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Research Article

Distribution and first insight into the reproductive biology of two species of the genus *Rhamdia* (Siluriformes, Heptapteridae) in a Biosphere Reserve

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Abstract

Distribution data and reproductive biology of freshwater catfishes of the genus *Rhamdia* remain insufficiently explored, limiting our knowledge of these ecologically, nutritionally, and economically important species. We provide updated distribution data and a preliminary study of the reproductive biology of the Pale catfish, *Rhamdia guatemalensis*, and the Filespin chulín, *Rhamdia laticauda* in the Tehuacán-Cuicatlán Biosphere Reserve (TCBR), Oaxaca, Mexico, based on vouchered records and analyses of sex ratio, sexual size dimorphism, size at first gonadal maturation, and total fecundity. Specimens were collected from 20 sites within the TCBR using electrofishing during two periods, 2006–2007 and 2015–2016. The Pale catfish was recorded in eight municipalities, whereas the Filespin chulín occurred in five, with a similar elevation range. Both species exhibited an overall sex ratio of 1:1 and female-biased sexual dimorphism in standard length (SL) and body mass (BM). Size at first sexual maturity was estimated at 97.6 mm SL in *R. guatemalensis* and 79 mm SL in *R. laticauda*. Both species exhibited high fecundity, with mean numbers of eggs per female of 9647 for the Pale catfish (n = 13) and 1457 for the Filespin chulín (n = 11). Fecundity was positively correlated with ovary weight in both species. Our results contribute to the understanding of the distribution and reproductive biology of native freshwater catfishes in the TCBR.

Key words: Fecundity, freshwater fishes, natural history, Neotropical catfishes

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Introduction

Natural distribution data are fundamental to understanding colonization processes in new habitats and to enhancing our knowledge of a species' geographic range and biogeographic history (Zunino and Zullini 2003). Reproductive biology, including sex ratio, sexual size dimorphism, length at first maturity, and fecundity, plays an essential role in elucidating the natural history of wild fishes (Winemiller 1989; Mattews 1998). Sexual size dimorphism refers to phenotypic differences in body dimensions and proportions between males and females

(Benítez 2013). Understanding it is crucial for comprehending species variation and limits. Length at first maturity is an important parameter for establishing minimum capture size and avoiding the exploitation of immature individuals and the consequent reduction of spawning stock (King 2007). These biological parameters can also inform effective fisheries management and conservation strategies (Olaya-Nieto et al. 2010; Rodriges-Filho et al. 2017).

Species of the genus *Rhamdia* Bleeker, 1858, are nocturnal catfishes widely distributed across a broad range of freshwater habitats throughout the Neotropical region, comprising 27 valid species (Fricke et al. 2024). These species are predominantly carnivorous, specializing in insects, particularly Diptera, suggesting that they play fundamental ecological roles within their habitats (Pagotto et al. 2011; Bonato and Fialho 2014; Julián-Caballero et al. 2024). They are also prey for several vertebrates (Lavariega et al. 2020; Carranza and Anderson 2023), and some serve as a food resource for the human community, with aquacultural potential (Martínez-Ramírez et al. 2004; Martínez-Ramírez et al. 2013). Despite the ecological importance, nutritional and economic value, and aquacultural potential of some Neotropical catfishes, information on their distribution and reproductive biology remains insufficiently documented for most species in the genus (Rapp Py-Daniel and Cox Fernandes 2005; Bockmann and Slobodian 2017). Most studies on sexual size dimorphism in the genus have concentrated on *R. quelen* (Quoy and Gaimard 1824) (Narahara et al. 1985; Gomiero et al. 2007) and have indicated the presence of female-biased sexual dimorphism in both total length and standard length. Therefore, it remains unclear whether other species of this genus display the same pattern.

