LENGTH-WEIGHT RELATIONSHIP AND CONDITION FACTOR OF ARMORED CATFISH (*PTERYGOPLICHTHYS* SSP.) IN THE GRIJALVA AND USUMACINTA RIVERS, MEXICO

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Abstract: Invasive alien species are one of the main threats to the biodiversity of ecosystems worldwide. The armored catfish is an invasive species that threatens biodiversity and freshwater fisheries in invaded areas. This fish belongs to the family Loricariidae, native to the Amazon basin in South America. In Mexico, it was first detected in 1995 in the Mezcala River, belonging to the Balsas basin. This study aimed to explore the length-weight relationship of *Pterygoplichthys* ssp. to observe whether the condition factor reveals variation from a dammed river (Grijalva) to a free-flowing river (Usumacinta). Given the physiological characteristics of armored catfish (benthic consumer, tolerance to hydrological disturbance and aquatic pollution, and wide reproductive range), we are certain that this fish will have a better value of condition factor in the Grijalva River than in the Usumacinta. The highest abundance of armored catfish was obtained in the Grijalva River (282 specimens). However, the largest and heaviest fish were caught in the Usumacinta River (34.4 ± 5.31 cm and 389 ± 138 g, respectively). The length-weight ratio showed a positive allometric growth rate in the Grijalva River ($b < 3$), while the Usumacinta River showed a negative allometric growth ($b > 3$). Furthermore, the condition factor demonstrated that armored catfish have superior conditions (greater robustness) in the Usumacinta River, which is a free-flowing river, in comparison to the dammed Grijalva River. Food availability, species population density, and intra- and interspecific competition undoubtedly played a pivotal role in fish condition. The information generated in this study provides a solid foundation for more detailed analysis of armored catfish populations, including sex and different bodies of water. This will help us to monitor the populations of P*terygoplichthys* spp. in the Mexican southeast more effectively.

Keywords: growth type, physiological condition, armored catfish.

RELACIÓN PESO-LONGITUD Y FACTOR DE CONDICIÓN DEL BAGRE ARMADO (*PTERYGOPLICHTHYS* SP.) EN LOS RÍOS GRIJALVA Y USUMACINTA, MEXICO

Resumen: Las especies exóticas invasoras son una de las principales amenazas para la biodiversidad de los ecosistemas de todo el mundo. El bagre armado es una especie invasora que amenaza la biodiversidad y la pesca de agua dulce en las zonas invadidas. Este pez pertenece a la familia Loricariidae, nativa de la cuenca del Amazonas en Sudamérica. En México se detectó por primera vez en 1995 en el río Mezcala, perteneciente a la cuenca del Balsas. Este estudio tuvo como objetivo explorar la relación longitud-peso de *Pterygoplichthys* ssp. para observar si el factor de condición revela variación de un río represado (Grijalva) a un río de flujo libre (Usumacinta). Dadas las características fisiológicas del bagre armado (consumidor bentónico, tolerancia al disturbio hidrológico y a la contaminación acuática, y amplio rango reproductivo), predecimos que este pez tendrá un valor más alto del factor de condición en el río Grijalva que en el Usumacinta. La mayor abundancia de bagre armado se obtuvo en el río Grijalva (282 ejemplares). Sin embargo, los peces de mayor tamaño y peso se capturaron en el río Usumacinta (34,4 ± 5,31 cm y 389 ± 138 g, respectivamente). La relación longitud-peso mostró una tasa de crecimiento alométrico positivo en el río Grijalva ($b < 3$), mientras que el río Usumacinta mostró un crecimiento alométrico negativo ($b > 3$). Además, el factor de condición demostró que el bagre armado tiene condiciones superiores (mayor robustez) en el río Usumacinta, que es un río de flujo libre, en comparación con el río Grijalva represado. La disponibilidad de alimento, la densidad poblacional de la especie y la competencia intra e interespecífica sin duda jugaron un papel fundamental en la condición de los peces. La información generada en este estudio proporciona una base para un análisis más detallado de las poblaciones de bagre acorazado, incluyendo la variable sexo y tipo de cuerpo de agua. Esto nos ayudará a monitorear de manera más efectiva las poblaciones de *Pterygoplichthys* ssp. en el sureste mexicano.

Palabras-clave: tipo de crecimiento, condición fisiológica, bagre armado.

INTRODUCTION

Invasive alien species represent a significant threat to the ecosystem's biodiversity. In inland aquatic ecosystems, species of the genus *Pterygoplichthys*, also known as armored catfish, suckermouth catfish, pleco, fishbowl cleaners or glass cleaners, have been identified as a key factor in the decline of biodiversity (Orfinger & Goodding 2018) and freshwater fisheries (Mendoza et al., 2007). The native distribution of the armored catfish (*Pterygoplichthys* spp., Gill 1858) is confined to Neotropical areas in Central and South America (Mendoza et al., 2007). In Mexico, the presence of the family Loricariidae has been documented since 1995, particularly in the Adolfo López Mateos dam in the state of Michoacán (Mendoza-Alfaro et al., 2009). In 2005, the capture of juvenile armored catfish in the Teapa and Usumacinta rivers (Tres Brazos) was reported (Barba, 2005). In 2014, its appearance in effluents of the Grijalva-Usumacinta watershed was confirmed (Sánchez et al., 2015; Ayala-Pérez et al., 2014).

Main impacts of the presence of armored catfish in freshwater bodies are: instability of bank margins caused by their burrows, which leads to riverbed siltation (Hoover et al., 2014; Nico et al., 2009), alteration of trophic dynamics and competition for space and food with native fish (Hoover et al. 2004; Nico & Martin, 2001), decline of fish populations by ingesting native fish eggs while bottom feeding (Chaichana et al., 2013; Chaichana & Jongphadunkiet 2012), in addition to the socioeconomic and health damage resulting from their abundance (Barba, 2007).

Armored catfish feed on bottom detritus (Capps, 2012), and its main feeding resources come from areas with a high degree of anthropogenic intervention, where there is greater nutrient input from runoff, alteration of riparian habitat, and increased resource availability, which promote eutrophication and avoid competitors (Wei et al., 2018), as well as worsen nutrient limitation for productivity in invaded ecosystems (Capps & Flecker 2013), reducing the quality and quantity of benthic resources that negatively influence higher trophic levels, and ultimately ecosystem structures and functions (Capps, 2012).

Armored catfish has shown a rapid expansion in the southeastern Mexico through the main rivers of the Grijalva-Usumacinta region (Lienart et al., 2013). In this region until recently, the existence of two species of armored catfish (*P. disjunctivus* and *P. pardalis*) had been reported (Lienart et al., 2013; Barba-Macías & Cano-Salgado, 2014; Barba-Macías et al., 2015). However, recent genetic studies of DNA mitochondrial have shown that the armored catfish distributed in the Grijalva-Usumacinta region belong to a single species or possibly are hybrids (Vargas-Rivas et al., 2023).

