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Population Aspects of *Pterygoplichthys* sp. (Siluriformes: Loricariidae) in the Champayán Lagoon System, Altamira, Tamaulipas, México.

Aspectos Poblacionales de *Pterygoplichthys* sp. (Siluriformes: Loricariidae) en el Sistema Lagunar Champayán, Altamira, Tamaulipas, México.

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ABSTRACT

A total of 316 individuals of *Pterygoplichthys* sp. from the Champayán Lagoon System (CHLS), Altamira, Tamaulipas, Mexico, were examined during 2023 – 2024, measuring total length (TL) and total weight (TW). Using monthly data analyzed in FISAT II, the length-weight relationship, relative condition factor, growth, mortality, capture probability, and exploitation level were determined. The estimated growth parameters were: $L\infty$ = 453.60 mm, K = 0.340 year^{-1}, t_0 = -0.636 and ϕ = 2.84. The mortality rate values were: Z = 0.830 year^{-1}, M = 0.420 year^{-1}, and F = 0.410 year^{-1}. The exploitation level (E = 0.490) was situated below the optimal level of 0.5, indicating that the species is underexploited and a low level of fishery utilization. The maximum age was 8.31 and 8.98 years, and the value of the length at first capture (L_{50} = 324 mm) was higher than the length of theoretical first sexual maturity (L_m = 236 mm). *Pterygoplichthys* sp. showed continuous recruitment throughout the year. Length-structured virtual population analysis (VPA) showed low natural and fishing mortality in *Pterygoplichthys* sp. for individuals ranging in size from 150 to 340 mm. A stock assessment, based on the study of length frequencies of *Pterygoplichthys* sp. in the CHLS, revealed that moderate growth, longevity, continuous recruitment, and an underexploited state favor its invasion. However, increasing fishing pressure on juveniles (≤ 250.0 mm) will lead to overexploitation and population collapse.

KEY WORDS: Invasive species, northeast, invasive sailfin catfish, Champayán Lagoon System.

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RESUMEN

Se examinaron 316 ejemplares de *Pterygoplichthys* sp. del Sistema Lagunar Champayán (CHLS), Altamira, Tamaulipas, México entre 2023 – 2024, midiendo longitud (TL) y peso total (TW). Con datos mensuales analizados en el software FISAT II, se determinó la relación longitud-peso, factor de condición relativa, crecimiento, mortalidad, probabilidad de captura y nivel de explotación. Los parámetros de crecimiento estimados fueron: $L\infty$ = 453.60 mm, K = 0.340 año^{-1}, t_0 = -0.636 y ϕ = 2.84. Los valores de la tasa de mortalidad fueron: Z = 0.830 año^{-1}, M = 0.420 año^{-1} y F = 0.410 año^{-1}. El nivel de explotación (E = 0.490) se situó por debajo del nivel óptimo de 0.5, lo que sugiere un estado de subexplotación y un bajo nivel de aprovechamiento pesquero. La edad máxima fue de 8.31 y 8.98 años y el valor de la longitud en la primera captura (L_{50} = 324 mm) fue superior a la longitud de la primera madurez sexual teórica (L_m = 236 mm). Pterygoplichthys sp. mostró un reclutamiento continuo a lo largo del año. El análisis de población virtual estructurado por longitud (VPA) mostró una baja mortalidad natural y por pesca en *Pterygoplichthys* sp. de tallas comprendidas entre 150 y 340 mm. Una evaluación poblacional basada en frecuencias de talla de *Pterygoplichthys* sp. en el CHLS reveló que un crecimiento moderado, longevidad, reclutamiento continuo y un estado de subexplotación favorecen su invasión. No obstante, incrementar la presión pesquera sobre juveniles (≤ 250.0 mm) propiciará la sobreexplotación y el colapso poblacional.

PALABRAS CLAVE: Especies invasoras, noreste, pez diablo invasor, Sistema Lagunar Champayán.

Introduction

Species of the Loricariidae family, such as *Pterygoplichthys pardalis*, *Pterygoplichthys disjunctivus*, and *Pterygoplichthys multiradiatus*, are regarded as exotic-invasive species, causing problems for aquatic ecosystems (Orfinger & Goodding, 2018) and fisheries, due to their rapid growth, reproductive and invasive success, and parental care (Sumanasinghe & Amarasinghe, 2013; Gibbs *et al*., 2013; Sousa *et al*., 2019; Raj *et al*., 2019; Aida *et al*., 2021). One problem posed by these species is that, once established, they are almost impossible to eradicate (Hill & Sowards, 2015).

An interesting fact is that these organisms, being popular as ornamental fish, were introduced incidentally into different ecosystems around the world (Orfinger & Goodding, 2018). In Mexico, it was first recorded as an invasive species in 1995 in the state of Guerrero (Guzmán

Revista Bio ciencias
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& Barragán, 1997); subsequently, it has been documented in several aquatic ecosystems of the southeast and southwest (Mendoza-Alfaro *et al*., 2007), as well as in the northwest (Ruiz-Campos *et al*., 2014), northeast (Amador-del Ángel *et al*., 2014; Mendoza-Ilizaliturri *et al*., 2022), and central Mexico (Mejía-Mojica *et al*., 2015). However, according to Mendoza-Alfaro *et al*. (2007), today the invasive sailfin catfish is considered one of the greatest threats to the biodiversity of continental ecosystems in Mexico and its freshwater fisheries.

In Mexico, several studies have been conducted on *Pterygoplichthys* spp., such as the research by Wakida-Kusunoki & Amador-del Ángel (2011), which examined the population of *Pterygoplichthys* pardalis in the Palizada River, Campeche. Castillo *et al.* (2014) analyzed the population structure of *Pterygoplichthys* spp. in the Chacalapa basin, Veracruz. Cruz (2016) evaluated some population and biological aspects of the genus *Pterygoplichthys* in the aquatic systems of the Veracruz metropolitan area, while Chávez (2022) studied the population dynamics of *Pterygoplichthys* spp. in the Amacuzac River and the Emiliano Zapata dam, Morelos. These studies on the invasive sailfin catfish contribute to future research focused on its management and control.