Seven species of this genus are currently recognized in Mexico (Hernández et al. 2015; Thomas and Sabaj 2020), among which two are frequently registered in state checklists (Obregón-Barboza et al. 1994; Martínez-Ramírez et al. 2004; Velázquez-Velázquez et al. 2016): the Pale catfish *R. guatemalensis* (Günther 1864) and the Filespin chulín *R. laticauda* (Kner 1857). In this country, the Pale catfish is found on the Pacific Slope from the state of Oaxaca to Chiapas, and on the Atlantic Slope, extending from Veracruz to Yucatán and Quintana Roo, while the Filespin chulín inhabits the waters of the Atlantic Slope from Río Jamapa, Veracruz, Mexico, to Quintana Roo (Perdices et al. 2002; Miller et al. 2005; Hernández et al. 2015; Schmitter-Soto 2019). Globally, both Neotropical catfishes are listed as Least Concern by the International Union for Conservation of Nature (Arroyave 2019; Schmitter-Soto 2019), indicating that sufficient information is lacking to make a direct or indirect assessment of their risk of extinction based on their distribution or population status. According to the Mexican legislation (SEMARNAT 2019), *R. guatemalensis* is listed as "subject to special protection" (Pr), whereas *R. laticauda* is not included. In Mexico, some populations of both species may be threatened by habitat degradation and invasive fish species (Martínez-Ramírez et al. 2013; Thomas and Sabaj 2020). Recent studies have updated distribution records of *R. guatemalensis* from cenotes in the Yucatán Peninsula (Arroyave and De La Cruz Fernández 2021) and documented the distribution of both catfishes in Chiapas (Buenavad-González et al. 2023).

In the state of Oaxaca, Martínez-Ramírez et al. (2004) documented the geographic distribution of these species, highlighting that the Pale catfish is more widely distributed than the Filespin chulín. Both catfishes occur across a mean altitudinal range of 200–600 m a.s.l., with elevation limits extending from 10

to 1950 m a.s.l. (Martínez-Ramírez et al. 2004). Later, Martínez-Ramírez and CONABIO (2023) provided a dataset occurrence of both species in two sub-basins in the Tehuacán-Cuicatlán Biosphere Reserve, Oaxaca (hereafter TCBR), Río Salado and Río Quiotepec without presenting the information in a tabulated form. One of the most important pieces of information for a specimen is its field-collection locality, which enables mapping and studies of distribution, biogeography, and conservation (Yesson et al. 2007). Such distributional data are necessary to properly contextualize new records from Oaxaca and other regions of Mexico. In the same state, *R. laticauda* was recently found in streams of the Zoque Rainforest of Santa María Chimalapa (López-Segovia et al. 2020).

For Mexican *Rhamdia* species, information on life histories, natural distributions, and environmental requirements is missing or incomplete, which may hinder conservation status assessments and limit the development of effective conservation measures (Thomas and Sabaj 2020). Information on the reproductive biology of these species in Mexico, such as sex ratio, length at first maturity, and fecundity is available primarily from populations in the states of Chiapas, Tabasco, and Quintana Roo (Chávez-Lomelí et al. 1989; Schmitter-Soto 1998; Soto-Galera 2006). Previous studies have reported a female-biased sex ratio in *R. guatemalensis* (Chávez-Lomelí et al. 1989; Soto-Galera 2006), whereas a male-biased sex ratio has been documented in *R. laticauda* (Soto-Galera 2006). Length at first maturity ranges from 80 to 100 mm standard length (SL) in the Pale catfish (Schmitter-Soto 1998; Soto-Galera 2006), whereas a value of 64.5 mm SL for combined sexes has been reported for the Filespin chulín (Soto-Galera 2006). Previous studies reported high fecundity ranging from 1400 to 16000 eggs in *R. guatemalensis*, whereas fecundity in *R. laticauda* ranged from 950 to 1100 eggs (Soto-Galera 2006).

The main goal of this study was to document the distribution and describe the reproductive biology of *R. guatemalensis* and *R. laticauda* in rivers of the TCBR, Oaxaca. Specifically, we aimed to: (1) analyze vouchered records from the study area available in GBIF (Martínez-Ramírez and CONABIO 2023) and compile them into a table including field-collection locality and elevation, (2) assess the sex ratio and sexual size dimorphism; and (3) estimate size at first gonadal maturation for the total population and total fecundity.

Methods

Study area and sampling sites

The TCBR spans the states of Puebla and Oaxaca in south-central Mexico. The portion located in Oaxaca, known as the Valle de Cuicatlán, covers 2962.7 km^2 (60.44%) across 31 municipalities (Lavariega et al. 2020). The water bodies in this region are from the Papaloapan River basin and the Mixteco-Balsas River basin (Martínez-Ramírez et al. 2010). Specimens of the genus *Rhamdia* were obtained from field collections conducted over two periods, 2005–2006 and 2015–2016, across different seasons of the year at 20 sampling sites throughout the Río Quiotepec and Río Salado sub-basins (Fig. 1) from the Papaloapan River basin. Samples were collected under permits (SGDPA/DGVS/09813/15) issued by the Mexican Ministry of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales, SEMARNAT) to EMR. Individuals were