Anthropogenic activities are the main threats in the Grijalva-Usumacinta Region (Toledo, 2003), e.g. Grijalva River has been recognized as one of the most polluted rivers in Mexico (Musálem et al., 2018; Toledo, 2003). Also, it is the most intervened river due to the system of four dams that allows the generation of electricity and protection of the city of Villahermosa (Ramos-Gutiérrez & Montenegro-Fragoso, 2012). This has caused the river to lose its natural variation in flooding and flow, which favors the permanence and entry of exotic species (Yossa & Araujo-Lima, 1998).

On the other hand, the Usumacinta River, although it is threatened due to activities of unsustainable agriculture (Soares & García, 2017), is still considered a natural river because it is free and seasonal flow (Salinas-Rodriguez et al., 2021) as well as present high degree of conservation of its riparian zones (Ochoa-Gaona et al., 2018).

Evaluation of length-weight relationships and condition indexes in fish provide indirect information on growth, maturity, reproduction, and nutrition, and therefore the general health of fish populations, which allows for comparative inter-population studies (Arismendi et al., 2011). On the other hand, the condition factor is an index reflecting interaction between biotic and abiotic factors in the physiological conditions of fishes (Getso et al., 2017). Therefore, the condition factor may vary among fish species in different locations (Blackwell et al., 2000). In fisheries science, condition factor (K) is used to compare the condition, fatness, or wellbeing of fish,this is based on the hypothesis that heavier fish of a particular length are in a better physiological condition (Seher & Suleyman, 2012).

This study was carried out to explore the growth pattern of the armored catfish (*Pterygoplichthys* spp.) in the Grijalva-Usumacinta region. Likewise, determine if the condition factor manifests changes in the population of this fish in two scenarios: in a dammed river (Grijalva) versus a free-flowing river (Usumacinta). We predict that the armed catfish will present high values of the condition factor in the Grijalva River, due to the degree of alteration in its hydrological and habitat conditions, which benefit the development and growth of the armed catfish.

METHODOLOGY

STUDY AREA

The study area comprises the hydrological region number 30 (RH30), formed by the Grijalva and Usumacinta rivers. Both rivers form the largest hydrological watershed in Mexico (1521 km); their catchment area holds approximately 112,500 km2, with an mean surface runoff of 101,517 hm3 representing the largest discharge to the Gulf of Mexico (CONAGUA, 2014; Hudson et al., 2005), after the Mississippi river which has a discharge of 16,792 m3.s-1 (Kemp et al., 2016). They converge in the same region and share similar climatic conditions. They also partially merge in the coastal plain of the state of Tabasco (CONAGUA, 2014) (Fig. 1).

FISH SAMPLING AND MEASUREMENT

Sampling was carried out at six sites (three per basin) based on normative appendix F of the Ecological Flow Standard (NMX-AA-159) (DOF, 2012), considering environmental, hydrological, and ecological traits. The sites selected in the Usumacinta River were: Lacantún, Jonuta and Tres Brazos, while in Grijalva they were: Amacohite, Ostitán and Chilapa (Fig. 1), covering the climatic seasons of the area: rainy season (october of 2017; 950 mm precipitation), northern season ("northern winds", february 2018; 660 mm) and dry season (march-april 2018; 270 mm) (n= 54 samples). For the collection of fish, a battery of three gillnets made of nylon monofilament with mesh opening 4 inches, with a length of 50 m and 5 m height (250 m2 of area) was used per site, placed for 8 hours during the night on the margin of the main channel of the river, to capture adults' fish and commercial sizes.

Armored catfish captured in both rivers were identified with taxonomic keys for Loricarids (Ambruster & Page, 2006; Page & Robins, 2006). However, considering Vargas-Rivas et al., (2023), specimens identified as P. pardalis or another specie (Ambruster & Page, 2006) and intermedium specimens (Bijukumar et al., 2015), here were recorded as *Pterygoplichthys* spp.

Total length (TL, hereafter) of fishes was recorded in the field with a 50 cm (± 1 mm) long wooden ichthyometer, measured from the tip of the snout to the end of the fish's caudal fin. Fish were also weighed with a portable electronic digital scale, an Uline H-9886 with 0.1 g accuracy.

LENGTH-WEIGHT RELATIONSHIP

Length-weight relationship was determined using the formula $W=aL^b$ (Le Cren, 1951), where W: is the live weight in grams (g) of the fish, L: is the total length of the fish in centimeters (cm), a: is the intercept and b: is the slope of the linear regression. For the linear regression model, the data for total length and weights were transformed using a logarithmic transformation (log10) (Froese, 2006).

Growth type of the fish population at the river was analyzed using a t test (Santos et al.,

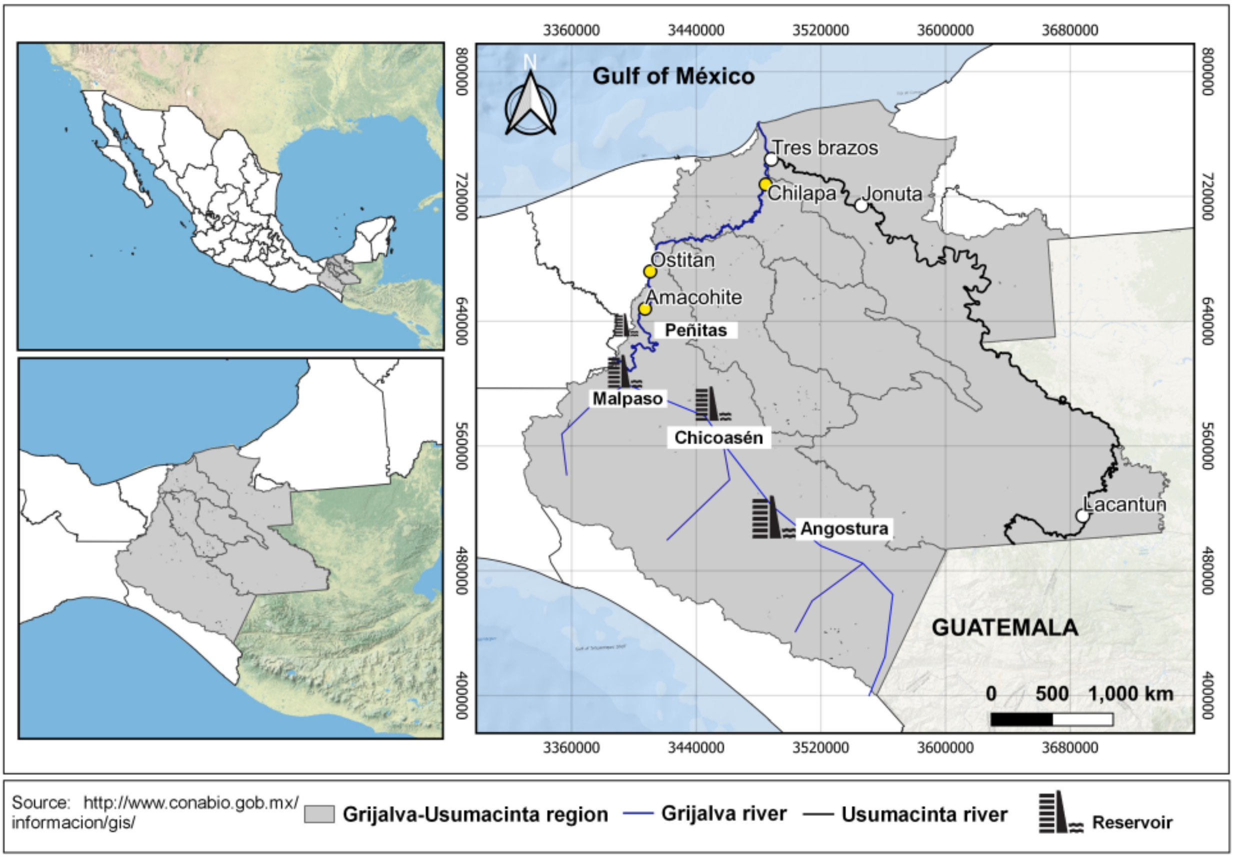


Fig. 1. Map of the Grijalva-Usumacinta watershed and sampling sites, Mexico.