The Champayán Lagoon System constitutes a hydraulic network located in the southern part of the state of Tamaulipas. This system serves as a means of communication for fishing communities and is the main source of water for domestic and industrial use in the metropolitan area, which includes the municipalities of Altamira, Ciudad Madero, and Tampico (CONAGUA, 2012). The environmental services that this lagoon system provides to society include direct benefits, such as the supply of drinking water and food through aquaculture and fishing (González-Castillo *et al*., 2024). However, the presence of various introduced species of socioeconomic relevance to fishermen has been identified (CONAPESCA, 2008). Furthermore, the presence of the invasive sailfin catfish was expected, given the region's hydrological interconnectivity.

Pterygoplichthys spp. is a group of invasive fish widely distributed worldwide, including Mexico, and invasive behavior in a wide variety of ecosystems, would be expected to be underexploited in water bodies in southern Tamaulipas. However, to date, no studies have been conducted on the biology and population dynamics of this invasive species in the Champayán Lagoon System. Furthermore, no study has been conducted to determine whether there is more than one species, as only *Pterygoplichthys* sp. has been reported (Mendoza-Ilizaliturri *et al*., 2022). However, based on specimens collected from around the world and from the aquarium trade, Wu *et al.* (2011) and Godwin *et al.* (2016) concluded that their morphology falls between *P. pardalis* and *P. disjunctivus*, suggesting they should be considered hybrids.

The relevance of this work is to understand the population dynamics of *Pterygoplichthys* sp. in the Champayán Lagoon System through means of length-based population assessment methodologies. This work could serve as a reference for future studies aimed at mitigation to reduce the impact of its populations, as well as the possibility of further increases in exploitation as a control strategy.

Material and methods

Revista Bio ciencias
ISSN 2007-3380

Study Area

The Champayán Lagoon System (CHLS) is located in the municipality of Altamira, in the state of Tamaulipas, at coordinates 22°23’10.94”N and 98°0’33.52”W. It is a body of water fed by the Guayalejo-Tamesí River with an approximate surface area of 213 km², a length of 38.4 km, and an average width of 5.6 km. The average recorded depth is 1.5 m, with a maximum depth of 5.9 m (Figure 1). The predominant climate in the region is warm subhumid with summer rainfall. The average annual temperature exceeds 22°C throughout the year; the highest values are recorded between May and September, fluctuating between 25°C and 29°C, and occasionally exceeding 40°C. The rainy season generally runs from June to October, with an average annual rainfall of 1,043 mm. September is the wettest month, averaging 250 mm, while the driest season runs from November to May. January and February are the driest months, with averages of 21.1 mm and 28.0 mm, respectively. These temperature and precipitation conditions result in a hot, humid summer and a dry, cold winter (CONAGUA, 2012).

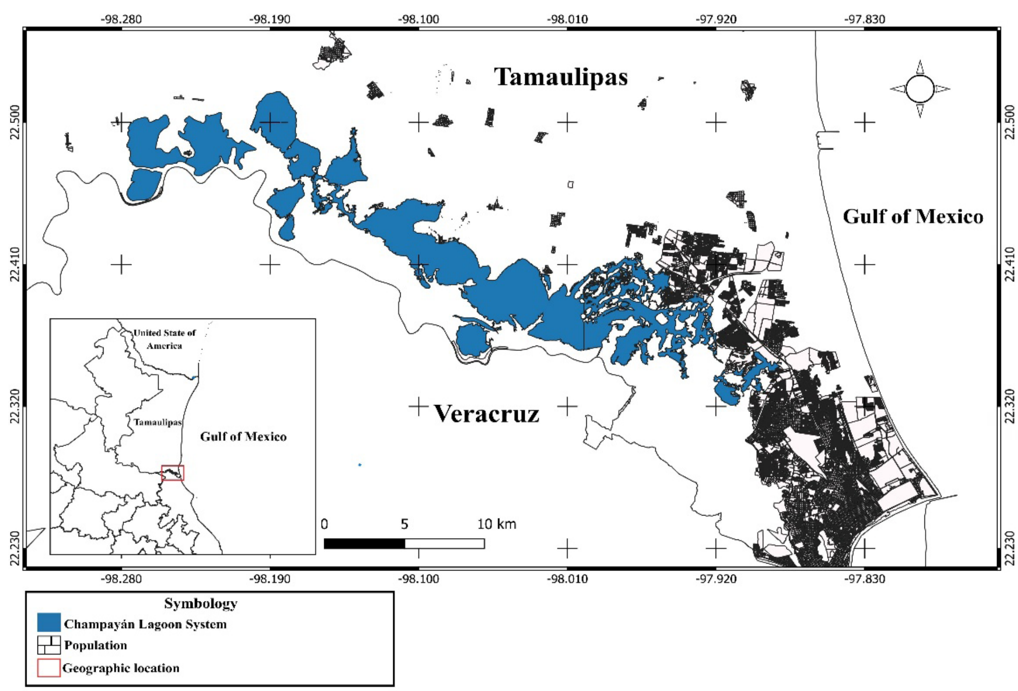

Figure 1. Location of the Champayán Lagoon System, Altamira, Tamaulipas.

Source: Own elaboration based on QGIS 3.38 Grenoble.

