POPULATION DYNAMICS OF THE BIGEYE CROAKER
MICROPOGONIAS MEGALOPS IN THE NORTHERN GULF OF CALIFORNIA

EDGAR ARNOLDO ARZOLA-SOTELO
Centro de Investigaciones Biológicas
del Noroeste, S.C.
Km 2.35 Carretera a Las Tinajas
Colonia Tinajas. CP. 85460
Guaymas, Sonora, México

JUANA LÓPEZ-MARTÍNEZ
Centro de Investigaciones Biológicas
del Noroeste, S.C.
Km 2.35 Carretera a Las Tinajas
Colonia Tinajas. CP. 85460
Guaymas, Sonora, México
ph: +52 (622) 221 2237
fax: +52 (622) 221 2238
jlopez04@cibnor.mx

CARLOS HIRAM RÁBAGO-QUIROZ
Centro Regional de Investigación Pesquera
INAPESCA
Carretera a Pichilingue Km. 1 S/N
Colonia Esterito. CP. 23000
La Paz, B.C.S., México

JESÚS GUADALUPE PADILLA-SERRATO
CONACYT – Facultad de Ecología Marina
Universidad Autónoma de Guerrero
Av. Gran Vía tropical No. 20 fraccionamiento
Las Playas, Acapulco, Guerrero, México

ENRIQUE MORALES-BOJÓRQUEZ
Centro de Investigaciones Biológicas
del Noroeste, S.C.
Av. Instituto Politécnico Nacional 195
Playa Palo de Santa Rita Sur, CP. 23096
La Paz, B.C.S., México

ABSTRACT

Knowledge of biomass and demographic aspects is important in fish stock assessments. These aspects were analyzed on *Micropogonias megalops* in the Gulf of California, Mexico, using biological data from catches in 2010–12. Individual growth was estimated following a multi-model approach. Logistic models were used for first maturity and fishing selectivity, and natural mortality by means of empirical equations and biomass by the Pennington estimation. The results showed that the von Bertalanffy model best described growth for combined data (w_i = 72.86 %), females (w_i = 67.82 %) and males (w_i = 69.42 %), but they showed sexual dimorphism on the species. First maturity was at 357.8 mm, fishing selectivity 323.35 and 366.35 mm for industrial and artisanal fleet, respectively, and average natural mortality of 0.51. Mean biomass was 14 412.9 tons contrasting the officially reported catch that represented only 8.7% of estimated biomass, showing evidence that *M. megalops* is still an underexploited resource.

INTRODUCTION

Globally, overfishing or species fishing at the permissible limit is a constant focus of alert (SOFIA 2016; World Bank 2017). The increasing demand of food by humans causes strong pressure on resources that have not been assessed, which has caused many fisheries to develop despite the lack of basic stock information, such as population dynamics, population renewal rates and available and exploitable biomass of the target species (Cope and Punt 2009; Cope 2013). In third world countries this case is very common (World Bank 2017).

In Latin America, fishing has become an important economic activity, generating employment and income for a large number of families. Likewise, it is an important source for worldwide food security, also making an important contribution to Latin American economies. Despite the importance of fishing and although management measures have been introduced in the region, problems of overcapacity still persist, and the condition of vulnerability of fishery resources continues to increase (Agüero 2007). It is common to exploit many of the target resources without the slightest knowledge, or concentrate on multispecies fisheries where there are no specific administrative management measures for the most important species of these fisheries. An example is the Bigeye croaker *Micropogonias megalops* (Gilbert 1890) in the Gulf of California, which is an endemic, very abundant and widely distributed species in the region (López–Martínez et al. 2010; Rábago–Quiroz et al. 2011). The Bigeye croaker has been commercially harvested as part of a multispecies fishery (DOF 2010) since the early 1990s, which has been a fishing alternative when shrimp catch rates are low (Román–Rodríguez 2000; Aragón–Noriega et al. 2009). Particularly in the Northern (NGC) and Upper Gulf of California (UGC), the Bigeye croaker is caught by two fishing fleets, artisanal (small vessels) and industrial (large vessels, ships), representing a very important commercial fishery for its high catch volumes and substantial economic value (Aragón–Noriega et al. 2009). The fishing season occurs from March to August when the reproductive period is observed, and its availability to the fishing fleets increases (Castro–González 2004).

Knowledge of basic biological aspects of *M. megalops* is limited, such as average individual growth, natural mortality, reproduction, fishing selectivity and changes in stock biomass. Some studies have been conducted to understand population dynamics, age, growth and reproduction of this species in the Northern and Upper Gulf of California (Román–Rodríguez 2000; Aragón–Noriega et al. 2015). Recently, individual growth was analyzed
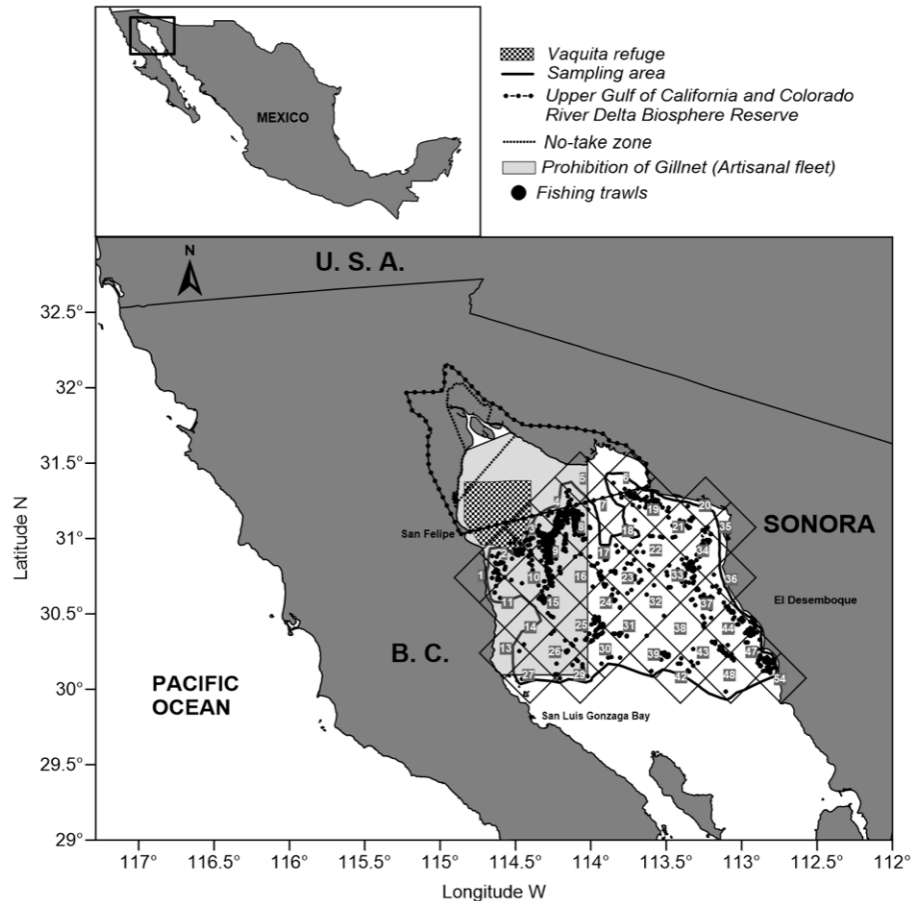
Figure 1. Study area and quadrant location for *Micropogonias megalops* sampling in the Northern Gulf of California (2010–12). Map includes the No-take zone for gillnets fishery (artisanal fleet) which includes the main species fishing areas for this fleet in the Northern Gulf of California, established temporarily in 2015, permanently since 2017, and vaquita refuge zone amplified in 2018 (DOF 2015, 2017, 2018).

based on a multi–model inference approach (Aragón-Noriega et al. 2015), but this analysis was supported on biological data from 1997–98 (Román-Rodríguez 2000). To our knowledge, more information about population dynamics and abundance aspects of the Bigeye croaker in the NGC is not available. For the genus *Micropogonias*, growth estimates have been reported in the Atlantic Ocean (Caribbean and South America) using the von Bertalanffy growth model (VBGM) (Manickchand-Heileman and Kenny 1990; Borthagaray et al. 2011), but more complete studies on population dynamics have not been found. Therefore, the objective of generating reliable, complete and current information on the Bigeye croaker becomes a relevant management matter for the stock in the Northwestern Mexican Pacific Ocean. Consequently, this study assessed important demographic aspects of the resource, such as growth, natural mortality, reproduction (sexual maturity and length at first maturity), fishing selectivity and the mean total biomass in the NGC during the 2010–12 period. The information generated in this study will contribute to the scientific understanding of the current biological and fishing sta-

tus of *M. megalops* population in the NGC. Likewise, this basic information could be used in the near future to adopt alternative fishing strategies for the species due to the recent establishment of a new no–take zone for artisanal fishing gear, such as gillnets (used to catch Bigeye croaker) and longline. This new no–take zone includes now many of the regular fishing areas (fishing grounds) of Bigeye croaker, so the refuge zone was recently amplified as part of the efforts directed to the protection of the vaquita *Phocoena sinus* in the Northern Gulf of California (Erisman et al. 2015; DOF 2015, 2017, 2018).

MATERIALS AND METHODS

Sampling

Bigeye croaker samples were collected from industrial and artisanal fishery catches from the NGC during the period from December 2010 to April 2012 (fig. 1). Additionally, a program of observers was implemented on board the industrial fleet throughout the whole year where fish caught by trawl nets were sampled. The industrial fleet used a net that had two otter boards

with double fishing tackle of 36 m long and mesh size of 90 mm while the artisanal fishery used a gillnet from 100 to 500 m long with 150-mm mesh size. Total length (mm) and total weight (g) of each individual caught were measured with a precision of 0.01 mm and 0.1 g. Sex and gonad maturity were obtained following the Nikolsky's morphochromatic scale (Nikolsky 1963), which is based on color and gonad texture, as well as its space in the abdominal cavity. Bigeye croaker specimens in stages I–II were considered immature (gonads flacid, transparent and less than one half of the space in the abdominal cavity), and those in stages III–V were considered mature (gonads colored and more than one half of the space in the abdominal cavity) (López-Martínez et al. 2011).