2002) (H0: b=3) with a confidence level (α=0.05). The test was performed using the hoCoef function of the FSA package (Ogle, 2016a) in the Rstudio program (R Core Team, 2022). Growth type can be isometric (b=3) when the weight of the fish increases proportionally to its length, negative allometric (b<3) when the growth pattern corresponds to individuals that are more elongated in length than in weight, or positive allometric (b >3) which tends to increase weight more than length (Froese, 2006).

Condition

Fish condition was assessed using two metrics (Blackwell et al., 2000); Fulton condition factor (K) and relative condition factor (Kn) (Neumann et al., 2012; Lloret et al., 2013). The Fulton condition factor (Ki) was calculated through the formula:

$K_i=W_i/L3/i*constant$,

where; Li and Wi are the observed length and weight for the i-th fish and the constant is a scale factor equal to 100.00 if metric units were measured (e.g., grams and centimeters) or, 10.00 if customary units were measured (e.g., pounds and inches) (Neumann et al., 2012).

The relative condition factor (Kn_i) of the fish was determined using the formula:

$Kn_i=w_i/W_i'$ (Le Cren 1951),

where; wi: is the observed weight of the fish caught, Wi': is the mean weight calculated from the length-weight relationship (Backwell et al., 2000). All calculations were performed as in Ogle, (2016b) for length-weight relationship, Fulton's condition factor K and relative condition factor (Kn) using R-studio software (R Core Team 2022).

Statistical Analysis

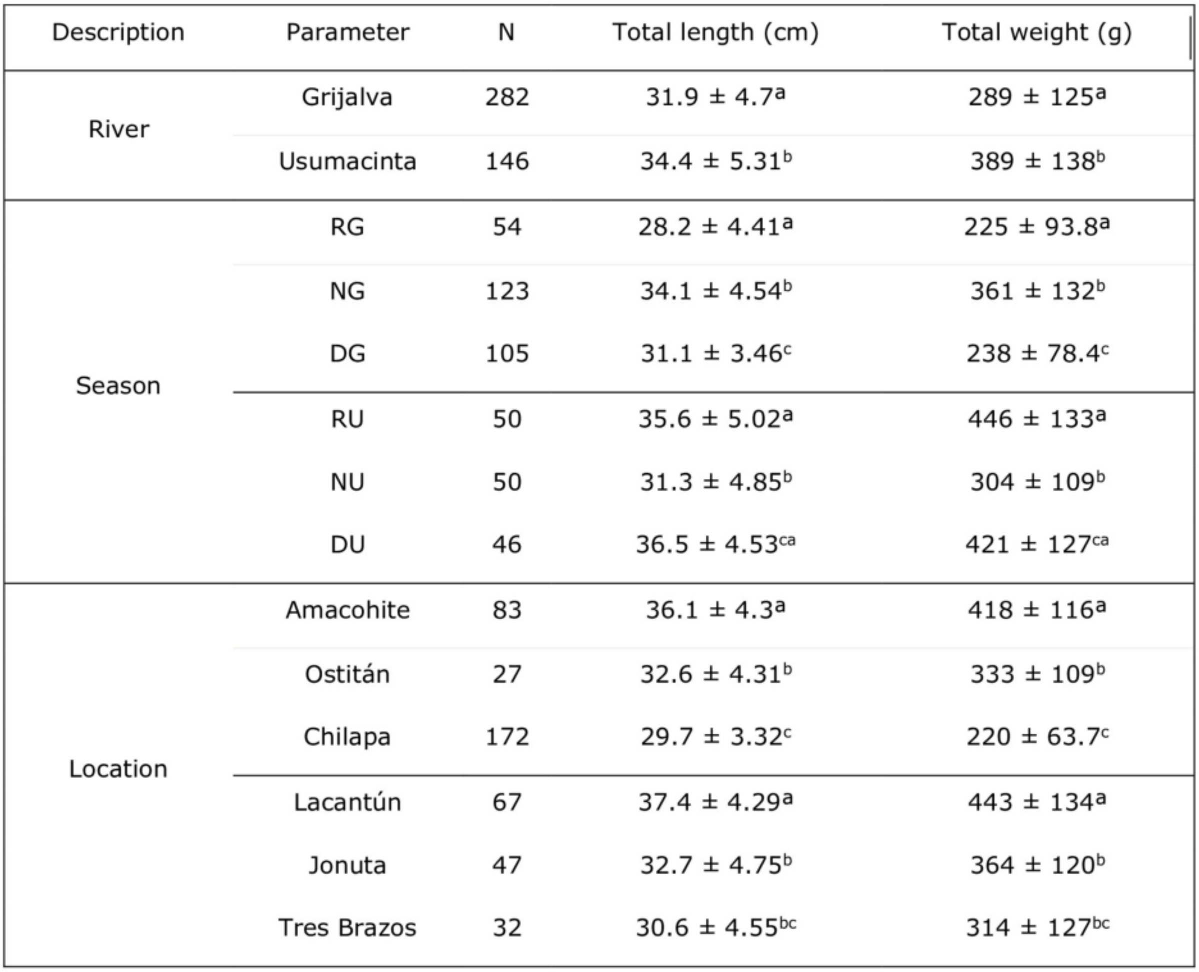
One-way analysis of variance (ANOVA) was employed to ascertain the existence of differences in TL (cm) and weight (g). When the data did not fulfil the assumptions of the ANOVA (Shapiro normality and Levene's homogeneity of variances), non-parametric statistics were utilized, for instance, the Kruskal-Wallis (KW) test. To test for differences in Fulton's condition factor (K) and relative condition factor (Kn) between rivers, seasons and sampling sites, an analysis of covariance (ANCOVA) was employed, with total length of fish serving as a covariate. The statistical assumptions of this test were validated using the Shapiro-Wilk test for normality and Levene's test for homogeneity of variances. All analyses were conducted using the RStudio package (R Core Team, 2022).