Sample Collection

Sampling of the invasive sailfin catfish was carried out through artisanal fishing between August 2023 and July 2024. The organisms were obtained using gillnets with mesh sizes of 10.47 and 11.43 cm. Total length (TL; mm) was recorded using an ichthyometer, and total weight (TW; g) of each individual was measured using an Ohaus digital scale with an estimated precision of 0.01 g. The identification of the invasive sailfin catfish was based on visible morphological characteristics, such as body shape, fin arrangement, ventral sucker mouth, and armoured head (Wakida-Kusunoki *et al*., 2007; Golani & Snovsky, 2013; Amador-del Ángel & Wakida-Kusunoki, 2014). Since *Pterygoplichthys* is the only genus of loricariids reported in the CHLS (Mendoza-Ilizaliturri *et al*., 2022), the identifications were assigned to this genus. It is important to mention that the species could not be identified due to the several variations in ventral coloration patterns, which do not correspond to *Pterygoplichthys pardalis* or *Pterygoplichthys disjunctivus*, since, according to several authors, there are hybrids between these two species (Wu *et al*., 2011; Bijukumar *et al*., 2015; Hussan *et al*., 2019).

Frequency of sizes, length-weight relationship, and relative condition

The length-frequency distribution analysis of the total length (TL; mm) of the collected fish was performed monthly, with the number of intervals calculated using Sturges' rule (Scherrer, 1984):

(Equation 1) $$K = 1 + 3.32\,(\mathrm{Log}_{10}\mathrm{n})$$

Where K = number of class intervals, n = total number of samples, with 10 being the number of intervals, which allowed for greater detail in the size structure of the invasive sailfin catfish.

To establish the corresponding stage of the collected specimens, the reference was taken from Nico (2010) and Nico *et al*. (2012), who consider the juvenile stage to be ≤ 250.0 mm and the adult stage to be ≥ 250.1 mm.

The length-weight relationship was estimated using the potential model:

(Equation 2) $$Y = aX^{b}$$

Where "a" is the intercept (initial growth coefficient) and "b" is the slope (allometry coefficient), under the assumption that if b < 3 there is negative allometric growth, if b = 3 the growth is isometric and if b > 3 the growth presented by the species is positive allometric growth (Berhan *et al*., 2019). The relative condition factor was estimated following the Le Cren (1951) equation:

(Equation 3) $$K = W / aL^{b}$$

Revista Bio ciencias
ISSN 2007-3380

Growth, Mortality, Age, and Exploitation Level

The growth of the invasive sailfin catfish was described using the von Bertalanffy model (1938), whose mathematical expression is:

(Equation 4) $$L_t = L\infty * [1 - e^{(-K*(t-t_0)})]$$

Subsequently, the growth performance index or phi-prime (Φ) was calculated using the Munro & Pauly (1983) equation:

(Equation 5) $$\phi = \mathrm{Log}(K) + 2 * \mathrm{Log}(L\infty)$$

t_0 was estimated using the empirical equation by Pauly (2024):

(Equation 6) $$\mathrm{Log}_{10}(-t_0) = -0.392 - 0.275 * \log 10\, L\infty - 1.038 * \log 10 K$$

For mortality rates, the total mortality value (Z) was calculated using the length-converted catch curve (Pauly, 1983). Natural mortality (M) was estimated using Pauly's empirical equation and a mean surface water temperature (T) of 29°C (Pauly, 1980):

(Equation 7) $$\mathrm{Log}\, M = -0.0066 - 0.279\, \mathrm{Log}\, L\infty + 0.6543 \log K + 0.4634 \log T.$$

The instantaneous fishing mortality rate (F) was obtained by subtracting M from Z:

(Equation 8) $$(F = Z - M)$$

The exploitation level was estimated based on the equation of Pauly & Munro (1984):

(Equation 9) $$E = F / (F + M)$$

The maximum age of the species was estimated using the equation proposed by Taylor (1958):

(Equation 10) $$A_{0.95} = t_0 + 2.996/K$$

Where $A_{0.95}$ is the maximum age or time required to reach 95 % of maximum length ($L\infty$).

Maximum age was also determined using the Pauly (1980) model:

(Equation 11) $$3/K$$

Where K represents the annual growth coefficient.

Recruitment, Length at First Capture, and Length at First Maturity

The recruitment pattern was determined following the procedures described by Gayanilo *et al*. (2005) and Pauly (1983). Using asymptotic length (L_∞) and growth coefficient (K) as input parameters, annual recruitment pulses were reconstructed by inverse projection of size frequency data.

The vulnerability of selected length groups (L_{25}, L_{50}, and L_{75}) was estimated using the length-converted catch curve method (Pauly, 1984; Gayanilo *et al*., 2005). Where L_{25} = length at which the gear retains 25 % of the fish entering the trawl; L_{50} = length at which 50 % of the fish are retained by the gear and considered equivalent to the mean length of the fish at first capture (L_{c50}); L_{75} = length at which 75 % of the fish are retained. The length at first sexual maturity (L_{m50}, mm) for *Pterygoplichthys* sp. The length of the sample was estimated using the equation proposed by Froese & Binohlan (2000), as follows:

(Equation 12) $$L_m = 0.8979 * \log(L\infty) - 0.0781$$

Length-Structured Virtual Population Analysis (VPA)

This analysis employed the modified method of Jones & Van Zalinge (1981) and Gayanilo *et al*. (2005). The input parameters were L_∞, K, M, F, and the length-weight relationship constants (a and b).

Data Analysis

The FiSAT II software (Gayanilo *et al*., 2005) was used to evaluate the population parameters of *Pterygoplichthys* sp. Growth parameters, including asymptotic length (L_∞) and growth coefficient (K), were estimated using the ELEFAN I routine, and the growth performance index or phi prima (Φ) was also calculated (Pauly & Munro, 1984). Total mortality (Z), natural mortality (M), and fishing mortality (F), as well as exploitation level (E), recruitment pattern, and size at first capture (L_{c50}), were determined using the ELEFAN II routine (Pauly, 1983). Additionally, a size-structured Virtual Population Analysis (VPA) was performed. The allometric coefficient of the length-weight relationship was verified using a Student's t-test with SPSS software.