Length structure and multinomial analysis

Total length (TL) distributions of Bigeye croaker, for both industrial and artisanal samples in the NGC, were obtained grouping TL frequencies in 5-mm intervals to identify modal groups, length groups or cohorts (year-classes) that refer to groups of individuals of approximately the same age belonging to the same population (Sparre and Venema 1997). Then, a multinomial analysis was performed based on the assumption that length distribution for each cohort showed a normal distribution. To identify the number of cohorts in samples, a visual inspection of the TL frequency distribution was performed, and together with prior knowledge of the species recruitment events, initial values for each modal group were defined as input values in the following multinomial equation:

$$F_i = \sum_{a=1}^{n} \left[\left(\frac{1}{\sigma_a \sqrt{2\pi}} \right) e^{\frac{(x_i - \mu_a)^2}{2\sigma_a^2}} \right] * P_a$$

Where F_i was the total frequency of the group length i; a and n were lower and upper sample limits (TL intervals), respectively; x_i was the medium point of length group i; μ_a was the medium length of cohort a; P_a was the weight factor of cohort a; and σ_a was the standard deviation of the length in cohort a. Parameters in this function were minimised with a nonlinear fit, using the Newton algorithm to determine model parameters with the following negative log likelihood function (Neter et al. 1996):

$$-LL_{\{X|\mu_a, \sigma_a, P_a\}} = \sum_{i=1}^{n} f_i Ln \left(\frac{F_i}{\sum F_i} \right) - \left[\sum f_i - \sum F_i \right]^2$$

Where $-LL_{\{X|\mu_a, \sigma_a, P_a\}}$ was the negative log likelihood of the data for the parameters μ_a, σ_a, P_a; f_i was the total of the frequency observed of length group i; F_i was the total frequency expected for length group i according

to the multinomial model (Haddon 2001; Montgomery et al. 2010; Rodríguez-Domínguez et al. 2012). Finally, Bigeye croaker cohorts were separated according to the separation index (S.I.) using the next equation (Sparre and Venema 1997):

$$S.I. = 2 * \frac{\mu_n - \mu_i}{\sigma_n + \sigma_i}$$

Where μ_n and μ_i were the mean TL of the modal groups n and i, respectively; σ_n and σ_i were the standard deviations of modal groups n and i, respectively. Therefore if S.I. > 2, then it would be viable to separate the normal components from the observed frequencies (Sparre and Venema 1997).

Growth

In 2000, Román-Rodríguez (2000) developed an age-length key of Bigeye croaker by means of *M. megalops* otolith readings sampled from 1997 to 1998 in the Upper Gulf of California. In this work, in absence of otolith readings for the Bigeye croaker sampled from 2010–12, we used that age-length key to assign age to the length of each specimen sampled from industrial and artisanal fisheries in the NGC (2010–12). Age assignment to length data of Bigeye croaker, for combined and separated by sex data, was made by means of proportional and percentage conversion of length frequencies to the ages established by this key. The age assignment to length data was made following the methodology proposed by Gulland and Rosenberg (1992) and Sparre and Venema (1997).

Growth models

A multi-model inference approach was followed to estimate growth parameters (Katsanevakis 2006; Katsanevakis and Maravelias 2008). For this purpose, four growth models were used (table 1); von Bertalanffy growth model (1938), Gompertz (1825), Logistic (Ricker 1975), and Schnute (1981). Specifically, for Schnute model, L_∞ and t_0 (defined by Schnute 1981 as τ_0) were calculated using the following equations where a case of solution type 1 was assumed:

$$L_\infty = \left[\frac{e^{aT_2} y_2{}^b - e^{aT_1} y_1{}^b}{e^{aT_2} - e^{aT_1}} \right]^{\frac{1}{b}}$$

and

$$\tau_0 = T_1 + T_2 - \frac{1}{a} Ln \left[\frac{e^{aT_2} y_2{}^b - e^{aT_1} y_1{}^b}{y_2{}^b - y_1{}^b} \right]$$

In this solution case, adjusted values of parameters a and b were different from zero ($a \neq 0$, $b \neq 0$); projected growth curve shape, theoretical and statistical interpretation bases had equivalence with VBGM.

TABLE 1
Candidate growth models for *Micropogonias megalops* data in the Northern Gulf of California.

Model	Equation	Parameter description
		$L_{(t)}$ is length at age t.
von Bertalanffy growth model (VBGM)	$L_{(t)} = L_\infty \left(1 - e^{-K(t-t0)}\right)$	L_∞ is asymptotic length.
Gompertz	$L_{(t)} = L_\infty e^{-K(t-t0)}$	K determines the rate of approach to L_∞ (the curvature parameter). t_0 is the hypothetical age at which the organism showed zero length (initial condition parameter). t is age at size $L_{(t)}$.
Logistic	$L_{(t)} = \dfrac{L_\infty}{\left(1 + e^{-K(t-t_0)}\right)}$	a is a relative growth rate (time constant). b is an incremental relative growth rate (incremental time constant).
Schnute ($a \neq 0, b \neq 0$)	$L_{(t)} = \left[\gamma_1{}^b + (\gamma_2{}^b - \gamma_1{}^b) \dfrac{1 - e^{-a(t-T_1)}}{1 - e^{-a(T_2 - T_1)}}\right]^{\frac{1}{b}}$	T_1 is the lowest age in the data set. T_2 is the highest age in the data set. γ_1 is the size at age T_1. γ_2 is the size at age T_2.

Growth parameters (θ) for all four candidate growth models were fitted using a maximum log likelihood function according to the following equation (Neter et al. 1996).

$$LL_{(\theta \mid data)} = -\left(\frac{n}{2}\right)\left(Ln(2\pi) + 2 * Ln(\sigma) + 1\right)$$

For standard deviation (σ) a multiplicative error structure was assumed where the analytical solution was given by:

$$\sigma = \sqrt{\frac{1}{n}\sum_{t=1}^{n}\left[Ln\, L_{obs(t)} - Ln\, \hat{L}_{(t)}\right]}$$

Where n represented the number of ages observed for the Bigeye croaker (Cerdenares-Ladrón de Guevara et al. 2011).

Confidence intervals

Confidence intervals (C.I.) for growth parameters contained in each candidate growth model were calculated using likelihood profiles (Venzon and Moolgavkar 1988; Hilborn and Mangel 1997), which were estimated based on Chi-squared distribution (χ^2) with m degrees of freedom (Zar 1999). Confidence intervals were defined as all values θ that satisfied inequality:

$$2[LL_{(\theta \mid data)} - LL_{(\theta \mid best)}] < \chi^2{}_{1,1-\alpha}$$

Where $LL(\theta \mid best)$ was the log likelihood of the most probable value of θ, and $\chi^2{}_{1,1-\alpha}$ were the distribution values of χ^2 with one degree freedom at a confidence level of $1-\alpha$; thus, the confidence interval at 95% for θ covered all values of θ that were twice the difference between the log likelihood in the likelihood profile and the best estimate of θ. Those values less than 3.84 were included into confidence intervals (Haddon 2001; Pawitan 2001).

Confidence intervals become wider when considering more than one parameter, which only occurs if there is any correlation between parameters. The von Bertalanffy growth model had the asymptotic length and growth coefficient parameters correlated. In this case the solution was to compute the likelihood based confidence region estimated from contours of constant log-likelihood over the target surface. This procedure was applied to the L_∞ and K parameters jointly to avoid the problem of parameter correlation. In this case the equation above must satisfy the inequality associated with the χ^2 distribution with two degrees of freedom where the reference value was less than 5.99 for two parameters (Haddon 2001, Pawitan 2001).

Model selection

Growth model selection for the Bigeye croaker was obtained using the Akaike information criterion (*AIC*) (Burnham and Anderson 2002; Katsanevakis 2006; Katsanevakis and Maravelias 2008) according to the following equation:

$$AIC = (2 \times LL) + (2 \times k)$$

The *AIC* differences (Δ_i) for each model were given by the following function:

$$\Delta_i = AIC_i - AIC_{min}$$

Where AIC_{min} represented the *AIC* for the best candidate growth model, and AIC_i was the *AIC* estimated for the rest of the growth models. For each growth model i, plausibility was estimated with the Akaike weight (w_i) given by (Burnham and Anderson 2002):

$$w_i = \frac{exp\left(-\frac{1}{2}\Delta_i\right)}{\sum_{k=1}^{4} exp\left(-\frac{1}{2}\Delta_k\right)}$$

Following the multi-model inference approach, an "averaged" model was calculated for L_∞ taking into account values of L_∞ and w_i of all four models by the following equation (Burnham and Anderson 2002):

$$\overline{L}_\infty = \sum_{i=1}^{4} w_i \hat{L}_{\infty, i}$$

Confidence intervals (95%) of asymptotic length values were estimated by means of t Student test using the following equation:

$$\hat{L}_\infty = \pm\, t_{d.f., 0.95} S.E.(\hat{L}_\infty)$$

Where

$$SE_g(\overline{L}_\infty) = \sum_{i=1}^{4} w_i * \left(\mathrm{var}(\hat{L}_{\infty,i}\,|\,g_i) + (\hat{L}_{\infty,i} - \hat{L}_\infty)^2\right)^{\frac{1}{2}}$$

Both growth theoretical curve (best candidate model) and observed age-length data were graphed out to show shape and trajectory of growth, for all data and separated by sex in Bigeye croaker.

Natural mortality, reproduction and selectivity

Natural mortality (M), which is one of the most cryptic parameters in population dynamics, was estimated for all data (combined) and separated by sex (females and males) of Bigeye croaker. It was based on metapopulation and empirical functions proposed by Pauly (1980), Jensen (1996), Richter and Efanov (1977), Hewitt and Hoenig (2005), and Then et al. (2015). The parameter values used to estimate M were those identified by the best candidate growth model (VBGM) for the species according to the multi-model analysis; age of first maturity based on size L_{50} was obtained through the Logistic model; longevity was obtained by the Taylor equation (1962) that involved L_∞ and K parameter values of VBGM; finally annual average water temperature (˚C) in the NGC (23˚C) was used (Siegfried and Sansó 2009).

For reproduction and selectivity analysis a Logistic model was used. When the reproduction analysis was carried out, only mature female data were considered from both industrial and artisanal fisheries. Mature females were considered as those individuals in stages from III to V. For calculating length-at-first sexual maturity (FSM), the probability of mature females accumulated in each length interval was used; parameter values were obtained with the Logistic model proposed by King (2007):

$$P_i = \frac{1}{\left(1 + e^{-r(TL - L_{50})}\right)}$$

Where P_i is mature females proportion; r is the slope of the logistic curve; TL is the observed length interval; and L_{50} is the average total length at which the individuals are found sexually mature. Parameter values in Logistic equation were fitted using Newton's method and as objective function the sum of squares criterion (Neter et al. 1996).

For the selectivity analysis both male and female organisms in all sizes were considered and analyzed separately for industrial and artisanal fishery data because both fisheries have differences in fishing gear characteristics (mesh size, length) and fishing ways or maneuvers (industrial trawling; artisanal gillnetting). In this case, the selectivity curve calculating P_i in the Logistic model is the proportion of Bigeye croaker organisms; r is the slope of the logistic curve; TL is the observed length interval; and L_{50} is the average length at which the species is caught by the fishing gear (industrial or artisanal). Parameter values in the Logistic equation were fitted also using Newton's method and as objective function the sum of squares criterion (Neter et al. 1996).