RESULTS

A total of 428 armored catfish were caught during the study period, 282 were caught in the Grijalva River and 146 in the Usumacinta River. The main descriptive parameters of the catfish (number of individuals-N, mean total length (TL) ± SD, mean weight ± SD, mean condition factor-K ± SD and mean relative condition factor-Kn ± SD) are shown in Tab 1. The length and weight of armored catfish in the Grijalva River ranged from 20.5-47 cm and 130-650 g respectively, while in the Usumacinta they ranged from 20-45 cm TL and 150-750 g weight, respectively (Fig. 2).

Longest and heaviest fish were caught in the Usumacinta River (34.4 ± 5.31 LT and 389 ± 138 g weight) (LT; TukeyHSD, p= 0.0001 and Dunn weight; p=0.0001) (Tab. 1). Temporally, the smallest (LT) and least heavy (g) fish in the Grijalva River were caught in the rainy season (RG) (28.2 ± 4.41 cm, 225 ± 93.8 g, respectively), while the longest (LT) and

Tab. 1. Mean value (± standard deviation) of the morphological parameters of armored catfish captured in the Grijalva and Usumacinta rivers. Rainy Grijalva (RG), northernly Grijalva (NG), dry Grijalva (DG), rainy Usumacinta (RU), northernly Usumacinta (NU) and dry Usumacinta (DU). N: sample size, values in the same column with different letter in superscript are statistically different (p<0.05).



Description	Parameter	N	Total length (cm)	Total weight (g)
River	Grijalva	282	31.9 ± 4.7^{a}	289 ± 125^{a}
	Usumacinta	146	34.4 ± 5.31^{b}	389 ± 138^{b}
Season	RG	54	28.2 ± 4.41^{a}	225 ± 93.8^{a}
	NG	123	34.1 ± 4.54^{b}	361 ± 132^{b}
	DG	105	31.1 ± 3.46^{c}	238 ± 78.4^{c}
	RU	50	35.6 ± 5.02^{a}	446 ± 133^{a}
	NU	50	31.3 ± 4.85^{b}	304 ± 109^{b}
	DU	46	36.5 ± 4.53^{ca}	421 ± 127^{ca}
Location	Amacohite	83	36.1 ± 4.3^{a}	418 ± 116^{a}
	Ostitán	27	32.6 ± 4.31^{b}	333 ± 109^{b}
	Chilapa	172	29.7 ± 3.32^{c}	220 ± 63.7^{c}
	Lacantún	67	37.4 ± 4.29^{a}	443 ± 134^{a}
	Jonuta	47	32.7 ± 4.75^{b}	364 ± 120^{b}
	Tres Brazos	32	30.6 ± 4.55^{bc}	314 ± 127^{bc}

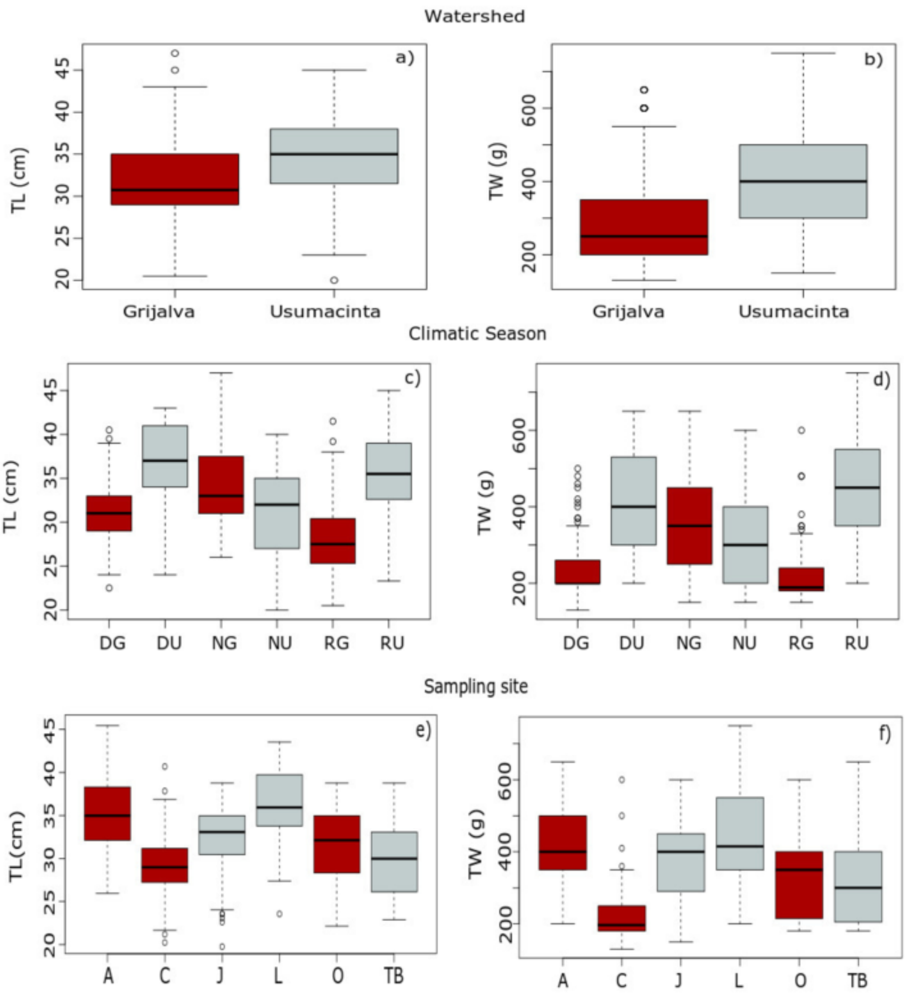


Fig. 2. Mean and standard deviation (SD) of the size and weight of fish captured by river (a,b, respectively), climatic season (c, d, respectively) and sampling site (e, f, respectively). TL: total length, TW: total weight, DG: dry Grijalva, NG: northern Grijalva, RG: rainy Grijalva, DU: dry Usumacinta, NU: northern Usumacinta, RU: rainy Usumacinta. A: Amacohite, C: Chilapa, J: Jonuta, L: Lacantún, O: Ostitán, TB: Tres Brazos. Data marked in red correspond to data from the Grijalva River.

heaviest (g) fish were caught in the northern season (NG) (34.1 ± 4.54 cm, 361 ± 132 g, respectively) (DunnTest, p> 0.05) (Tab. 1). For the Usumacinta River, the smallest (cm) and lightest (g) fish were caught in the northern (NU) season (31.3 ± 4.8 cm, 304 ± 109 g, respectively). The longest (cm) fish were caught in the dry season (DU) (36.5 ± 4.53 cm) and the heaviest in rains (RU) (446 ± 133 g), TukeyHSD, p> 0.05, respectively, (Tab.1).

By sampling site, in the Grijalva river, the largest and heaviest fish were caught in Amacohite (36.1 ± 4.3 cm and 418 ± 116 g, respectively), while the smallest and lightest were caught in Chilapa (29.7 ± 3.32 cm and 220 ± 63.7 g, respectively) (LT; TukeyHSD, p> 0.05 and weight; Dunn, p>0.05) (Tab.1). While for the Usumacinta River, the largest and heaviest fish were recorded at the Lacantún site (37.4 ± 4.29 cm and 443 ± 134 g) and, the smallest and lightest were recorded at Tres Brazos (30.6 ± 4.55 cm and 314 ± 127 g, respectively) (LT; TukeyHSD, p=0.0001 and weight; Dunn's, p=0.0001, respectively) (Tab. 1).