Results and Discussion

Pterygoplichthys sp., commonly known as the invasive sailfin catfish or pleco, is an exotic-invasive species in the CHLS. However, its introduction into this body of water is uncertain. It has been suggested that the species may have been introduced through accidental escapes from aquariums or through being kept as a household pet (Mendoza-Alfaro *et al*., 2007). This is because aquarists especially value juvenile specimens due to their ability to control algal growth in home aquariums (Sumanasinghe & Amarasinghe, 2013). Several species of invasive sailfin

Revista Bio ciencias
ISSN 2007-3380

catfish or pleco are likely present in the waters of the CHLS and the Tamesí River, as well as in other bodies of water in southern Tamaulipas. According to Mendoza-Alfaro *et al*. (2007) has suggested the presence of several species of the genera *Hypostomus* spp. and *Pterygoplichthys* spp. in the country; in addition, possible hybrids have been reported. Wu *et al*. (2011) suggested a potential hybrid origin among the introduced *Pterygoplichthys* species, which exhibited more aggressive behavior that may have enhanced their adaptability to established ecosystems. At present, the limited research on invasive species in the CHLS constrains the understanding of their current status and the ecological and social impacts they may impose on the region.

Size Frequency, Length-Weight Relationship, and Relative Condition

The results were obtained from 316 invasive sailfin catfish organisms. The size range was 153 to 428 mm (mean 301.7 ± 58.71), and they weighed 28 to 556 g (mean 259.4 ± 136.6). The highest proportion of organisms was observed between 264 and 373 mm, accounting for 62.34 % of the captured population (Figure 2).

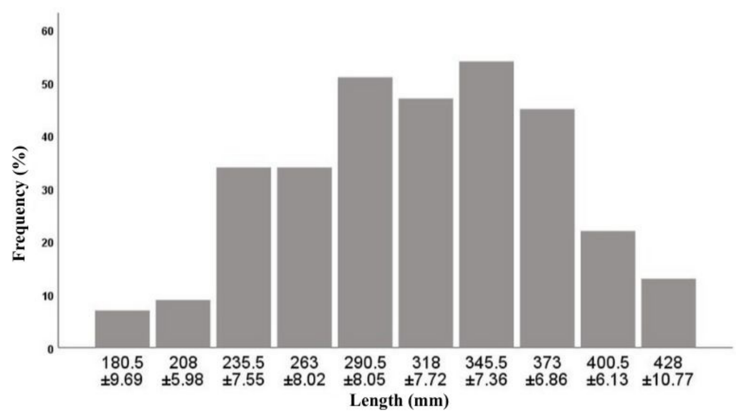

Figure 2. Size frequency distribution of *Pterygoplichthys* sp.

Source: Own elaboration based on SPSS software

The maximum size captured recorded in this study was 428 mm. However, this value was higher than that reported by Wakida-Kusunoki & Amador-del Ángel (2011), who obtained a maximum size of 422 mm for *P. pardalis*, and by Castillo *et al*. (2014), who reported a maximum size of 390 mm for *P. pardalis*, Cruz (2016), where the predominant maximum size in *P. pardalis*

Revista Biociencias
ISSN 2007-3380

and *P. disjunctivus* was 350 mm, while in *P. multiradiatus* was 340 mm. Cruz (2016) mentions that organisms of this genus reported nationally do not exceed 535 mm. However, the data on the maximum length it can reach in the wild are still being modified since new reports continue to be submitted, such as that recorded by Chávez (2022), who to date has recorded the largest size of 555 mm in *Pterygoplichthys* spp. in the state of Morelos. These differences or similarities may be directly due to the fishing gear used, since in some cases invasive sailfin catfish are collected from commercial fishing and others from experimental nets, which affects the size of the captured fish (Chávez, 2022). For example, smaller sizes, which have not been fully captured, tend to be underrepresented in length-frequency analysis. Similarly, when the fishing technique is directed toward larger-sized fish, this problem may reoccur (Ralston, 1990). Furthermore, Wilson *et al.* (2015) mention that the combined use of different fishing gears provides more precise estimates of individual parameters and presents significantly lower variance compared to the use of a single fishing gear type when estimating the von Bertalanffy growth model. This combination can improve the representativeness of the sample and optimize the estimation of said growth model.

In this lagoon system, 70 organisms in the juvenile stage (≤ 250.0 mm) were collected, which represented 22.08 % of the population, with the months of July to September having the greatest abundance. Likewise, 246 organisms in the adult stage (≥250.1 mm) were obtained, 77.92 % of the population, with the months of May, December, and January having the greatest abundance (Figure 3).

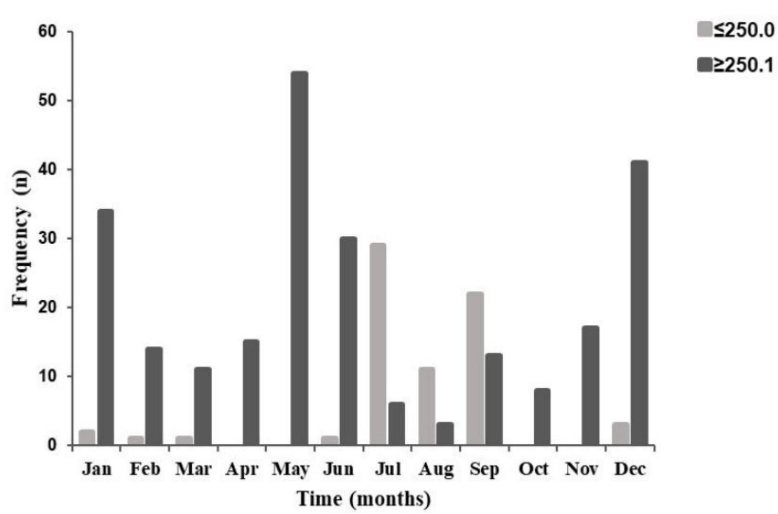

Figure 3. Distribution of stages of *Pterygoplichthys* sp.

Source: Own elaboration based on SPSS software.

