

Age and growth of the Pacific hake, *Merluccius productus* (Actinopterygii: Gadiformes: Merlucciidae), in the Gulf of California: A multimodel approach

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Abstract

Over the past decade, the fishery of Pacific hake, *Merluccius productus* (Ayres, 1855), has increased in the Gulf of California, Mexico; therefore, any biological–fisheries information is highly relevant for the management of this fishery, and information on age and individual growth would be fundamental to evaluate populations. The objective of the presently study was to assess age, based on otolith structure, and estimate growth parameters through a multimodel approach. Specimens were collected during research cruises of *BIP XI* from 2014 to 2019. Pacific hake from the Gulf of California ranged in length from 12.5 to 105 cm TL, reaching a maximum age of 13 years, and females were four years older than males. The logistic model was the best model to describe age–size data for both sexes. Females reached 50% of the maximum length at five years old and males reached that length at four years old.

Keywords

age structure, asymptotic length, growth rate, individual growth

Introduction

The population of the Pacific hake, *Merluccius productus* (Ayres, 1855), is distributed from northern Vancouver Island, Canada, to the northern Gulf of California (Cohen et al. 1990). It has been identified as a stocks structured population, with one highly migratory stock distributed from southern California to Queen Charlotte Sound in Canada.

Other stocks are found in limited geographic areas such as the Strait of Georgia, Queen Charlotte Strait, the western coast of the Baja California Peninsula (Iwamoto et al. 2004), and the Gulf of California (Mathews et al. 1973).

This species inhabits the California Current system and sustains important fisheries on the western coast of the USA, Canada, and southern Alaska, with catches of around 200 000 t per year, with a binational management

strategy between USA and Canada, organized through annual quotas (Hammel et al. 2015). In the Gulf of California, Mexico, Pacific hake was part of a multispecific fishery called “escama” (fish with scales), from 1990 to 2017. Until 2012 the mean catch value of this species was 855 t, between 2013 and 2017 the catch increased rapidly exceeding 8000 t per year. In 2018, a directed Pacific hake fishery was established with two management criteria, quotas (with reference to the biologically acceptable catch) and a maximum of 80 fishing vessels. The resource is available to the fishery from December to May (Anonymous 2018). More than 95% of the catch is exported to Spain and the rest remains on the local market (Anonymous 2022).

Due to the importance of this fishery and in order to improve management criteria, during the last four years, significant effort has been devoted to generating biological and fishery information that contributes to evaluating the effect of fishing. Some of those data, namely mortality, longevity, length at first maturity, age, and individual growth are used in structured models to assess population dynamics, and the results used as a guide in effective management of the fisheries (Morales-Nin 1992; Cerviño 2013; Ruiz-Domínguez and Quiñonez-Velázquez 2018).

One of the first studies to evaluate Pacific hake growth was carried out by Dark (1975) who used the otolith growth ring counts of the fish obtained off the western coast of the USA. The author reported accelerated growth during the first three years of life and slower growth thereafter, as well as differences between males and females after two to three years of age. Longevity was reported at 13 years, with the mean furcal length (FL) of 61.8 cm. Beamish (1979) analyzed the number of growth marks on whole otoliths with those on transverse sections of otoliths of Pacific hake from the Strait of Georgia stock, finding that the latter showed a greater number of growth marks than whole otoliths. The growth marks were more evident in organisms younger than 7 years of age; at older ages, the growth marks overlapped. The above-mentioned author reported organisms of 16 years of age and a mean FL of 44 cm. McFarlane et al. (1983) reported organisms with a maximum age of 20 years and a mean FL of 48 cm for this same area, but 83% of specimens were 4–11 years old, which would correspond to specimens measuring between 39 and 46 cm FL.

Salinas-Mayoral (unpublished*) addressed the individual growth of Pacific hake off the western coast of the Baja California Peninsula. Based on otolith sections, up to 12 age groups with a mean standard length (SL) of 27.5 cm were identified, significantly lower than those of the stock from the western coast of the USA. For the

stock that is fished in the northern area of the Gulf of California, individuals have been reported that reach 112 cm TL and weigh up to 7 kg (total weight, TW) (Nevárez-Martínez et al., unpublished**). This is the Pacific hake stock with the longest reported length (Zamora-García et al. 2020, Alvarez-Trasviña et al. 2022). However, basic biological aspects such as reproduction, feeding, age, and growth, are scarce for this region. This study focused on evaluating allometry, aging, and estimation of individual growth parameters of Pacific hake inhabiting the middle and northern Gulf of California, using the number of growth marks on otolith sections to estimate age, and a multimodel approach to analyze length at age data.

Materials and methods

Biological samples. Specimens of Pacific hake, *Merluccius productus*, examined in this study were obtained from exploratory fishing cruises carried out by the Instituto Nacional de Pesca y Acuicultura (INAPESCA) in February and April–May 2014, April and December 2015, October–November 2016, May 2017, and February 2019 with an average duration of 18 days. The cruises were conducted aboard the *BIP XI*, which was equipped with an otter trawl (33.8 m headline, 152-mm body mesh, and 89-mm codend mesh) cast from the stern and scientific echosounder (EK60). The prospected area comprises the middle and northern Gulf of California at depths close to 500 m (Fig. 1).

