Contrasting life-history strategies in the Ciénaga Grande de Magangué, a Neotropical floodplain: Reproduction, growth, and exploitation vulnerability of two endemic fishes

Estrategias de historia de vida contrastantes en la Ciénaga Grande de Magangué, una llanura aluvial neotropical: Reproducción, crecimiento y vulnerabilidad a la explotación de dos peces endémicos

Estratégias contrastantes de história de vida na Ciénaga Grande de Magangué, uma planície aluvial neotropical: Reprodução, crescimento e vulnerabilidade à exploração de dois peixes endêmicos

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Abstract
The Magdalena River basin supports one of the most relevant inland fisheries in northern South America, yet biological information on many endemic species remains scarce. This study investigated the reproductive biology, growth, and exploitation of the characin *Triportheus magdalenae* and the freshwater sciaenid *Plagioscion magdalenae* in the Ciénaga Grande de Magangué, a Neotropical floodplain wetland in the lower Magdalena River basin. Monthly samples were collected from artisanal landings at three landing sites over a hydrological year (September 2016–August 2017), and 2,210 individuals (1,459 *Triportheus magdalenae*; 751 *Plasgicion magdalenae*) were analyzed. For each specimen, total length, weight, sex, maturity stage, gonadosomatic index (GSI), hepatosomatic index (HSI), and condition factor (K) were recorded. Fecundity of mature females was estimated, and length–frequency data were analyzed with FiSAT II to obtain growth and exploitation parameters for *T. magdalenae* and preliminary growth parameters for *P. magdalenae*. Basin-scale landings for 2021–2022 were obtained from the Colombian Fisheries Statistics Service (SEPEC). Both species showed distinct seasonal spawning peaks associated with the flood pulse (March–May), but with contrasting life-history strategies. *T. magdalenae* matured early (female $L_{50} \approx 15.6$ cm TL), exhibited high relative fecundity (~5,000 oocytes per female), and rapid growth ($L\infty = 24.15$ cm TL; $K = 0.60$ yr^{-1}). Total mortality ($Z = 2.68$ yr^{-1}) and Pauly natural mortality ($M = 1.33$ yr^{-1}) yielded a fishing mortality $F = 1.35$ yr^{-1} and an exploitation rate $E = 0.50$, suggesting exploitation close to the conventional optimum for many tropical populations. In contrast, *P. magdalenae* matured later (female $L_{50} \approx 29.9$ cm TL), had fewer but larger oocytes, and lower growth rates; mortality and exploitation could not be robustly estimated due to limited length–frequency data. SEPEC data indicate that *T. magdalenae* and *P. magdalenae* together contributed ~2.8–5.4% of total basin landings in 2021–2022. Our results suggest that *T. magdalenae* currently tolerates moderate fishing pressure, whereas *P. magdalenae* appears more vulnerable, and support size limits and seasonal closures aligned with reproductive peaks in Neotropical floodplain fisheries. This study illustrates a scalable approach to assessing the exploitation status of endemic freshwater fishes in data-limited tropical river basins, providing empirical support to efforts to reconcile inland fish production with biodiversity conservation.

Keywords: reproductive biology, *Triportheus magdalenae*, *Plasgicion magdalenae*, freshwater fisheries, Colombia, fisheries management.

Resumen
La cuenca del río Magdalena alberga una de las pesquerías continentales más importantes del norte de Sudamérica, pero la información biológica sobre muchas especies endémicas sigue siendo escasa. Este estudio investigó la biología reproductiva, el crecimiento y la explotación del carácido *Triportheus magdalenae* y del esciénido de agua dulce *Plagioscion magdalenae* en la Ciénaga Grande de Magangué, un humedal de llanura aluvial neotropical en la cuenca baja del río Magdalena. Se recolectaron muestras mensuales de desembarques artesanales en tres puntos de desembarque durante un año hidrológico (septiembre de 2016 a agosto de 2017), y se analizaron 2210 individuos (1459 de *Triportheus magdalenae y* 751 de *Plagioscion magdalenae*). Para cada espécimen, se registraron la longitud total, el peso, el sexo, el estadio de madurez, el índice gonadosomático (IGS), el índice hepatosomático (IHS) y el factor de condición (K). Se estimó la fecundidad de las hembras maduras y se analizaron los datos de frecuencia de longitud con FiSAT II para obtener parámetros de crecimiento y explotación para *T. magdalenae* y parámetros de crecimiento preliminares para *P. magdalenae*. Los desembarques a escala de cuenca para 2021-2022 se obtuvieron del Servicio de Estadísticas Pesqueras de Colombia (SEPEC). Ambas especies mostraron picos de desove estacionales distintos asociados con el pulso de inundación (marzo-mayo), pero con estrategias de historia de vida contrastantes. *T. magdalenae* maduró temprano (hembra $L_{50} \approx 15{,}6$ cm TL), exhibió una alta fecundidad relativa (~5000 ovocitos por hembra) y un crecimiento rápido ($L\infty = 24{,}15$ cm TL; $K = 0{,}60$ yr^{-1}). La mortalidad total ($Z = 2{,}68$ yr^{-1}) y la mortalidad natural de Pauly ($M = 1{,}33$ yr^{-1}) dieron como resultado una mortalidad por pesca $F = 1{,}35$ yr^{-1} y una tasa de explotación $E = 0{,}50$, lo que sugiere una explotación cercana al óptimo convencional para muchas poblaciones tropicales. En contraste, *P. magdalenae* maduró más tarde (hembra $L_{50} \approx 29{,}9$ cm TL), tuvo menos ovocitos pero de mayor tamaño y tasas de crecimiento más bajas; la mortalidad y la explotación no pudieron estimarse de manera robusta debido a los datos limitados de frecuencia de longitud. Los datos de SEPEC indican que *T. magdalenae* y *P. magdalenae* juntas contribuyeron con ~2,8–5,4% del total de capturas de la cuenca en 2021–2022. Nuestros resultados sugieren que *T. magdalenae* tolera actualmente una presión pesquera moderada, mientras que *P. magdalenae* parece ser más vulnerable, y respaldan la implementación de límites de tamaño y vedas estacionales que coincidan con los picos reproductivos en las pesquerías de llanuras aluviales neotropicales. Este estudio ilustra un enfoque escalable para evaluar el estado de explotación de peces de agua dulce endémicos en cuencas fluviales tropicales con datos limitados, brindando apoyo empírico a los esfuerzos por conciliar la producción pesquera continental con la conservación de la biodiversidad.

Palabras clave: biología reproductiva, *Triportheus magdalenae, Plasgicion magdalenae*, pesquerías de agua dulce, Colombia, manejo pesquero

Resumo
A bacia do rio Magdalena abriga uma das pescarias continentais mais relevantes do norte da América do Sul, porém, as informações biológicas sobre muitas espécies endêmicas ainda são escassas. Este estudo investigou a biologia reprodutiva, o crescimento e a exploração do caracídeo *Triportheus magdalenae* e do peixe-agulha de água doce *Plagioscion magdalenae* na Ciénaga Grande de Magangué, uma área úmida de planície aluvial neotropical na bacia inferior do rio Magdalena. Amostras mensais foram coletadas em desembarques artesanais em três pontos de desembarque ao longo de um ano hidrológico (setembro de 2016 a agosto de 2017), e 2.210 indivíduos (1.459 *Triportheus magdalenae*; 751 *Plagioscion magdalenae*) foram analisados. Para cada espécime, foram registrados o comprimento total, o peso, o sexo, o estágio de maturação, o índice gonadossomático (IGS), o índice hepatossomático (IHS) e o fator de condição (K). A fecundidade de fêmeas maduras foi estimada e os dados de frequência de comprimento foram analisados com o FiSAT II para obter parâmetros de crescimento e exploração para *T. magdalenae* e parâmetros preliminares de crescimento para *P. magdalenae*. Os desembarques em escala de bacia para 2021–2022 foram obtidos do Serviço Colombiano de Estatísticas da Pesca (SEPEC). Ambas as espécies apresentaram picos sazonais de desova distintos associados ao pulso de inundação (março–maio), mas com estratégias de história de vida contrastantes. *T. magdalenae* atingiu a maturidade precocemente (L_{50} da fêmea $\approx 15{,}6$ cm CT), exibiu alta fecundidade relativa (~5.000 oócitos por fêmea) e crescimento rápido ($L\infty = 24{,}15$ cm CT; $K = 0{,}60$ ano^{-1}). A mortalidade total ($Z = 2{,}68$ anos^{-1}) e a mortalidade natural de Pauly ($M = 1{,}33$ ano^{-1}) resultaram em uma mortalidade por pesca $F = 1{,}35$ ano^{-1} e uma taxa de exploração $E = 0{,}50$, sugerindo uma exploração próxima ao ótimo convencional para muitas populações tropicais. Em contraste, *P. magdalenae* atingiu a maturidade mais tarde (L_{50} fêmea $\approx 29{,}9$ cm CT), apresentou menor número de oócitos, porém maiores, e taxas de crescimento mais baixas; a mortalidade e a exploração não puderam ser estimadas de forma robusta devido à limitação dos dados de frequência de comprimento. Os dados do SEPEC indicam que *T. magdalenae* e *P. magdalenae*, juntas, contribuíram com aproximadamente 2,8–5,4% do total desembarcado na bacia em 2021–2022. Nossos resultados sugerem que *T. magdalenae* tolera atualmente uma pressão de pesca moderada, enquanto *P. magdalenae* parece ser mais vulnerável, e corroboram a necessidade de limites de tamanho e períodos de defeso alinhados com os picos reprodutivos em áreas de pesca aluviais neotropicais. Este estudo ilustra uma abordagem escalável para avaliar o estado de exploração de peixes endêmicos de água doce em bacias hidrográficas tropicais com dados limitados, fornecendo suporte empírico aos esforços para conciliar a produção de peixes de água doce com a conservação da biodiversidade.

