roosterfish ranged from 0 to 8 years old. The age of the two youngest specimens sampled (5.2 and 6.9 cm FL) was 18 and 21 days, respectively). In this study, roosterfish over 5 years old were scarce and the majority (59 %) of sampled individuals were between 1 and 2 years of age (Fig. 6).

The parameters for each individual growth model are presented in Table 1 and the resulting growth curves in Fig. 6. Based on the lowest AIC value, the von Bertalanffy model provided the best fit for the individual growth of roosterfish.

4. Discussion

This study provides the first otolith-based age estimates for roosterfish greater than 1.5 years old and offers additional insight into the rapid growth rate of roosterfish. Individual growth parameters for this species had previously been estimated by counting daily growth increments (Ortega-García et al., 2017); however, aging of individuals > 86 cm FL (1.5 years) was not possible. This study is the first to document the seasonal differentiation of opaque and translucent growth increments along the edges of roosterfish otoliths (edge analysis). Findings suggests that most individuals retained in the BCS fishery are between one and two years old, with roosterfish smaller than 20 cm FL or greater than 100 cm FL rarely landed. In order to adequately represent a full range of body sizes (5.2–133 cm) and reduce bias in estimating individual growth parameters, samples were collected during all of the months of the year from 2010 to 2017. Sampling of both large and small individuals proved to be difficult given that sport fishing operations

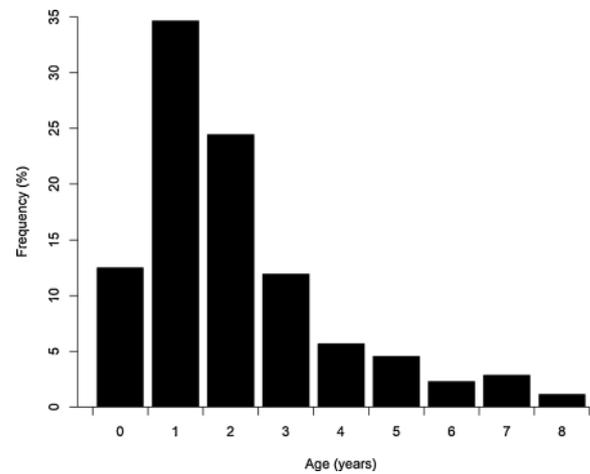


Fig. 6. Age structure of roosterfish (*Nematistius pectoralis*) sampled in Baja California Sur, Mexico (n = 266).

Table 1

Parameter values of the individual growth models (von Bertalanffy, Gompertz and Logistic) for roosterfish (*Nematistius pectoralis*) sampled along Baja California Sur, Mexico.

	L_{∞}	k	t_i	AIC
Von Bertalanffy	131.53	0.35	-0.23	81.89
Gompertz	124.79	0.57	1.12	88.99
Logístico	122.08	0.80	1.84	92.32

generally release trophy-sized roosterfish after capture (Ortega-García et al., 2017; Chávez-Arellano et al., 2019). Additionally, catches of smaller roosterfish in artisanal commercial operations tends to be minimal, further complicating sample collection efforts. In this study we also included samples from zooplankton trawls (1 cm mesh net), which

