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Research Article

Growth, mortality, exploitation rate and catch per unit effort (CPUE) of *Mugil setosus* in the central Mexican Pacific: An empirical approach

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ABSTRACT. The grey mullet (*Mugil setosus*) is a valuable resource for coastal communities in the central Mexican Pacific; however, it is currently at the maximum sustainable yield. To update the biological and fisheries indicators for its management, growth, mortality, and catch-per-unit effort (CPUE) parameters for *M. setosus* in Nayarit were estimated for 2023, based on the analysis of 1,581 specimens from five fishing areas. Significant differences in size structure were found between areas ($P < 0.05$), with a range of 14.5-14.8 cm in total length (TL). The estimated growth parameters were L_∞ = 40.5 cm, K = 0.43 yr^{-1}, and t_0 = 0.43 years. The total mortality rate (Z) was 0.63 yr^{-1}, natural mortality (M) was 0.40 yr^{-1}, and fishing mortality (F) was 0.22 yr^{-1}. The overall exploitation ratio (E = 0.35) suggests that the stock is under-exploited at the state level, although zone V showed an E = 0.63, indicating fishing pressure above the optimal level. Using the Gomez-Munoz model, the estimated maximum CPU in March is 171 kg $trip^{-1}$, with an average monthly production of 2,167 kg $trip^{-1}$ per fishing unit. It is concluded that the majority of the catch (77.4%) exceeds the size at first maturity (25.4 cm L_m), which favors the sustainability of the stock.

Keywords: *Mugil setosus*; fisheries management; catch per unit effort; exploitation rate; growth parameters

INTRODUCTION

Globally, mullets represent one of the most stable fishery resources for food security, with capture fisheries producing up to 700,000 t. According to the Food and Agriculture Organization (FAO) report, Mexico ranks 15th worldwide in mullet catches. It is among the top countries in Latin America, reporting an average annual catch of up to 50,000 t (FAO 2024, 2026).

According to CONAPESCA (2024) and FAO (2026), in the Central Mexican Pacific, the mullet fishery is a socio-economic activity of great importance to coastal communities, historically ranking among the top catches in the marine fish category, with the states of Nayarit and Sinaloa leading the way in production. Within this group, *Mugil setosus*, previously described as *M. curema* (Britzke et al. 2019), stands out as a key resource in Mexico's coastal fisheries. The Secretaría de Agricultura y Desarrollo Rural (SADER 2025)

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emphasizes that this fishery is currently operating at maximum sustainable yield, so constant monitoring is recommended to prevent stock depletion.

Studies on *M. setosus* have ranged from basic taxonomic descriptions to analyses of population dynamics. Research along the Michoacán coast has examined size structures, growth parameters, and exploitation rates, suggesting the species still has room for further exploitation (Meléndez-Galicia & Romero-Acosta 2010). Similarly, studies of this nature have been conducted in Colima (Gallardo-Cabello et al. 2005). Furthermore, researchers studied juvenile growth in the Gulf of California in the 1990s (Quiñonez-Velázquez & López-Olmos 2011). Other studies in Tamiahua Lagoon, Veracruz, estimated *M. curema* age using indirect methods (Ibáñez-Aguirre & Gallardo-Cabello 1996). In the rest of Latin America, research on the species is localized and scarce, and age and growth estimates are rarely addressed (Ruiz-Villanueva 2015).

To ensure the sustainable use of this resource, temporary fishing closures are a key measure. According to the Diario Oficial de la Federación (DOF 2025), the state of Nayarit and adjacent waters (from Jalisco to Baja California Sur) establish a fixed temporary closed season for *M. setosus* from April 1 to June 31 each year. This restriction aims to ensure recruitment of new cohorts, as the reproductive season is most intense in spring (Espino-Barr et al. 2016, Ruiz-Ramírez et al. 2017).

However, despite these regulatory efforts, the lack of specific, up-to-date information on *M. setosus* in Nayarit creates uncertainty that jeopardizes the effectiveness of catch quotas. Most of the current parameters are based on studies conducted more than three decades ago (Villaseñor-Talavera 1988). In this context, the present study highlights the need to update biological data and compile up-to-date species statistics, using empirical equations to estimate growth, natural mortality (M), fishing mortality (F), and the exploitation rate (E). Therefore, the von Bertalanffy growth model is particularly important because estimating its growth parameters is necessary to calculate M, F, and E (an essential indicator for assessing the status of a species stock) (Zhang et al. 2023, Turan 2026). It is also the most widely used model in fisheries science for describing the relationship between age and growth (Flinn & Midway 2021, Mainguy et al. 2026, Schlosser et al. 2026). In addition, the catch per unit of effort (CPUE) per trip was estimated using the model developed by Gómez-Muñoz (1990), which has proven to be a powerful tool for reconstructing catch time series in small-scale fisheries (Comesaña & Guerra 2019, Otero et al. 2005, Young et al. 2006).