Palavras-chave: biologia reprodutiva, *Triportheus magdalenae*, *Plasgicion magdalenae*, pesca em água doce, Colômbia, gestão pesqueira.

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1. Introduction

Inland fisheries contribute significantly to food security, livelihoods, and cultural identity in developing tropical countries, where fish are an important source of animal protein for rural populations (Cooke et al., 2016; FAO, 2025). In Colombia, inland fisheries are exclusively artisanal and small-scale, supporting thousands of households through harvesting, processing, and trade along important river basins, such as the Magdalena River system (Jiménez-Segura et al., 2022). Within this basin, the Ciénaga Grande de Magangué, located in the Momposina Depression in the La Mojana region, is a neotropical floodplain wetland that provides multiple ecosystem services, including flood regulation, nutrient retention, and high fish production that supports local markets in Magangué and surrounding municipalities (CRA, 2012; Jaramillo et al., 2023).

The fish assemblages of the Magdalena River basin exhibit high diversity and endemism, and several species are of critical ecological and socioeconomic importance (Reis, 2015). Among them, the endemic characiform *T. magdalenae* and the sciaenid *P. magdalenae* (river croaker) are primary to artisanal fisheries in the lower Magdalena and its floodplains (Mariguela et al., 2016; Morales, J., & García-Alzate, 2018). In 2016, landings from the Ciénaga Grande de Magangué reached 23,675 t, representing 10.77% of the total catch reported for the Magdalena River basin. *P. magdalenae* and *T. magdalenae* contributed 3.09% and 2.67% of this production, respectively, underscoring their economic relevance for riparian communities (De la Hoz and Manjarrés, 2016). Local fishers and official monitoring programs have reported declines in catch per unit of effort (CPUE) and increasing dominance of smaller size classes in landings, raising concerns about recruitment overfishing and the long-term sustainability of these stocks (Jiménez-Segura et al., 2022; Rivera-Cediel, 2024a; 2024b).

These local trends reflect broader global patterns. Tropical freshwater ecosystems are among the most threatened on the planet due to habitat degradation, flow regulation, pollution, invasive species, and overfishing (Arantes et al., 2019; Reis, 2015; Rojas-Luna et al., 2022). The International Union for Conservation of Nature (IUCN) estimates that around one quarter of freshwater fish species are threatened with extinction, while the Neotropics harbor more than three quarters of the global functional diversity of freshwater fishes, making this region both a biodiversity hotspot and a focal area for conservation and management (IUCN, 2023; Tagliacollo et al., 2024; Toussaint et al., 2016). World Fish Migration Foundation et al. (2024) indicated an 81% decline in migratory freshwater fish populations worldwide between 1970 and 2020, with Latin America showing the steepest reductions, largely driven by loss of connectivity and excessive exploitation.

Despite the socio-economic relevance of *T. magdalenae* and *P. magdalenae* in the Magdalena River basin and the growing concern about declining catches, there is still a marked lack of species-specific studies that jointly evaluate their reproductive biology, growth, and exploitation status in Colombian floodplain wetlands. Existing work has tended to focus either on taxonomy and distribution or on isolated reproductive descriptors for localities, providing little integrated evidence on how life-history traits, fishing pressure, and flood-pulse dynamics interact in the Ciénaga Grande de Magangué and the lower Magdalena River.

The Ciénaga Grande de Magangué is a floodplain system hydrologically connected to the Magdalena River through the El Chorro channel, and its seasonal flood pulses strongly influence habitat availability, trophic pathways, and fish life cycles (CRA, 2012; Jaramillo et al., 2023). As in other Neotropical floodplains, rising water levels create nursery and feeding areas that favor reproduction and early development, while low-water periods concentrate fish and increase catchability (Agostinho et al., 2004; FAO, 1997, 1998, 2017).

Within this Neotropical floodplain wetland, *T. magdalenae* is a small-bodied, *zooplanktivorous* species that matures early and exhibits reproductive migrations strongly associated with hydrological pulses, characteristics that generally confer resilience but also make populations sensitive to intensive exploitation of juvenile cohorts (Morales & García-Alzate, 2018; Novakowski et al., 2008). In contrast, *P. magdalenae* is the only sciaenid known to complete its entire life cycle in freshwater, attaining larger sizes and displaying a life-history strategy with later maturation and potentially higher vulnerability to sustained fishing pressure (Santos, 2010; Valentim, 1998). These two endemic fishes exemplify contrasting life-history strategies, opportunistic vs. more periodic sensu Winemiller (1989), as further discussed by Logez et al. (2015) and Wootton and Smith (2014), that are widely represented in Neotropical floodplain fish assemblages.

Effective management of artisanal fisheries in such systems requires species-specific biological information. Reproductive parameters, including sex ratio, size at first, and mean sexual maturity, spawning seasonality, and fecundity, are inputs for defining minimum legal capture sizes, designing closed seasons that protect peak spawning periods, and evaluating the resilience of exploited stocks to fishing and environmental variation (Vazzoler, 1997; Echevarría et al., 2015; Sánchez-Núñez et al., 2024; Lowerre-Barbieri et al., 2011; Wootton and Smith, 2014; Baldisserotto et al., 2019).

In Colombia, the minimum capture size established for *T. magdalenae* (15 cm) coincides with the size at first maturity reported in local studies, suggesting that many individuals may be removed from the population before completing even one reproductive event (SEPEC, 2019; 2021, Valdelamar-Villegas, 2006). Official statistics from the SEPEC for 2021–

2022 document high fishing effort and substantial landings of *T. magdalenae* and *P. magdalenae* in the Magdalena basin, providing an opportunity to integrate biological indicators with fishery-dependent data to assess exploitation status (Duarte et al., 2022a, 2022b).

This study addresses this gap by providing the first integrated assessment of reproductive traits, growth parameters, and exploitation status for *T. magdalenae* and *P. magdalenae* in a Neotropical floodplain wetland of the Magdalena River basin. Size structure, sex ratio, reproductive indices, size at first, mean sexual maturity, and fecundity were characterized, and growth and exploitation parameters were obtained from size-frequency data for T. magdalenae using FiSAT II, together with preliminary growth parameters for *P. magdalenae*.

2. Materials and methods

2.1. Study area

Ciénaga Grande de Magangué is a floodplain wetland of high biological diversity and marked socio-economic importance within the Magdalena River basin (Jiménez-Segura et al., 2022). Its mosaic of aquatic habitats, together with intensive artisanal fisheries, sustains food security and livelihoods for surrounding riparian communities. Within this socio-ecological system, species such as *T. magdalenae* and *P. magdalenae* are relevant components of local fisheries (Jiménez-Segura et al., 2022; Mariguela et al., 2016).

Hydrologically, the wetland is connected to the mainstem Magdalena River through the El Chorro canal, a waterway of approximately 1,200 m that mediates seasonal flooding and allows fish migrations between the river and the floodplain. Under low to moderate water levels, the system maintains around 430 km² of permanent water surface, which can expand to more than 1,000 km² during peak flood periods (CRA, 2012; Jaramillo et al., 2023). Geographically, Ciénaga Grande de Magangué is bounded to the north by Punta Piedra and Punta Arena, to the south by Jarillón Sur and the towns of El Retiro and Madrid, and to the east by the Magangué–Mompós road.