Biomass estimation

To estimate the total stock biomass during the fishing season, the swept area method was applied. Fishing operation data (geographic position, trawling speed and duration) obtained by onboard observers (industrial fleet) were used, as well as onboard registered catch and catch data reported by commercial fleet in NGC were considered. Swept area is the effective trawling area of one tow in a determinate time, and covered area is the effective area covered during each fishing trip. It was estimated by: $\alpha = \omega * \upsilon * d$, where ω was the effective trawl net width; υ was towing velocity; and d was tow duration. Once the swept area was estimated, total biomass (B) in the fishing ground was given by: $B = Cw/v * (A/a)$, where Cw was catch rate; v was vulnerability of fish to the net; A was total area, and a was the swept area. Vulnerability of fish to trawling was difficult to estimate (King 1997), but values ranging from 0.5 (in current work) to 1 were normally assumed (Francis et al. 2003). To obtain a greater precision (a smaller variance) in the abundance estimates, a stratification of the total area was carried out, obtaining abundance estimates for a determinate sampled area (quadrant) and improving estimation efficiency; then, the sample was extrapolated to the total area of influence of the industrial fleet in the NGC ($A = 12\ 683\ \text{km}^2$).

The abundance estimates by the swept area method were used in this study based on the following assumptions: (a) the distribution area "total area" of the population was constant and, therefore, the average population density was at all times directly proportional to the total size of the "total area"; (b) the population was homogeneously distributed in the "total area", so if we sampled
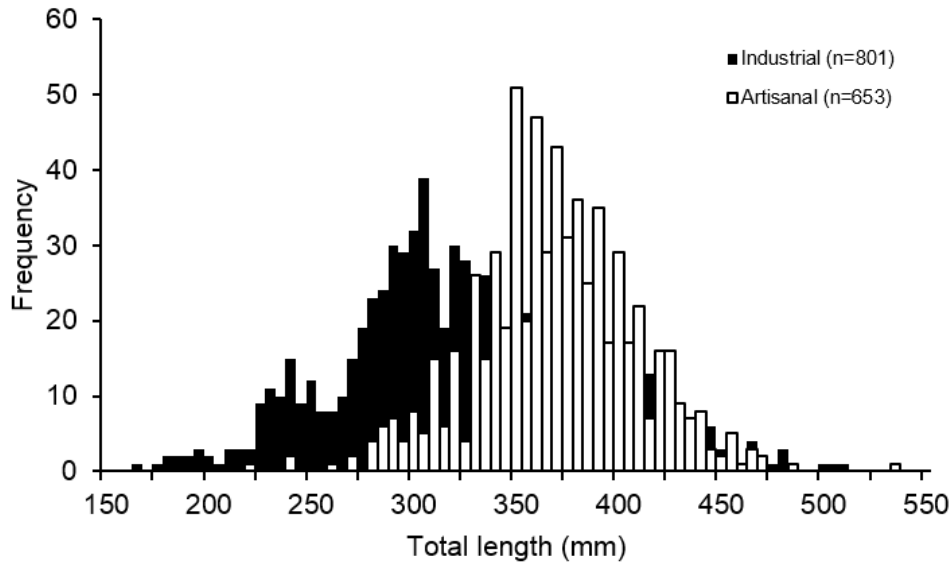
Figure 2.   Length frequency distribution of *Micropogonias megalops* in the Northern Gulf of California (2010–12). Catches of industrial fishery (full bars) and artisanal fishery (empty bars).

a fraction, its density represented a quantity of individuals per area that was equal to the average density of the total population; (c) all individuals had the same catch probability; and (d) the swept area was standardized to one hour.

Due to the large number of zeros in the fishing hauls and to reduce the variance caused by the spatial distribution of the species, the abundance estimates were supported in the calculation of the mean and the variance of a delta distribution. The Pennington estimator (which uses delta distribution) was used to obtain average abundance estimates per quadrant and for the total area of the sampled quadrants. For this analysis, the NAN-SIS program developed by Jeppe Kolding (Version Sept 2000) was used (Pennington 1985, 1996; Pierce et al. 1998; Folmer and Pennington 2000; Morales-Bojórquez 2002).

RESULTS

A total of 1454 Bigeye croaker specimens were analyzed from industrial and artisanal fishery in the NGC, of which total length (TL) ranged from 165 to 535 mm. The organisms from industrial fisheries showed a total length interval from 165 to 508 mm while those caught from artisanal fishery varied from 220 to 535 mm (fig. 2). The industrial fishery caught smaller individuals than those observed in the total length structure of the artisanal fishery; the average total length of Bigeye croaker in the industrial fishery was 325.6 mm $\pm$ 59.9 mm, and for artisanal fishery the average was 367.85 mm $\pm$ 39.47 mm. The industrial fishery showed four modal values in total length structure, which were based on the observed maximal peaks in the total length frequencies (195 mm, 240 mm, 305 mm, 370 mm and 415 mm); in

contrast, the artisanal fishery showed only three modal values of 300 mm, 350 mm and 425 mm. The qualitative data description showed evidence of a difference in the age groups that were harvested by each fleet.

Multinomial analysis

Separation of Bigeye croaker cohorts was performed for the nine sampling periods available where seven belonged to the industrial fleet (December 2010–March 2012) and two to the artisanal fleet (March–April 2012) (fig. 3). The industrial fishery caught three to four cohorts, of which the lowest and highest mean lenght were 191.21 mm $\pm$ 9.73 and 507.50 mm $\pm$ 1.87, respectively (table 2). The artisanal fishery also caught three to four cohorts, of which the smallest and highest mean length were 297.17 mm $\pm$ 20.08 and 549.1 mm $\pm$ 17.06 respectively (table 3).

The length analysis combining both information sources showed the presence of a total of five modal groups, whose average length are shown in the order from the smallest to the largest: (1) 191.2 $\pm$ 13.0 mm TL (12.3%); (2) 237.7 $\pm$ 12.7 mm TL (15.3%); (3) 292.2 $\pm$ 16.5 mm TL (18.8%); (4) 363.2 $\pm$ 42.0 (23.4%); and (5) 465.6 $\pm$ 35.5 mm TL (30.0%).

Growth

Age was assigned to the sampled organisms, whose ages were from 1–17 years. The best-represented ages were two- and five-year old individuals. The smallest individual had a length of 171.0 mm TL and an age of two years while the largest one had a length of 490.50 mm TL with an assigned age of 12 years. Bigeye croaker age-length data were adjusted to the four candidate
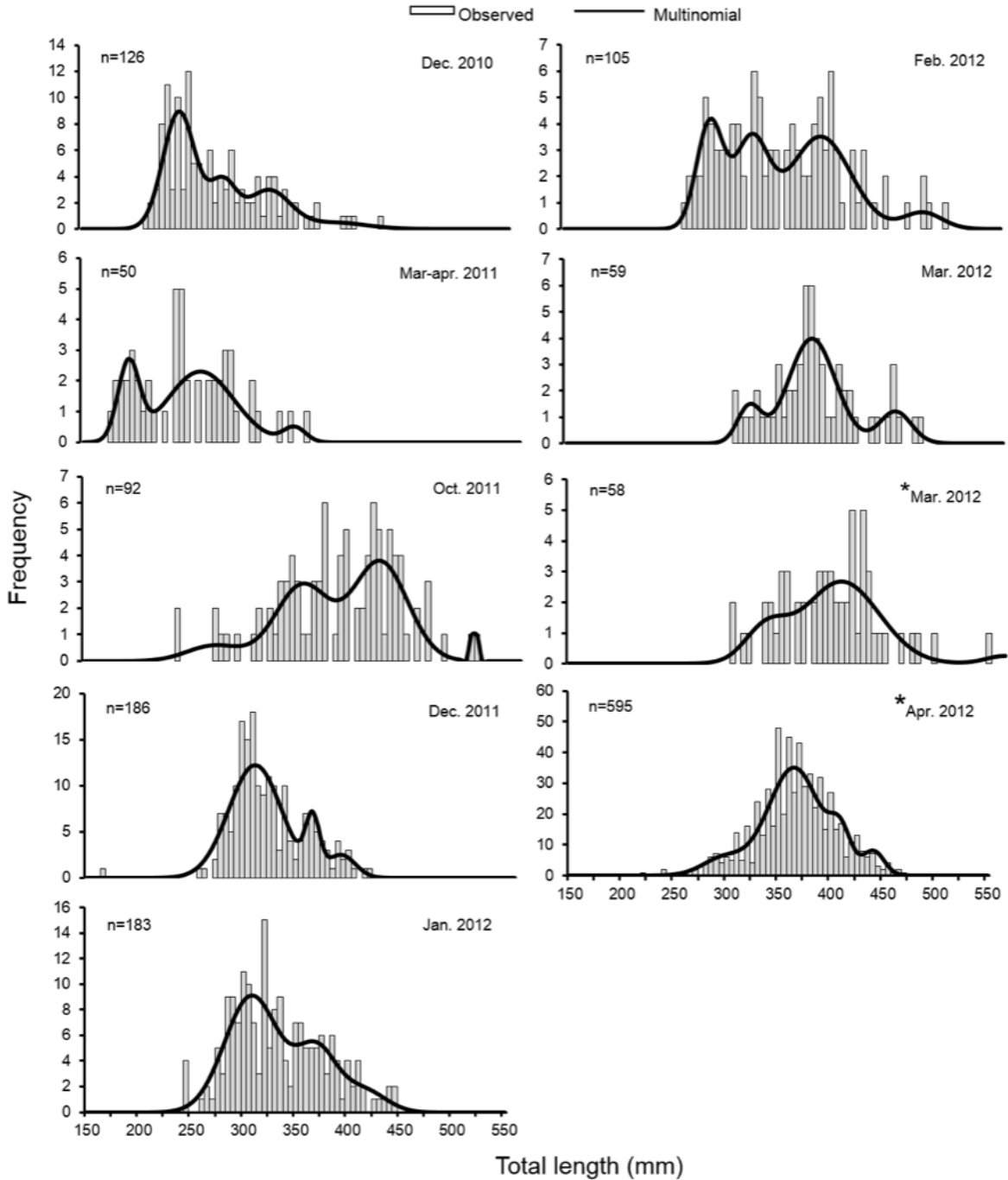
Figure 3.   Multinomial analysis of *Micropogonias megalops* in the Northern Gulf of California. *Artisanal Fishery.