MATERIALS AND METHODS

Study area

This study was conducted in the coastal fishing communities of the state of Nayarit, Mexico (22°22′38″N-105°26′27″W and 22°41′22″N-105°16′41″W) (Fig. 1). Data were collected for 1,581 ind at commercial inshore fishing sites in the coastal municipalities of Tecuala (TC), Rosamorada (RM), Tuxpan (TP), Santiago Ixcuintla (SI), San Blas (SB), Compostela (CP) and Bahía de Banderas (BB). Fish were caught using gillnets and cast nets, set from small boats in 2023. The total length (TL) ±0.1 cm of the fish and total weight (TW) ±0.1 g were recorded to identify spatial variations in size structure between sampling points. A non-parametric approach was used, as the data did not follow a normal distribution. Therefore, the Kruskal-Wallis test (H) was applied, followed by a Dunn's (1964) *post-hoc* multiple comparison test. To reduce the type I error rate that might arise from the number of comparisons, the *P*-values were adjusted using the Bonferroni correction via RStudio software (RStudio Team 2020).

Growth parameters

The parameters of the von Bertalanffy growth model were estimated using empirical equations based on the maximum length (L_{max}) of the organisms. The asymptotic length (L_∞) was estimated using the equation by Pauly & Morgan (1987):

$$L_\infty = L_{max}/0.95 \quad (1)$$

The growth constant (K) was calculated using the equation given by Moreau et al. (1986):

$$K = 5.4\ (L_\infty)^{-0.6811} \quad (2)$$

The age at birth (t_0) was estimated using Pauly's equation (1979):

$$\log(-t_0) = 0.3922 - 0.2752 \times \log(L_\infty) - 10.38 \times \log(K) \quad (3)$$

Similarly, longevity (T_{max}) was estimated using Pauly's equation (1983):

$$T_{max} = \frac{3}{K} + t_0 \quad (4)$$

The growth performance index (Ø) was used to compare the parameters obtained in the different sampling areas, and was calculated using the equation by Pauly & Munro (1984):

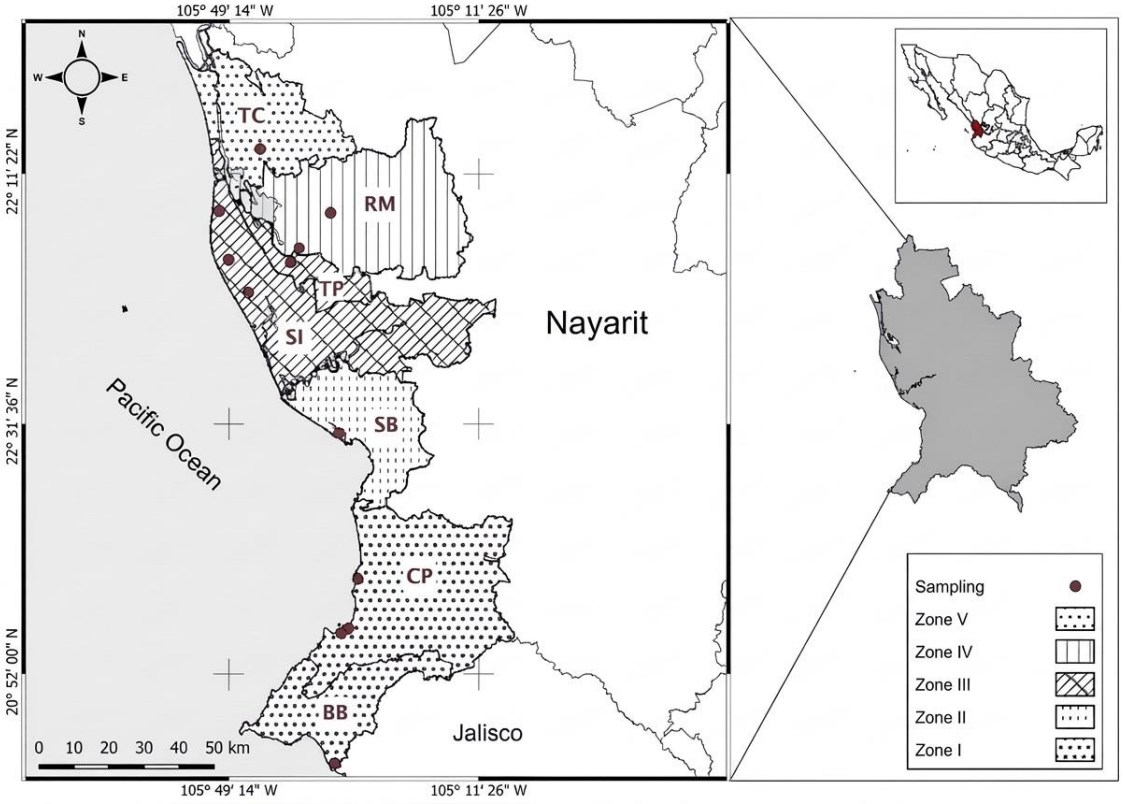


Figure 1. Sampling points of the *M. setosus* mullet fishery on the coast of the state of Nayarit. BB: Bahía de Banderas, CP: Compostela, SB: San Blas, SI: Santiago Ixcuintla, TP: Tuxpan, RM: Rosamorada, TC: Tecuala.

$$Ø = \log(K) + 2 \times \log(L_\infty) \quad (5)$$

The equation by Froese & Binohlan (2000) was used to estimate the length at first sexual maturity (L_m):

$$\log(L_m) = 0.9469 \times \log(L_\infty) - 0.1162 \quad (6)$$

The maximum yield size (L_{opt}) was calculated using the equation by Froese & Binohlan (2003):

$$\log(L_{opt}) = 1.0421 \times \log(L_\infty) - 0.2742 \quad (7)$$

Natural mortality (M) and exploitation rates

M rate was also estimated using the equation proposed by Taylor (1958):

$$M = -\frac{\ln(1-0.95)}{A_{0.95}} \quad (8)$$

where longevity ($A_{0.95}$) is based on the parameters of the von Bertalanffy (1938) growth model:

$$A_{0.95} = t_0 + 2.996/K \quad (9)$$

Total mortality (Z) was estimated using the equation proposed by Beverton & Holt (1959), based on the L_∞ and K parameters of the von Bertalanffy growth model:

$$Z = \frac{K(L_\infty - L)}{(L - L_C)} \quad (10)$$

where L_c is the length of the first catch (cm), and L is the average length of the sample (cm).