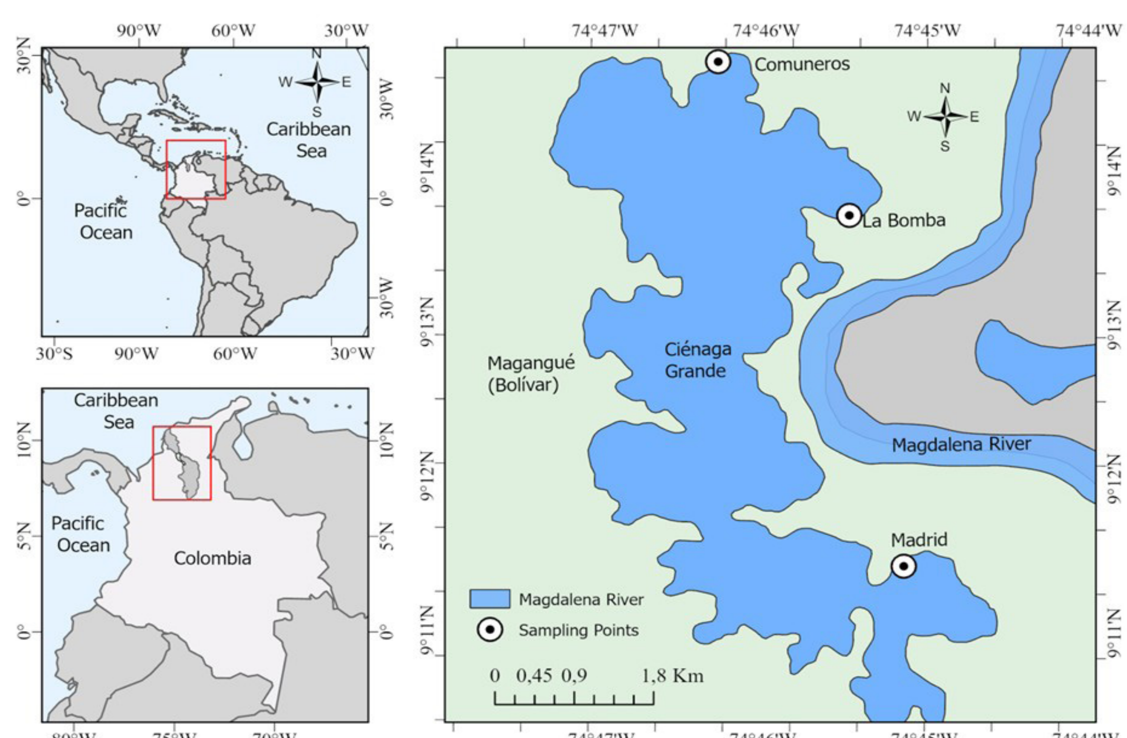

Figure 1. Location of the Ciénaga Grande de Magangué in the lower Magdalena River basin (Colombia) and position of the three artisanal landing sites sampled in this study (La Bomba, Comuneros, and Madrid).

Three sampling stations were defined to encompass the wetland's main ecological sectors. La Bomba (9°13'44.83" N, 74°45'29.12" W), Comuneros (9°14'43.64" N, 74°46'18.93" W), and Madrid (9°11'29.35" N, 74°45'05.98" W) (Figure 1). Station locations were chosen based on fishing intensity, ease of access, and the representation of contrasting habitat types in the wetland mosaic (CRA, 2012). Owing to its geographic setting and environmental traits, the study area is considered representative of other floodplain wetlands distributed along the Magdalena River basin.

2.2. Sample collection

Artisanal fish landings were monitored monthly from September 2016 to August 2017, with two sampling visits per month to each landing site. Specimens were obtained from commercial catches conducted by local fishers using monofilament gillnets, the most common gear in the area (SEPEC, 2019; 2021; Jiménez-Segura et al., 2022). All individuals of *T. magdalenae*, and *P. magdalenae* present in the catches were measured. For each fish, total length (TL) and standard length (SL) were measured with an ichthyometer to the nearest millimeter, and total body weight (W) was recorded using a digital scale with 0.1 g precision, following standard procedures for inland fish studies (Bagenal and Tesch, 1978; Vazzoler, 1997). A subset of individuals was dissected by means of a ventral incision to remove gonads and liver, which were dried in a ventilated oven at 60 °C until a constant weight, and then weighed. Mature ovaries were preserved in 10% buffered formalin for subsequent gravimetric fecundity counts. Gonad development was assessed macroscopically based on external morphology, color, and vascularization, using maturity scales previously validated for Neotropical fishes (Vazzoler, 1997; Santos et al., 2010), rather than histological criteria.

Descriptive statistics for length and weight presented in this study were calculated from the updated, quality-checked artisanal landings database, after removing obvious data-entry errors and inconsistencies detected during the revision of the original undergraduate dataset. As a result, some mean values differ slightly from those reported in the earlier thesis but are fully consistent with the raw measurements used for the present analyses.

2.3. Laboratory procedures

In the laboratory, fixed ovaries were rinsed, dried, and weighed again. Each ovary was divided into three sections (anterior, middle, and posterior), and a 1 g subsample was taken from each section. Subsamples were placed in Gilson's fluid until complete dissociation of connective tissue, and oocytes were counted under a stereomicroscope, following the gravimetric method described by Bagenal and Tesch (1978) and Holden and Raitt (1975).

Sex was determined macroscopically from gonadal morphology. Sex ratio (female: male) was computed for each species and period and evaluated against the expected 1:1 proportion using a chi-square test (χ^2), as recommended for fish reproductive studies (Vazzoler, 1997; Zar, 2010). Gonadal development stages were classified using the maturity scales applied in previous studies: Martins (2005) and Valdelamar-Villegas (2006) for *T. magdalenae* and Bayuelo Espitia (2000) for *P. magdalenae*, ensuring comparability with regional assessments of reproductive status in Magdalena floodplain fishes.

2.4. Reproductive indices

For each specimen, the gonadosomatic index (GSI), hepatosomatic index (HSI), and condition factor (K) were calculated from the biometric data. These indices are widely used to infer reproductive activity and energy allocation in teleost fishes (Babiker and Ibrahim, 1979; Vazzoler, 1997). GSI, HIS, and K were computed as (1), (2), and (3):

$$- \ GSI = (Wg / W) \times 100 \qquad (1)$$
$$- \ HSI = (Wl / W) \times 100 \qquad (2)$$
$$- \ K = 100 \times (W / TL^{b}) \qquad (3)$$

where Wg is gonad weight (g), Wl is liver weight (g), W is total body weight (g), TL is total length (cm), and b is the slope of the length–weight relationship obtained from log-transformed data (Bagenal and Tesch, 1978; Vazzoler, 1997; Wootton and Smith, 2014; Froese, 2022). Monthly means of GSI, HSI, and K were used to identify reproductive periods and to describe seasonal changes in energetic condition consistent with patterns observed in other neotropical freshwater fishes (Froese, 2022; Baldisserotto et al., 2019).

2.5. Fecundity

Fecundity was estimated only for females with mature ovaries. Absolute fecundity (F) was obtained using the gravimetric method of Holden and Raitt (1975), assuming a homogeneous distribution of oocytes throughout the ovary. For each female, the number of oocytes (n) in the subsample was counted, and absolute fecundity was estimated as (4):

$$F = (n \times Pg) / Pm \qquad (4)$$

where Pg is total ovary weight (g), and Pm is subsample weight (g) (Bagenal and Tesch, 1978; Holden and Raitt, 1975). Relative fecundity was expressed as the number of oocytes per unit of total length (oocytes $\cdot cm^{-1}$) and per unit of body weight (oocytes $\cdot g^{-1}$), which allows comparison among individuals and between species with different body sizes (Echevarría et al., 2015; Vazzoler, 1997).

2.6. Fishery landing data

To place the local biological results in a broader fisheries context, we used official artisanal landing statistics compiled by the Servicio Estadístico Pesquero Colombiano (SEPEC). We extracted data for the Magdalena River basin from the national reports for 2021 and 2022, which provide monthly and annual landings (t) for major species and commercial categories (Duarte et al., 2022a, 2022b). For each year, we obtained total annual landings in the basin, annual and monthly landings of T. magdalenae and P. magdalenae, and the percentage contribution of these species to the multispecies catch. These SEPEC data were used in a descriptive, non-parametric way to compare basin-wide exploitation patterns with the 2016–2017 biological results from the Ciénaga Grande de Magangué (Jiménez-Segura et al., 2022).

2.7. Fishery landing data

Sex ratios (female: male) were tested for deviation from the expected 1:1 ratio using chi-square tests (χ^2) at a significance level of $\alpha = 0.05$ (Zar, 2010). Length–weight relationships for each species were fitted using the potential model $W = a \cdot TL^b$, with parameters a and b estimated by least-squares regression of log-transformed weight and length (Bagenal and Tesch, 1978; Vazzoler, 1997).

Size at first sexual maturity (initial maturity) was defined as the smallest total length at which mature individuals (stage IV) were observed. Mean size at sexual maturity (L_{50}) was estimated by grouping individuals into length classes, calculating the proportion of mature fish in each class, and fitting a logistic curve to the length–maturity data, following Borda (2004) and Vazzoler (1997).

Length-frequency data were analyzed in FiSAT II to estimate growth and mortality parameters. For T. magdalenae, the von Bertalanffy growth function (VBGF) parameters (asymptotic length $L\infty$, growth coefficient K, and theoretical age at zero length t_0) were obtained using standard routines for tropical fish stocks (Gayanilo et al., 2005; Sparre & Venema, 1998). Total mortality (Z) was estimated from the length-converted catch curve, natural mortality (M) from empirical models based on growth parameters and environmental temperature, and fishing mortality (F) was derived as $F = Z - M$. The exploitation rate (E) was calculated as $E = F/Z$ and interpreted in relation to reference values for tropical coastal and inland fisheries (Gulland, 1971; Sparre & Venema, 1998; Costa et al., 2018; Lorenzen, 2022). For P. magdalenae, only preliminary VBGF growth parameters ($L\infty$, K, t_0) were obtained because the length-frequency distribution was truncated and sample sizes were small in some length classes, and these values were therefore not used to estimate mortality or exploitation rates.

Temporal variation in GSI, HIS, and K was described graphically. For P. magdalenae, differences in mean GSI among months were evaluated using one-way ANOVA when assumptions of normality and homoscedasticity were met, and significance was assessed at $\alpha = 0.05$ (Zar, 2010). All analyses followed standard procedures in fish reproductive and population dynamics studies (Bagenal and Tesch, 1978; Vazzoler, 1997; Gayanilo et al., 2005).