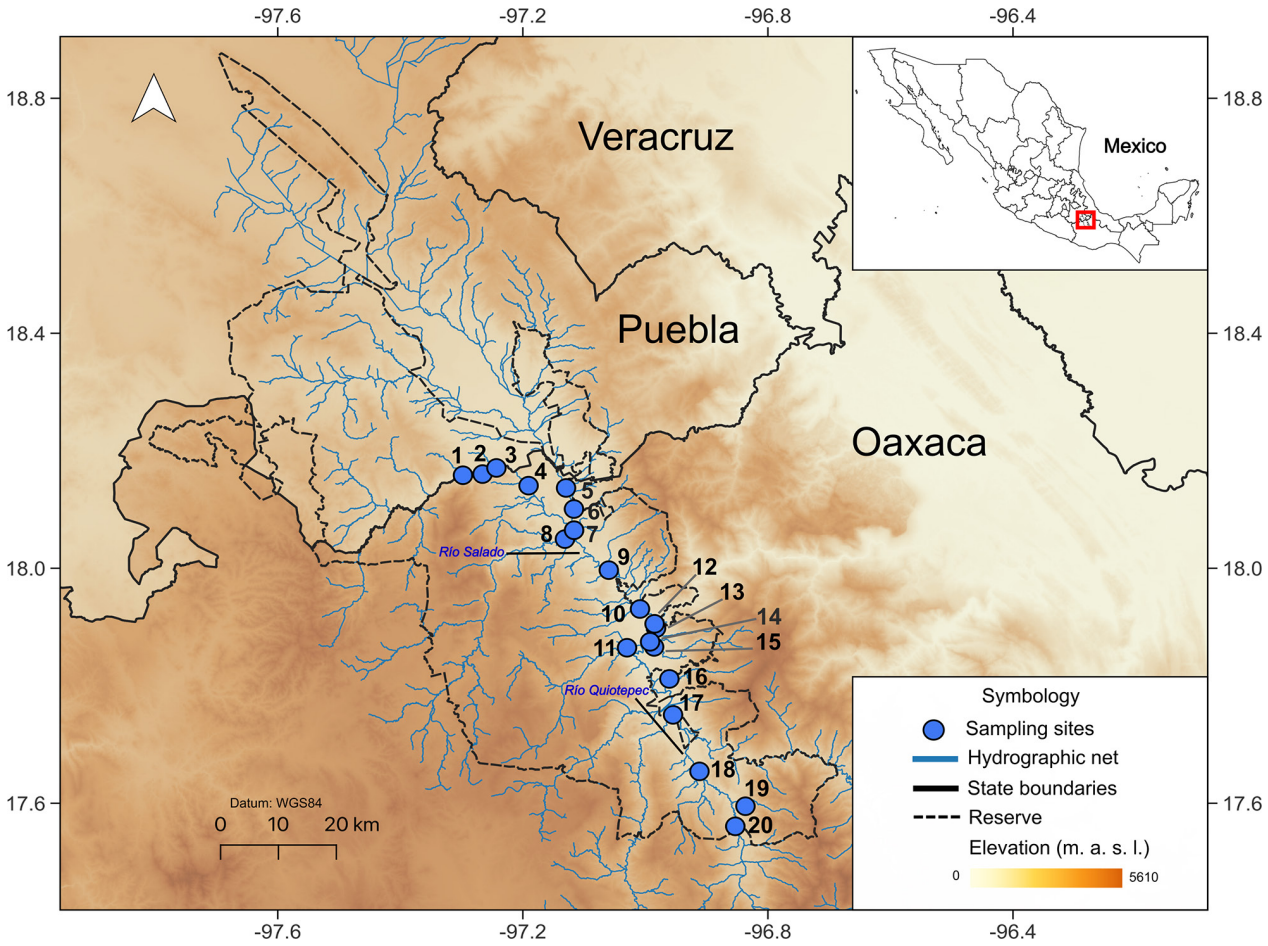

Figure 1. Sampling sites where catfishes of the genus *Rhamdia* were collected in the Tehuacán-Cuicatlán Biosphere Reserve, Oaxaca, Mexico. Additional details are provided in Table 1.

collected using electrofishing devices, preserved in 70–90% ethanol, and deposited in the Collection of Continental Fish at CIIDIR Unidad Oaxaca IPN, Mexico (OAX.PEC.122.0302). Identification of preserved specimens was conducted using taxonomic keys (Miller 1984; Bussing 1998; Hernández et al. 2015).