LENGTH-WEIGHT RELATIONSHIP

The analysis of the length-weight relationship of catfish in the Grijalva River shows that the variability of weight is 79.57% (R^2=0.7957) explained by total length. The regression is highly significant ($F_{(1,280)}$=1096, p-value < 2.00e-16). The slope (t-value = 33.1, p-value < 2.00e-16) and the intercept (t-value = -15.31, p-value = 2e-16) are statistically different from zero. The optimal equation of the line is log (Wt) = -2.065 + 2.977 * log (Lt) in the transformed scale and Wt = 0.1267 $Lt^{2.977}$ in the original scale. It should be noted that α=e and the intercept is e-2.065. Conversely, the analysis of the growth type of armored catfish in the Grijalva river revealed fish with positive allometric growth (with 95% confidence, the slope is between 2.80 and 3.15) (Fig. 3a and 3b).

In contrast, the analysis of the length-weight relationship of armored catfish in the Usumacinta River revealed that weight variability is explained by 60.88% (R^2=0.6088) by total length. The regression is highly significant ($F_{(1,144)}$=224, p-value < 2.2e-16). Both the slope (t-value=14.97, p-value < 2.00e-16) and the intercept (t-value=-3.72, p-value=0.0001) are statistically different from zero. The value is statistically significant (p < 0.0001), with a t-value of 14.97 for the slope and a t-value of -3.72 for the intercept. The

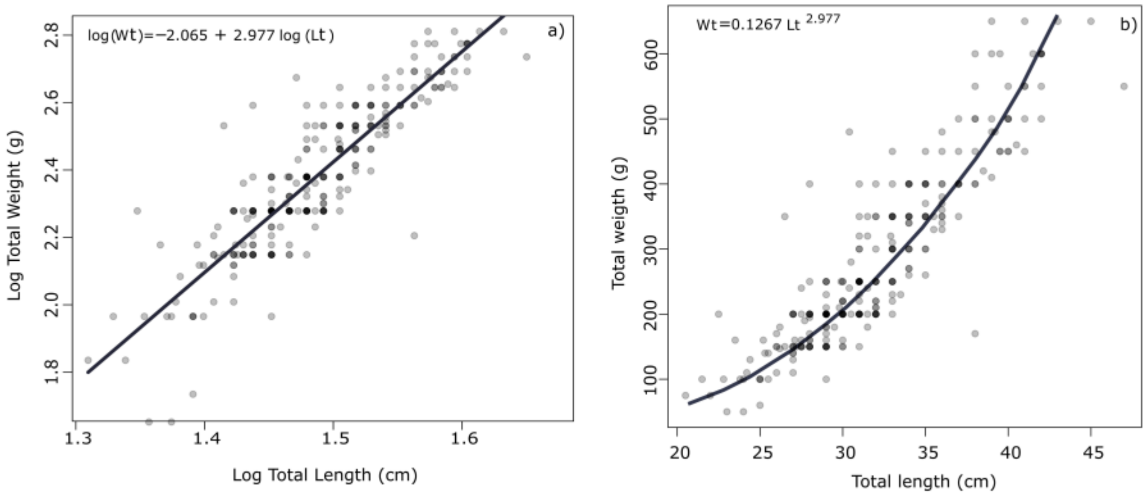


Fig. 3. a) Length-weight relationship (LWR) with logarithmically transformed data of individuals of Pterygoplichthys spp. captured in the Grijalva River and line of best fit. b) LWR with non-transformed data of individuals of Pterygoplichthys spp. Grijalva River.

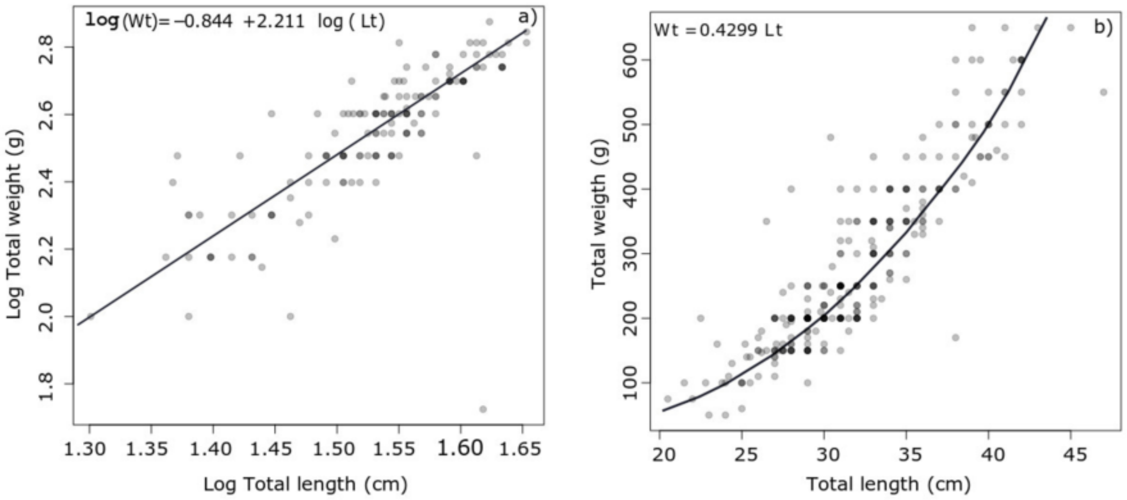


Fig. 4. LWR with logarithmically transformed data of individuals of Pterygoplichthys spp. captured in the Usumacinta River and line of best fit a). LWR with non-transformed data of individuals of Pterygoplichthys spp. Usumacinta River b).

optimal fitting equation of the line is log (Wt) = -0.844 + 2.211 * log (Lt) on the transformed scale, and $Wt = 0.4299\ Lt^{2.211}$ on the original scale. It should be noted that ɑ = e and the intercept = $e^{-0.844}$. The growth rate of armored catfish in the Usumacinta River exhibited a negative allometric growth rate, with a 95% confidence interval for the slope between 1.91 and 2.50. This is illustrated in Figs. 4a and 4b.

CONDITION

ANCOVA of the condition factor K and Kn revealed significant differences between the Grijalva and Usumacinta rivers ($F_{(1,425)}$=50.4, p=0.0001 and $F_{(1,425)}$=49.74, p=0.0001, respectively). The post hoc test with Bonferroni adjustment (estimated marginal means, or EMEMs) indicated that the mean K score was statistically significantly higher in the Usumacinta River (0.994 ± 0.01, with data adjusted to mean ± standard error) compared to the Grijalva river (0.85 ± 0.01), p< 0.001.