Fishing mortality (F) was calculated using the equation:

$$F = Z - M \quad (11)$$

In addition, the optimal fishing mortality (F_{Opt}) and the critical fishing mortality (F_{limit}) were estimated using Patterson's (1992) equation:

$$F_{Opt} = 0.5 \times M \quad (12)$$

$$F_{limit} = 2/3 \times M \quad (13)$$

Similarly, the exploitation rate (E) of the fishery was estimated; this represents the proportion of organisms that died as a result of fishing pressure, in accordance with the equation proposed by Beverton & Holt (1966):

$$E = F / Z \quad (14)$$

Catch per unit of effort (CPUE)

To estimate CPUE, 80 questionnaires were administered to small-scale fishermen engaged in catching *M. setosus*. The surveys collected data on fishing gear characteristics (length, drop, mesh size, etc.), the most commonly used vessels for catching scaly fish, the

Table 1. Characteristics of the fishing gear and vessels used in the *M. setosus* fishery. Ø: performance index.

Fishing net	Length (m)	Width (mesh)	Mesh size (cm)	Ø of thread (mm)	No. networks
Gillnet	70 - 90	50	5 - 7.6	0.27 - 0.35	3
Cast net	2.5 - 3.5	1200 - 1500	2.5 - 7.6	0.35 - 0.40	2
Vessel characteristics					
	Length (m)	Width (m)	Storage (kg)	HP engine power	
Small boat	5 - 9	1 - 2	350 - 1200	8 - 75	

fishing season, and the fishing regime (days and hours spent fishing per month) (Table 1).

Gómez-Muñoz model

The two-stage Gómez-Muñoz model (1990) was used to estimate CPUE per trip. In the first stage, the model parameters were determined from surveys of *M. setosus* fishermen; in the second stage, these parameters were used to estimate each vessel's catch.

Stage 1: parameters and variables

Measures of central tendency (mean or mode) were used to determine the respective parameter values. The mode is required for estimating the month of the start of the fishing season (S_s), duration of the fishing season (L_s), rate of decline in catch (I), and month of maximum catch (M_{max}), whilst maximum catch (C_{max}) and minimum catch (C_{min}) were determined by the mean of the catches per trip recorded by each vessel.

Based on these key parameters, a set of catch curves was estimated and calibrated using survey data. The data provided determined whether the rate of decline in catches after reaching C_{max} was slow (I = 1), moderate (I = 2), or rapid (I = 3), based on the ratio of the time elapsed between the start and end of the fishing season (E_{FS}).

If the decay curve is of the I = 1 type (a slow decay), then:

$$Z_{C1} = \frac{(M_{max}\text{-}S_S)\ I}{(S_S+L_S\text{-}1\text{-}M_{max})} \quad (15)$$

where Z_{C1} is the time elapsed between the start of the fishing season and M_{max}.

If the decline curve is of the type I = 2 or I = 3 (an intermediate or rapid decline), then:

$$Z_{C2} = \frac{(S_S+L_S\text{-}M_{max}\text{-}1)\ I}{(M_{max}\text{-}S_S)} \quad (16)$$

where Z_{C2} is the time elapsed between M_{max} and the end of the fishing season.

Subsequently, the relationship between catches and the duration of the fishing season (x) was calculated based on parameter I, as described below:

If the growth curve is of the type I = 1 (slow), then x is calculated as follows:

$$x = \frac{[(t\text{-}S_S)+Z_{C1}\ (t\text{-}S_S\text{-}l+1)]\ I}{(L_S\text{-}1)} \quad (17)$$

where t is the duration of the fishing season in months.

If the decay curve is of type I = 2 or 3 (intermediate or rapid), then x is calculated as follows:

$$x = \frac{[(t\text{-}S_S\text{-}L_S+1)+Z_{C2}\ (t\text{-}S_S)]\ I}{(L_S\text{-}1)} \quad (18)$$

Subsequently, the bell-shaped function $f(x) = e^{(-(-x^2/2))}$ was used; by restricting the range of the independent variable x and scaling the function values, it was transformed to obtain a curve showing the monthly CPUE per trip per vessel (Ct).

Stage 2: estimation of the monthly catch per trip and per vessel

Once the value of f(x) for each month was known (using a normal distribution function with a maximum coinciding with month M_{max}), CPUE per trip per vessel (Ct) was estimated for the duration of the fishing season (months) using the following equation:

$$Ct = \frac{[C_{max}(f(x)\text{-}f(I))+C_{min}(1\text{-}f(x))]}{(1\text{-}f(x))} \quad (19)$$

The Ct values obtained range between C_{min} and C_{max}.