3. Results and discussion

3.1. Basin-scale artisanal fishery context

SEPEC statistics for 2021–2022 confirm that the Magdalena River basin sustains one of the largest inland fisheries in northern South America, with total artisanal landings of 18,959.8 t in 2021 and 15,213.5 t in 2022 (January–October). Within this multispecies fishery, *T. magdalenae* and *P. magdalenae* contributed 1.2% and 1.6% of total landings in 2021, and 3.0% and 2.4% in 2022 (January–October), respectively (Table 1).

Table 1. Annual artisanal landings (t) in the Magdalena River basin in 2021–2022 and proportional contribution (%) of *T. magdalenae* and *P. magdalenae* to total inland catches, based on SEPEC statistics (2021 and 2022) (Duarte et al., 2022a, 2022b).

Year	Total artisanal landings	Landings of *T. magdalenae*	Total	Landings of *P. magdalenae*	Total
		(t)	%	(t)	%
2021	18,959.8	227.3	1.2	298.4	1.6
2022	15,213.5	451.8	3.0	364.6	2.4

The combined contribution of both species thus increased from ~2.8% to ~5.4% in only two years, highlighting their growing relevance for food security and income in the basin. To link this basin-scale picture with local biological information, Table 2 integrates SEPEC landings with headline life-history traits and exploitation indicators derived from the present study. This increase in the relative contribution of *T. magdalenae* and *P. magdalenae* to total landings is consistent with the 'fishing down the food web' pattern described for multi-species inland fisheries, whereby declining stocks of larger, high-trophic-level fishes lead to increasing dependence on smaller-bodied or previously secondary species. In the Magdalena basin, rising landings of these endemic fishes therefore likely reflect both changes in fish community structure and a reorientation of fishing effort towards more resilient, yet still vulnerable, components of the assemblage.

Table 2. Basin-scale fishery relevance and key biological traits of *T. magdalenae* and *P. magdalenae*. The table integrates SEPEC landings for the Magdalena River basin (2021–2022) with a few headline biological indicators from this study in the Ciénaga Grande de Magangué.

Species	Basin-scale fishery importance, SEPEC 2021–2022)	Biological traits (this study, Ciénaga Grande de Magangué)	Exploitation status (integration of FiSAT II and SEPEC)
T. magdalenae	Total artisanal landings were 18,959.8 t in 2021 and 15,213.5 t in 2022 (January–October). Landings of *T. magdalenae* were 227.3 t (1.2% of total) in 2021 and 451.8 t (3.0% of total) in 2022 (January–October), indicating a rising relative contribution to the multispecies inland fishery.	Small-bodied, fast-growing characiform with early maturation. Female $L_{50} \approx 15.6$ cm TL; mean absolute fecundity ≈ 4,977 oocytes per mature female; single main spawning peak in May associated with the rising-water period; continuous recruitment throughout the year.	Von Bertalanffy growth parameters: $L\infty \approx 24.15$ cm TL, $K \approx 0.60$ yr^{-1}. Total mortality $Z \approx 2.68$ yr^{-1}, natural mortality $M \approx 1.33$ yr^{-1}, and fishing mortality $F \approx 1.35$ yr^{-1}, yielding an exploitation rate $E \approx 0.50$, which suggests exploitation close to the conventional optimum for many tropical stocks.
P. magdalenae	Landings of *P. magdalenae* were 298.4 t (1.6% of total) in 2021 and 364.6 t (2.4% of total) in 2022 (January–October). The combined contribution of *T. magdalenae* and *P. magdalenae* to total basin landings increased from ~2.8% in 2021 to ~5.4% in 2022 (January–October).	Medium-sized freshwater sciaenid with later maturation. Female $L_{50} \approx 29.9$ cm TL; mean absolute fecundity ≈ 6,656 oocytes per mature female; main spawning season concentrated between January and April, with an additional earlier peak inferred in September; reproductive activity closely associated with the flood pulse.	Preliminary growth estimates indicate larger asymptotic size and lower growth rates than in *T. magdalenae*. Mortality and exploitation rates could not be robustly estimated due to limited length–frequency data. The combination of later maturation and lower, more variable relative fecundity suggests higher vulnerability to size-selective fishing and environmental change.

At the basin level, both species are moderate contributors to total landings, but at the scale of the Ciénaga Grande de Magangué, they are key components of artisanal catches and of the functional structure of the floodplain fish assemblage. For *T. magdalenae*, early maturation (female $L_{50} \approx 15.6$ cm TL), high relative fecundity, and fast growth suggest a comparatively resilient, opportunistic life-history strategy. In contrast, *P. magdalenae* matures at larger sizes (female $L_{50} \approx 29.9$ cm TL) and exhibits lower and more variable relative fecundity, characteristics typical of more periodic or K-selected strategists and indicative of higher vulnerability to size-selective fishing. These contrasts underscore the need to interpret SEPEC trends in light of species-specific biology when designing management measures for Neotropical inland fisheries.

3.2. Sample characteristics, length structure, and condition

Over the 12-month monitoring period (September 2016–August 2017), a total of 2,210 fish were examined, with catches dominated by *T. magdalenae* and a smaller but substantial contribution of *P. magdalenae* (Table 3). Of these, 1,459 *T. magdalenae* and 751 *P. magdalenae* had both total length (TL) and total weight (W) recorded and were used in the length–weight analyses summarized in Table 3. *T. magdalenae* was represented mainly by small to medium-sized individuals, whereas *P. magdalenae* encompassed much larger fish and a wider size spectrum. This contrast indicates that the sampling covered multiple size classes and life stages for both species, from juveniles to adults, reflecting natural population structure as well as the size-selective nature of artisanal gillnet fisheries in the Ciénaga.

Table 3. Sample sizes (N), range, and mean of total length (TL) and total weight (W), and parameters of the length–weight relationship ($W = a \cdot TL^b$) for *T. magdalenae* and *P. magdalenae* in the Ciénaga Grande de Magangué.

Species	N	TL range (cm)	TL mean (cm)	W range (g)	W mean(g)	a	b	r^2	Growth type
T. magdalenae	1,459	10.0–30.0	18.1 ± 2.6	9.0–156.0	57.6 ± 25.2	0.0052	3.19	0.83	Positive allometric (b > 3)
P. magdalenae	751	10.0–56.0	21.3 ± 3.6	1.5–2,227.0	91.6 ± 104.8	0.0141	2.82	0.50	Slightly negative allometric (b < 3)

Length–weight relationships ($W = a \cdot TL^b$) were highly significant ($P < 0.001$) for both species (Table 3). For *T. magdalenae* (N = 1459), TL ranged from 10.0 to 30.0 cm and W from 9.0 to 156.0 g, with a mean (± SD) TL of 18.1 ± 2.6 cm and a mean W of 57.6 ± 25.2 g. The fitted L–W regression yielded a = 0.0052, b = 3.19, and $r^2 = 0.83$, indicating clear positive allometric growth (b > 3), whereby larger individuals become proportionally heavier as they grow. In contrast, *P. magdalenae* (N = 751) showed TL between 10.0 and 56.0 cm and W between 1.5 and 2227.0 g, with a mean TL of 21.3

± 3.6 cm and a mean W of 91.6 ± 104.8 g. Its L–W relationship (a = 0.0141, b = 2.82, $r^2 = 0.50$) suggests slightly negative allometric growth ($b < 3$) and a much larger scatter around the regression line, consistent with more heterogeneous body condition and size structure in the catches. Such deviations from isometry and the associated changes in condition have been widely reported for Neotropical characiforms and sciaenids in productive floodplains (Bagenal and Tesch, 1978; Vazzoler, 1997; Barbosa et al., 2010) and imply that larger individuals contribute disproportionately to biomass and reproductive output, making their protection particularly relevant for long-term stock productivity (Hilborn et al., 2025).

The contrasting length–weight relationships of the two species further underline their different life-history strategies. The positive allometry of *T. magdalenae* indicates that larger individuals tend to be proportionally heavier and in better condition, a pattern commonly observed in well-fed fishes from productive floodplains (Bagenal and Tesch, 1978; Vazzoler, 1997; Froese, 2006). This is consistent with a fast-growing, highly productive characin that exploits pulsed food resources in floodplain habitats. By contrast, the slightly negative allometry and lower goodness of fit of the L–W relationship for *P. magdalenae*, together with the greater scatter around the mean curve, are consistent with a more heterogeneous body condition and size structure in the catches. Similar variability in condition and growth has been documented for freshwater sciaenids in Amazonian and Colombian floodplains (Barbosa et al., 2010), and may reflect spatial and temporal heterogeneity in diet, energy allocation, and habitat quality. Such patterns can increase the species' vulnerability to growth overfishing and environmental change, particularly when fishing selectively removes larger, slow-growing individuals.

Length–frequency distributions (Figure 2A-B) revealed that most *T. magdalenae* fell within the 13–16 cm TL classes, with a clear dominance of intermediate sizes and few very small or very large individuals.