Revista Bio ciencias
ISSN 2007-3380

According to the criteria by Nico (2010) and Nico *et al*. (2012), the highest record of organisms in the adult stage occurred in the summer seasons. This may be related to the breeding season, because it is the period of greatest activity of these organisms; which increases their capture, and therefore an increase in the capture per unit of effort (Wakida-Kusunoki & Amador-del Ángel, 2011). Likewise, the beginning of said behavior results in the increase of organisms in size and weight (Chávez, 2022) and gonadal development, which occurs in the warm months, extending from April to October (Castillo *et al*., 2014). This behavior for this study is similar to that reported by Chávez (2022) who observed an increase in reproductive activity with the highest capture of adults in the months of April to July, while Castillo e*t al.* (2014) observed greater activity in the months of June and July in Chacalapa, Veracruz, and Rueda-Jasso *et al*. (2013) reported greater increases in activity from July to September in the "Infiernillo" dam in Michoacán. Other factors such as temperature, resource availability, and biotic interactions (competitors and predators) are key elements that benefit the maturity and reproduction of fish species, leaving the juvenile stage to enter the adult (reproductive) stage (Alp *et al*., 2003). It has been documented that in species of the genus *Pterygoplichthys*, individuals reach their first reproductive phase at shorter lengths ($\leq$ 250 mm; 130 to 220 mm) (Samat *et al*., 2016; Sousa *et al*., 2019; Tamsil *et al*., 2024). These organisms are classified as juveniles in another research (Nico, 2010; Nico *et al.,* 2012; Hossain *et al.,* 2018)

Regarding the length-weight relationship of *Pterygoplichthys* sp., a statistically significant difference was recorded ($t = 0.001$, $p < 0.05$). A value of $b = 3.029$ was determined, which evidenced isometric growth. The following equation was also established: ($TW = 0.007 * TL^{3.029}$ $r = 0.953$) (Figure 4). Other studies have reported in invasive sailfin catfish with a value of ($b < 3.0$; Wakida-Kusunoki & Amador-del Ángel, 2011; Chávez, 2022), which means that according to these authors these organisms are preferentially increasing their length more than their weight, indicating that this species has a relatively slow growth rate and consequently tends to decrease its weight (Jisr *et al*., 2018). Likewise, Castillo *et al*. (2014) recorded a value of ($b < 3.0$) for male individuals and ($b > 3.0$) for females, which means that females gain more weight per unit of size than males. On the other hand, Cruz (2016) reported a value of $b > 3.0$ for females, whereas for males he obtained $b = 3.0$. The latter value is consistent with the results of the present study, indicating that length and weight increased proportionally (Balai *et al*., 2017). Likewise, the relative condition factor (Kn) indicates the well-being/condition of the fish. It was estimated to be $Kn = 1.04$, which revealed a normal growth condition, under the assumption that $Kn \geq 1$ indicates a better growth condition, while $Kn < 1$ indicates a poor growth condition (Maurya *et al*., 2018). Factors that influence the well-being/growth condition of fish include food availability, diseases, and physicochemical factors of the habitat environment (Le Cren, 1951; Jisr *et al*., 2018), so the invasive sailfin catfish in the present study could have the necessary resources available for optimal growth, such as: lack of predators, variability in water quality, food availability, high concentration of organic matter from domestic and industrial activities, since the latter has a strong correlation between the density and survival of the invasive sailfin catfish in contaminated sites (Escalera-Vázquez *et al*., 2019; Elfidasari *et al*., 2020a, 2020b). According to González-Castillo *et al*. (2024), zones of eutrophication and hypoxia have been detected in the CHLS, as well as high concentrations of ammoniacal nitrogen, however, *Pterygoplichthys* sp. It can tolerate poor water quality, as well as excess nitrogen in the form of ammonia and nitrate, which are harmful to other species (Wei *et al*., 2018).

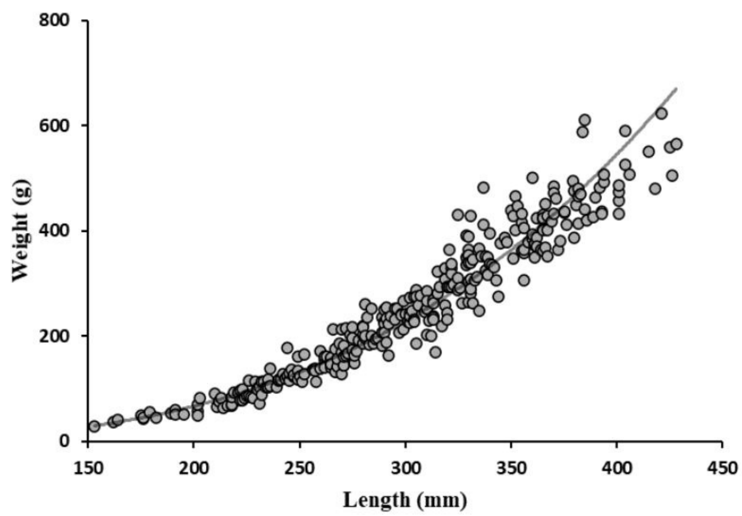

Figure 4. Relationship between length and weight variables of *Pterygoplichthys* sp.

Source: Own elaboration based on SPSS software.

Growth, mortality, and age

The growth parameters of *Pterygoplichthys* sp. In the CHLS presented the following values: L∞ of 453.60 mm, the K value was 0.340 year^{-1}, and t_0 was -0.636. The L∞ and K values obtained in this study are within the range reported for various species of the genus *Pterygoplichthys* in research carried out in different regions of the world (Gibbs *et al*., 2013; Sumanasinghe & Amarasinghe, 2013; Sousa *et al*., 2019; Raj *et al*., 2019; Wickramaratne *et al*., 2020; Aida *et al*., 2021; Chávez, 2022). However, L∞ of the present study was higher in most cases than reported (Sumanasinghe & Amarasinghe, 2013; Sousa *et al*., 2019; Wickramaratne *et al*., 2020; Aida *et al*., 2021). The highest value of L∞ (791.0 mm) was recorded in *P. pardalis* in Morelos, Mexico (Chávez, 2022), while the lowest value L∞ (331.0 mm) was observed in *P. disjunctivus* in Sri Lanka (Wickramaratne *et al*., 2020).