The variable $f(I) = e^{(-(-I^2/2))}$ was used as a standard function to transform the dependent variable I into a form corresponding to rates of decline in catches: slow (I = 1), medium (I = 2), or rapid (I = 3).

RESULTS

Size structure

During the sampling period, 1,581 *M. setosus* specimens were collected; 1,117 were females, and 464 were

males. Females ranged in size from 15.9 to 38.5 cm, with a mean of 28.3 cm, and in weight from 31.1 to 490 g, with a mean of 25.8 g. Males ranged in TL from 14.8-35.6 cm, with a mean of 25.8 cm; the weight range was 26.3-455 g, with a mean of 156 g. The non-parametric Kruskal-Wallis test revealed highly significant differences in the TL of *M. setosus* among sampling sites ($H(6) = 220$; $P < 0.001$), demonstrating that the size is not homogeneous.

Dunn's *post-hoc* test identified three main groups based on similarity in sizes (Fig. 2). The first group comprised the municipalities of BB, CP, SI and TP; the second group comprised SB and RM; and the third group comprised the municipality of TC.

Based on the above results, the sampling sites were classified into five zones: Zone I comprises the municipalities of BB and CP; Zone II: SB; Zone III: SI and TP; Zone IV: RM; and Zone V: TC (Table 2). Areas comprising more than one municipality are mainly because they share local authorities of similar size and are geographically adjacent. In the case of the municipalities that make up Zone III, although they did not differ in size from Zone I, they were grouped into separate zones because their territories are located a considerable distance apart. They were therefore considered as independent zones. The same criterion was applied to Zones II and IV, as they have similar conditions. This information can be verified on the map showing the study area (Fig. 1).

Zone I (n = 210) had the smallest-sized fish, with a mean total length of 23.9 cm and a range of 13.5-36.5 cm (TL). Zone II (n = 217) had an average length of 28.3 cm and a range of 21-36.6 cm (TL). In Zone III (n = 655), an average size of 26.8 cm was observed, with a range of 18.7-38.5 cm (TL). Zone IV (n = 294) had a mean length of 27.9 cm, ranging from 20.8 to 36.4 cm (TL). Finally, zone V (n = 205) was the zone with the largest sizes, with a mean of 30.9 cm and a range of 23.8-36.6 cm (TL) (Fig. 3).

von Bertalanffy growth parameters

The species exhibited an L_∞ ranging from 38.3 to 40.5 cm among the five zones, with the largest asymptotic length (40.5 cm) recorded in Zone III and for the total sample. K values ranged from 0.43 to 0.45 yr^{-1}, with a constant growth of K = 0.43 yr^{-1} calculated for the overall sample. Among the zones studied, the highest value was recorded in Zone IV (0.45 yr^{-1}). The estimate of age at birth showed no significant variation in this case (0.42-0.43 yr^{-1}); in both the overall sample and Zone III, was estimated at 0.43 yr^{-1}, whereas the remaining zones showed a t_0 of 0.42 yr^{-1} (Table 3). The estimated longevity (T_{max}) for the total sample was 7.34 years. Zone III had the highest longevity (T_{max} = 7.34 year), which was consistent with the overall result, whilst the lowest longevity was found in Zone IV (T_{max} = 7.07 year). The growth performance index for the total sample was Ø = 2.85, matching that found in Zone III. For the remaining zones, an index of Ø = 2.82 was calculated (Table 3).

The estimated length at first maturity (L_m) for the total sample of *M. setosus* was 25.4 cm (Table 4), whilst in the different zones this parameter ranged around 24 cm, except for Zone III (25.4 cm). The size at maximum yield was L_{opt} = 25.18 cm (total sample and Zone III) and in the remaining zones did not exceed 23 cm. Because the difference between the average size at maturity and the size at maximum yield was minimal, only 22.52% of the organisms were caught below the sizes estimated by these parameters, ensuring that most of the population had reproduced at least once.

Mortality coefficients (M) and exploitation rate (E)

M calculated for the entire sample and for Zone III was 0.40. In contrast, Zones I, II, IV, and V had an estimated value of 0.42. The lowest F were found in Zones I, II and IV (0.20-0.23), in contrast to Zones III and V, which had F values of 0.32 and 0.74, respectively. Z values ranged from 0.62 (Zones I and II) to 1.16 (Zone V), with a Z value of 0.63 for the total sample (Table 4). Taking the Z value of the overall sample as a reference, the annual survival rate $S = e^{-Z}$ was estimated using Ricker's conventional method (1975), yielding S = 0.532, indicating that 53.2% of the population survives the year and 46.8% dies. Similarly, if Z is set to 100% and the male-to-female ratio is calculated on that basis, 63.4% of the population dies naturally and 34.9% as a result of fishing. Furthermore, the estimated E of the fishery for the entire sample was 0.35, whilst the remaining zones showed a range of 0.32-0.63, with zone V (E = 0.63) exhibiting the highest E for the sand smelt *M. setosus*.

Biological reference points

The estimated values for F_{opt} were 0.20 for both the overall sample and Zone III, whilst for the remaining zones they were 0.21. Furthermore, estimated F_{limit} values showed little variation, with the lowest value in zone III (F_{limit} = 0.27), as in the entire sample. Zones I, II, IV and V, meanwhile, had a F_{limit} of 0.28 (Table 4). Following the proportionality example given in the previous section, the ideal F rate to ensure a healthy fishery is 31.7% for the entire sample, whilst the maximum F rate is 42.8%.