This pattern is consistent with intense exploitation of fast-growing floodplain species, where larger and older individuals are progressively removed (Agostinho et al., 2004). In *P. magdalenae*, the length–frequency distribution was broader, spanning from small juveniles to large adults, but still showed a concentration around intermediate size classes. The coexistence of juvenile and adult *P. magdalenae* in landings suggests that current fishing practices capture individuals across multiple life stages, potentially increasing vulnerability to both recruitment and growth overfishing if effort intensifies.

The high standard deviation of body weight observed for *P. magdalenae* (91.6 ± 104.8 g) compared with *T. magdalenae* (57.6 ± 25.2 g) (Table 3) is consistent with a broader spectrum of size and age classes being harvested, from small juveniles to large adults. Similar wide dispersions in weight, coupled with extended length ranges, have been reported for freshwater sciaenids exploited in Amazonian and Ucayali floodplain systems, where commercial catches include both immature and fully mature individuals (Barbosa et al., 2010; Riofrío, 2009; Valentim, 1998). In such environments, selective retention of larger fish, driven by market preferences and gear selectivity, accentuates the contribution of older, heavier individuals to mean and variance in body mass, even when a high proportion of smaller fish is also present in the landings.

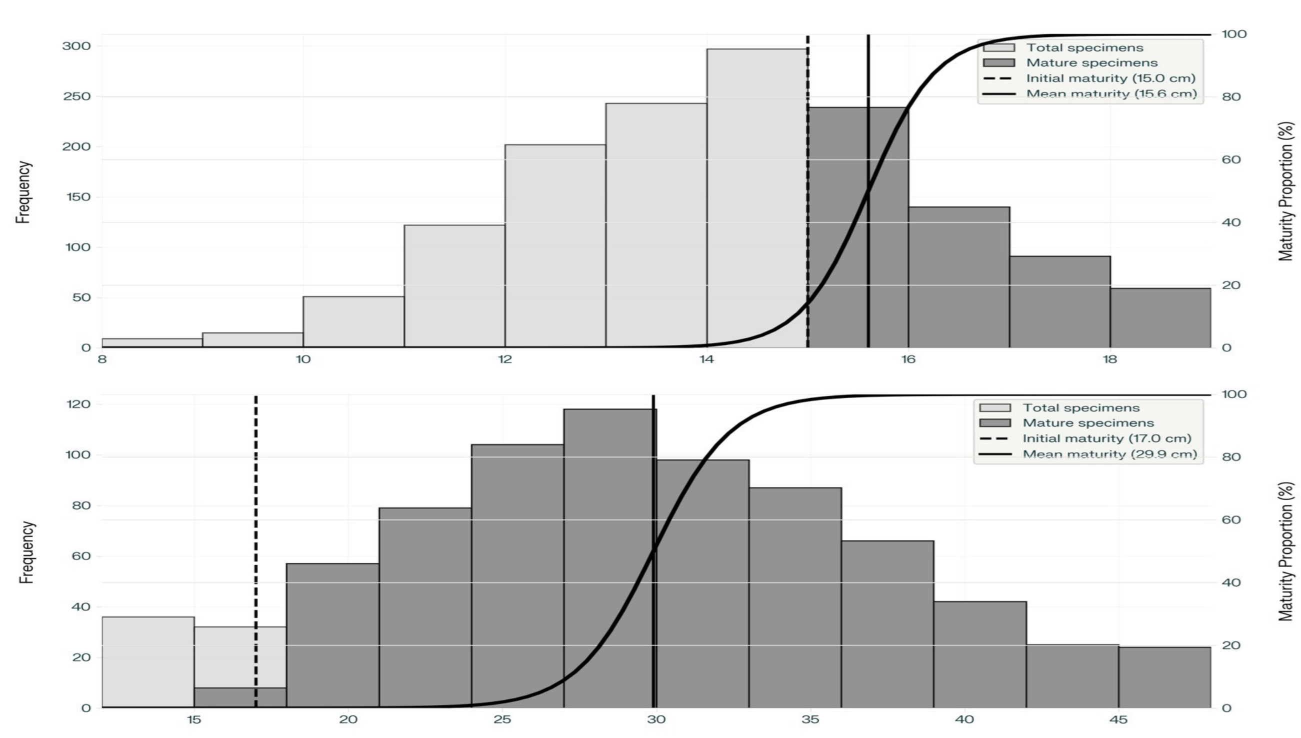

Figure 2. Size frequency distribution and sexual maturity curves for (A) *T. magdalenae* and (B) *P. magdalenae* in the Ciénaga Grande de Magangué, Colombia. Vertical lines indicate initial maturity (dashed) and mean maturity (solid) sizes.

Beyond reflecting life-history differences between the two species, this large variability in body mass for *P. magdalenae* resonates with broader evidence of shifting body-size structures in Neotropical floodplain fisheries. Long-term datasets from the Upper Paraná floodplain indicate progressive declines in mean body size and a disproportionate loss of large migratory fishes under sustained fishing and environmental alteration (Lopes et al., 2020). Similar patterns have been documented for other tropical freshwater assemblages, where size-selective harvesting interacts with hydrological change to erode the abundance of large, late-maturing species (Matthews et al., 2022; Su et al., 2023). In this context, the presence of very large *P. magdalenae* individuals in the Ciénaga Grande de Magangué suggests that key spawners are still present but may be increasingly at risk, reinforcing the need for regulations that explicitly protect the largest size classes.

The condition factor K also varied between species and through time. In *T. magdalenae*, K ranged from 0.45 to 0.61, with peak values in November 2016, coinciding with pre-spawning gonadal development. For this species, temporal variation in K showed a significant positive correlation with GSI ($r = 0.72$, $P < 0.01$), indicating that individuals in better condition allocate more energy to reproduction. *P. magdalenae* exhibited higher mean condition factor values ($K \approx 2.8$) compared to *T. magdalenae*, reflecting the larger body size and different metabolic requirements of this species. The condition factor patterns in *P. magdalenae* showed less pronounced seasonal variation, consistent with the extended reproductive preparation period characteristic of larger-bodied sciaenids. These differences in condition factor dynamics between species reflect their contrasting life-history strategies and resource allocation patterns during reproductive cycles (Echevarría et al., 2015; Reis, 2015).

3.3. Sex ratios and temporal distribution of sexes

Sex ratios deviated significantly from the expected 1:1 ratio in both species. *T. magdalenae* exhibited a sex ratio of 1:3 (female: male), with 367 females and 1,101 males ($\chi^2 = 367.0$, df = 1, $P < 0.0001$; 95% confidence interval for the female proportion: 0.23–0.27; Cramér's V = 0.50, indicating a moderate-to-large effect size). *P. magdalenae* showed an even more pronounced deviation, with a sex ratio of 1:6 (female: male), comprising 110 females and 658 males ($\chi^2 = 391.0$, df = 1, $P < 0.0001$; 95% confidence interval for the female proportion: 0.12–0.17; Cramér's V = 0.71, large effect size). Similar male-biased sex ratios have been reported for *P. magdalenae* in other Amazonian systems, with ratios ranging from 2.02:1 to 2.7:1 (male: female), attributed to differential spatial distribution patterns and fishing gear selectivity (Barbosa et al., 2010; Olaya-Nieto et al., 2007). In sciaenid fishes, sex ratio deviations often reflect environmental stress responses, with males typically showing greater tolerance to adverse conditions than females (Vicentini & Araújo, 2003).

Thus, our data indicate a strong male bias in the *T. magdalenae* catch and a tendency towards male dominance in *P. magdalenae*, although the latter should be interpreted cautiously given the limited female sample size.

Table 4. Reproductive parameters of *T. magdalenae* and *P. magdalenae* in the Ciénaga Grande de Magangué.

Species	Sex ratio F:M (nF:nM; χ^2; P)	Initial size at maturity (cm TL)	Mean size at maturity L_{50} (cm TL)	Month of peak GSI (GSImax)	Mean absolute fecundity (oocytes/female)	Relative fecundity per length (oocytes·cm^{-1})	Relative fecundity per weight (oocytes·g^{-1})	n mature females (fecundity)
T. magdalenae	1:3 (367:1,101; $\chi^2 = 367.0$; $P < 0.0001$)	15.0	15.6	May 2017 (7.30)	4,977 ± 2,554	303 ± 159	0.51 ± 0.06	19
P. magdalenae	1:6 (110:658; $\chi^2 = 391.0$; $P < 0.0001$)	17.0	29.9	March 2017 (18.97)*	6,656 ± 5,956	181 ± 423	181.9 ± 423.5	7

*With a secondary increase in GSI observed in September 2016 (GSI ≈ 8.29), suggesting an earlier spawning peak.

For *P. magdalenae*, the smallest mature female observed during the study measured 17.0 cm TL (Table 4), indicating the onset of sexual maturity at relatively small sizes. However, the logistic model fitted to the proportion of mature females by length class yielded a much larger size at 50% maturity ($L_{50} \approx 29.9$ cm TL; Table 4, Figure 2B), indicating that the bulk of reproductive output is concentrated in older, larger individuals. This distinction between minimum and mean size at maturity is particularly important when evaluating the match between biological thresholds and the current legal minimum size.