The K value determines the rate at which a species approaches its L∞ and has been linked to longevity or lifespan of species (Beverton & Holt, 1959). The K value in this study was found to be very close to the results of previous research (Sumanasinghe & Amarasinghe, 2013; Sousa *et al*., 2019; Wickramaratne *et al*., 2020). The maximum K value (0.53 year^{-1}) was observed in *P.*

Revista Bio ciencias
ISSN 2007-3380

pardalis in Indian waters (Raj *et al*., 2019), while the lowest value (0.13 year^{-1}) was also recorded in *P. pardalis* in Morelos, Mexico (Chávez, 2022). Generally, higher L_∞ values are associated with lower K values and vice versa. As K values decrease, the longevity of the organism tends to increase, whereas when K values are higher, the organism's lifespan is shorter (King, 1995, 2007). In this context, according to the age estimation based on size frequency using the von Bertalanffy model, invasive sailfin catfish in Indian exhibit a higher K value, suggesting faster initial growth but shorter lifespan. In their first year, they reach a length of 38 mm and in the second, 224 mm, achieving a near-asymptotic size around 15 years of age. On the other hand, invasive sailfin catfish in Morelos, Mexico, have a lower K value but greater longevity, growing 68 mm in the first year and 151 mm in the second, reaching an asymptotic length at 38 years, which so far represents the highest L_∞ value and the lowest K value. For the invasive sailfin catfish in the CHLS, the growth curve described an asymptotic pattern, with an initial growth of 52 mm during the first year. In the second and third years, growth is moderately rapid, while in subsequent years the growth rate gradually decreases. Although the model projection suggests that the species would reach its theoretical maximum length around 25 years, the maximum observed longevity (t_{max}) in this study ranged from 8.31 to 8.98 years (Taylor, 1958; Pauly, 1980). This value is higher than that reported in other studies (5.66 – 7.31 years; Sousa *et al*., 2019; Raj *et al*., 2019), suggesting that the population in the CHLS has greater survival or that habitat conditions are so favorable that they allow individuals to live longer. This finding is not contradictory but rather reflects the nature of the model: while the sampled individuals reach a biological age close to 9 years, the low curvature ratio (K) indicates that theoretically they would require a longer period to stabilize their total growth. It is worth noting that this projected longevity figure represents the second highest value compared to that reported by other authors, whose observed lifespan usually ranges between 6 and 18 years. (Gibbs *et al*., 2013; Sumanasinghe & Amarasinghe, 2013; Sousa *et al*., 2019; Aida *et al*., 2021). The increase in fish length will decrease as their age increases, since each organism's growth rate is closely related to its age. Young fish typically experience faster growth compared to adults. Although the growth of longer-lived fish will continue, it will do so more slowly, given that the proportion of energy derived from food decreases, while the energy allocated to reproduction, maintenance of physical condition, and regeneration of damaged cells increases with age (Suwarni & Sri, 2021). The Loricariidae family is large, making it challenging to define age and growth characteristics across species. However, it has been determined that its asymptotic length can range between 350 and 750 mm, since these growth patterns can be influenced by the environmental pressure that affects the organism, including factors such as eating habits, seasonality, fishing activity, and temperature, among others (Canosa & Bertucci, 2023).

In relation to the estimation of growth parameters, the growth performance index or phi-prime (Φ) in the present study was 2.84, which relates the parameters of L_∞ and K. Both differences and similarities were identified among loricariids worldwide. Likewise, Sumanasinghe & Amarasinghe (2013) reported a value of Φ = 2.71) for *P. pardalis*, while Gibbs *et al.* (2013) documented values of Φ 3.10 and 2.84) for *P. disjunctivus,* and Raj *et al*. (2019) recorded a value of Φ = 3.10) for *P. pardalis*. However, the estimated growth rate (K) and growth index (Φ) of *Pterygoplichthys* sp., for this study are correct within the range recommended for fast-growing tropical species (K = 0.330 – 0.670 year^{-1}; Kienzle, 2005) and (Φ = 2.65 – 3.32; Baijot *et al*., 1997; Montchowui *et al*., 2022), suggesting that the CHLS the invasive sailfin catfish has a moderate growth (Φ =

2.84, K = 0.340 year^{-1}). These differences and similarities could be due to habitat characteristics, geographic distribution, environmental factors, estimates from different data analysis methods, sample size, capture mode and selectivity of fishing gear (Hoyle *et al*., 2024). In this same context, Pauly & Munro (1984) mention that this test provides an indication of the reliability of the age and growth estimates, since it has been suggested that the values of the growth performance index or phi-prime (Φ) test are similar for the same species and genera. Such moderate growth rate (K, Φ), a low value of K, a high value of L∞ , together with a prolonged longevity, isometric growth, a normal condition factor, indicate that the invasive sailfin catfish in the CHLS does not require accelerated growth to reach sexual maturity and reproduce, which is considered as k-selection traits (Pianka, 1974; Adams, 1980; Boyce,1984). This contrasts with other small fish, such as sardines (Clupeidae), anchovies and herring (Engraulidae), which have high K values, lower L∞ values, rapid growth, early maturation, and short lifespans, characteristics associated with r-selection traits, because they are prey for larger fish (Samsun *et al*., 2004; González-Cabellos *et al*., 2016).