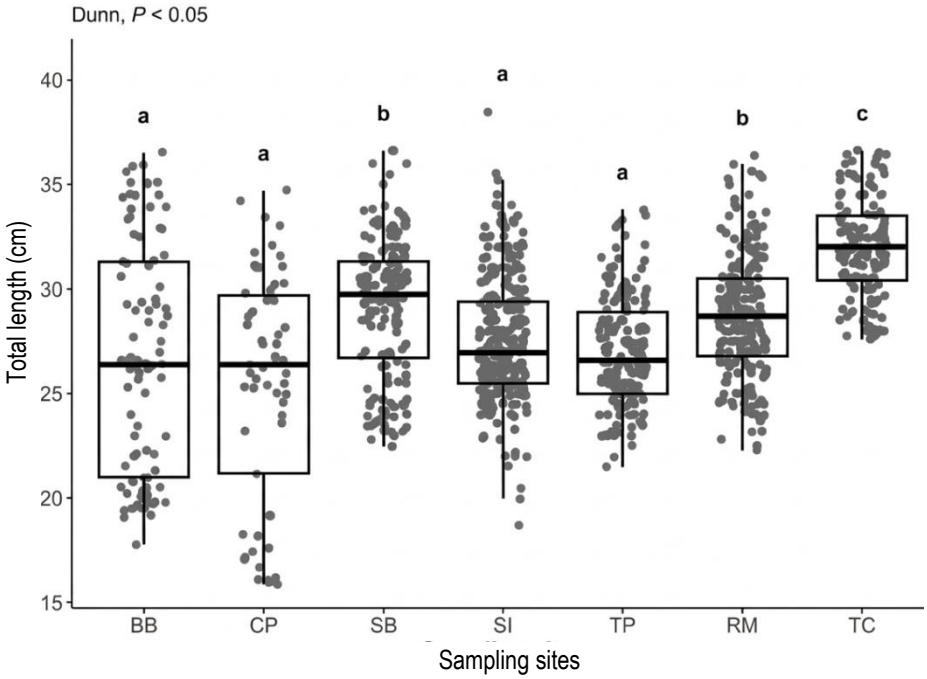


Figure 2. Comparison of sizes of *M. setosus* mullet between sampling sites. BB: Bahía de Banderas, CP: Compostela, SB: San Blas, SI: Santiago Ixcuintla, TP: Tuxpan, RM: Rosamorada, TC: Tecuala. Different letters indicate significant differences between sampling sites.

Table 2. Delimitation of sampling points by zones, number of organisms (n), and sizes of *M. setosus*. BB: Bahía de Banderas, CP: Compostela, SB: San Blas, SI: Santiago Ixcuintla, TP: Tuxpan, RM: Rosamorada, TC: Tecuala, LT: total length.

Zone	Town	n	Females/males	Size LT mean/range (cm)
I	BB and CP	210	150 / 60	23.9 / (13.5-36.5)
II	SB	217	160 / 57	28.3 / (21.0-36.6)
III	SI and TP	655	457 / 198	26.8 / (18.7-38.5)
IV	RM	294	213 / 81	27.9 / (20.8-36.4)
V	TC	205	137 / 68	30.9 / (23.8-36.6)

Estimation of catch per unit effort (CPUE)

Two types of fishing gear were used to catch *M. setosus*: gillnets and cast nets (Table 1). The first and most commonly used type measures up to 90 m in length, with 50 vertical meshes and a minimum mesh size of 5 cm; up to three nets of this type are used per vessel. Second, they used cast nets with a maximum length of 3.5 m and a minimum mesh size of 2.5 cm, with up to two nets per vessel. Small vessels, up to 9 m in length, were also used and were equipped with an outboard motor with a minimum power of 8 hp.

Regarding fishing regulations, the fishing season for *M. setosus* in the state of Nayarit runs from July to March, with a fixed closed season from April to June. During the season, fishermen fish an average of 20 days per month, with about 4 h of active fishing per day, and set 3-4 sets (gillnets) per trip.

The parameter values used to feed the model are set out in Table 5. According to the model's projections, catch levels for the sample as a whole show a relatively small increase, remaining stable from the start of the fishing season (July) through to September. Subsequently, in October, catches increased markedly, peaking in March (Fig. 4). The highest CPUE was 171 kg trip^{-1} vessel^{-1}, while the lowest was recorded in July, at an average of 63 kg trip^{-1} vessel^{-1}. The estimated