Monthly sex ratios (Figure 3A-B) revealed distinct temporal patterns. In *T. magdalenae*, females were captured throughout most of the year except in September 2016 and January 2017, whereas males dominated the catch between October–December 2016 and March–April 2017, with a peak male proportion of 85% in November 2016. Female abundance increased again in February 2017 and during May–August 2017, coinciding with the main reproductive period. For *P. magdalenae*, females were absent from landings in April and June–August 2017, whereas males were most common between September 2016 and February 2017, with a peak in December 2016.

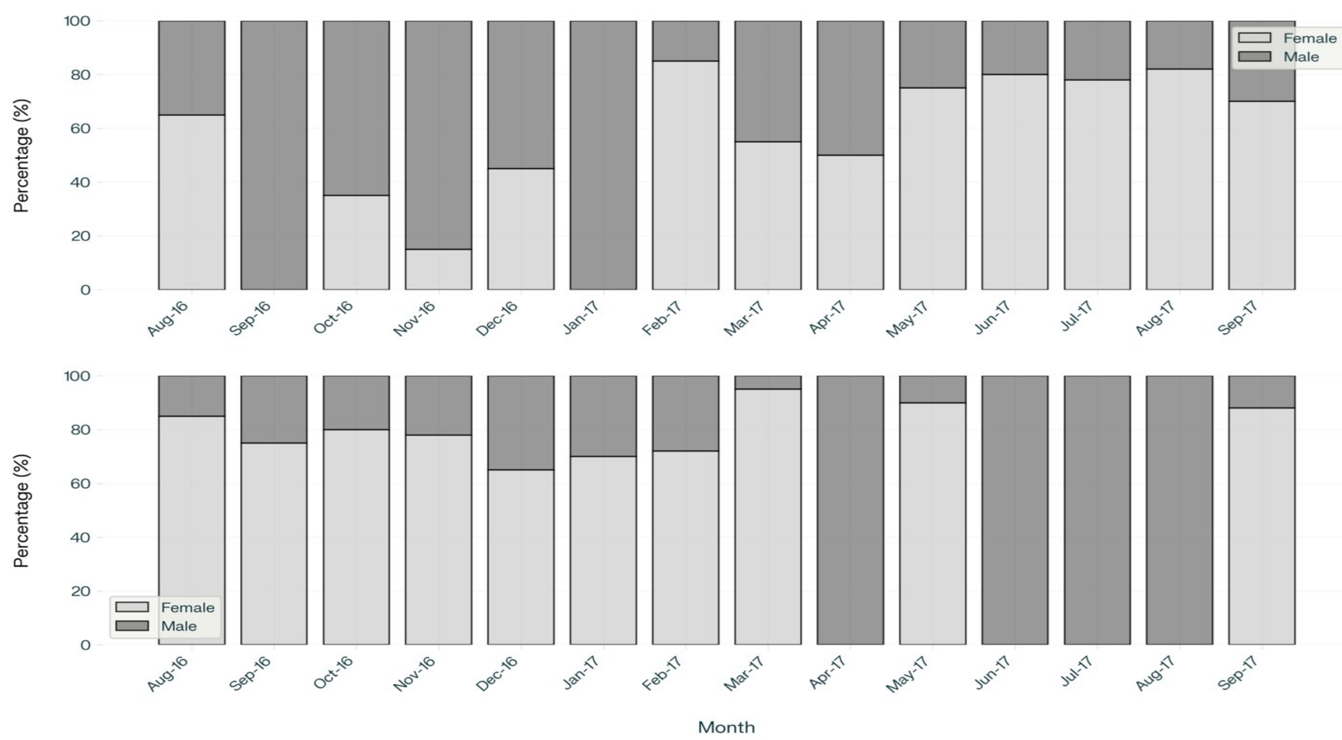

Figure 3. Temporal distribution of sex ratios for (A) *T. magdalenae* and (B) *P. magdalenae* in the Ciénaga Grande de Magangué, Colombia. Data show seasonal variations in the capture of males and females throughout the study period.

Deviations from 1:1 sex ratios and temporal segregation of sexes have been widely reported in Neotropical fishes and can result from sex-specific habitat use, differential migration during reproductive cycles, gear selectivity, or environmental stressors (Lucano-Ramírez et al., 2005; Vicentini and Araújo, 2003). For *P. magdalenae*, male-biased sex ratios similar to those observed here have been documented in Amazonian populations, with male: female ratios between 2.0:1 and 2.7:1, attributed to spatial segregation and greater catchability of males in gillnets (Barbosa et al., 2010; Olaya-Nieto et al., 2007). In sciaenids, males often tolerate degraded conditions better than females, which may also contribute to skewed sex ratios in impacted environments (Vicentini and Araújo, 2003; Mazrouh & Mahmoud, 2009). The predominance of males in our samples suggests that current fishing practices may remove males more heavily, but also raises the possibility that mature females occupy habitats or depth strata not fully sampled by the prevailing gears.

3.4. Reproductive cycles and flood-pulse synchrony

Seasonal variation in gonadosomatic index revealed clear reproductive cycles in both species. For *T. magdalenae*, female GSI values began to increase in March 2017 (GSI ≈ 2.1), peaked in May 2017 (GSI = 7.30), and then declined sharply, indicating a single, synchronous spawning event during the rising-water period (Figure 4A; Table 4). Post-spawning months (June–August 2017) were characterized by low GSI (0.8–1.2) and a high proportion of immature individuals, consistent with a reproductive strategy that concentrates spawning just before or at the onset of flooding, when newly inundated habitats offer abundant food and shelter for larvae and juveniles (Winemiller, 1989; Agostinho et al., 2004).

In *P. magdalenae*, the mean female GSI was higher overall (4.77 on average) and exhibited more complex temporal dynamics (Figure 4B). A primary spawning peak was observed in March 2017 (GSI = 18.97), preceded by increasing GSI values from January onwards and followed by a rapid decline in April (GSI = 2.15). A secondary reproductive period was inferred from elevated GSI in September 2016 (8.29), suggesting that an earlier spawning event occurred in mid-2016, before the start of sampling. One-way ANOVA detected significant differences in GSI among months ($F = 6.85$, $P < 0.0001$), indicating strong seasonality in reproductive activity. The hepatosomatic index showed corresponding patterns, with peaks in September 2016 (HSI = 2.05) and March 2017 (HSI = 0.81), reflecting mobilization of hepatic energy reserves during pre-spawning periods.

These patterns fit well within the flood-pulse paradigm for Neotropical rivers, where spawning is often synchronized with the rising limb of the hydrograph (Junk et al., 1989; Agostinho et al., 2004; FAO, 1997, 1998, 2017). In the Ciénaga Grande de Magangué, rising water levels expand floodplain habitats and increase primary and secondary production, thereby enhancing larval survival and growth. The single, well-defined spawning peak in *T. magdalenae* and the apparently bi-annual pattern in *P. magdalenae* suggest different degrees of flexibility in reproductive timing: *T. magdalenae* behaves as a typical small-bodied, highly seasonal spawner, while *P. magdalenae* exhibits a more extended or plastic reproductive schedule, consistent with previous reports for sciaenids in the Amazon and Magdalena basins (Valentim, 1998; Santos, 2010; Santos, 2006).