growth models for all combined and separated by sex data; parameter values, confidence intervals and Chi-square values are shown in Table 4. The VBGM and Schnute growth models showed the highest asymptotic lengths and lowest growth coefficient values among all candidate models. In the same case, when sex separated data were analyzed, higher values in asymptotic length and lower in growth coefficient were recorded by females compared to males. Best growth model

selection considering *AIC* and *wi* values and confidence intervals (95%) for the Bigeye croaker are shown in Table 5. VBGM was the model that best adjusted to Bigeye croaker age-length data according to *AIC* and *wi* for combined and sex separated data. Figure 4 shows curve trajectories projected by the VBGM, as well as the likelihood contour joint confidence intervals of these parameters L_∞ and K, where covariance in values is evidenced for the species. Likelihood profiles for

TABLE 2
**Cohorts of Bigeye croaker *Micropogonias megalops*
caught in the Northern Gulf of California by
industrial fishery (2010–12). TL is total length in mm,
S.D. is standard deviation and S.I. is separation index.**

Date	Cohort	TL (mm)	S.D.	S.I.	Age (years)
Industrial fishery					
Dec. 2010	1	240.89	15	n.a	3
n: 126	2	281.44	12.6	2.93	3
	3	324.65	20.24	2.62	4
	4	387.19	28.61	2.55	5
Mar–Apr. 2011	1	191.21	9.73	n.a	2
n: 50	2	257.11	30.48	3.27	2
	3	343.25	10.17	4.23	4
Oct. 2011	1	269.14	24.92	n.a	3
n: 92	2	349.63	24.57	3.25	4
	3	421.21	24.99	2.88	5
	4	507.5	1.87	6.42	★
Dec. 2011	1	307.09	24.65	n.a	3
n: 186	2	360.71	6.54	3.43	4
	3	387.79	13.23	2.73	5
Jan. 2012	1	307.52	25.74	n.a	3
n: 183	2	369.67	19.57	2.74	4
	3	415.62	20.75	2.27	5
Feb. 2012	1	283.37	12.11	n.a	3
n: 105	2	321.59	15.59	2.75	4
	3	385.13	27.69	2.93	5
	4	478.82	17.48	4.14	11
Mar. 2012	1	317.67	10.9	n.a	4
n: 59	2	375.05	21.43	3.54	4
	3	451.47	14.47	4.25	12

TABLE 3
**Cohorts of Bigeye croaker *Micropogonias megalops*
caught in the Northern Gulf of California by
artisanal fishery (2012). TL is total length in mm,
S.D. is standard deviation and S.I. is separation index.**

Date	Cohort	TL (mm)	S.D.	S.I.	Age (years)
Artisanal fishery					
Mar. 2012					
n: 58	1	330.45	19.31	n.a	3
	2	399.82	34.65	2.57	4
	3	549.10	17.06	5.77	★
Apr. 2012					
n: 595	1	297.17	20.08	n.a	3
	2	364.57	24.98	2.99	4
	3	409.15	10.03	2.54	4
	4	440.79	10.04	3.15	9

*Not assigned by the age-length key

TABLE 4
**Parameter values, confidence intervals (95%) and Chi–squared probability (χ^2) obtained with likelihood profiles for each
candidate model for *Micropogonias megalops* combined data and separated by sex data in the Northern Gulf of California. L_∞ is
asymptotic total length; K determines the rate of approach to L_∞; t_0 is the hypothetical age at which the organism showed
zero length; a is relative growth rate; b is incremental relative growth rate; Y_1 is length at age T_1; and Y_2 is length at age T_2.**

Model	Combined (C.I. 95%)	χ^2	Female (C.I. 95%)	χ^2	Male (C.I. 95%)	χ^2
VBGM						
L_∞ (mm)	439.8 (437.65–442.15)	0.072	458.83 (455.28–462.64)	0.051	423.25 (418.8–427.6)	0.018
K (annual)	0.264 (0.261–0.267)	0.023	0.235 (0.231–0.238)	0.107	0.302 (0.295–0.310)	0.047
t_0 (years^{-1})	−1.97 (−1.91– −2.03)	0.018	−2.24 (−2.34– −2.16)	0.082	−1.65 (−1.75– −1.56)	0.068
Gompertz						
L_∞ (mm)	429.6 (428–432)	0.206	447.07 (443.50–450.50)	0.031	412.93 (408.55–417.10)	0.041
K (annual)	0.346 (0.342–0.352)	0.134	0.312 (0.305–0.321)	0.091	0.399 (0.387–0.412)	0.027
t_0 (years^{-1})	−0.55 (−0.62– −0.50)	0.056	−0.64 (−0.725– −0.565)	0.023	−0.41 (−0.50–0.30)	0.015
Logistic						
L_∞ (mm)	422.6 (420.5–424.5)	0.094	439.09 (435.50–442.50)	0.041	405.94 (401.75–410.25)	0.019
K (annual)	0.432 (0.424–0.442)	0.001	0.393 (0.380–0.407)	0.110	0.50 (0.480–0.522)	0.043
t_0 (years^{-1})	0.34 (0.29–0.40)	0.020	0.36 (0.27–0.45)	0.048	0.39 (0.285–0.485)	0.037
Schnute						
a	0.264 (0.256–0.272)	0.033	0.235 (0.225–0.247)	0.044	0.302 (0.285–0.320)	0.010
b	1.010 (1.009–1.011)	0.122	1.016 (1.015–1.017)	0.140	1.004 (1.003–1.006)	0.170
Y_1 (mm)	225.40 (222.5–228.5)	0.046	224.49 (220.34–228.85)	0.006	227.59 (222.00–233.40)	0.027
Y_2 (mm)	411.2 (408.0–414.5)	0.099	414.83 (409.75–420.0)	0.025	410.77 (404.35–417.30)	0.030
L_∞ (mm)	444.83	—	467.73	—	425.04	—
t_0 (years^{-1})	−1.94	—	−2.20	—	−1.64	—

TABLE 5
**Growth model selection for *Micropogonias megalops* combined and sex separated data in the Northern Gulf of California,
where *k* is the number of parameters for each model; *AIC* is the Akaike's information criterion; Δ_i is Akaike's differences;
w_i is Akaike's weight for each model; TL is total length in mm, and S.E. is the standard deviation.**

| Data	Models	k	AIC	Δ_i	w_i (%)	Asymptotic TL	S.E.
Combined	VBGM	3	2334.48	0.00	72.86	439.86	1.25
	Gompertz	3	2345.26	10.78	0.33	429.68	0.04
	Logistic	3	2353.46	18.98	0.01	422.64	0.00
	Schnute	4	2336.48	2.00	26.80	444.84	1.03
	Multi-model averaged					441.16	2.32
Female	VBGM	3	1040.41	0.00	67.82	458.83	1.16
	Gompertz	3	1045.22	4.81	6.13	447.08	0.80
	Logistic	3	1048.66	8.25	1.10	439.10	0.23
	Schnute	4	1042.41	2.00	24.95	467.73	1.92
	Multi-model averaged					460.12	4.11
Male	VBGM	3	672.84	0.00	69.44	423.25	0.79
	Gompertz	3	678.28	5.44	4.57	412.93	0.47
	Logistic	3	682.97	10.13	0.44	405.94	0.08
	Schnute	4	674.84	2.00	25.55	425.04	0.56
	Multi-model averaged					423.17	1.89
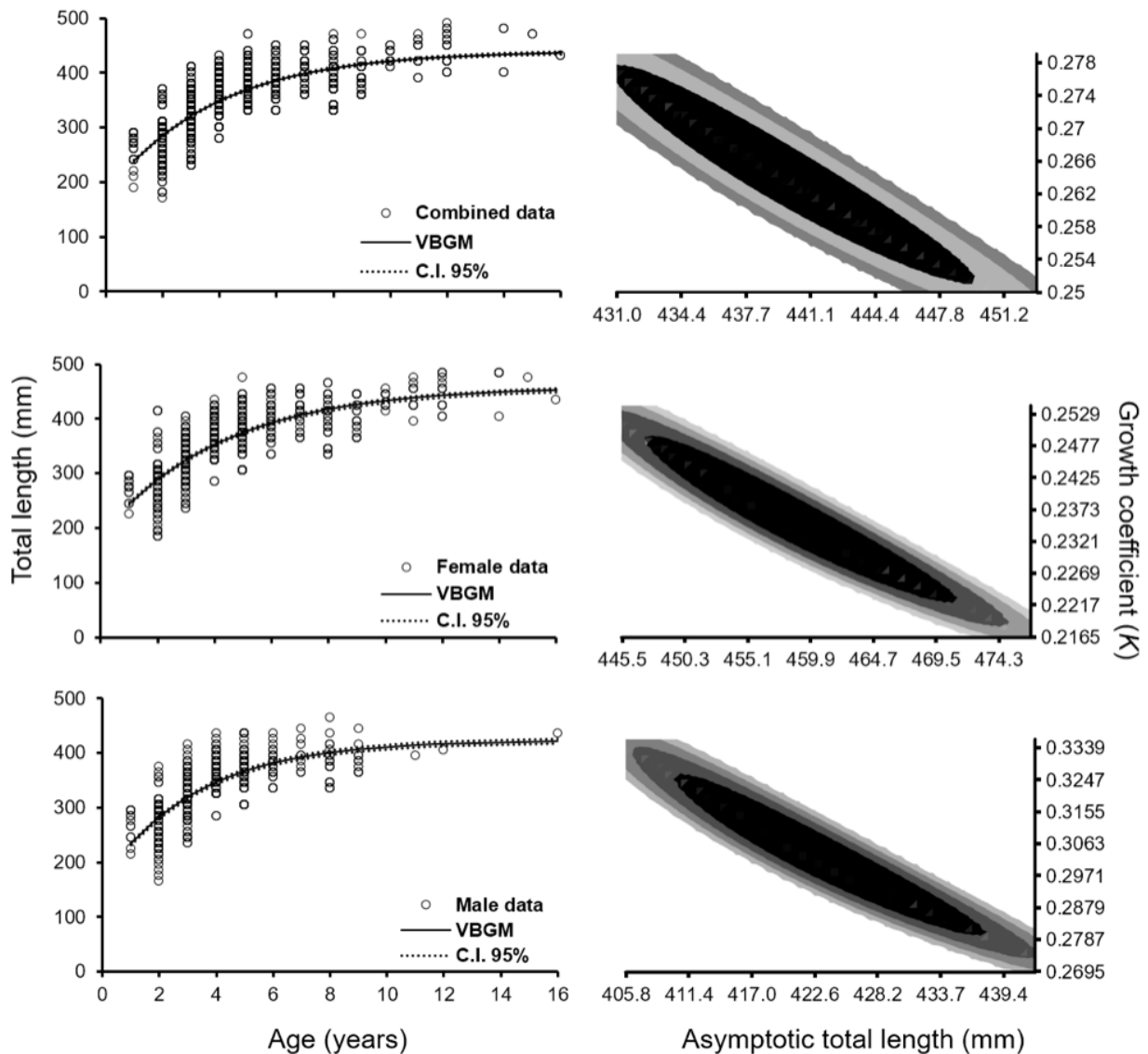
Figure 4.   Growth curves and likelihood contours for parameters L_∞ and K estimated by the von Bertalanffy growth model for Bigeye croaker *Micropogonias megalops* combined and sex separated data in the Northern Gulf of California. The area in black denotes joint confidence intervals (χ^2 test, $p < 0.05$).
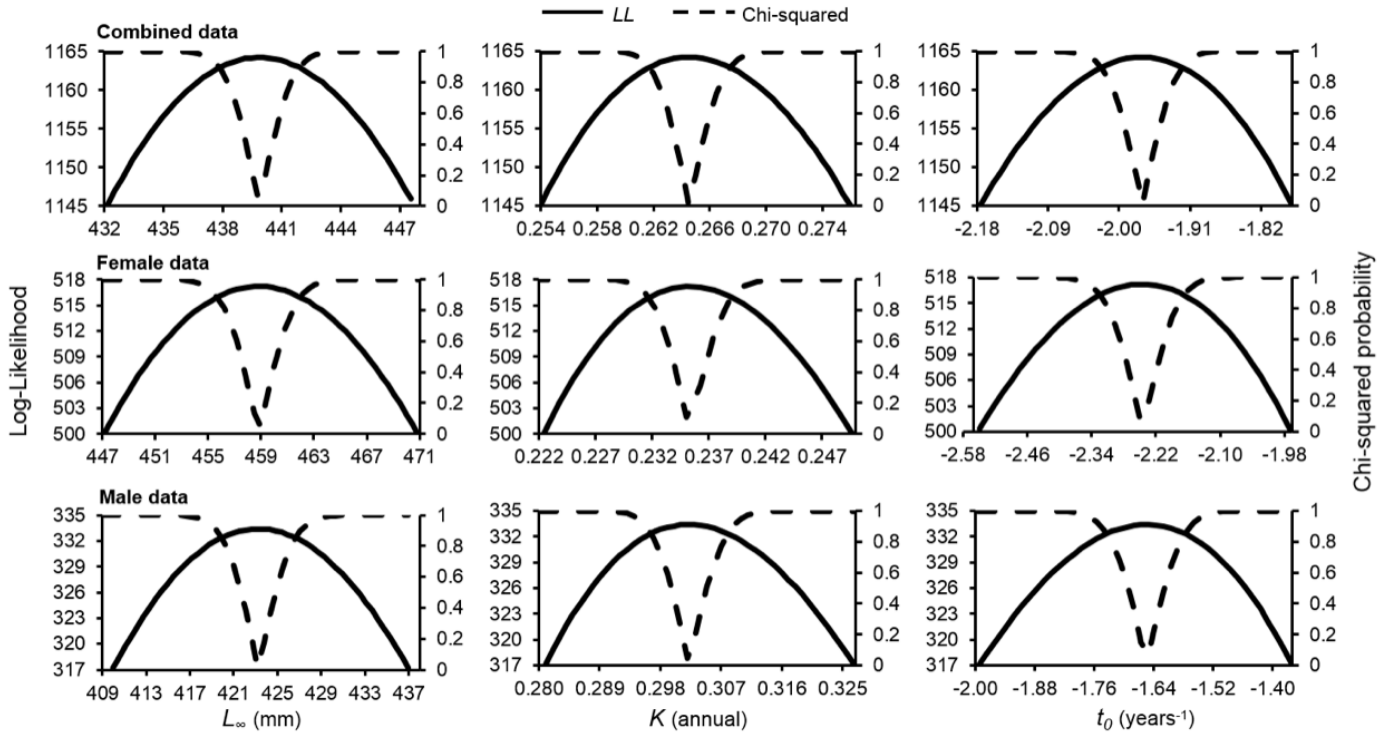
Figure 5. Likelihood profiles for parameters L_∞, K and t_0 estimated by the von Bertalanffy growth model for Bigeye croaker *Micropogonias megalops* combined and sex separated data.