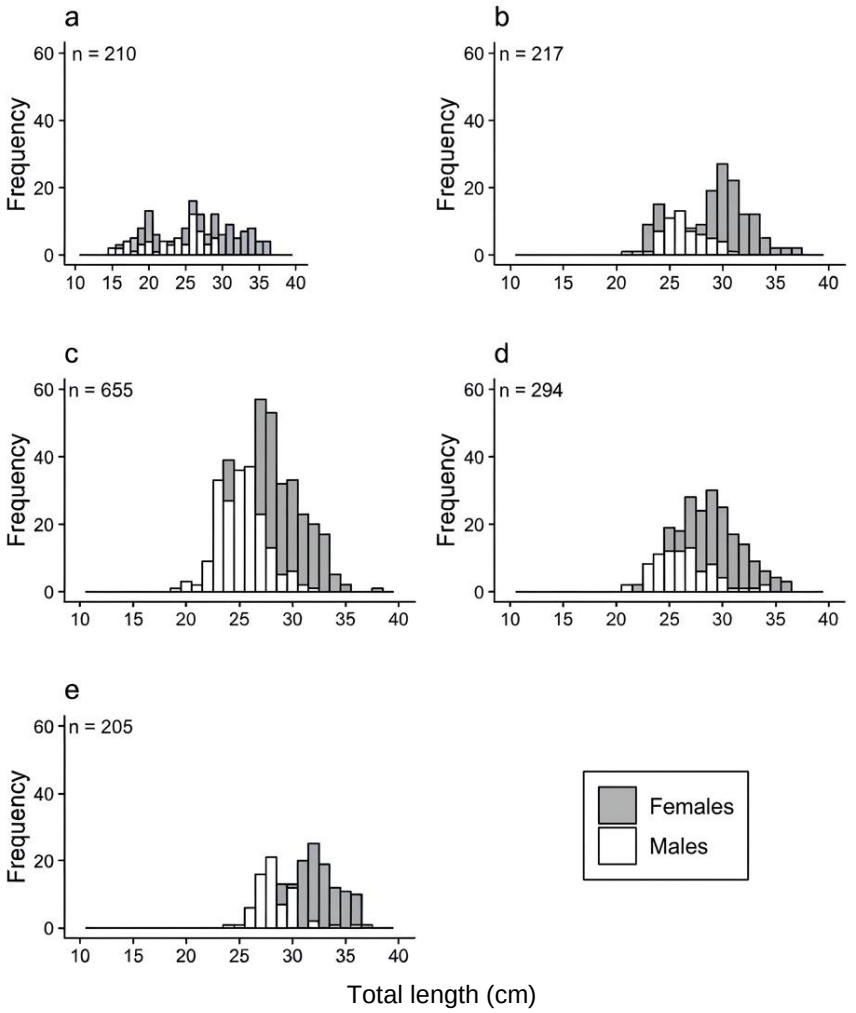


Figure 3. Size distribution of *M. setosus* by classified areas. a) Zone I, b) Zone II, c) Zone III, d) Zone IV, and e) Zone V.

Table 3. Growth parameters (L_∞, K, t_0), longevity (T_{max}) and performance index (Ø) of *M. setosus*. L_∞: asymptotic length, K: growth constant and t_0: age at birth.

Zone	L_∞ (cm)	K (yr^{-1})	t_0 (year)	T_{max}	Ø
I	38.4	0.44	0.42	7.08	2.82
II	38.5	0.44	0.42	7.10	2.82
III	40.5	0.43	0.43	7.34	2.85
IV	38.3	0.45	0.42	7.07	2.82
V	38.5	0.44	0.42	7.10	2.82
Total	40.5	0.43	0.43	7.34	2.85

maximum monthly catch was 3,420 kg, whilst the lowest was 1,260 kg, with an average of 2,167.12 kg $month^{-1}$ $vessel^{-1}$. For each net used, a catch of up to 57 kg was estimated, with an average of 36.11 kg net^{-1} $vessel^{-1}$ (Table 6).

In contrast, Zones I and III had the lowest average CPUE per trip (71.91 and 72.95 kg $trip^{-1}$ $vessel^{-1}$), whereas Zones IV and V had the highest values (Table 6). Zone I recorded an average monthly catch of 1,438.21 and 23.97 kg $vessel^{-1}$ per fishing net used. In

Table 4. Size at first maturity (L_m), size at maximum yield (L_{opt}), mortality parameters (M, F, Z), biological reference points (F_{opt}, F_{limit}), and exploitation rate (E) of the *M. setosus* fishery. M: natural mortality rate; F: fishing mortality; Z: overall mortality; F_{opt}: optimal fishing mortality; F_{limit}: fishing mortality.

Zone	L_m (cm)	L_{opt} (cm)	M	F	Z	F_{opt}	F_{limit}	E
I	24.22	23.82	0.42	0.20	0.62	0.21	0.28	0.32
II	24.28	23.89	0.42	0.20	0.62	0.21	0.28	0.32
III	25.47	25.18	0.40	0.32	0.73	0.20	0.27	0.44
IV	24.16	23.75	0.42	0.23	0.66	0.21	0.28	0.35
V	24.28	23.89	0.42	0.74	1.16	0.21	0.28	0.63
Total	25.47	25.18	0.40	0.22	0.63	0.20	0.27	0.35

Table 5. Parameters of the Gómez-Muñoz model obtained from interviews with *M. setosus* fishermen. S_S: start of the fishing season; L_s: duration of the fishing season; C_{max}: maximum catch per trip; C_{min}: minimum catch per trip; M_{max}: month of maximum catch; E_{FS}: end of the fishing season; I: decrease in catch after the peak.