Distribution

All these records were provided by Martínez-Ramírez and CONABIO (2023). For records lacking elevation data, values were obtained from the elevatr package v 0.99.1 (Hollister et al. 2025), and elevation profiles were refined for both species (Table 1). A distribution map was generated using QGIS v. 3.32.3 (QGIS Development Team 2025).

Reproductive biology

SL was measured to the nearest 0.01 mm using a Mitutoyo digital caliper, and body mass (BM) was recorded using a digital balance (Sartorius N° BL1500S, precision of 0.01 g). An abdominal incision was performed to determine the sex macroscopically. Sexual maturity was assessed based on the external appearance of the gonads using a six-stage maturity scale (Nikolsky 1963), modified by Marcano et al. (2007). Under this scale, individual maturity was

Table 1. Localities, altitudes, and coordinates of the studied sites. *Estimated with elevatr package. Sources: Authors and Martínez-Ramírez and CONABIO (2023).

Site	Locality	Altitude (m a.s.l.)	Coordinates	*R. guatemalensis*	*R. laticauda*
1	Río Salado, San Antonio Nanahuatipam, Oaxaca, sitio 3.	1031	18.158333°N, 97.297694°W	X	X
2	Ejido San Pedro Tetitlán, San José Miahuatlán, sitio 1.	977	18.160250°N, 97.265778°W		X
3	Ejido San Pedro Tetitlán, San José Miahuatlán, sitio 2.	959	18.170778°N, 97.243083°W	X	X
4	Río Salado, San Antonio Nanahuatipam, sitio 1.	844	18.140583°N, 97.190611°W	X	X
5	Río Salado, San Antonio Nanahuatipam, sitio 2.	851*	18.136667°N, 97.129417°W	X	
6	Ignacio Mejía, Teotitlán de Flores Magón.	738	18.100806°N, 97.116528°W	X	
7	Río Salado, San Juan de los Cués.	703	18.064722°N, 97.116333°W	X	X
8	Río Xiquila, Santa María Tecomavaca.	706	18.049611°N, 97.131250°W		X
9	Paraje El Cambio, Santa María Tecomavaca.	615	17.996750°N, 97.059639°W	X	
10	Paraje a 300 m al Suroeste del Puente el Salado	537	17.930611°N, 97.008750°W	X	X
11	Río Los Sabinos, Santa María Tecomavaca.	595	17.864639°N, 97.029889°W	X	X
12	Paraje El Mezquite, Santiago Quiotepec.	524	17.90538°N, 96.984944°W		X
13	Río Sendo, Santiago Quiotepec.	609*	17.897917°N, 96.982500°W	X	
14	Paraje a 30 m al Norte del puente del ferrocarril, Santiago Quiotepec.	547	17.874778°N, 96.992278°W	X	X
15	Río Cacahuatal, Santiago Quiotepec.	669*	17.866083°N, 96.985694°W	X	
16	Río Grande, San Juan Bautista Cuicatlán.	653	17.811583°N, 96.960750°W	X	X
17	Río Chiquito, San Pedro Chicozapotes.	614	17.767056°N, 96.954722°W		X
18	Río Las Vueltas, Santiago Dominguillo.	807*	17.654167°N, 96.911667°W		X
19	Terracería a Pueblo Viejo, Zoquiapam Boca de los Ríos.	976	17.594861°N, 96.836611°W		X
20	Río de Zoquiapam Boca de los Ríos.	918	17.560667°N, 96.853167°W	X	

classified into six stages: stage 1 as virgin, stage 2 as immature, stage 3 as maturing, stage 4 as mature, stage 5 as spermiated/ovulated, and stage 6 as spent/spawned. All individuals at stage 3 or higher were considered mature.

Statistical analysis

All individuals of the same species collected from different sampling periods and sites were pooled for analysis. Since the sampling sites were geographically close, this approach was intended to increase the representativeness of each species while reducing potential bias associated with small sample sizes.

Sex ratio

The overall sex ratio for both species during the survey periods was assessed for significant deviations from 1:1 using a chi-square test (χ^2) (Sokal and Rohlf 2009).

Sexual size dimorphism

The sexual dimorphism index (SDI) was calculated as the ratio of the mean SL and BM values for males and females, following Lovich and Gibbons (1992). When no sexual dimorphism is present, SDI takes a value of 0, while negative and positive values reflect male-biased and female-biased sexual dimorphism, respectively. Length frequency distributions were plotted with 10 mm classes for SL for females and males (Wickham 2016). Differences in length frequency

distributions between females and males were assessed using Kolmogorov-Smirnov goodness of fit test. This analysis was performed using the ks.test function from the dgof package v.1.5.1 (Arnold and Emerson 2011).