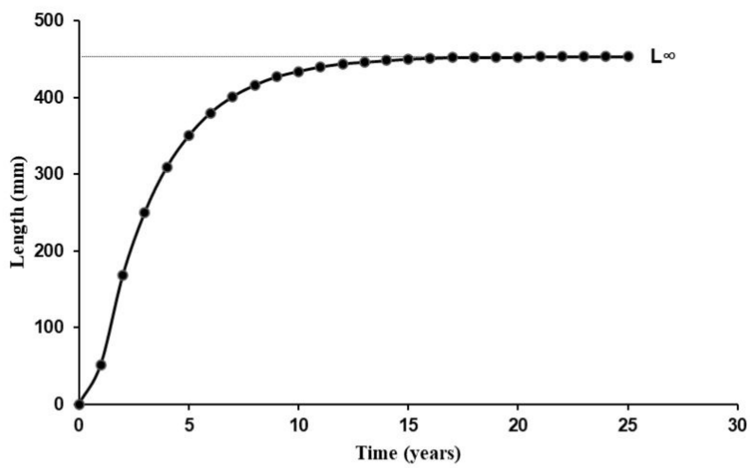

Figure 5. Length growth curve for *Pterygoplichthys* sp. according to the von Bertalanffy (1938) model.

Source: Own elaboration based on SPSS software.

The total mortality rate was: Z = 0.830 year^{-1}, while natural mortality (M = 0.420 year^{-1}) exceeded the fishing mortality rate (F = 0.410 year^{-1}), indicating that the invasive sailfin catfish die more from biological causes than from fishing activity. This is because CHLS fishermen do not yet consider the invasive sailfin catfish as their primary commercial target (Balderas-Mancilla

Revista Bio ciencias
ISSN 2007-3380

et al., 2025). Natural mortality can be affected by a variety of biological factors, such as disease and age, as well as environmental factors, including water quality and pollution. Table 1 indicates that *Pterygoplichthys* sp. in the CHLS is in a state of underexploitation, with an exploitation level of E = 0.490. A value greater than E = 0.5 would indicate overexploitation of the resource, while a value less than E = 0.5 would indicate an optimal level of exploitation (Gulland, 1971). This suggests that the invasive sailfin catfish in the CHLS are not being caught or are not in demand for commercial purposes (Balderas-Mancilla *et al*., 2025). Additionally, a low value of natural mortality (M) compared to other studies (Sousa *et al*., 2019; Raj *et al*., 2019; Aida *et al*., 2021) may contribute to its success as an invasive species.

Table 1. Population parameters of *Pterygoplichthys* sp. during the period 2023–2024.

Population parameters	
Asymptotic length ($L\infty$) in mm	453.60
Growth coefficient (K) year^{-1}	0.340
Age of the fish at zero length (t_0)	-0.636
Growth performance index or phi- prime (Φ)	2.84
Total mortality (Z) year^{-1}	0.830
Natural mortality (M) year^{-1}	0.420
Fishing mortality (F) year^{-1}	0.410
Exploitation level (E)	0.490
Maximum age (Taylor, 1958)	8.31 years
Maximum age (Pauly, 1980)	8.98 years

Source: Own elaboration

Recruitment and Capture Probability

The recruitment pattern of the *Pterygoplichthys* sp. population showed uninterrupted activity throughout the sampling periods, with peak numbers between February – May and August, while the lowest values were observed in September (Figure 6). This constant recruitment is a key factor in the species' invasive success, based on early sexual maturity under favorable conditions. Several authors have documented maturity at sizes of 130 – 240 mm worldwide (Samat *et al*., 2016; Tamsil *et al*., 2024), while in Mexico, sizes of 190 – 300 mm have been recorded (Rueda-Jasso *et al*., 2013; Cruz, 2016). This adaptive advantage, combined with parental care and the construction of nests that protect the fry (Lienart *et al*., 2013), allows juveniles to reach sizes where their bony armor makes them less vulnerable.

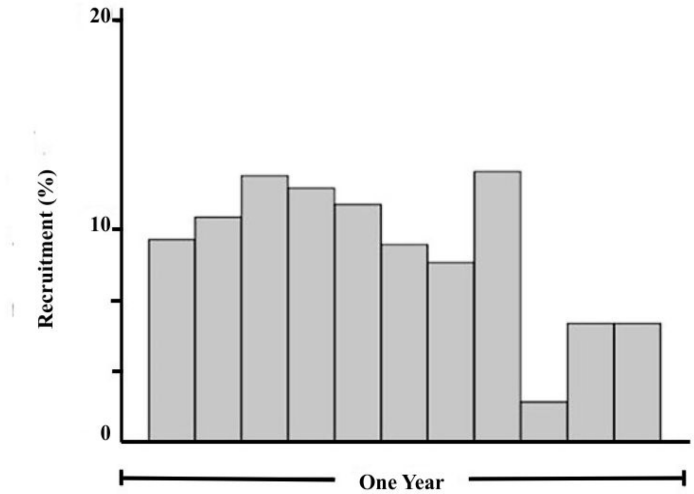

Figure 6. Annual recruitment pattern of *Pterygoplichthys* sp.

Own elaboration based on FISAT II software

In this context, the total length (TL) of the first catch in the study area was L_{c50} = 324 mm. The lengths of the 25% (L_{c25}) and 75% (L_{c75}) percentiles were estimated at 291 mm and 356 mm, respectively (Figure 7). Furthermore, the catch length (L_{c50} = 324 mm) was greater than the theoretical length at first sexual maturity (L_{m50} = 236 mm), indicating that, under the current system, individuals are captured after having completed at least one reproductive cycle. From an invasive species management perspective, these results suggest that the current fishing gear is selective toward larger sizes, allowing a significant fraction of the population to reach maturity and ensuring the constant recruitment mentioned above. Therefore, as an effective control measure, a reduction in the mesh size of the fishing gear is recommended. Lowering the L_{c50} to include juveniles and young adults (below 236 mm) would exert selective pressure that could lead to overexploitation of the breeding population. This population control strategy is consistent with Vallejo & Soriano (2011), who propose greater pressure on the capture of all life stages, and with Raj *et al*. (2019), who suggest that removing small individuals is essential to accelerate the eradication of the species.