Model parameters	Zone					
	General	I	II	III	IV	V
S_S	7	7	7	7	7	7
L_s	9	9	9	9	9	9
C_{max} (kg trip^{-1})	171	122.2	187.5	124	191.3	284.3
C_{min} (kg trip^{-1})	63	35.5	90.6	36	53.1	146.2
M_{max}	3	3	3	3	3	3
E_{FS}	4	4	4	4	4	4
I	3	3	3	3	3	3

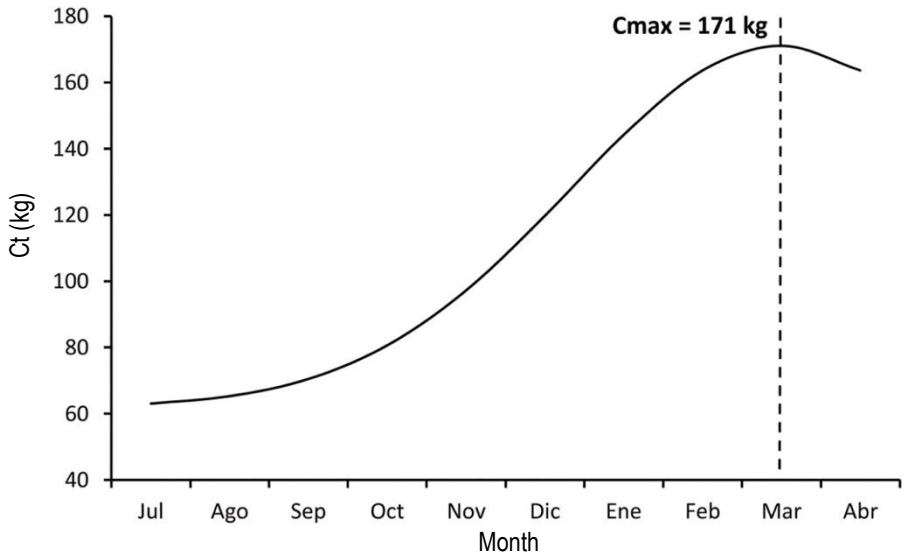


Figure 4. Estimation of the CPUE per trip per vessel (Ct) of the total sample of *M. setosus*. Cmax: maximum catch.

Table 6. Estimated catches by the model per vessel, for the total sample (months) and monthly average of catches by identified zones.

Capture per unit of effort (kg vessel^{-1})			
Months	By fishing net	By trip	By monthly
July	21	63	1260
August	21.75	65.27	1305.40
September	23.49	70.47	1409.51
October	26.8	80.61	1612.34
November	32.41	97.24	1944.86
December	39.92	119.78	2395.78
January	48.07	144.22	2884.50
February	54.52	163.58	3271.69
March	57	171	3420
Mean	36.11	108.35	2167.12
Zone		Monthly mean	
I	71.91	1438.21	23.97
II	131.29	26625.89	43.76
III	72.95	1459.13	24.31
IV	111.13	2222.78	37.04
V	204.19	4083.94	68.06

Zone V, the maximum average monthly catch was estimated at 4,083.94 and 68 kg vessel^{-1} per fishing net used.

DISCUSSION

In the present study, the maximum length of *M. setosus* was found to be 38.5 cm, which is larger than previously reported for a mature female, ranging from 20 cm (Cabrera-Paez et al. 2020), 30 cm (Froese & Pauly 2025), up to 32 cm (Robertson et al. 2024). Females were significantly larger than males (H; $P < 0.05$), a finding also reported for *M. curema* in the Pacific (Villaseñor-Talavera 1988, Ibáñez-Aguirre & Gallardo-Cabello 1996, Cabral-Solís 1999, Ruiz-Ramírez et al. 2017, Sánchez-Venegas et al. 2018). This pattern has been observed in various species because, according to Wootton (1992), organism size determines gamete volume; in other words, females tend to be larger to maximize oocyte production.

The differences observed in size distribution among the areas studied are attributed primarily to the type of fishing gear used for harvesting, as mesh size determines the overall structure of the catch size distribution (Hamley 1975, Millar & Fryer 1999, ICES 2004, Yang & Herrmann 2022), consistent with the design of the fishing gear used in this fishery, given that in Zone I, the sand smelt (*M. setosus*) is mainly caught using cast nets with a minimum mesh size of 2.5 cm, which in turn is consistent with the record of the smallest sizes found at that location. In contrast, in Zones II, III, IV and V, the striped seabream is caught using gillnets with a minimum mesh size of 5 cm, which is why larger individuals were found.

The estimated growth parameters for the species were $L_\infty = 40.5$ cm, $K = 0.43$ yr^{-1}, and $t_0 = 0.43$ year; these values were higher than those reported by Villaseñor-Talavera (1988) in San Blas, Nayarit, who found $L_\infty = 33.8$, $K = 0.34$, and $t_0 = 1.11$ year. In other studies in the Mexican Pacific, Cabral-Solís (1999) reported $L_\infty = 35.8$, $K = 0.21$, and $t_0 = -0.55$ year, while Gallardo-Cabello et al. (2005) in Colima reported similar values for L_∞ (36.47) and K (0.219). In contrast, Ibañez-Aguirre et al. (1999), Meléndez-Galicia & Romero-Acosta (2010) and Salgado-Cruz et al. (2020) estimated L_∞ values greater than 40 cm. However, it is observed that in both this study and those cited previously, values of $K < 0.5$ were found; thus, it is inferred that this species exhibits moderately slow growth. According to Sparre & Venema (1998), this growth type is evident when K is between 0.3 and 0.5 and is common in many coastal species. The growth performance index was Ø = 2.82 across most areas, indicating similar growth throughout the population. These values align with those reported by Cabral-Solís (1999) and Meléndez-Galicia & Romero-Acosta (2010), which ranged from 2.08 to 2.75.