Size at first maturity

The length at which 50% of individuals reach sexual maturity (L_{m50}) and the length at which 95% of individuals reach sexual maturity (L_{m95}) were estimated for the total sample of each species because generalized linear models with a binomial distribution are sensitive to sample size, particularly with small samples (Dunn and Smyth 2018). First, the maturity stage of each specimen was converted to a binomial distribution value (immature = 0, mature = 1). Maturity curves were then fitted using a generalized linear model (Smart 2023), with standard length as the predictor variable and maturity stage as the response variable. This analysis was conducted using the Estimate_Len_Maturity function from the AquaticLifeHistory package v.1.0.5 (Smart 2023).

Fecundity

Specimens collected from the 2015–2016 period were used to determine fecundity since they were considered fresh material. Samples at maturity stages 4 and 5 (Nikolsky 1963) were analyzed in accordance with Lorenzoni et al. (2011) to estimate total fecundity (F). Ovaries were carefully removed and weighted using the same digital balance described above. We follow the methodology of Gomiero et al. (2007) to preserve the eggs of the two species. A total of 100 eggs were collected from the anterior, middle, and posterior sections of each gonad, both left and right, and the weight of the eggs was measured using a digital balance (Sartorius N° TE214S). Then, F was calculated by the gravimetric method (Tresierra and Culquichicón 1995): F = nG/g, where n is the number of mature eggs in the subsample, G is the total weight of eggs (g), and g is the weight of the subsample (g).

All analysis was carried out in R Studio v. 2026.01 (Posit Team 2026) after previously removing outlier data. We used boxplot analysis for detecting and removing outliers in fecundity dataset (Spitzer et al. 2014). Observations falling outside 1.5 times the interquartile range were excluded from subsequent analyses (Posit Team 2026). Accordingly, two observations were removed from the *R. laticauda* fecundity dataset, reducing the sample size from 13 to 11 individuals. The Shapiro–Wilk test was used to assess the normality of fecundity and ovary weight data in both species. The Spearman rank correlation test (Kassambara 2025) was used to assess correlations between fecundity and ovary weight, a commonly reported approach in Neotropical fishes (Olaya-Nieto et al. 2010; Segura-Guevara et al. 2021).

Results

Distribution

Rhamdia guatemalensis was recorded between 537 and 1031 m a.s.l. across eight municipalities: San Antonio Nanahuatipam, San José Miahuatlán, San Juan Bautista Atatlahuca, San Juan Bautista Cuicatlán, San Juan de

los Cués, Santa María Tecomavaca, and Teotitlán de Flores Magón. *Rhamdia laticauda* specimens were collected between 524 and 1031 m a.s.l. and were found in the same municipalities, except in Teotitlán de Flores Magón (Table 1). In this region, *R. guatemalensis* typically inhabits pools or slow-flowing rivers containing submerged vegetation and organic debris, such as algae, trunks, leaves and branches, whereas *R. laticauda* is associated with rocky riffles and stream currents. A total of 302 specimens were examined, 97 *R. guatemalensis* (mean SL 94.74 mm ± 35.33 mm) and 205 *R. laticauda* (mean SL 87.32 mm ± 16.94 mm) (Table 2).

Table 2. Morphometric data of *Rhamdia guatemalensis* and *Rhamdia laticauda* in southern Tehuacán-Cuicatlán Biosphere Reserve. Mean and standard deviation of the standard length (SL) and biomass (BM).

Species	Samples (*n*)	SL (mm)	BM (g)
	Undifferentiated (*n* = 16)	57.03 ± 10.07	2.59 ± 1.41
R. guatemalensis	Females (*n* = 32)	121.14 ± 35.68	26.66 ± 25.16
	Males (*n* = 49)	99.71 ± 27.01	15.71 ± 13.31
	Total (*n* = 97)	99.74 ± 35.33	17.16 ± 18.97
	Undifferentiated (*n* = 11)	61.17 ± 16.46	4.46 ± 3.68
R. laticauda	Females (*n* = 93)	91.96 ± 15.28	12.66 ± 7.36
	Males (*n* = 101)	85.88 ± 15.69	10.05 ± 8.41
	Total (*n* = 205)	87.32 ± 16.94	10.94 ± 7.98