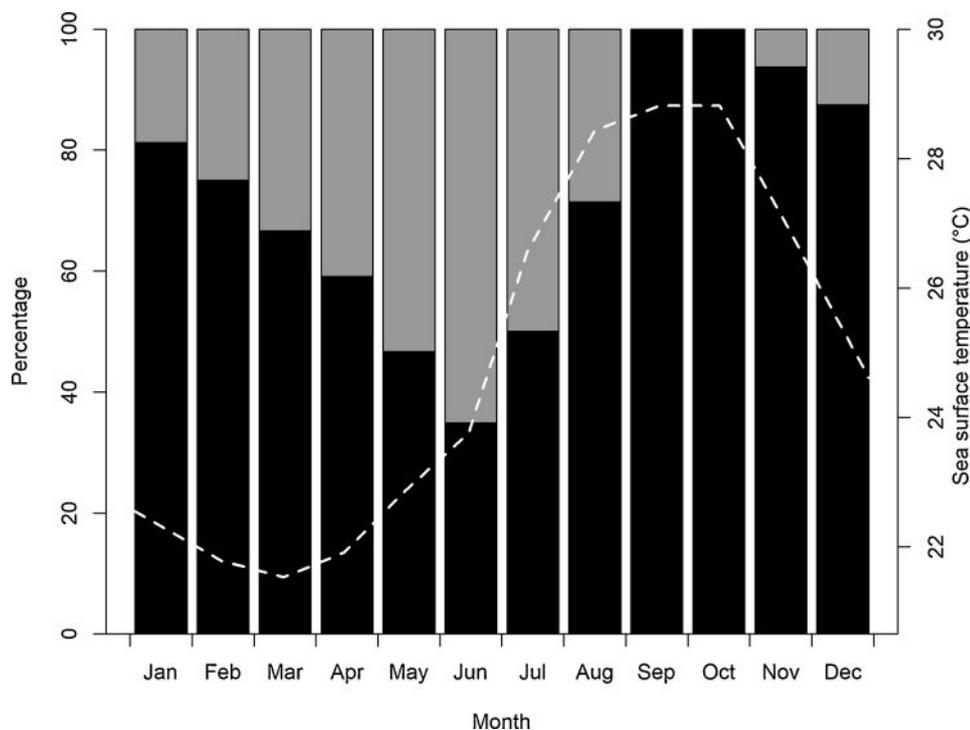


Fig. 5. Monthly percentage of opaque (black bars) and translucent (gray bars) edges in cross sections of roosterfish otoliths (*Nematistius pectoralis*; n = 266) and monthly average sea surface temperature (SST, white line) in waters of Baja California Sur, Mexico.

provided access to very small organisms that would have otherwise been difficult to collect and allowed a better fit of the models to the data.

4.1. Age structure

In the present study, the average fork length at age 1 was 60.63 ± 1.68 cm, which corresponds with length-at-age estimates reported by Ortega-García et al. (2017; mean = 66 cm FL) and Chávez-Arellano et al. (2019; range = 43–92 cm FL). Although roosterfish age estimates ranged from 0 to 8 years in this study, most individuals were estimated at 1–2 years-old. Ortega-García et al. (2017) estimated ages from 0 to 1.5 years, since it was difficult to differentiate growth increments in older individuals. Chávez-Arellano et al. (2019) reported between 0 and 4 growth increments, although most roosterfish dorsal spines exhibited 0–2 increments, a finding that also aligns with this study. Unlike the Chávez-Arellano et al. (2019) work, this study measured the sagittal otoliths of roosterfish, a structure commonly used to estimate the age of many different species (Campana and Thorrold, 2001). In contrast to the dorsal spines, the nucleus of the roosterfish otolith is not affected by reabsorption and vascularization, a problem encountered in the previous roosterfish aging work (Chávez-Arellano et al., 2019). This ensured that there was no loss or masking of the first growth increment(s), a problem that can impact the validity of the age estimation. For similar reasons, Campana and Thorrold (2001) proposed that the otolith is the preferred hard structure for estimating age in fish, as deposition occurs continuously throughout the life of the organism. In this study, sagittal otoliths appeared to be a reliable structure for aging roosterfish as there was a significant relationship between the radius of the otolith and fork length of the fish, and a high precision (low CV value) in the counting of growth increments among readers.

A basic assumption in age estimation is that the growth of hard structures is proportional to the growth of the fish (Bagenal, 1974). In this study, the relationship between the radius of the otolith and fish length was linear and significant, indicating proportionality between both measurements and suggesting that the radius of the otolith increases as the length of the organism increases. A linear relationship has been reported between fish length and the size of the hard structure used to estimate age in other large pelagic fish species, such as dolphinfish (*Coryphaena hippurus*, Solano-Fernández et al., 2015), blue marlin (*Makaira nigricans*, Hill et al., 1989) and striped marlin (*Kajikia audax*, Kopf and Davie, 2011), among others. For the roosterfish, Chávez-Arellano et al. (2019) also found a significant linear relationship between the diameter of the fourth dorsal-fin spine and fish length; in addition, they reported that the number of growth increments increased with the diameter of the spines.

4.2. Growth increments reading

Annuli were clearly observed in the cross sections of sagittal otoliths, which was reflected in the low CV value ($CV = 5.67$), suggesting agreement (precision) in the growth increments counting between both readers. In general, CV values of less than 10 % are considered acceptable for estimating age (Morison et al., 1998). Chávez-Arellano et al. (2019), reported similar results for roosterfish by the count of growth increments using cross sections of the fourth dorsal-fin spine and by Ortega-García et al. (2017) in counting daily growth increments using cross sections of sagittal otoliths. Ortega-García et al. (2017) indicated that the precision in the count of daily growth increments decreased with increasing age.

4.3. Otolith edge analyses

The use of edge analyses provided to be an effective tool for validating the yearly deposition of growth increments on the sagittal otoliths of roosterfish, a finding that was lacking in the previous age and growth studies performed by both Ortega-García et al. (2017) and

Chávez -Arellano et al. (2019). Edge analysis revealed that opaque increments form seasonally during the months of September-October with a single maximum percent occurrence of translucent increments in June (Fig. 4), suggesting an annual periodicity for growth increment formation (Campana, 2001). Although additional age validation methods (i.e. chemical markers) may be warranted, such studies can be costly and time consuming, particularly for a species that is not frequently retained (Fig. 7).