Once the echo sounder detected a fish school (energy), the vessel turned to drop the net and trawl for 30 min at an average speed of 3 knots. The catches obtained during each set were placed on the deck, separated by species, and weighed [kg]. Subsequently, the bycatch identification at the lowest taxonomic level was carried out using the diagnostic characteristics described by Fischer et al. (1995). When the Pacific hake per set exceeded 500 kg, a random sample of 100 organisms was selected and TL (± 0.1 cm) and TW (± 0.1 g) were recorded, grouped in intervals of 2 cm TL and from each interval were selected up to 5 organisms whose TL, SL (± 0.1 cm), TW were measured, sex and gonadal maturity were assigned visually (macroscopic) and the otoliths were extracted (biological sample, BS).

Total length–total weight relation. This relation for Pacific hake, *Merluccius productus*, was calculated for each sex (male, female) and for pooled data, using the following equation (Sparre and Venema 1998)

$$TW = aTL^b$$

* Salinas-Mayoral CA (2018) Dinámica poblacional de la merluza del Pacífico *Merluccius productus* (Ayres, 1855), en la Costa Occidental de BCS, México. Tesis Maestría. Centro de Investigaciones Biológicas del Noroeste, S.C. La Paz, Baja California Sur, México.

** Nevárez-Martínez MO, Balmori-Ramírez A, Santos-Molina JP, Cervantes-Valle C, López-Martínez J, Méndez-Tenorio JF, Anguiano-Carrasco ML, Acevedo-Cervantes A, Miranda-Mier E, Morales-Azpeitia R, Valdivia-Herrera E (2007 [unpublished]) Prospección de merluza y bacalao: distribución, tamaño poblacional e ictiofauna asociada en el Golfo de California. Clave: SAGARPA-2003-C01-047.

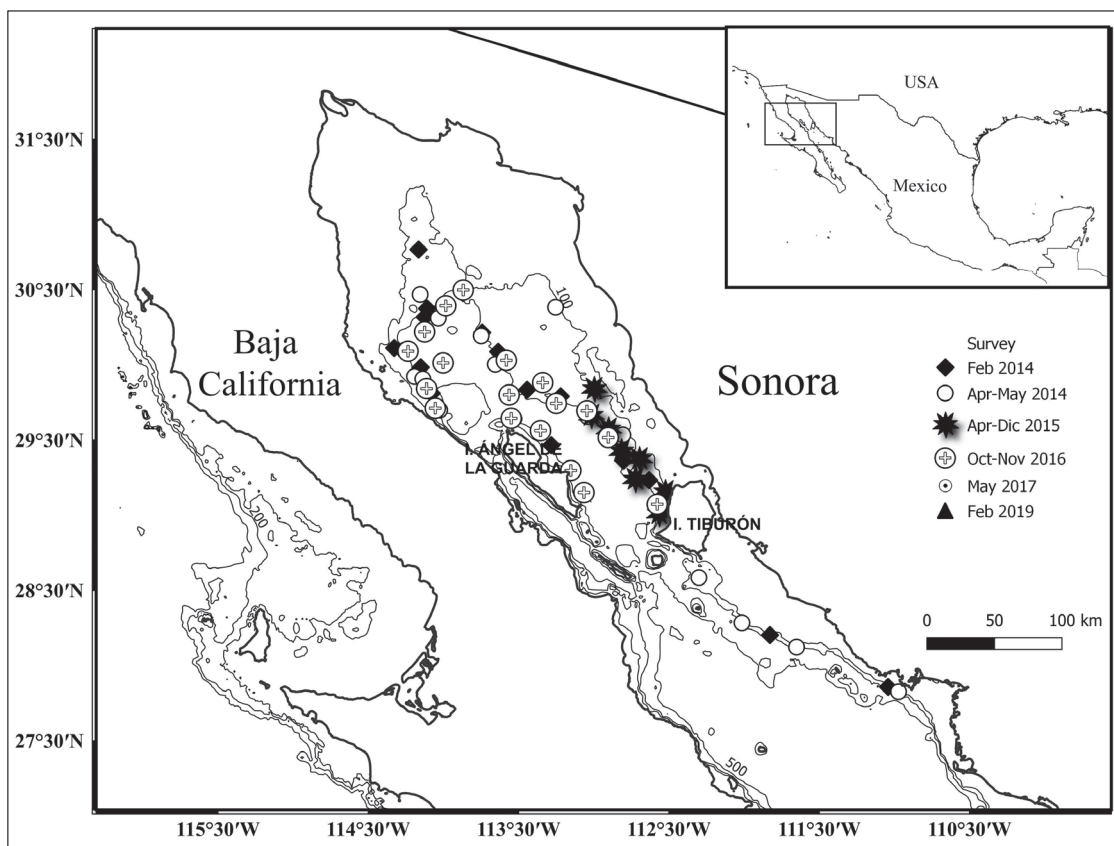


Figure 1. Study area the middle and northern Gulf of California, and sampling stations during research cruises.

where TW is the total weight [g], TL is the total length [cm], a is the intercept, and b is the allometry coefficient. A Student's t -test was used to identify the type of growth, i.e., isometric ($b = 3$) or allometric ($b \neq 3$): $t = (b - 3)SE^{-1}$, where SE is the standard error, with an α of 5%, $t = 1.96$ (Zar 1999).