Sex ratio and sexual size dimorphism

The overall sex ratio did not differ significantly from the expected 1:1 ratio for both species (*R. guatemalensis*: $x^2 = 3.6$, $p > 0.05$; *R. laticauda*: $x^2 = 0.3$, $p > 0.05$). In *R. guatemalensis*, females ranged from 49.5 to 213.1 mm SL and males from 54 to 183.3 mm SL (Fig. 2A). In *R. laticauda*, females measured between 56.5 to 133.4 mm SL. In comparison, males ranged from 54 to 126.7 mm SL (Fig. 2B). The SDI calculated using the mean SL for males and females was 1.21 for *R. guatemalensis* and 1.07 for *R. laticauda*. Using mean BM for each sex, the index was 1.7 for *R. guatemalensis* and 1.26 for *R. laticauda*, indicating female-biased sexual size dimorphism in both species (Table 2). Length frequency distributions differed between sexes of *R. guatemalensis* ($D = 0.45$, $p < 0.05$) and *R. laticauda* ($D = 0.25$, $p < 0.05$). Males showed lower variation in SL, whereas a greater proportion of females occurred in the 110–150 mm SL range for *R. guatemalensis* and the 80–120 mm SL range for *R. laticauda*, respectively (Fig. 2).

Size at first maturation and fecundity

We examined 81 specimens of *R. guatemalensis* and 185 of *R. laticauda*. Considering the entire sample of both sexes, we classified 40.7% of individuals as immature and 59.3% as mature for *R. guatemalensis*, and 34.1% as immature and 65.9% as mature for *R. laticauda*. The mean size at sexual maturity (L_{m50}) was estimated at 97.6 ± 3.5 mm SL whereas the L_{m95} was 128.2 ± 7.2 mm in *R. guatemalensis* (Fig. 3A). In *R. laticauda*, L_{m50} was estimated at 79 ± 2.1 mm and L_{m95} at 111 ± 4.9 mm (Fig. 3B).