TABLE 6
Comparison of the growth parameter values obtained by means of the von Bertalanffy model for Bigeye croaker in previous and current work in the Northern Gulf of California. Growth parameter values obtained are shown using combined and separated by sex data.

Source	$L_{\infty \text{ (mm)}}$	$K_{\text{(annual)}}$
Román–Rodríguez 2000 (combined)	815.90	0.51
Females	826.90	0.53
Males	814.40	0.48
Aragón–Noriega et al. 2015 (combined)	448.00	0.37
Females	461.00	0.37
Males	429.00	0.41
Current work (combined)	439.86	0.26
Females	458.83	0.23
Males	423.25	0.30

TABLE 7
Natural mortality obtained through six different empirical equations that involve growth parameter values, age of massive maturity and longevity of the Bigeye croaker, and mean sea surface temperature in the Northern Gulf of California. M values are shown for combined data and separated by sex, also average global values of Natural mortality and standard deviations are shown.

Equation	M (combined)	M (Females)	M (Males)
Pauly (1980)	0.60	0.55	0.67
Jensen (1996)	0.39	0.35	0.45
Richter and Efanov (1977)	0.52	0.52	0.52
Hewitt and Hoenig (2005)	0.45	0.40	0.51
Then et al. (2015) Tmax	0.63	0.57	0.71
Then et al. (2015) K and L_∞	0.44	0.40	0.50
Average	0.51	0.46	0.56
Standard deviation	0.09	0.09	0.10
Lim inf. 95 %	0.41	0.37	0.46
Lim sup. 95 %	0.60	0.56	0.66

each growth parameter of the best growth model are shown in Figure 5. Table 6 shows comparison between the growth parameter values obtained by the VBGM in current work and those obtained by the same growth model in previous works for the species in the Northern Gulf of California.

Natural mortality, reproduction and selectivity

Natural Mortality (M) of the Bigeye croaker was obtained taking into account the adjusted growth parameter values from the VBGM. Table 7 shows annual M values for the species according to six different equations:

Pauly (1980), Jensen (1996), Richter and Efanov (1977), Hewitt and Hoenig (2005) and Then et al. (2015) when considering longevity values in years (Tmax combined = 9.39; females = 10.5; males = 8.27) and when considering growth parameter values. The results indicated that Bigeye croaker showed that M values in males were higher than those recorded by females for all six equations.

Monthly percentages of Bigeye croaker mature females for an annual cycle in the NGC are shown in
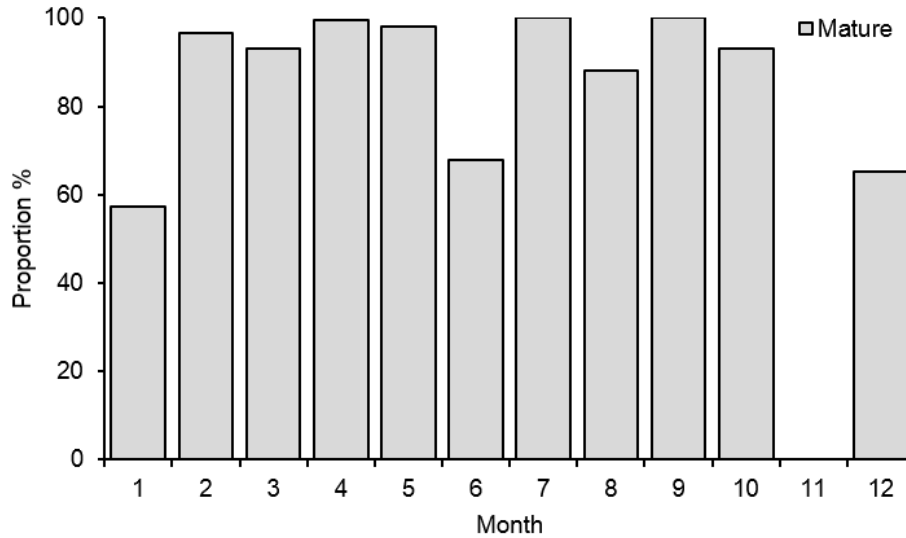
Figure 6.   Monthly percentage of mature females of *Micropogonias megalops* in the Northern Gulf of California during an annual cycle.
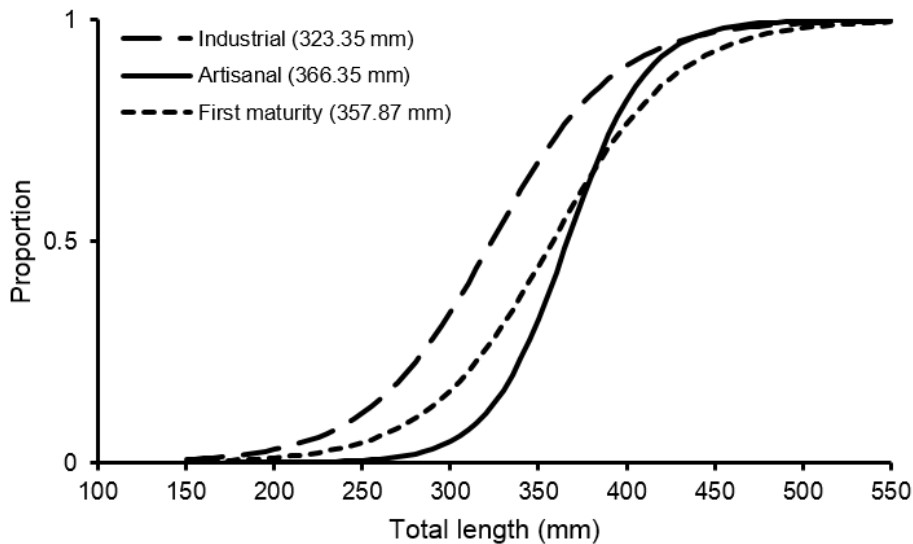

Figure 7.   Length at first sexual maturity curve and fishing selectivity curves for *Micropogonias megalops* during the period from 2010 to 2012 in the Northern Gulf of California.