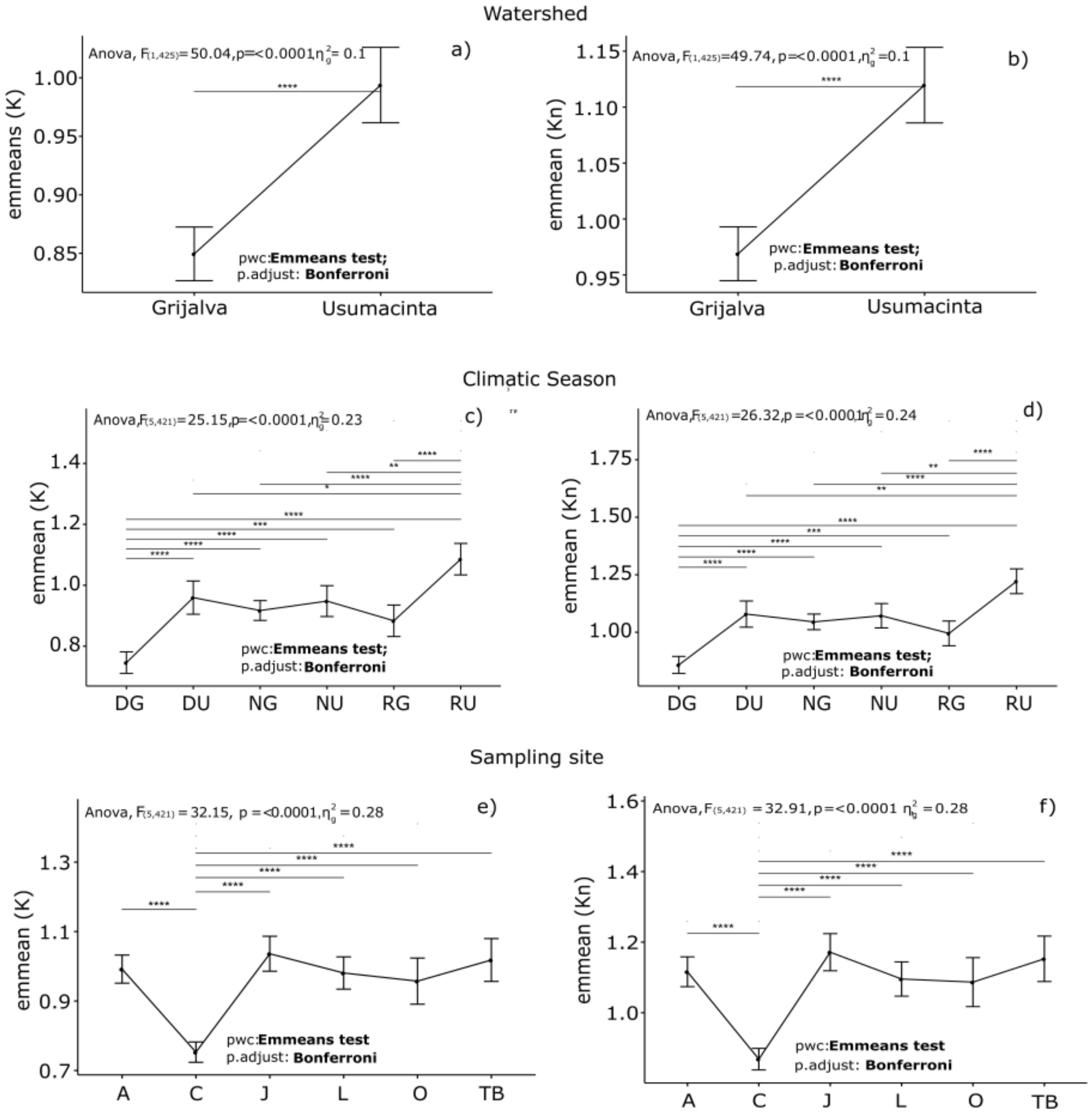


Fig.5. Analysis of covariance (ANCOVA) of condition factor K and relative condition factor Kn comparing estimated marginal means (EMMEAN) by rivers (Figs. a and b), climatic seasons (Figs. c and d) and sampling sites (Figs. e and f). DG: Grijalva dry, NG: Grijalva northerly, RG: Grijalva rainfall, DU: Usumacinta dry, NU: Usumacinta northerly, RU: Usumacinta rainfall. A: Amacohite, O: Ostitán, C: Chilapa, J: Jonuta, L: Lacantún and TB: Tres Brazos. Significant differences are marked by * (p>0.05).

Similarly, the mean Kn score was found to be statistically significantly higher in Usumacinta (1.12 ± 0.01) compared to Grijalva (0.969 ± 0.01), p> 0.001 (Fig.5a, 5b, respectively).

ANCOVA demonstrated that the condition factors K and Kn exhibited significant differences between climatic seasons for the Grijalva and Usumacinta rivers (F($_{5,421}$)=25.15, p=0.0001 and F$_{(1,421)}$=26.32, p=0.0001, respectively). The post hoc EMEMs indicated that the mean K score was statistically significantly higher in the RU season (1.09 ± 0.02), while the lowest score was obtained in the DG season (0.74 ± 0.01), p<0.001 (Fig. 5c). Additionally, EMMEMs post hoc revealed statistically significant differences between the RU and DG seasons for Kn, with mean scores of 1.22 ± 0.02 and 0.85 ± 0.01, respectively (Fig.5d).

Conversely, ANCOVA demonstrated that the condition factors K and Kn exhibited significant differences between sampling sites (F$_{(5,421)}$=32.15, p=0.0001 and F$_{(1,421)}$=33, p=0.0001, respectively). The post hoc test with Bonferroni adjustment (EMEMs) indicated that the mean K score was statistically significantly higher at the Jonuta site on the Usumacinta River (1.04 ± 0.02) compared to the Chilapa site (0.75 ± 0.01) on the Grijalva River (Fig. 5e). Additionally, the post hoc test yielded comparable outcomes for Kn at both sampling sites (Jonuta = 1.17 ± 0.02, Chilapa = 0.87 ± 0.01), as illustrated in Fig. 5f (and in supplementary material Fig.6, the trend of the condition factor with respect to size (LT) and location is presented).

Discussion

Grijalva River has been significantly impacted, resulting in a deterioration of its ecological condition (Lázaro-Vázquez et al., 2018; Musálem et al., 2018; Nygren, 2021). This results in conditions that favour the presence of exotic species tolerant to environmental disturbance, such as the armored catfish (Yossa & Araujo-Lima, 1998; Wei et al., 2018).

Chilapa sampling site on the Grijalva River may be functioning as a nesting and nursery area for armored catfish. This site is distinguished by its location in the lower reaches of the basin, situated downstream of the city of Villahermosa, Tabasco. Furthermore, the floodplain area exhibits greater sediment deposition, organic matter, lower energy, and a shallower slope (Lineart et al., 2013). This scenario is conducive to the rapid growth and dispersal of armored catfish (Yossa & Araujo-Lima, 1998; Lineart et al., 2013; Barba-Macías et al., 2017; Wei et al., 2018).