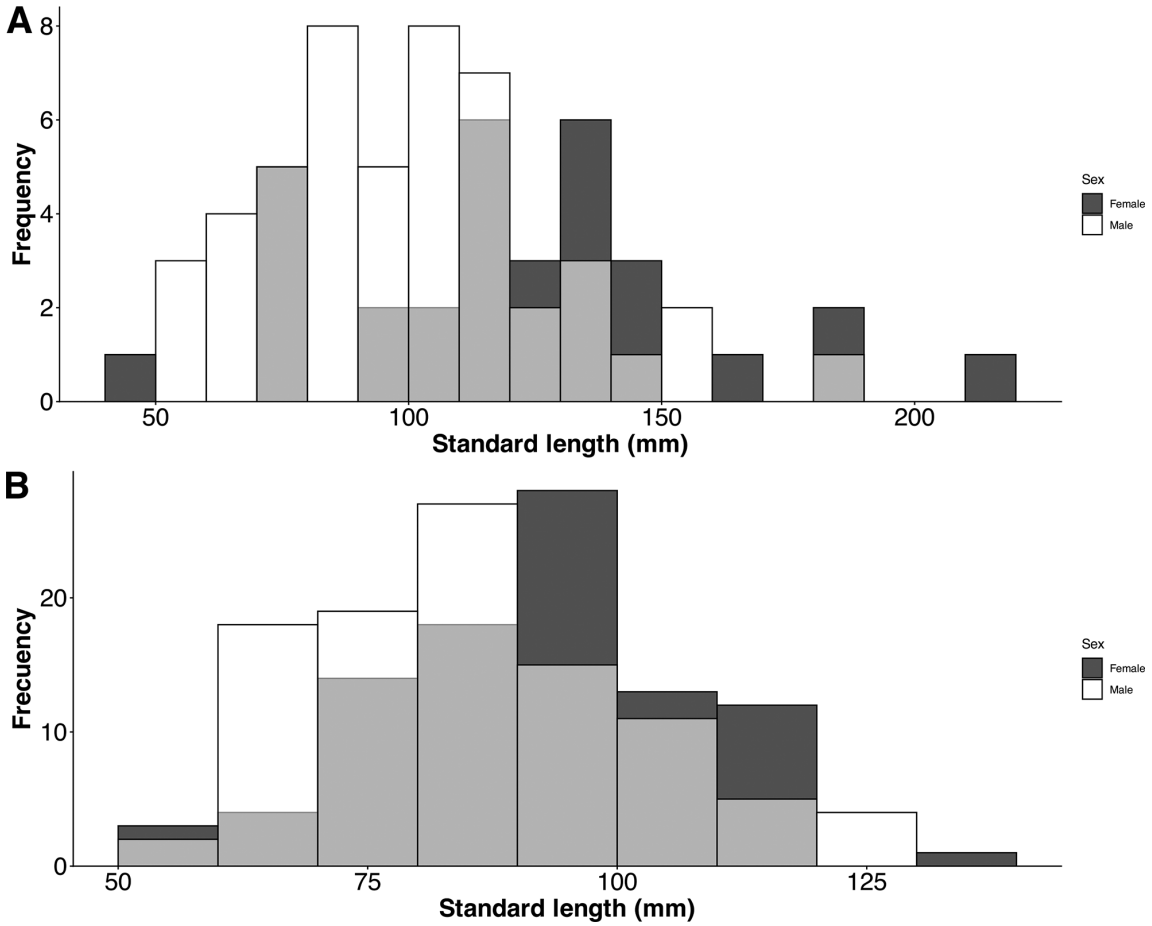

Figure 2. Standard length frequency distributions of *Rhamdia guatemalensis* (**A**) and *Rhamdia laticauda* (**B**). The gray shading indicates where the distributions overlap.

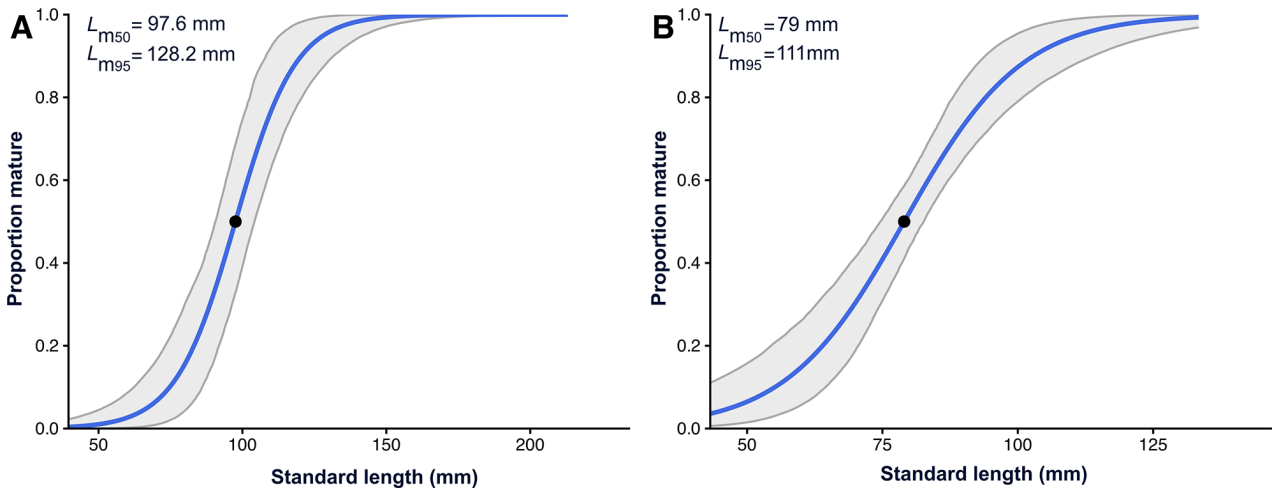

Figure 3. Length at first maturity of *Rhamdia guatemalensis* (**A**) and *Rhamdia laticauda* (**B**). The calculated size at 50% maturity is denoted by the point black and the gray shaded represents the 95% confidence intervals of the logistic ogive.

The fecundity of *R. guatemalensis* (*n* = 13, 90.3–213.05 mm SL) ranged from 2403 to 25077 eggs with an average of 9647 ± 6138 eggs. In contrast, *R. laticauda* (*n* = 11, 87.6–111 mm SL) showed lower fecundity, with an average of 1457 ± 322 eggs. Fecundity was significantly correlated with ovary weight in *R. guatemalensis* (rs = 0.95, p < 0.05) (Fig. 4A) and *R. laticauda* (rs = 0.68, p < 0.05) (Fig. 4B).