Age determination. To select the organisms that will define the sub-sample for age determination, and be representative of the Pacific hake, *Merluccius productus*, length-structure from the total sample, the lengths of the SB per cruise were grouped in 2 cm TL intervals. To estimate the maximum number of organisms per interval to be selected, a random sampling was drawn, increasing the size of the sample selected in each event as a function of the interval absolute frequency. The differences between the re-samplings were evaluated with a multiple analysis of variance (Kruskal–Wallis) and when the test was significant, that sample size was defined as the number to select per length interval (Salcido-Guevara et al. 2014).

The otoliths selected for age determination were washed with fresh water and phosphate-free soap using a brush with fine bristles to avoid damaging the otoliths. The left otolith was used for reading the growth marks; if that otolith was damaged or lost, the right otolith was used. The otoliths were embedded in epoxy resin and allowed to cure for 24 h. Dorsal–ventral sections were taken from the center of the nucleus of each otolith using a ISOMET BuehlerMet Low Speed cutter. Sections were polished with sandpaper (800 μ m grit and 1500 μ m grit)

until growth marks were clearly defined. To make growth marks more evident, sections were stained for 20 min in a solution of 0.2 g neutral red, 1 g sodium chloride, 100 ml distilled water, and 0.5 ml acetic acid (Easey and Millner 2008). Finally, the sections were photographed using a stereoscope with a video digitizer system (OLYMPUS SZ61) with reflected light.

The readings of the growth marks in the otolith sections were made by three readers independently. Due to the staining process of the otolith sections, the opaque band acquired a less intense color than the hyaline band (Fig. 2). We as-

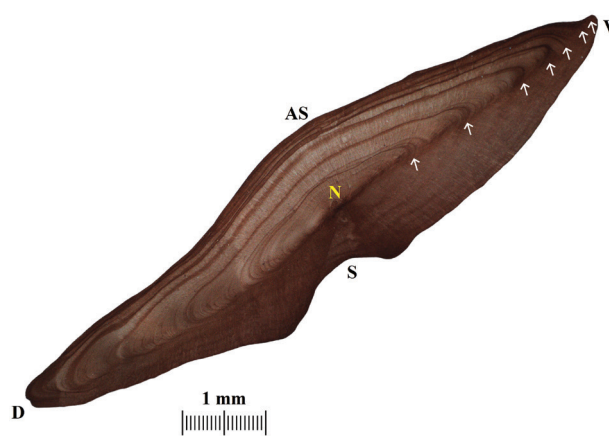


Figure 2. Transversal cuts of otolith sagitta of Pacific hake, *Merluccius productus*, in the Gulf of California. N = nucleus, D = dorsal, V = ventral, S = sulcus, AS = Antisulcus. Female of 68 cm TL.

sume an annual periodicity deposition of a growth mark (opaque band plus hyaline band) according to Dark (1975).

The index of the mean percentage error (IMPE) (Beamish and Fournier 1981)* was calculated to assess the precision of the age determinations between three independent readers using the following equation

$$\text{IMPE} = \frac{1}{N} \sum_{j=1}^N \left(\frac{1}{R} \sum_{i=1}^R \frac{|X_{ij} - X_j|}{X_j} \right) * 100\%$$

where N is the number of fish aged, R = number of times each fish was aged, X_{ij} is the i^{th} age determination of the j^{th} fish, X_j is the mean age calculated for the j^{th} fish.

The coefficient of variation (CV) proposed by Chang (1982) was also calculated, using the previously defined variables

$$\text{CV} = \frac{1}{N} \sum_{j=1}^N \sqrt{\frac{\frac{1}{R} \sum_{i=1}^R (X_{ij} - X_j)^2}{R-1}}{X_j} * 100$$

Evaluation of individual growth. A multimodel approach was applied to the age–length data of Pacific hake, *Merluccius productus*, according to Burnham and Anderson (2002). The candidate models describe a curve that tends towards an asymptotic value (L_{∞} asymptotic); this parameter is the only one with the same biological meaning in all the models (Table 1). Growth models were fitted by maximizing the log–normal likelihood function with Newton’s algorithm (Haddon 2001).

Table 1. Candidate growth models to describe trend age–length data for Pacific hake, *Merluccius productus*, in the Gulf of California.

Growth model	Curve	Parameter
VBGM	Inverse exponential	3
Gompertz	Sigmoid	3
Logistic	Sigmoid	3
Schnute–Richards	Sigmoid	5

VBGM = von-Bertalanffy growth model.

Selection of the best model. Akaike’s information criterion (AIC) was used to select the best model to describe the age–length data trend of Pacific hake, *Merluccius productus*, considering the goodness-of-fit and the number of model parameters

$$\text{AIC} = 2(k - \text{LL})$$

where LL is the likelihood value of each adjusted model and k is the number of parameters of the model. The model with the lowest AIC value (AIC_{\min}) was selected as the best model.