The catfishes presented sizes and weights comparable to those reported for their congeners in other invaded regions of Mexico (Tab.2). The maximum lengths recorded for *Pterygoplichthys* spp. in the Grijalva and Usumacinta rivers were larger than those reported by Gibbs et al. (2013). It has been documented that fishes of the family Loricariidae can reach sizes between 30 and 50 cm total length (TL) (Ayala-Pérez et al., 2014), while other authors report that they can reach 70 cm TL. (Mendoza et al., 2007; Liang et al., 2005; Page & Burr, 1991) and can weigh up to 1,000 g (Barba et al., 2015).

The largest and heaviest armored catfish were caught in the Usumacinta River. Nevertheless, the sizes were like those reported nationally, while the weight values are the highest, according to national reports (Tab.2).

The armored catfish has been considered as a specie with negative allometric growth (b<3), supported by our results and literature supporting this fact (Liang et al., 2005; Samat et al., 2008; Wakida-Kusunoki & Amador del Angel, 2011; Rueda-Jasso et al.,2013; Jumawan et al. 2016; Wickramaratne et al.,2020; Lai et al, 2020; Quasim & Jawad, 2022). However, here we also report fish with positive allometric growth; (b>3) in the Usumacinta River. Similar to that reported by Ayala-Pérez et al., (2014) in Laguna de Términos, Campeche, Mexico.

Based on Nielsen & Johnson (1983), negative allometric growth is common in fish of the Loricariidae family, probably due to the external restriction imposed by the hard bony plate they possess. Whereas positive allometric growth in fish can be related to good condition (Santos et al., 2002; Lopez & Sidorkewicj, 2008), given by the environments that provide potential food sources (Gomiero & Braga, 2005; Liang et al., 2005).

It was observed that K and Kn presented high values in the rainy season for both rivers, where limnological parameters influence nutrient loading and phyto- and zooplankton production (increased food) (Peterson et al., 2004; Gomiero & Braga, 2005). Likewise, in this season, armoured catfish show greater reproductive activity, ovarian development and higher gonadosomatic index (Rueda-Jasso et al., 2013; Lacshani et al., 2023). This contrasts with Gomeiro & Braga (2005), who mention that fish may present low K and Kn values in the rainy season, because in many species, the rainy season coincides with reproductive activity and weight loss/robustness may be associated with this activity (Gomiero & Braga, 2005).

On the other hand, some authors mention that drops in the condition factor can be related to the intensity of foraging (restriction to some resources) or to the beginning of the reproductive period (Gomiero & Braga 2005; Gibbs et al., 2013; García et al. al., 2016). Here the low values of K and Kn occurred in the dry season, where possibly the availability of food due to competition has influenced this result (Gomiero & Braga 2005; Gibbs et al., 2013; García et al., 2016).

It was expected that the armored catfish would present isometric growth and higher K and Kn values in the Grijalva River. However, these values were higher in the Usumacinta River, a free-flowing river that still presents natural characteristics (Ochoa-Gaona et al., 2018; Salinas-Rodríguez et al., 2021). The presence of this fish in the Usumacinta River puts the trajectory of native fish populations at risk, mainly species that feed at the same trophic level, as these fish monopolize resources and drive out competitors (Hoover et al., 2004). Added to this are the latent threats catfish pose to freshwater ecosystems and wildlife (Hoover et al., 2014; Orfinger & Goodding, 2018).

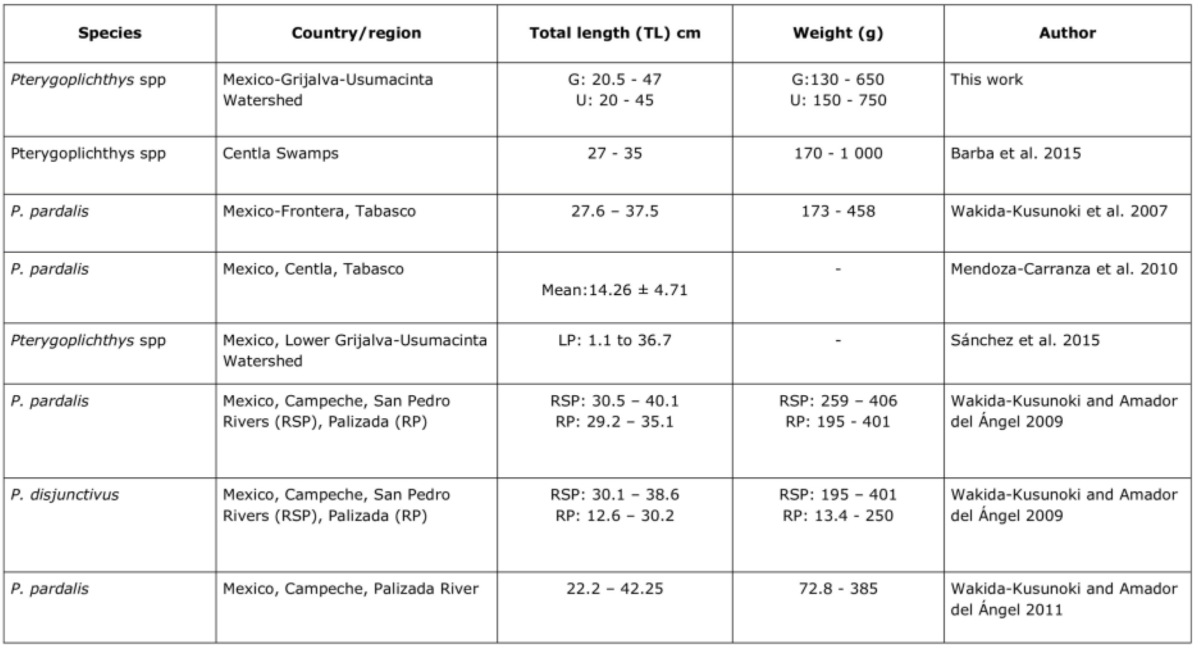
Although armored catfish have been reported to have a wide tolerance to sites of low environmental quality (Wei et al., 2018). It is likely that in the Grijalva River, environmental conditions are influencing K and Kn parameters. Mainly, because environmental changes affect fish growth and maturity, influencing reproductive traits to compensate for growth (Wilson et al., 2019). Therefore, the smaller size, higher abundance, and low K and Kn values in Grijalva can be explained by variations in their life history (i.e. phenotypic plasticity traits) (Wei et al., 2022).

In other words, armoured catfish direct less energy to body size and weight, which is evidenced by lower length, weight, and condition factor values. Catfish may exhibit a slower growth rate, smaller size, and earlier reproductive maturity (Wei et al., 2022). Also, they may exhibit higher numbers of eggs per female (Samat et al., 2016) and exhibit different egg size classes (probably for multiple spawning) (Lineart 2010, Wakida-Kusunoki et al., 2011). In addition, intraspecific competition for food and space also plays an important role in fish population development (Ward et al., 2006).

Conversely, the larger size and weight of catfish in the Usumacinta may be related to predation and predator richness (Wei et al., 2022), i.e., catfish may be expending more energy on growth to reach a large size in a short period of time to avoid predation (Reissen 1999).