Figure 6. The L_{50} value obtained by the Logistic model for the species FSM was 357.87 mm TL ($a = 10.08$; $b = 0.028$; $r = 0.028$) with an adjusted value of $R^2 = 0.983$, according to the sum of squared residuals. Likewise, for selectivity curve calculation the following values were obtained; for industrial gear selectivity L_{50} value was 323.35 mm TL ($a = 9.13$; $b = 0.03$; $r = 0.03$) and an adjusted value of $R^2 = 0.986$ while for artisanal selectivity L_{50} value was 366.35 mm TL ($a = 16.44$; $b = 0.04$; $r = 0.04$) and an adjusted value of $R^2 = 0.998$. Figure 7 shows comparing projected curves obtained by the Logistic model for reproduction and both industrial and artisanal gear selectivity on Bigeye croaker.

Biomass estimation

Fishing hauls (N = 254) were used to estimate total biomass in a total area of 54 quadrants. Only 184 hauls (20 quadrants) were performed for Bigeye croaker caught in the NGC from June 2010 to July 2011. Table 8 shows the mean biomass estimates by quadrant. Five quadrants had 88% of the estimated total biomass (30, 33, 37, 44 and 47). The mean biomass estimate in the total area was 14 412 t. The official Bigeye croaker total catch for NGC in study period was 1 248 t. This catch represented only 8.7% of the estimated biomass of the resource in current work.

TABLE 8
Quadrant relative biomass estimation and mean relative biomass for *Micropogonias megalops* in the Northern Gulf of California during the 2010–11 period.

Quadrant	Quadrant area (Km²)	Mean Biomass (Tons)	Lower and upper limits
2	320	105.2	(4.3–206.1)
3	273	91.1	(11.8–170.3)
4	307	76.2	(24.4–129.1)
6	239	145.5	(8.5–282.5)
7	195	4	
8	570	149.3	(97.6–201.0)
9	592	190.4	(108.0–272.7)
10	592	321.4	(45.7–597.0)
15	588	61.9	(11.8–111.9)
16	592	75.2	(7.8–142.6)
17	510	8	
19	449	2	
24	592	2	
30	532	2143	
33	592	3006	(1513.8–4498.2)
34	532	76.3	(21.5–131.2)
37	592	2482.7	(250.8–4714.6)
44	592	2645	(25.1–5264.3)
47	487	2413.7	(697.5–4129.9)
54	40.18	414	(40.2–787.8)
	Mean total biomass	14412.9	
	Quadrant mean biomass	720.645	

DISCUSSION

Many world fishery resources lack the necessary information to carry out robust stock assessments in a timely manner before being exploited by humans. Fish stock assessments consider several sources of biological information, such as average individual growth, maturation, natural mortality rates, changes in length or age composition, and stock abundance estimates (Hilborn and Walters 1992; Quinn and Deriso 1999; Cooper 2006). Thus, the importance of research, such as the study presented here, that generates information dependent and independent of the fisheries, allows management decisions in situations of limited information of the target species of the fishery (Ricard et al. 2011).

Bigeye croaker stock is an example of that situation where a lack of updated biological and fishery information for a stock exists and urgently needs to be generated, since the species has commercial importance in the NGC (Aragón-Noriega et al. 2009). Román-Rodríguez (2000) has the most complete research up to now for the species in the UGC, in which population dynamics and fishery data are presented. It is known that from the 1997–98 period until years close to current work (2010–12), fishing effort (artisanal fleet) increased by 38.7% (Aragón-Noriega et al. 2009), which by itself is a sufficient reason to carry out precise analyses of the resource situation today. Recently, individual growth of Bigeye croaker has been analyzed (Aragón-Noriega et al. 2015) even though this analysis was carried out using population age and size data obtained in 1997–98 period (Román-Rodríguez 2000). It is known that environmental and anthropogenic (fishing) forcing could have effects on fish population structure and biology (Hsieh et al. 2010; Perry et al. 2010; Hidalgo et al. 2011), hence the importance to evaluate more recent Bigeye croaker fishery data (Páez-Osuna et al. 2016; García-Morales et al. 2017). However, it is up to this study in which basic aspects of this species population were considered, incorporating two recent data sources that were the industrial and artisanal fishery catches in the NGC (2010–12).

Bigeye croaker lengths found in both industrial and artisanal fishery catches in NGC were variable between months and years where cohort displacements were shown througout time; this phenomenon is associated with biological and ecological aspects, such as reproduction, food or the environment (Román-Rodríguez 2000). In the global analysis of total length, the largest individuals were recorded in samples obtained by artisanal fishery (220–535 mm TL) and not by those obtained by industrial fishery (165–508 mm TL). It could be explained by selectivity of the fishing gear used by each fishery since they showed differences in mesh size that could have influenced the length range caught (Catalano and Allen 2010). Another possible factor is the fishing area where fleets (industrial and artisanal) operate. Based on the geographical coordinate data obtained by the industrial fleet, it has been shown that this fleet operates mainly from the southern part of the Reserve line of the UGC and covers a great part of the NGC. According to Rodríguez-Quiroz (2008) and Erisman et al. (2015), the artisanal fleet in UGC and NGC caught Bigeye croaker from the southern part of the nuclear area in the Upper Gulf, including part of the northwestern area of the vaquita (*Phocoena sinus*) refuge zone and along the northern coast of the state of Sonora. This fleet was performing its activities mainly within the reserve, exploiting aproximately 75% of the area (Rodríguez-Quiroz 2008). Since 2015, 2017 and 2018 a new permanent no-take zone has been established for artisanal fishing gears like gill nets and longline (fig. 1). This measure is part of the efforts aimed at the protection of the vaquita *Phocoena sinus* in the Northern Gulf of California. Erisman et al. (2015) mentioned that according to the Bigeye croaker traditional fishing areas, this new no-take zone included the complete and most important fishing areas for the artisanal fleet (DOF 2015, 2017, 2018). Taking this measure has affected artisanal fisheries and fishermen in the area negatively due now to lesser fishing grounds and number of target species that they can fish, which could bring serious socioeconomic problems in the near future in NGC.

The multinomial analysis of the population denoted mean lengths from three to four cohorts per sampling

period. General length structure (2010–12) showed a total of five well–defined cohorts, showing that commercial fishing (industrial and artisanal) in the area does not act on isolated cohorts of Bigeye croaker but upon several age groups simultaneously (Cadima 2003). Individual growth assessment of Bigeye croaker was performed from a multi-model approach (Burnham and Anderson 2002), which is relatively new in fisheries (Cruz-Vázquez et al. 2012). It was used for the first time on new age-length data of this species (2010–12) in the NGC. Theoretical growth curves shown for each model according to the observed data described very similar trajectories with an accelerated growth at the beginning of curves to stablelize as they got to greater lengths and older ages.

For this growth analysis in Bigeye croaker when combined and female and male age-length data were modeled, the VBGM showed the highest Akaike weight followed by Schnute model. Based on the fact that w_i values were <90% for all four models, an averaged model was calculated using L_∞ parameter values from all models (Burnham and Anderson 2002; Katsanevakis 2006; Katsanevakis and Maravelias 2008). This averaged model showed a value of L_∞ = 441.16 mm TL for combined data, 460.12 mm LT for females and 423.17 mm LT for males. Because it did not show any biological assumption or a specific curve type, its information was limited to one parameter (L_∞), which can be translated to a poor understanding of the species individual growth from physiological and ontogenical viewpoints. Recently, Mendívil-Mendoza et al. (2017) showed that obtaining a true average model was possible in this kind of analysis. It was achieved for a species from the same Family (Sciaenidae) as Bigeye croaker, the gulf curvina (*Cynoscion othonopterus*), species distributed in the same study area of current work. For that analysis, they used the special solution cases of the Schnute model, where they obtained curve trajectories and growth parameter values (K and L_∞) with equal biological bases and statistical interpretation of those models that have been used traditionally for individual growth analysis in fishery sciences (VBGM, Logistic and Gompertz). These are particular properties of the Schnute growth model because it is a nested and versatile model that has the ability to project both asymptotic and non-asymptotic growth curves in a particular age–length data set (Schnute 1981). The Schnute growth model and its special solution cases are recommended for even finer studies that describe growth in the species. In our study, the growth parameters obtained by the VBGM were considered as the most reliable for this analysis to describe growth of the Bigeye croaker, based on *AIC* and Akaike weight values. Our results coincide with those obtained by Aragón-Noriega et al. (2015) where they also showed that the VBGM was the best model for this species.

Confidence intervals obtained for both L_∞ and K growth parameters jointly, estimated by VBGM, showed a probability surface contour where the asymptotic length and growth coefficient values showed a strongly inverse correlation; when one of the parameters increased its value, the other one decreased and vice versa. This covariance of growth parameters in the species occurs in the same way for data of the entire population, as well as data separated by sex.

Maximum observed length data in Bigeye croaker from 2010–12 in the NGC was 535 mm TL while that reported in 2000 was 490 mm TL (Román-Rodríguez 2000; Aragón-Noriega et al. 2015). Theoretical values obtained by VBGM for this work showed a much lower value of L_∞ than those reported in Román-Rodríguez (2000) for the species by using the same model. On the other hand, Aragón-Noriega et al. (2015), when analyzing age-length data reported by Román-Rodríguez (2000) but from a multi-model approach, also concluded that VBGM best described the Bigeye croaker growth (w_i = 91.87%) with L_∞ values close but little higher to those obtained in this work (combined and separated by sex). Fischer et al. (1995) mentioned that *M. megalops* reaches to an approximate length of 40 cm (400 mm). At an international level, individual growth of *M. furnieri* in a coastal lagoon of Uruguay obtained L_∞ = 302 mm TL (Borthagaray et al. 2011) estimated with VBGM, which was less than the value estimated for the Bigeye croaker of the NGC. Growth of *M. furnieri* individuals that live in Rocha Lagoon, Uruguay was more accelerated (K = 0.19) than that of those that live in the continental shelf (Borthagaray et al. 2011). Its growth was analyzed in waters of Trinidad where the parameter values for VBGM were separated by sex, in males L_∞ = 653 mm TL and K = 0.16 and in females L_∞ = 829 mm TL and K = 0.13 (Manickchand-Heileman and Kenny 1990). Data confirmed that this species showed a greater asymptotic length and a slower growth, according to K in waters of Trinidad than in Rocha Lagoon in Uruguay. The Bigeye croaker *M. megalops* in the NGC showed a similar growth pattern with parameter values of L_∞ = 439.8 mm TL and K = 0.26 for all data but showed differences in between sexes, being females the ones that reached larger sizes with a less accelerated growth compared to male data. The growth coefficient value was lower than those reported by Román-Rodríguez (2000) and by Aragón-Noriega et al. (2015). Differences in L_∞ and K values are currently notable, less than those described for the species before (table 6). These differences could be due to mainly two reasons: (1) a bad estimate of growth parameters in 2000 (improved by Aragón-Noriega et al. 2015), which could be a probable explanation since the value of L_∞ shown for the Bigeye croaker in Román-Rodríguez (2000) did not come close to that reported for the spe-