AIC differences ($\Delta i = \text{AIC}_i - \text{AIC}_{\min}$) were estimated to evaluate the statistical support of the models (Burnham

and Anderson 2002). Models with $\Delta i > 10$ have no statistical support and have to be omitted from the analysis; models with $\Delta i \leq 2$ have high support; and models with $4 < \Delta i < 7$ have medium support. Each model’s parsimony was evaluated by calculating the AIC weight (w_i), using the equation proposed by Burnham and Anderson (2002):

$$w_i = \frac{e^{-0.5\Delta i}}{\sum_{i=1}^4 e^{-0.5\Delta i}}$$

Comparison of individual growth. Once the best model for males and females of Pacific hake, *Merluccius productus* was obtained, a comparison of the growth parameters was made using the likelihood test of Kimura (1980).

$$\chi_k^2 = -N * \ln \left(\frac{\text{SCR}_a}{\text{SCR}_b} \right)$$

where k represents the degrees of freedom (number of parameters), N is the total number of observations from both curves combined, SCR_a is the total sum of squared residuals of the model adjusted to each dataset, and SCR_b is the total sum of squared residuals of the model using all data.

Confidence intervals. Once the best model was identified, the uncertainty associated with the estimated parameters was evaluated by estimating the 95% confidence intervals according to Venzon and Moolgavkar (1988) and Hilborn and Mangel (1997) using the likelihood profile method. The estimates are based on the χ^2 distribution with m degrees of freedom (Zar 1999), according to the following inequality:

$$2[\text{LL}(\theta \backslash \text{data}) - \text{LL}(\theta \backslash \text{best})] < \chi_{1, 1-\alpha}^2$$

where $\text{LL}(\theta \backslash \text{best})$ is the likelihood of the most likely value of θ and $\chi_{1, 1-\alpha}^2$ are the values of the χ^2 distribution with one degree of freedom at a confidence level of $1 - \alpha$.

Results

The size frequency distribution of Pacific hake, *Merluccius productus* ranged from 12.5 to 105 cm TL; females measured between 16 and 105 cm TL and males measured between 12.5 and 83 cm TL. Females weighed between 21 and 7500 g and males weighed between 9.8 and 4200 g (Fig. 3). The TL–TW relation of females, males, and sexes combined (Fig. 4. A, B, C) shows values of b ranging between 3.11 and 3.14 and were not significantly different from 3, so we concluded that the Pacific hake presents isometric growth (Table 2).

Age determination. The aging subsample was integrated by selecting up to 15 Pacific hake, *Merluccius productus* for each length interval (2 cm) ($\text{KW} = 28.07$, $P > 0.05$). The absolute frequency in the length intervals < 16 cm and > 78 cm TL was less than 15, all of which were incor-

* The original authors Beamish and Fournier (1981) and many subsequent ones referred to this index imprecisely as the “index of the average percentage error” (IAPE).

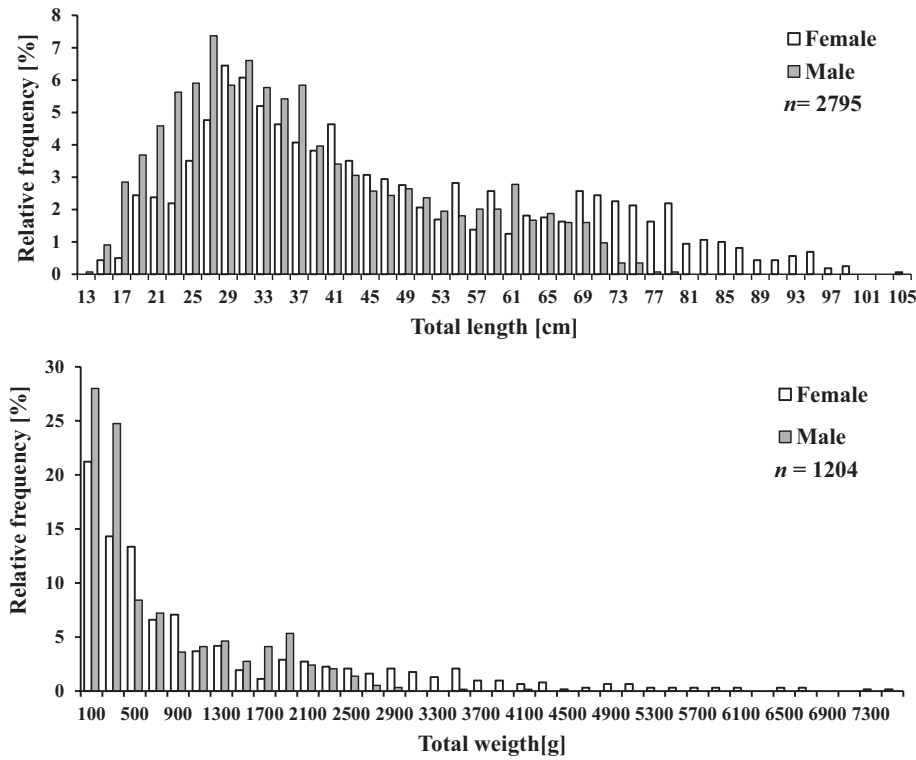


Figure 3. Length and weight frequency distribution by sex of Pacific hake, *Merluccius productus*, in the Gulf of California during research cruises from 2014 to 2019.