The estimated lifespan ranged from 7.0 years for the overall sample to the identified areas, consistent with Villaseñor-Talavera (1988), who reported a lifespan of 7.5 years in San Blas, Nayarit, for the same species. Other studies conducted in the Mexican Pacific reported lifespans of 13.6 years (Cabral-Solís 1999) and 9.1 years (Meléndez-Galicia & Romero-Acosta 2010). Furthermore, Ibáñez-Aguirre et al. (1999) estimated a lifespan of 17.7 years from otoliths and 14.8 years from scales for *Mugil curema* in the Gulf of Mexico. In most cases, this parameter yields very high values when estimated using direct methods (hard structures).

The highest total mortality rate was estimated for Zone V ($Z = 1.16$), whilst for the total sample it was $Z = 0.63$. The M coefficients in the study were 0.40 for both the total sample and each identified zone; these values were higher than those estimated for F in general, except for Zone V ($F = 0.74$), suggesting that the survival of the stock is not affected by the fishing pressure exerted. A similar pattern was reported in Michoacán (Meléndez-Galicia & Romero-Acosta 2010). In contrast, another study in Nayarit reported $M = 0.26$ and $F = 0.45$ (Villaseñor-Talavera 1988); similarly, in Colima, a higher F (0.60) was reported

(Cabral-Solís et al. 2007). The highest E was found in Zone V (0.63), consistent with Villaseñor-Talavera (1988), whilst the lowest was E = 0.32 (Zones I and II). For the total sample, E = 0.35, which, according to Gulland (1971), indicates that this fishery is under-exploited.

Catch data from inshore fisheries lack reliability and accuracy, as the inability to monitor the number of fishermen makes it difficult to accurately quantify resource extraction. To reduce this bias, various studies have shown that interviews with fishermen and fishing cooperatives provide reliable information for estimating catches of species of interest (Rocha et al. 2004, Young et al. 2006, Comesaña & Guerra 2019, Pacheco-Rovira & Morales-Guerrero 2021, Avendaño et al. 2022). Using the parameters from the Gómez-Muñoz model, researchers could, for the first time, produce a more reliable estimate of the CPUE for *M. setosus*. However, to determine total catch in a specific area, it is essential to have precise figures for the number of fishermen and vessels (Avendaño et al. 2022). Therefore, comprehensive fieldwork should be conducted to gather this information and obtain a more accurate estimate of *M. setosus* catches in Nayarit, which will help better manage the fishery for this species.

This study focused primarily on determining catch volume for individual vessels across Nayarit, rather than estimating the fishery's total catch, because Mexico's official fisheries agency (IMIPAS) records data only on fishermen engaged in scaly-fish fishing and does not specify how many fishermen actually catch this species, making that figure highly ambiguous. According to Ruiz-Domínguez et al. (2023), this is because, in tropical regions, more than one species is fished simultaneously, making it difficult to collect accurate catch and effort data. However, the method applied in this study yielded positive results in estimating true catches for this and other fisheries in Latin America and Spain (Simón et al. 1996, Otero et al. 2005, Pacheco-Rovira & Morales-Guerrero 2021, Avendaño et al. 2022).

CONCLUSIONS

According to von Bertalanffy's growth parameters, *M. setosus* exhibits moderately slow growth, with K values ranging from 0.43 to 0.45 yr^{-1}, and a maximum asymptotic length of L_∞ = 40.5 cm was estimated.

Although mortality parameters generally remain stable, given that M is lower than F (M = 0.40 and F = 0.22), Zone V shows signs of intense fishing pressure, with F exceeding M (F = 0.74), resulting in an E above the level considered optimal (E = 0.63) compared to the estimate for the total sample (E = 0.35), which leads us to pay special attention to the fishing of mullet in this zone.

According to estimates based on biological reference points, the fishery currently operates within narrow exploitation margins, with F_{opt} values of 0.20-0.21 and F_{limit} values of 0.27-0.28, where the F rate must not exceed these values to ensure the sustainability of the species; otherwise, the long-term stability of the resource will be compromised.

According to the CPUE estimated by the Gómez-Muñoz model, mullet catch increases exponentially after the closed season, generally peaking in March at 171 kg $trip^{-1}$ $vessel^{-1}$. Furthermore, Zones IV and V exhibit the highest yields, with a notable monthly CPUE of 4,083.94 kg $trip^{-1}$ $vessel^{-1}$ in Zone V. Finally, it was demonstrated that the Gómez-Muñoz model is a useful tool for estimating CPUE in coastal fisheries, as it collects data directly from fishermen. Therefore, it is considered that this model should be the first step toward a monitoring system that fills the gaps in official information.

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Credit author contribution

D.A. Carrillo-Isiordia & J.M.J. Ruiz-Velazco: conceptualization, validation, methodology, formal analysis, writing-original draft; O.I. Zavala-Leal & J.M.J. Ruiz-Velazco: Funding acquisition, project administration, review, and editing; O.I. Zavala-Leal & F. Valdez-González: methodology, data curation and formal analysis; N. Estrada-Pérez & J.M.J. Ruiz-Velazco: methodology, validation, supervision, review and editing; C.A. González-Huerta & E. Isiordia-Pérez: methodology, formal analysis and review. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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