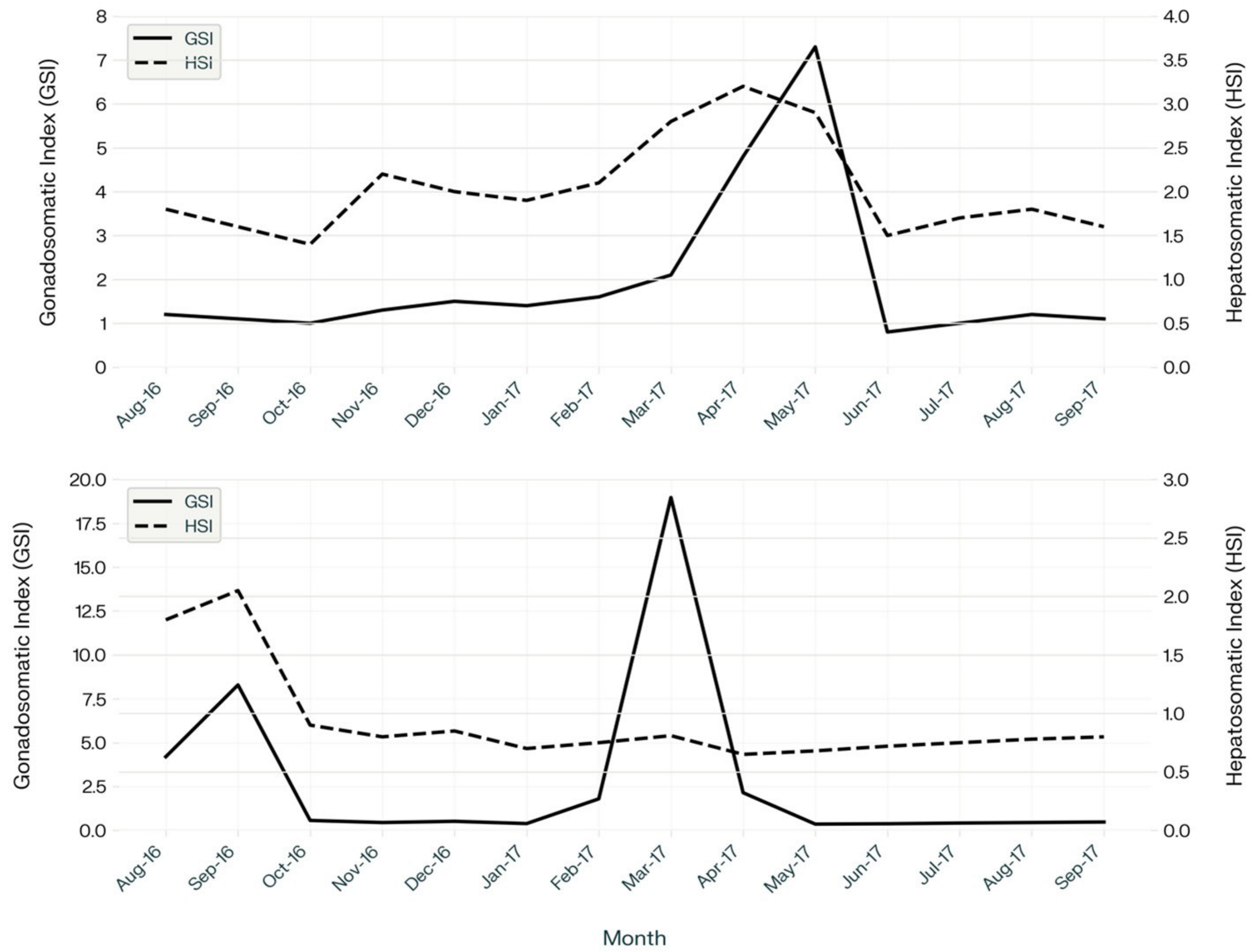

Figure 4. Seasonal variation in gonadosomatic index (GSI), hepatosomatic index (HSI) and condition factor (K) for *T. magdalenae* and *P. magdalenae* in the Ciénaga Grande de Magangué. (A) Mean monthly GSI (± SE) for females of *T. magdalenae*. (B) Mean monthly GSI (± SE) for females of *P. magdalenae*. (C) Mean monthly HSI and condition factor K for *T. magdalenae*. (D) Mean monthly HSI and condition factor K for *P. magdalenae*. Shaded areas (or highlighted months) indicate the main reproductive periods inferred from GSI peaks.

3.5. Size at maturity and fecundity

Size at sexual maturity differed markedly between the two species (Table 4; Figure 2). In *T. magdalenae*, the smallest mature female (initial maturity) measured 15.0 cm TL, and the logistic maturity curve yielded a mean size at maturity (L_{50}) of 15.6 cm TL (Figure 2A). In *P. magdalenae*, initial maturity occurred at 17.0 cm TL, but the estimated L_{50} was much larger, at 29.9 cm TL (Figure 2B). These values are consistent with life-history theory: small-bodied, fast-growing species tend to mature early at relatively small sizes, whereas larger, longer-lived fishes postpone reproduction to later life stages (Nikolsky, 1963; Winemiller, 1989; Cech, 2000).

The proximity of *T. magdalenae* L_{50} to the current legal minimum capture size (15 cm standard length) is a cause for concern. Under such regulations, a substantial fraction of individuals can be harvested after only one, or even before any, reproductive event, potentially leading to recruitment overfishing if fishing effort remains high or increases (SEPEC, 2019; 2021; Valdelamar-Villegas, 2006). In contrast, the much larger L_{50} of *P. magdalenae* implies a longer juvenile period and greater vulnerability to growth overfishing: if fishing targets size classes well below 30 cm TL, many individuals will be removed before contributing significantly to the spawning stock.

Fecundity estimates further illustrate contrasting strategies (Table 4). Absolute fecundity averaged 4,977 ± 2,554 oocytes per female in *T. magdalenae* and 6,656 ± 5,956 oocytes in *P. magdalenae*. Relative fecundity per unit length was 303 ± 159 oocytes $\cdot cm^{-1}$ for T. magdalenae and 181 ± 423 oocytes $\cdot cm^{-1}$ for *P. magdalenae*, whereas relative fecundity per unit weight reached 0.51 ± 0.06 oocytes $\cdot g^{-1}$ in *T. magdalenae* and showed high variability in *P. magdalenae*. These values are comparable to those reported for related species in other Neotropical systems (Fawole and Arawomo, 2000; Echevarría et al., 2015; Riofrío, 2009), but the high coefficient of variation in *P. magdalenae* (CV ≈ 89.5%) suggests substantial individual variation in reproductive investment, linked to female size, age, and nutritional status.

Early maturation and relatively high relative fecundity in *T. magdalenae* are characteristic of an opportunistic life-history strategy, which can confer resilience to moderate fishing pressure and environmental variability, provided that flood pulses and nursery habitats are maintained (Winemiller, 1989; Morales & García-Alzate, 2018; Novakowski et al., 2008). By contrast, delayed maturation, lower and more variable relative fecundity, and extended reproductive preparation in *P. magdalenae* align more closely with a periodic or K-selected strategy, which tends to be more sensitive to persistent size-selective fishing and habitat degradation (Reis, 2015; Rojas-Luna et al., 2022).

3.6. Growth and exploitation status of T. magdalenae and preliminary estimates for P. magdalenae

Length–frequency analysis in FiSAT II yielded coherent growth and mortality estimates for *T. magdalenae* in the Ciénaga Grande de Magangué. The von Bertalanffy parameters ($L\infty \approx 24.15$ cm TL, $K \approx 0.60$ yr^{-1}, $\phi' \approx 2.5$) and the length-converted catch curve (Figure 5C) indicate total mortality $Z \approx 2.68$ yr^{-1}. Using Pauly's empirical equation based on L∞, K, and ambient temperature, natural mortality was estimated at $M \approx 1.33$ yr^{-1}, yielding fishing mortality $F \approx 1.35$ yr^{-1} and an exploitation rate $E = F/Z \approx 0.50$ (Table 5). The reconstructed recruitment pattern (Figure 5B) suggests continuous recruitment throughout the year, with marked peaks in June and August.

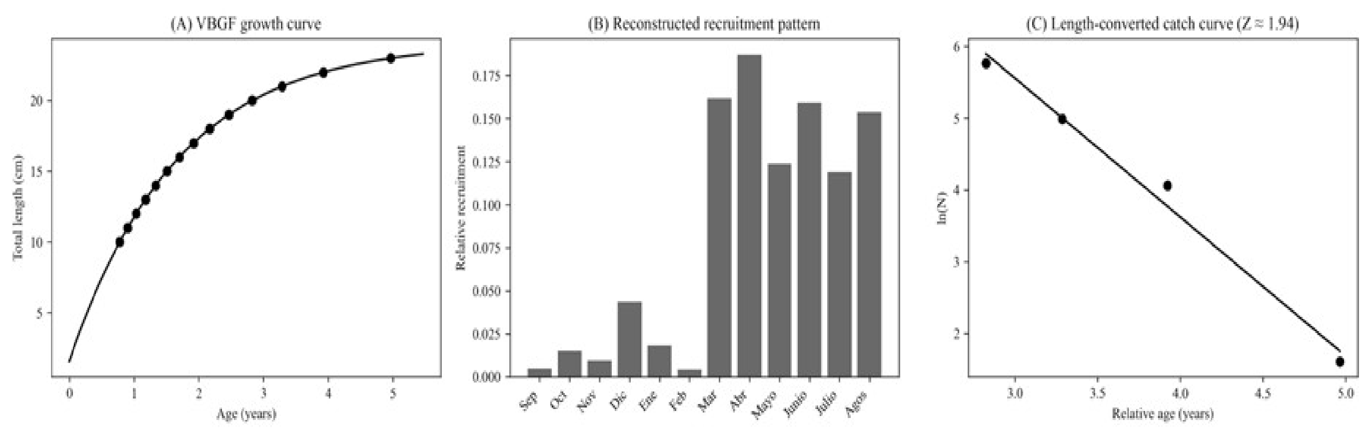

Figure 5. Growth and exploitation of *T. magdalenae* in the Ciénaga Grande de Magangué based on length–frequency data and von Bertalanffy growth modelling. (A) Von Bertalanffy growth curve fitted to observed length–class midpoints, showing the predicted growth trajectory in length as a function of age. (B) Reconstructed annual recruitment pattern, expressed as the relative contribution of each month to the total length–frequency sample; higher bars indicate stronger recruitment pulses. (C) Length-converted catch curve, plotting ln(N) against relative age; the slope of the regression line provides an estimate of total mortality (Z), which can be combined with natural mortality (M) to obtain fishing mortality (F) and exploitation rate (E).

The growth parameters estimated for *T. magdalenae* (Table 5; Figure 5) are consistent with the life-history profile of medium-sized Triportheus species from Amazonian floodplain lakes, which tend to show relatively small asymptotic lengths, high growth coefficients, and elevated natural mortality, typical of short-lived, fast-growing r-strategists exploited by artisanal multispecies fisheries (Salomão et al., 2023). Similar patterns of rapid growth and high fishing mortality have been reported for Triportheus albus, T. angulatus, and T. auritus in central Amazon floodplains, where yield-per-recruit analyses indicate that some stocks are already being exploited above maximum sustainable levels (Salomão et al., 2023). According to Gulland's (1971) rule of thumb, an exploitation rate of $E \approx 0.5$ can be viewed as an approximate upper limit for sustainable harvest in many tropical stocks, implying that *T. magdalenae* in the Ciénaga Grande de Magangué is currently being taken at or very close to this putative optimum (Alam et al., 2021). Values clearly above this threshold are typically interpreted as evidence of overexploitation in recent length-based assessments of data-poor tropical fisheries (Alam et al., 2021; Salomão et al., 2023).