Table 2. Total length–total weight relation of the Pacific hake, *Merluccius productus*, in the Gulf of California.

Sex	N	Equation	R ²
Female	622	TW = 0.000003 × TL ^{3.11}	0.98
Male	582	TW = 0.000003 × LT ^{3.14}	0.97
Both sex	1204	TW = 0.000003 × LT ^{3.11}	0.98

In all three cases the growth type was isometric ($P < 0.05$); N = number of specimens studied, TW = total weight, TL = total length.

porated into the age subsample. From the total organisms sampled (2795), 468 were selected to assign age (60% females and 40% males).

High inter-reader precision was observed for the number of growth marks on otolith sections (APE = 1.7 and CV = 2.4). Up to 13 age groups were identified for Pacific hake that inhabit the Gulf of California. Females were longer-lived than males, 13 and 9 years old, respectively. Age group 5 was the most abundant in females and age group 4 in males (Fig. 5).

Individual growth parameters and selection of the best model. All candidate models (von Bertalanffy, Gompertz, Logistic, and Schnute–Richards) presented similar theoretical curves to describe the length–age data trend for the Pacific hake, *Merluccius productus* (Fig. 6). The parameters of the models have different meaning except L_{∞} . This parameter varied from 112.85 to 214.15 cm TL in females and from 80.59 to 118.63 TL in males (Table 3).

AIC differences identified three of the four candidate models with sufficient statistical support ($\Delta < 4$) to describe the somatic growth of Pacific hake in the Gulf of

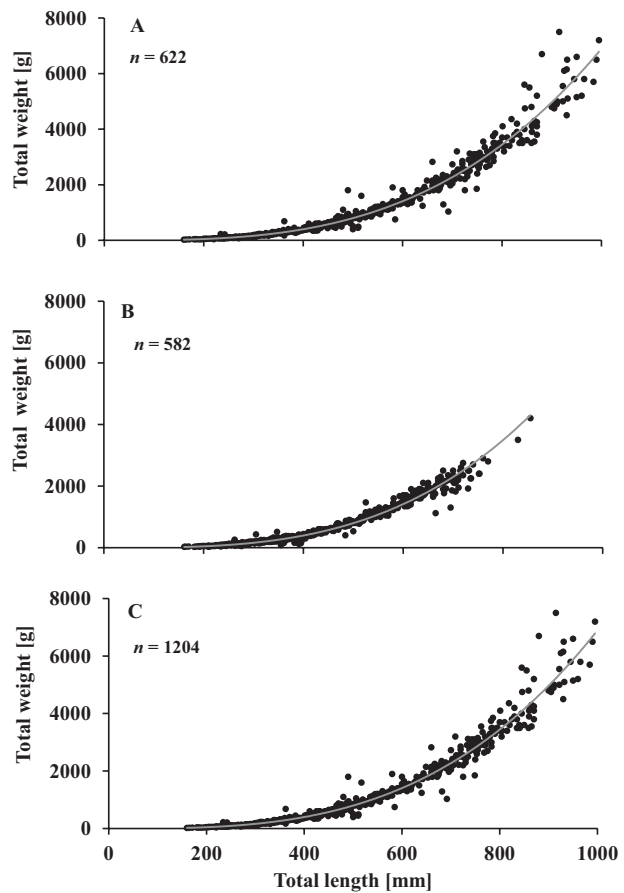


Figure 4. Total length–total weight relation of Pacific hake, *Merluccius productus*, in the Gulf of California (A) females, (B) males, (C) both sex.

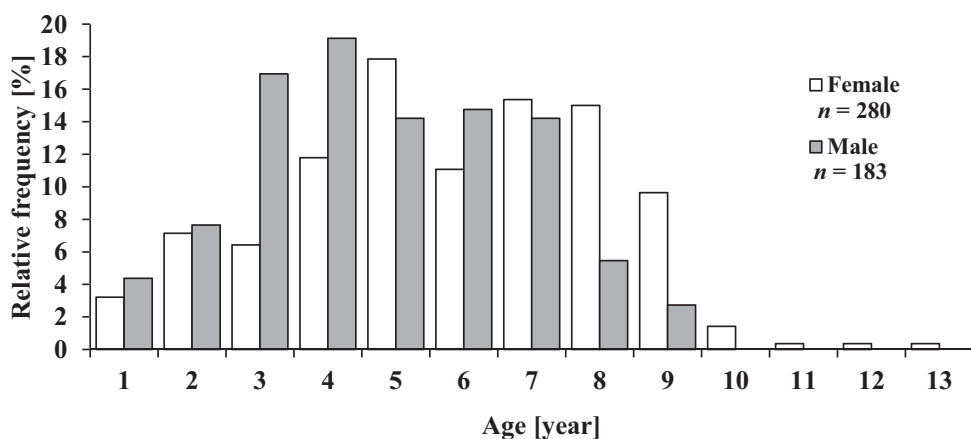


Figure 5. Age structure of Pacific hake, *Merluccius productus*, in the Gulf of California.