Revista Bio ciencias
ISSN 2007-3380

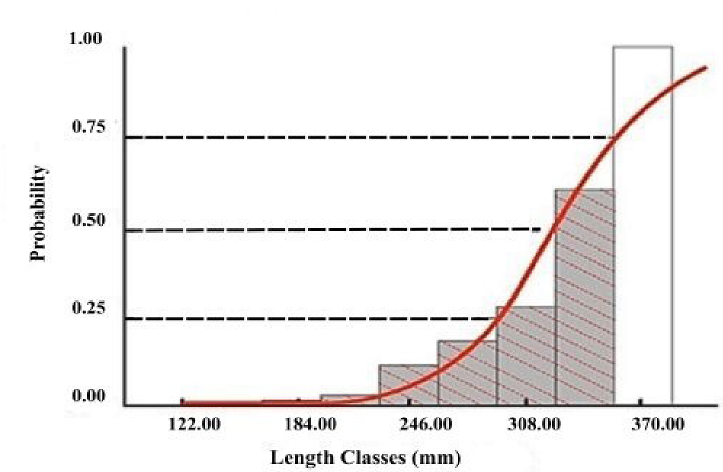

Figure 7. Capture probability (L_{25}, L_{50} and L_{75}) of *Pterygoplichthys* sp.

Own elaboration based on FISAT II software

Length-structured virtual population analysis (VPA)

The VPA was performed using input parameters L∞, K, M, a, b, and Ft (terminal fishing mortality assumed to be 0.5), and the results determined fishing mortality values less than 0.43 for each length group. The analysis indicated low fishing mortality in total length groups (TL) less than 340.0 mm, while the highest mortality was observed in length groups greater than 340.1 mm. The VPA indicates that the species has a high survival rate, which is attributed to low natural mortality and reduced fishing pressure (Figure 8). A simulation of VPA-related to increased fishing mortality indicates that an increase in fishing pressure, using methods used in experimental fisheries, could exponentially reduce the juvenile population before they reach sexual maturity. However, the effects on the population of larger size classes will be less significant because the probability of survival and maturation into adults is high due to low natural mortality in the absence of predators (Raj *et al*., 2019). Although increased fishing mortality can negatively affect populations, eliminating this invasive species poses a challenge in the CHLS. This is largely due to the survival and adaptation strategies of the invasive sailfin catfish (Escalera-Vázquez *et al*., 2019; Elfidasari *et al*., 2020a, 2020b; Aida *et al*., 2021). Furthermore, a relevant aspect is the limited attention the municipal government has paid to implementing a program to control or eradicate this species, since, according to fishermen's testimonies, this could entail a considerable cost for the authorities (Balderas-Mancilla *et al*., 2025). Currently, no economic value has been determined for the captured fish, leading fishermen to return them to the lagoon due to lack of interest. However, fishermen are willing to learn how to take advantage of this organism and to establish opportunities for collaboration with municipal and state authorities to control or eradicate this invasive species or, failing that, seek economic benefits derived from it.

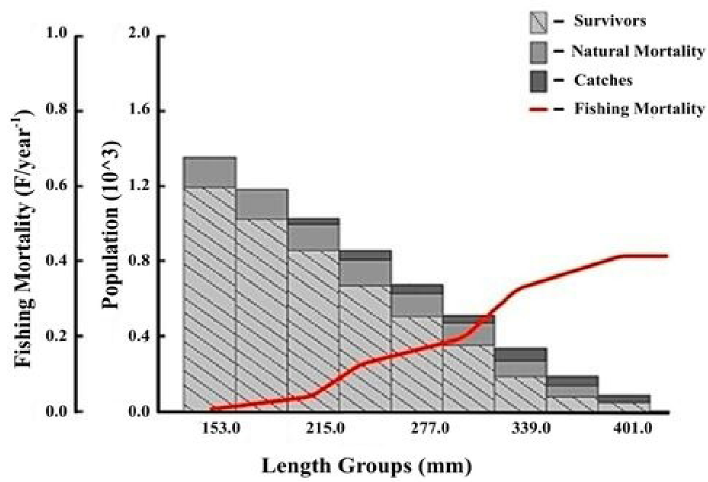

Figure 8. Length-structured virtual population analysis (VPA) of *Pterygoplichthys* sp.

Own elaboration based on FISAT II software

Conclusions

This research provides an updated analysis of the invasive sailfin catfish population in a highly important fishing region in southern Tamaulipas, specifically in the CHLS. This study can serve as a reference for implementing control or eradication strategies for this invasive species. Furthermore, this study indicates that moderate growth, long lifespan, and consistent recruitment throughout the year are likely factors contributing to the successful invasion of *Pterygoplichthys* sp. in the study area and in other areas near the CHLS. Currently, the *Pterygoplichthys* sp. population is underexploited, suggesting potential for increasing exploitation levels and adding commercial value to this resource. Transforming this invasive species into a usable resource would be the most important management action, allowing for population control. Increased fishing pressure targeting organisms ≤ 250 mm could have a significant impact on individuals before they reach first sexual maturity, potentially leading to overexploitation of this invasive species. Furthermore, a deeper understanding of reproductive strategies and the identification of spawning areas is essential to understanding the behavior of the invasive sailfin catfish, which would facilitate the development of strategies for its control and possible eradication.

Revista Bio ciencias
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Authors contribution

Conceptualization of the work: B.M.U.J., C.A.J., A.M.A.L., S.C.M.I., P.A.J., D.I.C.A., C.C.R.M. C.S.F.L; Field trip, writing and preparation of the manuscript: B.M.U.J., C.A.J., A.M.A.L., S.C.M.I; Editing and review: B.M.U.J., P.A.J., D.I.C.A., C.C.R.M. C.S.F.L

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Informed consent statement

Informed consent was obtained from all subjects involved in the study.

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Conflict of interest

The authors declare that they have no conflict of interest.

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