The continuous recruitment pattern, combined with relatively fast growth, likely contributes to the capacity of *T. magdalenae* to withstand sustained fishing pressure in the short term. However, this apparent equilibrium is fragile: if environmental changes, altered flood regimes, water quality degradation, reduce recruitment, or shift spawning phenology, the same level of fishing mortality would quickly push the stock towards overexploitation (Cooke et al., 2016; Jiménez-Segura et al., 2022).

Table 5. Growth and exploitation parameters estimated with FiSAT II for *T. magdalenae*, and preliminary growth parameters ($L\infty$, K, t_0, ϕ') for *P. magdalenae*, in the Ciénaga Grande de Magangué. Total mortality (Z), natural mortality (M), fishing mortality (F), and exploitation rate (E) were estimated only for *T. magdalenae* due to limitations in the length–frequency data for *P. magdalenae*.

Species	$L\infty$ (cm TL)	K (yr^{-1})	t_0 (yr)	ϕ' (growth performance)	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})	E = F/Z	Recruitment pattern/comments
T. magdalenae	24.15	0.60	−0.11	2.5	2.68	1.33	1.35	0.50	Continuous recruitment throughout the year, with pronounced peaks in June and August.
P. magdalenae	34.70	0.131	0.237	2.2	NA	NA	NA	NA	Length–frequency data are insufficient to obtain reliable Z, M, F, and E estimates; only preliminary growth parameters are reported.

Note: Growth parameters for Plagioscion magdalenae are preliminary and were derived from a truncated length–frequency distribution dominated by intermediate size classes. Because of the strong influence of gear selectivity and the under-representation of both small juveniles and large adults in the landings, these estimates were not used to derive mortality or exploitation rates and should be interpreted with caution.

For *P. magdalenae*, the von Bertalanffy parameters derived from FiSAT II must be interpreted as preliminary because they were estimated from a length-frequency distribution truncated by gillnet selectivity. Although the largest individual in the sample reached 56.0 cm TL (Table 3; Figure 2B), the asymptotic length ($L\infty \approx 34.7$ cm TL) and very low growth coefficient ($K \approx 0.13$ yr^{-1}; Table 5) almost certainly underestimate the true size range and exaggerate the degree of slow growth. In freshwater sciaenids from Amazonian and Colombian floodplains, $L\infty$ values well above the maximum observed length and K between 0.2 and 0.4 yr^{-1} are more typical (Barbosa Santos et al., 2010; Riofrío, 2009; Valentim, 1998). In this context, the combination of large maximum body size (Lmax = 56.0 cm TL; Table 3) and late mean size at maturity ($L_{50} \approx 29.9$ cm TL; Table 4) provides a more stronger indication of intrinsic vulnerability than any single length-based growth estimate. Even under conservative assumptions, current catches that include many individuals well below 30 cm TL imply substantial removal of pre-spawning females and a high susceptibility to growth and recruitment overfishing.

3.7 Management implications in a Neotropical floodplain wetland

When the evidence from SEPEC statistics (Tables 1–2), local biological parameters (Tables 3–4), and growth–mortality analyses (Table 5; Figure 5) is integrated, a coherent picture emerges. *T. magdalenae*, an endemic, small-bodied characiform, exhibits early maturation, relatively high relative fecundity, continuous recruitment, and an exploitation rate close to the nominal optimum ($E \approx 0.50$). These traits confer a certain resilience to sustained fishing pressure, but only as long as hydrological connectivity and floodplain habitats are preserved. *P. magdalenae*, in contrast, matures at much larger sizes, has more variable fecundity, and appears to be captured across a broad range of life stages, including many pre-reproductive individuals. Its life-history strategy and sex ratio patterns suggest a higher vulnerability to both environmental degradation and size-selective fishing.

From a management perspective, three implications are particularly relevant. First, the current legal minimum size for *T. magdalenae* (15 cm) is essentially equivalent to L_{50} and should be reconsidered. Increasing the minimum capture size to 17–18 cm TL would allow most individuals to spawn at least once before entering the fishery, improving recruitment and buffering the stock against interannual variability (Valdelamar-Villegas, 2006; FAO, 1997). Second, species-specific closed seasons that align with reproductive peaks, March for *P. magdalenae* and May for *T. magdalenae*, would protect spawning aggregations and enhance the effectiveness of existing regulations, especially if co-designed and enforced with artisanal fishers (Cooke et al., 2016; Springer, 2023). Third, protecting critical spawning and nursery habitats (shallow, vegetated floodplain zones) and maintaining the natural flood pulse are indispensable for sustaining recruitment, particularly for *P. magdalenae*, whose reproductive cycle appears tightly coupled to hydrological variability.

More broadly, the contrasting life-history strategies documented here illustrate how endemic fishes in Neotropical floodplain wetlands differ in their vulnerability to exploitation and environmental change. Integrating species-specific reproductive biology, growth, and fishery-dependent data, as done in this study, provides a powerful basis for adaptive, ecosystem-based management of inland fisheries. In the case of the Ciénaga Grande de Magangué and the wider Magdalena River basin, such an approach supports the design of evidence-based size limits, seasonal closures and habitat protection measures that contribute simultaneously to biodiversity conservation, food security and the achievement of multiple Sustainable Development Goals (SDGs 2, 14 and 15).

Although our analysis focuses on a single floodplain wetland and two endemic species, the approach and insights are broadly applicable to other tropical river basins where data are scarce but artisanal fisheries are central to local livelihoods. Many African and Asian floodplain systems, for example, share similar combinations of multi-species fisheries, incomplete biological information, and rapidly changing hydrological regimes. In such contexts, simple yet robust indicators, such as sex ratios, size at maturity, length-based growth and exploitation estimates, and relative contributions to basin-wide landings, can provide an operational basis for prioritizing management interventions and for benchmarking the status of inland fisheries against global biodiversity and food-production targets.

5. Conclusions

This study provides comprehensive baseline data on the reproductive biology of *T. magdalenae* and *P. magdalenae* in the Ciénaga Grande de Magangué, revealing critical information for fisheries management. Both species exhibit synchronous spawning patterns with distinct seasonal peaks, biased sex ratios favoring males, and reproductive parameters indicating potential fishing pressure impacts. Taken together, these results indicate that *T. magdalenae* is currently harvested at levels close to, but not clearly exceeding, conventional exploitation targets ($E \approx 0.50$), whereas *P. magdalenae* appears intrinsically more vulnerable to growth overfishing and habitat degradation because of its larger maximum size, later maturation, and more periodic life-history strategy.

The current legal capture size for *T. magdalenae* (15 cm) coincides with sexual maturity, potentially affecting reproductive success and population sustainability. The evidence for bi-annual spawning in *P. magdalenae* and the observed fecundity patterns suggest that both species have evolved reproductive strategies adapted to the variable environmental conditions of the Magdalena River basin.

Management recommendations include: (1) increasing the minimum capture size for *T. magdalenae* from the current 15 cm to at least 17–18 cm TL, so that most individuals can spawn at least once before being harvested; this type of adjustment has been shown to improve recruitment and buffer stocks against interannual variability in other Neotropical floodplain fisheries; (2) enforcing species-specific closed seasons that protect the main reproductive peaks, March for *P. magdalenae* and May for *T. magdalenae*, to safeguard spawning aggregations and enhance the effectiveness of existing regulations, particularly when closures are co-designed and enforced with artisanal fishers; and (3) protecting critical spawning and nursery habitats (shallow, vegetated floodplain zones) and maintaining the natural flood pulse, which are key to sustaining recruitment in floodplain river systems. Together, these measures would help to align local fishery practices with the life-history traits of these endemic fishes and improve the resilience of the Ciénaga Grande de Magangué fishery under variable environmental conditions.

Future research should focus on population genetics to assess connectivity between populations, long-term monitoring to track population trends, and investigation of environmental factors affecting reproductive success. These studies will provide essential information for adaptive management strategies, ensuring the long-term sustainability of these endemic species in the Ciénaga Grande de Magangué ecosystem. The implementation of these science-based management recommendations will contribute to multiple SDG targets: SDG 14.4 (sustainable fisheries management), SDG 2.3 (supporting small-scale food producers), and SDG 15.1 (conservation of freshwater ecosystems). Beyond the Magdalena River basin, our results provide rare, integrated evidence on how contrasting opportunistic and more periodic life-history strategies mediate the responses of endemic floodplain fishes to exploitation and hydrological variability. Applying similar analyses across other Neotropical and tropical basins would help to identify general rules linking reproductive traits, size-selective fishing, and vulnerability to environmental change. Such comparative work is essential for building a global evidence base that supports realistic, ecosystem-based management of data-poor inland fisheries under accelerating climate and land-use change. This integrated approach demonstrates how species-specific reproductive biology research can inform policy decisions that simultaneously address food security, biodiversity conservation, and sustainable development objectives in neotropical wetland systems.

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