California (Table 4). However, none has a $w_i > 95\%$ to be a winning model (Burnham and Anderson 2002). The best model for females and males was Logistic with $w_i = 74.00\%$ and $w_i = 60.03\%$, respectively.

The differences in growth (Logistic model) between sex were significant ($\chi^2 = 38.16 P < 0.05$). The asymptotic length estimates for females and males (127.57 cm TL,

85.40 cm TL, Table 5) were not significantly different ($\chi^2 = 1.44 P > 0.05$; $\chi^2 = 0.8 p > 0.05$, respectively) from the length maximum recorded in the samplings (105 cm in females and 83 cm in males).

Based on the multimodel approach, the mean asymptotic length for females was 136.33 cm TL, and 95.07 cm TL for males.

Table 3. Growth models parameter of the Pacific hake, *Merluccius productus*, for both sex.

Growth model	Sex	K (annual)	L_∞ [cm]	t_0 [years ⁻¹]	LL	R^2
VBGM	F	0.08	163.72	0.00	24.73	0.99
Gompertz	F	0.13	214.15	8.10	58.57	0.99
Logistic	F	0.32	127.57	6.53	60.35	0.99
Schnute–Richard	F	0.06	112.85	0.00	60.72	0.99
Multimodel	F		136.33			
VBGM	M	0.11	108.89	0.00	28.84	0.99
Gompertz	M	0.19	118.63	4.69	44.90	0.99
Logistic	M	0.41	85.40	4.55	45.58	0.99
Schnute–Richard	M	0.11	80.59	0.00	45.84	0.99
Multimodel	M		95.07			

VBGM = von-Bertalanffy growth model; F = female, M = male; K = growth coefficient, L_∞ = asymptotic length, t_0 in VBGM and Schnute–Richard models is the hypothetical age at which the hake showed zero length; t_0 in Gompertz and Logistic model corresponds to and inflection point on the growth curve, LL = likelihood value.

Table 4. Akaike’s information criterion (AIC) values, AIC differences, and AIC weight of the candidate models to describe the trend of the age–length data of the Pacific hake, *Merluccius productus*, by sex.

Growth model	Sex	AIC	Δ AIC	$w_i\%$
VBGM	F	-43.38	71.25	2E-16
Gompertz	F	-111.06	3.57	12.43
Logistic	F	-114.63	0.00	74.00
Schnute–Richard	F	-111.23	3.39	13.54
VBGM	M	-51.54	33.48	0.00
Gompertz	M	-83.66	1.36	30.48
Logistic	M	-85.02	0.00	60.03
Schnute–Richard	M	-81.33	3.69	9.49

VBGM = von-Bertalanffy growth model; F = female, M = male.

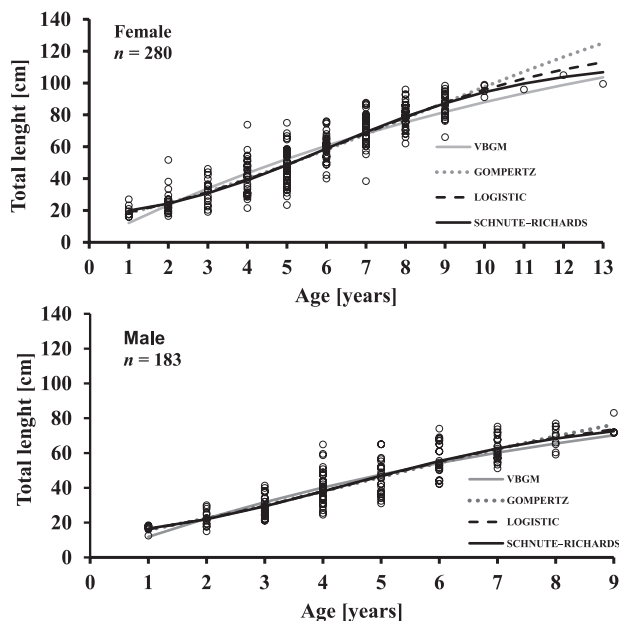


Figure 6. Individual growth curves (interpreted by four different models) of Pacific hake, *Merluccius productus*, in the Gulf of California.

Table 5. Logistic model, 95% confidence intervals (CI) of the growth parameters of the Pacific hake, *Merluccius productus*, by sex for the Gulf of California stock.

Parameter	Female			Male		
	Lower CI	Mean	Upper CI	Lower CI	Mean	Upper CI
L_∞	125.00	127.57	130.50	83.00	85.40	87.50
K	0.30	0.32	0.33	0.39	0.41	0.43
t_0	6.42	6.53	6.63	4.43	4.55	4.67

Discussion

This study addressed the age determination, allometry, and individual growth of Pacific hake, *Merluccius productus*, with information from research cruises from 2014 to 2019 in the north-central part of the Gulf of California. In general, Pacific hake has a population structured in stocks (Iwamoto et al. 2004) with a maximum length of 112 cm TL (Nevárez-Martínez et al., unpublished*) and some individuals attaining up to 20 years of age (MacFarlane et al. 1983) throughout its distribution area in the eastern Pacific Ocean. The age structure is similar for all the stocks, while differences in the size structure between the stocks have been observed, being the one that inhabits the western coast of Baja California Sur with the smallest size and has been defined as a “dwarf stock” (Vrooman and Paloma 1977). The stock that inhabits the Gulf of California has the longest sizes (Zamora-García et al. 2020; Nevárez-Martínez et al., unpublished*).