cies in specialized fish databases as in Fischer et al. (1995), Nelson (2006), Froese and Pauly (2016) and Robertson and Allen (2015); (2) the possible explanation is that the values of the estimated parameters for 2000 decreased due to environmental changes through time or a continuous and intense fisheries of the population in the NGC and UGC (Hsieh et al. 2010; Perry et al. 2010; Hidalgo et al. 2011; Páez-Osuna et al. 2016; García-Morales et al. 2017). It could be explained by the fact that biological needs of *M. megalops* changed throughout approximately 15 years (from 1997–98 to 2010–12), investing the greatest part of the energy obtained by feeding in reproduction and not in growth (Quinn and Deriso 1999). Thus, the species tends to reach its sexual maturity at a younger age and smaller length as a type of survival strategy or mechanism. The length at first sexual maturity (FSM) obtained by the Logistic model in this study was L_{50} = 357.87 mm TL, theoretically reached at three years of age. Román-Rodríguez (2000) reported a value of L_{50} = 394.84 mm TL, which was 10% greater (36.98 mm) than that obtained in this study. Although the difference is little, there is evidence of a decrease in average length at which the Bigeye croaker reaches its reproductive maturity. If FSM (357.86 mm TL) and L_∞ (439.86 mm TL) were obtained for the 2010–12 data in the NGC, a difference of 82 mm could be noted between the occurence of one phenomenon and the other one. Likewise, the information analyzed sustained the Bigeye croaker FSM reached 81% of asymptotic length, which is why it is very likely that during the species growth, the arrival of FSM respresents the most important point of inflexion of the ontogenic cycle of the species. In such a way that species growth is accelerated during the first years and slows down after the arrival of the FSM. According to that shown by the lengths during all the analysis period, the population showed a fraction of mature individuals at all times, which is why although the species reproduction takes place as maximum from March to August (Castro-González 2004), in favorable conditions it showed a continuous recruitment.

As to Natural mortality (M) of Bigeye croaker six values were calculated by means of six diferent equations for all combined, female and male data. These M values varied between sexes and also by the methods used (table 7). Several authors have mentioned that the instantaneous coefficient of M is the most cryptic parameter in population dynamics (Gallucci et al. 1996; Quinn and Deriso 1999) and the majority of estimates are made by means of empirical equations, taking as a reference other key processes of population life, such as size of first maturity, longevity, among others (Then et al. 2015). Pauly (1980) and Pauly et al. (1984) highlighted their equation of mortality that included, in addition to the speed of growth, the environmental conditions imperative in

the environment as forcing the metabolism, which is the average temperature of the environment. This ultimate equation derives from the analysis of several fish species belonging to several families, which already contain natural mortality estimates. The Bigeye croaker showed natural mortality values ($M_{average}$ = 0.51, 0.46 and 0.56 for combined, female and male data respectly) similar to those observed by families where the species are more long-lived than what occurred in the Gulf of California as the Scianids (same Family as the *M. megalops*) where the M values were 0.20–0.80 and to the members of the Family Merlucciidae with values of M = 0.37–0.69. Nevertheless, there are evident differences in M values between sexes where males have a little superior value compared to females. Román-Rodríguez (2000) estimated by Pauly's (1984) equation a value of M = 0.36, which is a little lower but closer to those estimated in the NGC for the 2010–12 data. The low M value is a phenomenon that is regularly present in fish populations, as the Bigeye croaker, with slow growth (low K) and high longevity (17 years according to Román-Rodríguez 2000). Moreover, the M calculus must be certain since this phenomenon is related with the growth parameters L_∞ and K of VBGM (Pauly 1980; Jensen 1996; Then et al. 2015), which besides being sustained with physiological basis, it turned out to be statistically the best model within the candidate models in the description of the Bigeye croaker growth. These natural mortality results, together with the low FSM, could be the evidence that Bigeye croaker still has high capacity of population doubling, which translates into a highly available biomass of the resource in the study area. The biomass estimated for this resource showed evidence of that previously mentioned since higher values were recorded in relation to what has been caught of Bigeye croaker in the NGC during the last years. Annual landing values in metric tons in the area were around 3000 in 2009, 2600 in 2010 and 3500 in 2011 (Aragón-Noriega et al. 2015). The official catches reported during the study period represented a small fraction (8.7%) of the mean biomass estimated in the NGC, showing evidence that *M. megalops* was an underexploited resource, but this information should be checked and contrasted with other methods depending on the fishery.

In terms of current management, the Bigeye croaker is part of a multispecies fishery that takes place in the northern part of the Gulf of California (DOF 2010), where as mentioned, there are two types of fleet, artisanal (small vessels) and industrial (ships). However, considering the volumes caught, the economic yield generated from them and the importance of job creation (Aragón Noriega et al. 2009), the Bigeye croaker should be managed as an independent fishery; the information in this study could contribute to this change in management.

According to the National Fisheries Charter (Carta Nacional Pesquera CNP) (a normative instrument that specifies management schemes for Mexican fishery resources), continuing with the current management scheme (multispecific fishery) would make it difficult to specify the maximum fishing effort of the different populations that compose this complex resource; the same CNP mentioned that it was necessary to increase the information available to develop prediction models.

One of the most important challenges to address if this change is made for a specific fishery of the Bigeye croaker is the establishment of specific fishing grounds and fishing gears for resource captures, in order to not adversely affect endangered species, such as the vaquita (*Phocoena sinus*) or the totoaba (*Totoaba mcdonaldi*) in the UGC Reserve zone. Likewise, spatial and temporal runs (rout of migration and movements) of the resource should be better known to establish new areas with catchability in places far away from critical areas (breeding or co-habitat of endangered species) in the UGC and NGC.

If the Bigeye croaker is separated as an independent fishery, it will be possible to implement specific administrative measures that consider, among others: fishing period, fishing gear allowed, size of first catch by regulation of selective fishing gear and effort limitations considering that it is a resource shared by two fleets. Likewise, actions should be carried out once the resource is separated as an independent fishery, as preparing the Fishery Management Plan that would ultimately contribute to a sustainable management of the resource in accordance with the guidelines of international standards. On the other hand, the correct management will benefit the region economically and ecologically, considering that good management is critical for an area of interest for biodiversity as the NGC where a protected natural area exists bordering the area dealt with in this study.

ACKNOWLEDGMENTS

LITERATURE CITED

Agüero, M. 2007. Alternativas de medición y gestión de la capacidad y esfuerzo pesquero en América Latina y el Caribe. 37–58 pp In: Agüero, M. (ed.). Capacidad de pesca y manejo pesquero en América Latina y el Caribe. FAO Documento Técnico de Pesca. No. 461. Roma, FAO. 403p.

Aragón-Noriega, E. A., W. Valenzuela-Quiñones, H. Esparza-Leal, A. Ortega-Rubio, and G. Rodríguez-Quiroz. 2009. Analysis of management options for artisanal fishing of the bigeye croaker *Micropogonias megalops* (Gilbert, 1890) in the upper Gulf of California. Int J Biodivers Sci Ecosyst Serv Manage. 5: 208–214.

Aragón-Noriega, E. A., E. Alcántara-Razo, W. Valenzuela-Quiñónez, and G. Rodríguez-Quiroz. 2015. Multi-model inference for growth parameter estimation of the Bigeye Croaker *Micropogonias megalops* in the Upper Gulf of California. Rev Biol Mar Ocean. 50(1), 25–38.

Bertalanffy, L. von. 1938. A quantitative theory of organic growth (Inquiries on growth laws. II). Hum Biol. 10: 181–213.

Borthagaray, A. I, J. Verocai, and W. Norbis. 2011. Age validation and growth of *Micropogonias furnieri* (Pisces-Sciaenidae) in a temporally open coastal lagoon (Southwestern Atlantic-Rocha-Uruguay) based on otolith analysis. J Appl Icthyol. 27: 1212–1217.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach. Springer. 2nd Ed. New York, N.Y. 488p.

Cadima, E. L. 2003. Manual de evaluación de recursos pesqueros. Documento Técnico de Pesca. No. 393. Roma, FAO. 162p.

Castro-González, J. J. 2004. Estudio base y estrategias de manejo del chano *Micropogonias megalops,* caso Alto Golfo de California. Tesis de maestría, Ensenada, B.C: Universidad Autónoma de Baja California.

Catalano, M. J., and M. S. Allen. 2010. A size- and age-structured model to estimate fish recruitment, growth, mortality, and gear selectivity. Fish Res. 105: 38–45.

Cerdenares-Ladrón-De-Guevara, G., E. Morales-Bojórquez, and R. Rodríguez-Sánchez. 2011. Age and growth of the sailfish *Istiophorus platypterus* (Istiophoridae) in the Gulf of Tehuantepec, Mexico. Marine Biology Research. 7(5): 488–499.

Cope J. M. 2013. Implementing a statistical catch-at-age model (Stock Synthesis) as a tool for deriving overfishing limits in data-limited situations. Fish. Res. 142:3–14.

Cope J. M. and A.E. Punt 2009. Length-Based Reference Points for Data-Limited Situations: Applications and Restrictions. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1:169–186.

Cruz-Vásquez, R., G. Rodríguez-Domínguez, E. Alcántara-Razo, and E. A. Aragón-Noriega. 2012. Estimation of individual growth parameters of the Cortes geoduck *Panopea globosa* from the central Gulf of California using a multimodel approach. J Shellfish Res. 31(3): 725–732.

Diario Oficial de la Federación. 2010. Acuerdo mediante el cual se da a conocer la actualización de la Carta Nacional Pesquera. Jueves 2 de diciembre de 2010. México, DF. CNP 2010.

Diario Oficial de la Federación. 2015. Acuerdo por el que se suspende temporalmente la pesca comercial mediante el uso de redes de enmalle, cimbras y/o palangres operadas con embarcaciones menores, en el Norte del Golfo de California. Diario Oficial de la Federación. 10/04/2015. México. (Cons. 13/02/2018).

Diario Oficial de la Federación. 2017. Acuerdo por el que se prohíben artes, sistemas, métodos, técnicas y horarios para la realización de actividades de pesca con embarcaciones menores en aguas marinas de jurisdicción federal de los Estados Unidos Mexicanos en el Norte del Golfo de California, y se establecen sitios de desembarque, así como el uso de sistemas de monitoreo para dichas embarcaciones. Diario Oficial de la Federación. 30/06/2017. México. (Cons. 13/02/2018).

Diario Oficial de la Federación. 2018. Acuerdo por el que se modifican diversas disposiciones del diverso por el que se establece el área de refugio para la protección de la vaquita (*Phocoena sinus*). Diario Oficial de la Federación. 20/04/2018. México. (Cons. 20/04/2018).