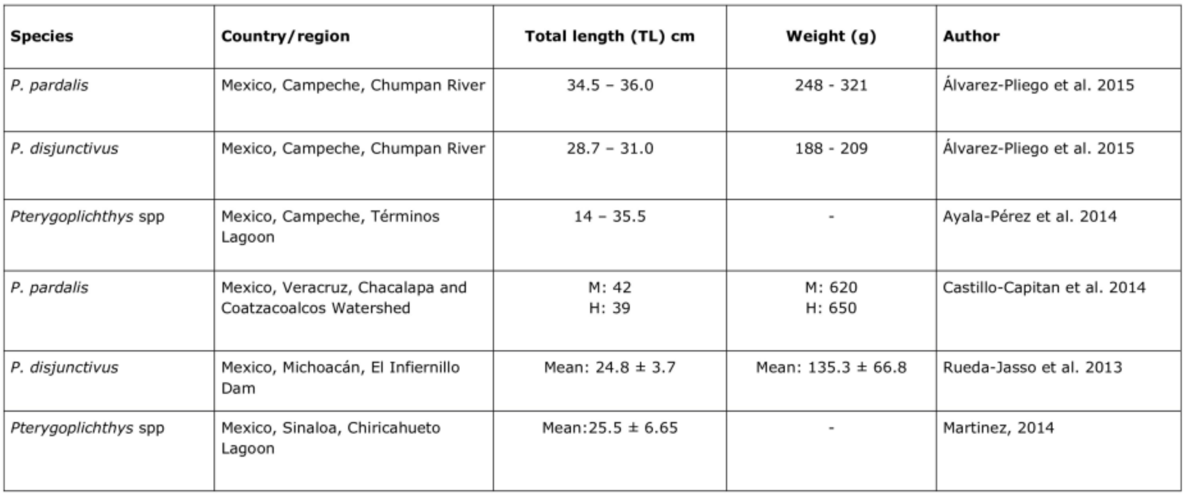
In its natural range, armed catfish are preyed upon by crocodiles, otters, and some large fish (Mendoza et al., 2007). In Mexico, it has been documented that predation is beginning to be carried out by some predatory fish species (Centropomus undecimalis; Megalops atlanticus; C. poeyi) (Toro-Ramírez et al., 2014; Wakida-Kusonoki & Toro-Ramírez, 2016) and a species of aquatic bird, the olive cormorant (Phalacrocorax brasilianus)(Ríos-Muñoz 2015). Therefore, a greater richness of predatory species could play an important role

Tab 2. Lengths and weights recorded for specimens of Pterygoplichthys evaluated in Mexico. G: Grijalva, U: Usumacinta. LP: Pattern length. M: male, H: female.



Species	Country/region	Total length (TL) cm	Weight (g)	Author
Pterygoplichthys spp	Mexico-Grijalva-Usumacinta Watershed	G: 20.5 - 47 U: 20 - 45	G:130 - 650 U: 150 - 750	This work
Pterygoplichthys spp	Centla Swamps	27 - 35	170 - 1 000	Barba et al. 2015
P. pardalis	Mexico-Frontera, Tabasco	27.6 – 37.5	173 - 458	Wakida-Kusunoki et al. 2007
P. pardalis	Mexico, Centla, Tabasco	Mean:14.26 ± 4.71	-	Mendoza-Carranza et al. 2010
Pterygoplichthys spp	Mexico, Lower Grijalva-Usumacinta Watershed	LP: 1.1 to 36.7	-	Sánchez et al. 2015
P. pardalis	Mexico, Campeche, San Pedro Rivers (RSP), Palizada (RP)	RSP: 30.5 – 40.1 RP: 29.2 – 35.1	RSP: 259 – 406 RP: 195 - 401	Wakida-Kusunoki and Amador del Ángel 2009
P. disjunctivus	Mexico, Campeche, San Pedro Rivers (RSP), Palizada (RP)	RSP: 30.1 – 38.6 RP: 12.6 – 30.2	RSP: 195 – 401 RP: 13.4 - 250	Wakida-Kusunoki and Amador del Ángel 2009
P. pardalis	Mexico, Campeche, Palizada River	22.2 – 42.25	72.8 - 385	Wakida-Kusunoki and Amador del Ángel 2011

Continuation tab.2



Species	Country/region	Total length (TL) cm	Weight (g)	Author
P. pardalis	Mexico, Campeche, Chumpan River	34.5 – 36.0	248 - 321	Álvarez-Pliego et al. 2015
P. disjunctivus	Mexico, Campeche, Chumpan River	28.7 – 31.0	188 - 209	Álvarez-Pliego et al. 2015
Pterygoplichthys spp	Mexico, Campeche, Términos Lagoon	14 – 35.5	-	Ayala-Pérez et al. 2014
P. pardalis	Mexico, Veracruz, Chacalapa and Coatzacoalcos Watershed	M: 42 H: 39	M: 620 H: 650	Castillo-Capitan et al. 2014
P. disjunctivus	Mexico, Michoacán, El Infiernillo Dam	Mean: 24.8 ± 3.7	Mean: 135.3 ± 66.8	Rueda-Jasso et al. 2013
Pterygoplichthys spp	Mexico, Sinaloa, Chiricahueto Lagoon	Mean:25.5 ± 6.65	-	Martinez, 2014

as a biological barrier for the expansion and establishment of the armed catfish (Wei et al. al., 2022) in invaded areas.

Armored catfish represents a persistent threat to native fauna in invaded areas. As it has no economic or food value in Mexico, this fish is not exploited, and its populations in invaded areas are not regulated or controlled (Mendoza-Carranza et al., 2018).

CONCLUSION

Armed catfish caught in the Usumacinta River presented a higher condition factor than those from the Grijalva River, it is likely that the quantity and nutritional quality of the feed influenced this parameter, however, it is necessary to evaluate this factor for better predictions.

The largest armored catfish caught was at the sampling point closest to city of Villahermosa (Grijalva: Chilapa). This increase in the abundance of captured fish could be associated with different factors, such as the availability of food resources and nesting areas as well as the amount and type of organic waste.

Our results show that the captured fish correspond to fish in adult stage, with a negative allometric growth rate in both rivers. In the Grijalva river, the lack of seasonal extremes in the flow and water level has allowed the presence of a greater number of fish in the sampled sites.

The capture of armored catfish in the Usumacinta River possibly indicates that armored catfish are adapting to extreme water flow conditions, which favors the life history patterns of this fish. However, given that invasive species can modify their life history patterns to take advantage of new habitats, it may not be possible to make an adequate or accurate prediction of how armored catfish behave in different types of invaded habitats.

According to this study, the welfare of armored catfish in both rivers was good, meaning that in both rivers these fish found sufficient resources to develop and maintain populations over time. Anthropogenic activities currently impacting both rivers favor the presence of this fish, which is why it is essential to carry out reforestation campaigns along the riverbanks and design strategies to manage the use of agrochemicals in the region.

A more exhaustive study of the armored catfish population currently distributed in both rivers is encouraged, considering the bodies of water and canals adjacent to the main channel, analyzing the main sources of organic material mainly in urban areas, as well as in crop and livestock areas

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