According to data from fisheries and research cruises, the length structure of Pacific hake in the extreme north of its range (Canada) varies from 6 cm to 81 cm FL, for the coast of the USA from 10 to 80 cm TL and for the western coast of Baja California Sur from 9 cm to 28 cm SL. In comparison, the length structure for the Gulf of California varies from 10 cm to 112 cm TL. This suggests that in the northern part of the species' range, exploitation has reduced the largest groups in length. This is not the case for the stock on the western coast of Baja California Sur, since it has not been commercially exploited.

Changes in length structure should be reflected in allometry (Genner et al. 2010). For the Pacific hake, a long-lived species, the effects would be due to fishing that mainly reduces the largest groups in length. The species throughout its distribution has different periods of exploitation, the northern stocks have been exploited since the middle of the 20th century (Best 1962), while the stock in the Gulf of California has been exploited since the 1990s, and that of the western coast of Baja California Sur has not been exploited commercially. Throughout its distribution area and regardless of its size structure, the species presents isometric growth (Best 1962; MacFarlane and Beamish 1985; Zamora-García et al. 2020; Nevárez-Martínez et al., unpublished*; Salinas-Mayoral, unpublished**). The variation of the allometry coefficient (2.63 to 3.11) could be explained by differences in sam-

pling period, year of study, region, and physical and environmental conditions (Soykan et al. 2015).

Changes to the size structure of species that are the target of fisheries is an important indicator of changes to community dynamics and population vulnerability (Tagliafico et al. 2012). This is because fishing will reduce the largest groups in the population and with the greatest reproductive potential, directly affecting recruitment and ecosystem dynamics through size-dependent predation. That is, by reducing the size structure of the reproductive stock, the number of oocytes produced is also reduced, due to the direct relation between the length of females and fecundity (McFarlane and Saunders 1997). In addition, Denton-Castillo (unpublished***) comments that females with longer sizes increase the reproductive potential of the population by producing higher quality oocytes and having more spawning events during the reproductive season.

We approached the age determination using the number of growth marks on otolith sections. Beamish (1979) for Pacific hake and Piñeiro and Sainza (2003) for European hake, *Merluccius merluccius* (Linnaeus, 1758), noted that otolith sections should be used for organisms > 5 years of age because growth marks in the older fish overlap. Although the number of growth marks between otolith sections and whole otoliths was not compared in this study, it was noted that growth marks on larger whole otoliths were not as evident as on otolith sections.

Differences in growth patterns by sex have been reported for Pacific hake (Dark 1975; McFarlane and Beamish 1985; Salinas-Mayoral, unpublished**). In the presently reported study, it has not been the exception; the females were longer-lived and reached greater length than the males and showed differences in the growth pattern. Apparently, this characteristic is common to the genus *Merluccius* due to morphological and biological differences between the sexes. Males reach maturity at an earlier length and age than females, hence this difference maximizes the reproductive potential for the species (Denton-Castillo, unpublished***). MacFarlane and Beamish (1985) show these differences by sex for the stock that inhabits the northern part of the distribution of the species, Dark (1975) for the stock that inhabits the coasts of the USA, Salinas-Mayoral (unpublished**) for the western coast of Baja California Sur and Zamora-García (unpublished****) for the Gulf of California.

* Nevárez-Martínez MO, Balmori-Ramírez A, Santos-Molina JP, Cervantes-Valle C, López-Martínez J, Méndez-Tenorio JF, Anguiano-Carrasco ML, Acevedo-Cervantes A, Miranda-Mier E, Morales-Azpeitia R, Valdivia-Herrera E (2007 [unpublished]) Prospección de merluza y bacalao: distribución, tamaño poblacional e ictiofauna asociada en el Golfo de California. Clave: SAGARPA-2003-C01-047.

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*** Denton-Castillo J (2018) Agregaciones y aspectos reproductivos de la merluza *Merluccius productus* (Ayres, 1855) en el centro y norte del Golfo de California. Tesis Maestría. Universidad Autónoma de Sinaloa. Mazatlán, Sinaloa, México.

**** Zamora-García OG (2021) Ecología pesquera y dinámica poblacional de la merluza norteña *Merluccius productus* (Ayres, 1855) del norte del golfo de California. Tesis Doctorado. Universidad Nacional Autónoma de México. Ciudad de México, México.