Fischer, W., F. Krupp, W. Schneider, C. Sommer, K. E. Carpenter, and V. H. Niem. 1995. Pacífico centro oriental; Guía FAO para la identificación de especies para los fines de la pesca. FAO; Roma. II–III: 648–1652p.

Folmer, O., and M. Pennington. 2000. A statistical evaluation of the design and precision of the shrimp trawl survey off West Greenland. Fish Res. 49(2), 165–178.

Francis, C. R., R. J. Hurst and J. A. Renwick. 2003. Quantifying annual variation in catchability for commercial and research fishing. Fish. Bull., 101(2), 293–304.

Froese, R., and D. Pauly. 2016. FishBase. www.fishbase.org, version (10/2016).

Gallucci, V. F., S. B. Saila, D. J. Gustafson, and B. J. Rothschild. 1996. Stock Assessment: Quantitative methods and applications for small scale fisheries. (Vol. 1). CRC Press, Boca Raton, Florida.

García-Morales, R., J. López-Martínez, J. E. Valdez-Holguin, H. Herrera-Cervantes, and L. D. Espinosa-Chaurand. 2017. Environmental Variability and Oceanographic Dynamics of the Central and Southern Coastal Zone of Sonora in the Gulf of California. Remote Sensing, 9(9), 925.

Gilbert, C. H. 1890. A preliminary report on the fishes collected by the streamer 'Albatross' on the Pacific coast of North America during the year 1889, with descriptions of twelve new genera and ninety-two new species. Proc US Nat Mus. 13: 49–126.

Gompertz, B. 1825. On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. Philos Trans R Soc Lond B Biol Sci. 115: 513–583.

Gulland, J. A., and A. A. Rosenberg. 1992. Examen de los métodos que se basan en la talla para evaluar las poblaciones de peces. FAO Documento Técnico de Pesca No. 323. Roma, FAO. 112p.

Haddon, M. 2001. Modelling and quantitative methods in fisheries. Boca Raton, FL: Chapman and Hall/CRC. 406p.

Hidalgo, M., T. Rouyer, J. C. Molinero, E. Massutí, J. Moranta, B. Guijarro, and N. Stenseth. 2011. Synergistic effects of fishing-induced demographic changes and climate variation on fish population dynamics. Marine Ecology Progress Series, 426, 1–12.

Hilborn, R., and M. Mangel. 1997. The ecological detective. Confronting models with data. Monographs in Population Biology. Princeton, NJ: Princeton Academic Press. 315p.

Hilborn, R., and C. J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Kluwer Academic Publishers, New York.

Hsieh, C. H., A. Yamauchi, T. Nakazawa, and W. F. Wang. 2010. Fishing effects on age and spatial structures undermine population stability of fishes. Aquatic Sciences, 72(2), 165–178.

Jensen, A. L. 1996. Beverton and Holt life history invariants result from optimal tradeoff of reproduction and survival. Can J Fish Aquat Sci. 54: 987–989.

Katsanevakis, S. 2006. Modelling fish growth: model selection, multi-model inference and model selection uncertainty. Fish Res. 81: 229–235.

Katsanevakis, S., and D. Maravelias. 2008. Modelling fish growth: multi-model inference as a better alternative to a priori using von Bertalanffy equation. Fish Fish. 9: 178–187.

King, M. G. 1997. Fisheries biology, assesment and management. Fishing news books. Osney Mead, Oxford, England. 341p

King, M. G. 2007. Fisheries Biology, Assessment and Management. 2nd edition, Blackwell Scientific Publications, Oxford: pp. 211–219.

López-Martínez, J., J. Rodríguez-Romero, N. Y. Hernández-Saavedra and E. Herrera-Valdivia. 2011. Population parameters of the Pacific flagfin mojarra *Eucinostomus currani* (Perciformes: Gerreidae) captured by shrimp trawling fishery in the Gulf of California. Revista de Biología Tropical, 59(2), 887–897.

López-Martínez J., E. Herrera-Valdivia, J. Rodríguez-Romero, and S. Hernández-Vázquez. 2010. Composición taxonómica de peces integrantes de la fauna de acompañamiento de la pesca industrial de camarón del Golfo de California, México. Rev Biol Trop. 58: 925–942.

Manickchand-Heileman, S. C., and J. S. Kenny. 1990. Reproduction, age, and growth of the whitemouth croaker *Micropogonias furnieri* (Desmarest 1823) in Trinidad waters. Fish Bull. U.S. 88: 523–529.

Mendivil-Mendoza, J. E., Rodríguez-Domínguez, G., Castillo-Vargasmachuca, S. G., Ortega-Lizárraga, G. G., and Aragón-Noriega, E. A. 2017. Estimación de los parámetros de crecimiento de la curvina golfina *Cynoscion othonopterus* (pisces: Sciaenidae) por medio de los casos del modelo de Schnute. Interciencia, 42(9).

Montgomery, S. S., C. T. Walsh, M. Haddon, C. L. Kesby, and D. D. Johnson. 2010. Using length data in the Schnute Model to describe growth in a metapenaeid from waters off Australia. Mar Freshwater Res. 61: 1435–1445.

Morales-Bojórquez, E. 2002. Bayes theorem applied to the yield estimate of the Pacific sardine (*Sardinops sagax caeruleus* Girard) from Bahia Magdalena, Baja California Sur, Mexico. Cienc Mar. 28(2), 167–179.

Nelson, J. S. 2006. Fishes of the World. 4th ed. Hoboken. New Jersey, USA: John Wiley and Sons. XIX: 601p.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied linear statistical models. New York, NY: McGraw-Hill. 1408p.

Nikolsky, G. V. 1963. The Ecology of Fishes. Academic Press. London, UK. 352 pp.

Páez-Osuna, F., J. A. Sánchez-Cabeza, A. C. Ruíz-Fernández, R. Alonso-Rodríguez, A. Piñón-Gimate, J. G. Cardoso-Mohedano, F. J. Flores-Verdugo, J. L. Carballo, M. A. Cisnero-Mata, and S. Álvarez-Borrego. 2016. Environmental status of the Gulf of California: A review of responses to climate change and climate variability. Earth-Science Reviews, 162, 253–268.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J Conseil. 39(2), 175–192.

Pauly, D., J. Ingles, and R. Neal. 1984. Application to shrimp stocks of objective meathods for the estimation of growth, mortality and recruitment-related parameters from length-frequency data (ELEFAN I and II).

Pawitan, Y. 2001. In All Likelihood: statistical modeling and inference using likelihood. Oxford: Oxford University Press. 528p.

Pennington, M. 1983. Efficient estimators of abundance, for fish and plankton surveys. Biometrics, 281–286.

Pennington, M. 1985. Some statistical techniques for estimating abundance indices from trawl surveys. Fish Bull. U.S. 84: 519–526.

Pennington, M. 1996. Estimating the mean and variance from highly skewed marine data. Fish Bull. 94(3), 498–505.

Perry, R. I., P. Cury, K. Brander, S. Jennings, C. Möllmann, and B. Planque. 2010. Sensitivity of marine systems to climate and fishing: concepts, issues and management responses. Journal of Marine Systems, 79(3–4), 427–435.

Pierce, G. J., N. Bailey, Y. Stratoudakis, and A. Newton. 1998. Distribution and abundance of the fished population of *Loligo forbesi* in Scottish waters: analysis of research cruise data. ICES J Mar Sci: J. Conseil. 55(1), 14–33.

Quinn, J. T., and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press. New York. 452p.

Rábago-Quiroz, C. H., J. López-Martínez, J. E. Valdez-Holguín, and M. Nevárez-Martínez. 2011. Distribución latitudinal y batimétrica de las especies más abundantes y frecuentes en la fauna acompañante del camarón del Golfo de California, México. Rev Biol Trop. 59: 255–267.

Ricard, D., C. Minto, O. P. Jensen, and J. K. Baum. 2012. Examining the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. Fish Fish. 13(4): 380–398.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. J Fish Res Board Can. 191: 383p.

Robertson, D. R., and G. R. Allen. 2015. Peces Costeros del Pacífico Oriental Tropical: un sistema de información. Instituto Smithsonian de Investigaciones Tropicales, Balboa, República de Panamá.

Rodríguez-Domínguez, G., S. G. Castillo-Vargasmachuca, R. Pérez-González, and E. A. Aragón-Noriega. 2012. Estimation of the individual growth parameters of the brown crab *Callinectes bellicosus* (Brachyura, Portunidae) using a multi-model approach. Crustaceana. 85(1): 55–69.

Rodríguez-Quiroz, G. 2008. Sociedad, pesca y conservación en la Reserva de la Biósfera del Alto Golfo de California y Delta del Río Colorado. CIBNOR. Tesis de doctorado. 134p.

Román-Rodríguez, M. J. 2000. Estudio poblacional del chano norteño, *Micropogonias megalops* y la curvina Golfina *Cynoscion othonopterus* (Gilbert) (Pisces: Sciaenidae), especies endémicas del Alto Golfo de California, México. Instituto del Medio Ambiente y Desarrollo Sustentable del Estado de Sonora. Informe final SNIB-CONABIO proyecto No. L298. México, DF.

Schnute, J. 1981. A versatile growth model with statistically stable parameters. Can J Fish Aquat Sci. 38: 1128–1140.

Siegfried, K., and B. Sansó. 2009. A review for estimating natural mortality in fish populations. Tech. rep., SEDAR 19 Research Document 29.

SOFIA 2016, El estado mundial de la pesca y la acuicultura 2016. Contribución a la seguridad alimentaria y la nutrición para todos. FAO Roma. 224 pp

Sparre, P, and S. C. Venema. 1997. Introducción a la evaluación de recursos pesqueros Tropicales. Parte 1. Manual. FAO Documento Técnico de Pesca. Valparaiso, Chile. 306 (1): 420p.

Taylor, C. C. 1962. Growth equations with metabolic parameters. J. Conseil. 27 (3): 270–286.

Then, A. Y., J. M. Hoenig, N. G. Hall and D. A. Hewitt. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES J Mar Sci, 72(1), 82–92.

Venzon, D. J., and S. H. Moolgavkar. 1988. A method for computing profile-likelihood-based confidence intervals. Appl Stat. 37: 87–94.

World Bank. 2017. The Sunken Billions Revisited: Progress and Challenges in Global Marine Fisheries. Washington, DC: World Bank. Environment and Sustainable Development series. Doi: 10.1596/978-1-4648-0919-4. License: Creative Commons Attribution CC BY 3.0 IGO.

Zar, J. H. 1999. Biostatistical Analysis. Englewood Cliffs, NJ: Prentice-Hall. 633p.