The highest percentages of opaque edges were recorded during the months with the highest temperatures and the highest percentages of translucent edges were recorded in the months with the lowest temperatures. Growth increment formation within calcified structures of bony fish have been shown to be largely influenced by seasonal environmental conditions and physiological processes (Campana, 2001). Previous studies have proposed that translucent increments are associated with periods of slow growth, reduced resource availability and low temperatures, while opaque increments are linked to periods of rapid growth during periods of high food availability and increased temperatures (Morales-Nin, 1991; Beckman and Wilson, 1995). In this study, the highest percentages of translucent edges coincide with the months of reproduction (June-August), a period in which energy is largely devoted to spawning and organismal growth is minimal (Ortega-García et al., 2018). In contrast, the seasonal occurrence of opaque edges peaked in September and October when water temperatures were elevated and most available energy is destined for growth (Cubillos and Arancibia, 1993).

4.4. Growth modeling

This study used three different models to assess roosterfish growth and found that the VBGM had the lowest AIC value and best fit the roosterfish data (Table 1). According to Burnham and Anderson (2002), models with an AIC difference >10 with respect to the model with the lowest AIC score, are not supported and should be omitted from any future consideration. In contrast, models with an AIC difference of less than 2 have substantial support; and models that have a difference between 4 and 7 have considerably low support. In the present study, both the Gompertz and Logistic models presented AIC differences greater than 7 (Table 1), which is why they were omitted from any future consideration (Burnham and Anderson, 2002).

To obtain a better estimate of the individual growth parameters, specifically of t_0 , Prince et al. (1987) highlighted the importance of including lengths and ages of larvae in the analysis. In this study, the two smallest organisms (5.2 and 6.9 cm FL) were aged by counting daily growth marks and included in the estimation of individual growth parameters to improve model fit. The VBGM parameters obtained in the

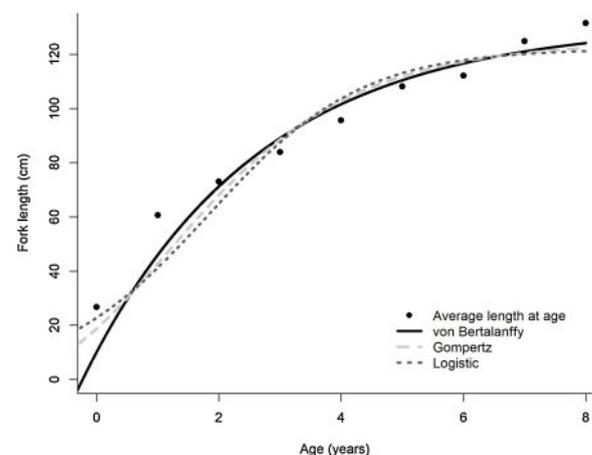


Fig. 7. Individual growth curves fitted to the average length-at-age data for roosterfish (*Nematistius pectoralis*) sampled along Baja California Sur, Mexico.

present study suggest that roosterfish exhibit accelerated growth in the first year of life, reaching ~50 % (60 cm LF) of its maximum average length. After the first year, the growth rate decreases progressively until age 8 when it reaches minimum values. The values of k (0.47) and L_{∞} (163.77) reported by Ortega-García et al. (2017) were significantly greater (*likelihood ratio test*, $p < 0.05$) than those found in the present study. These differences could be due to the fact that larger individuals (up to 133 cm FL and 8 years old) were sampled in this study, which may have exhibited low growth compared to the younger individuals (fast growth) analyzed by Ortega García et al. (2017). Comparing the individual growth of the roosterfish with that of other large pelagic fish, we observed lower growth rates than those of the blue marlin and dolphinfish (Prince et al., 1991; Solano-Fernández et al., 2015), yet higher growth rates than several jack species (*Caranx caninus*, *Caranx ignobilis*, *Caranx melampygus* and *Seriola dumerili*) (Manooch III and Potts, 1997; Smith and Parrish, 2002; Espino-Barr et al., 2008).

5. Conclusions

Despite previous attempts to age roosterfish, this work was able to successfully model growth curves for roosterfish up to 8 years of age. This study also corroborated the number of daily growth increments reported by Ortega-García et al. (2017) for one-year-old organisms. Additional age validation work may be necessary to conclusively document age parameters for this species; however, findings support previous works by Chávez-Arellano et al. (2019) and Ortega-García et al. (2017) and provide additional insight into the rapid growth of this popular gamefish. Although there is currently no management plan for roosterfish in Mexico due to its low commercial exploitation, this study provides basic age and growth parameters that may be used in future stock assessment models.

6. Credit authorship contribution statement

Uljanov Jakes-Cota: Investigation, methodology, writing. **Rafael Chavez-Arellano:** methodology, writing original draft. **Chugey Sepulveda:** provided funding, conceptualization, edited text. **Scott Aalbers:** conceptualization, edited text. **Sofía Ortega-García:** Conceptualization, writing, research coordination. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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