Finally, using the multimodel approach, it was possible to identify the best model to describe the change in length as a function of age in Pacific hake in the Gulf of California, this being the logistic model, which is characterized by presenting three growth stanzas, the first during the juvenile stage, the second a rapid growth in length and includes an inflection point of the curve, which is linked to the age of sexual maturity (L_{50}) and later a reduction in the growth rate when approaching the asymptotic length. For the Gulf of California stock, the inflection point of the growth curve (related to the sexual maturity process, L_{50}) was estimated at 52.7 cm TL in females and 38.4 cm TL in males (Denton-Castillo, unpublished*).

With reference to the estimated length at age for each of the Pacific hake stocks, a decrease in the annual percentage reaching L_{∞} is evident, showing a direct trend with respect to latitude, this being greater in the northern stocks on average 75% of L_{∞} at the third year of age in Canada and up to 60% for the coast of the USA (Dark 1975; McFarlane and Beamish 1985), and lower in the stocks that are distributed in the south; west coast of Baja California Sur 28% of the L_{∞} at the third year of age (Salinas-Mayoral, unpublished**), and in the presently reported study for the third year of age the Pacific hake reaches 30% of the L_{∞} (Table 6). This could be related, mainly to the level of exploitation to which the stocks have been subjected (Genner et al. 2010) and indirectly to the sur-

face temperature of the sea, which affects the productivity and prey availability.

In conclusion, the Pacific hake stock in the Gulf of California shows isometric growth, reaching up to 13 years of age and the growth pattern was significantly different between sex, and the model that best described the trend of the length–age data was the logistic model. The estimates of L_{∞} for both sex are not significantly different from the reported lengths ($\chi^2 = 1.05 P > 0.05$; $\chi^2 = 0.80 P > 0.05$ for females and males, respectively). Regarding the periodicity of the growth marks, even though the results of Dark (1975) suggest an annual periodicity, we consider that this is still an unfulfilled task, especially due to the difficulty of having samples for at least a complete annual cycle (Campana et al. 1995).

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Table 6. Summary of estimates of growth parameters of Pacific hake, *Merluccius productus*, by various authors.

Reference	Growth model	Sex	Age [years]	L_{∞} [cm]	k [years]	t_0	Area
Dark 1975	von Bertalanffy	Female	13	61.23 FL	0.30	0.01	California, Oregon and Washington
		Male	12	56.29 FL	0.34	0.20	
McFarlane and Beamish 1985	von Bertalanffy	Both	20	44.5 FL	0.45	-0.173	Strait of Georgia, Canada Off Shore Stock
		Both	18	56.9 FL	0.23	-3.94	
Balart-Páez, unpublished ¹	von Bertalanffy	Both		31.3 SL	0.48	-1.29	Western coast of the Baja California Peninsula
		Female	5	31.5 SL	0.49	-1.25	
		Male	4	31.5 SL	0.47	-1.35	
Salinas-Mayoral, unpublished ²	von Bertalanffy	Both		31.02 SL	0.11	0.01	Western coast of the Baja California Peninsula
		Female	12	40.03 SL	0.04	0.01	
		Male	5	34.1 SL	0.06	0.01	
Zamora-García, unpublished ³	Gompertz	Female	13	87.16 SL	0.28	2.24	Gulf of California, Mexico
		Male	9	78.27 SL	0.30	1.99	
Presently reported study	Logistic	Female	13	127.57 TL = 113.23 SL	0.32	6.53	Gulf of California, Mexico
		Male	9	85.40 TL = 82.33 SL	0.41	4.55	

¹Balart-Páez EF (2005) Biología y ecología de la merluza Bajacaliforniana, *Merluccius angustimanus* Garman, 1899, en la Costa Occidental de Baja California Sur, México. Tesis de Doctorado. Universidad Autónoma de Nuevo León. Nuevo León, México. The thesis of Balart-Páez originally referred to “*Merluccius angustimanus*” which is currently accepted as *Merluccius productus*.

²Salinas-Mayoral CA (2018) Dinámica poblacional de la merluza del Pacífico *Merluccius productus* (Ayres, 1855), en la Costa Occidental de BCS, México. Tesis Maestría. Centro de Investigaciones Biológicas del Noroeste, S.C. La Paz, Baja California Sur, México.

³Zamora-García OG (2021) Ecología pesquera y dinámica poblacional de la merluza nortea *Merluccius productus* (Ayres, 1855) del norte del golfo de California. Tesis Doctorado. Universidad Nacional Autónoma de México. Ciudad de México, México.

L_{∞} = asymptotic length, K = growth coefficient, t_0 in von Bertalanffy model is the hypothetical age at which the hake showed zero length; t_0 in Gompertz and Logistic model corresponds to and inflation point on the growth curve, FL = furcal length, SL = standard length, TL = total length.

* Denton-Castillo J (2018) Agregaciones y aspectos reproductivos de la merluza *Merluccius productus* (Ayres, 1855) en el centro y norte del Golfo de California. Tesis Maestría. Universidad Autónoma de Sinaloa. Mazatlán, Sinaloa, México.

** Salinas-Mayoral CA (2018) Dinámica poblacional de la merluza del Pacífico *Merluccius productus* (Ayres, 1855), en la Costa Occidental de BCS, México. Tesis Maestría. Centro de Investigaciones Biológicas del Noroeste, S.C. La Paz, Baja California Sur, México.

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