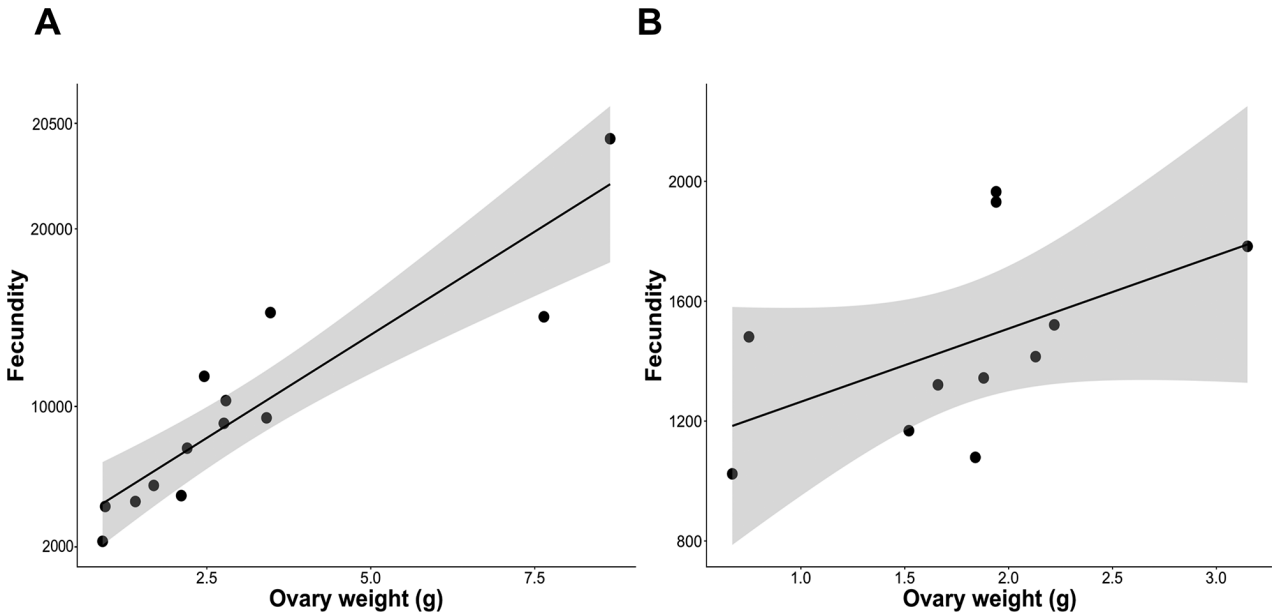

Figure 4. Linear regression between fecundity and ovary weight in *Rhamdia guatemalensis* (**A**) and *Rhamdia laticauda* (**B**). The gray shaded indicates the 95% confidence interval of the regression line.

Discussion

Distribution

Our results indicate that both species occupy only a small portion of the 31 municipalities within the Oaxaca portion of the TCBR (Martínez-Ramírez et al. 2010) and share the same subbasins, Río Quiotepec and Río Salado, which suggests a restricted and habitat-specific distribution. The elevation profiles for both species stated in the present study fit well with those reported by Martínez-Ramírez et al. (2004). Furthermore, each species appeared to exhibit distinct substrate preferences, consistent with previously documented patterns (Hernández et al. 2015; Thomas and Sabaj 2020). Together with the known dietary specialization documented for these species, which includes prey such as Ephemeroptera, Plecoptera, and Megaloptera that are sensitive to contamination (López-López et al. 2019; Julián-Caballero et al. 2024), these findings highlighted the need for continued monitoring of their populations in this region.

Sex ratio and sexual dimorphism

In the present study, both species exhibited an overall sex ratio close to 1:1. In fish populations with balanced or female-biased sex ratios, reproductive output depends primarily on oocyte production rather than sperm supply (King 2007; Wootton and Smith 2014). Consequently, deviations from this pattern, particularly reductions in the proportion of females, may indicate habitat alteration or selective overfishing of females (Overzee and Rijnsdorp 2015). Female dominance has been reported for *R. guatemalensis* (Chávez-Lomelí et al. 1989; Soto-Galera 2006). However, male dominance was reported for *R. laticauda* (Soto-Galera 2006). In agreement with our results, in other Siluriformes species, it is common to record either a 1:1 ratio or a female-dominated sex ratio. For example, female dominance has been reported in

Pseudoplatystoma tigrinum (Valenciennes 1840), *Pimelodella lateristriga* (Lichtenstein 1823) and *Pimelodus yuma* (Villa-Navarro et al. 2017) (Moraes et al. 2013; Pérez and Fabré 2018; Segura-Guevara et al. 2021). The discrepancies observed among studies (Table 3) could be attributable to a combination of external factors, such as geographic location, season, and fishing methods and equipment, as well as internal factors, including feeding habits, the physiological state of the analyzed samples, mortality rates, and greater reproductive effort by females (Nikolsky 1963; Wootton 1999).

In our study, both catfish exhibited female-biased sexual size dimorphism in SL and BM, and their length frequency distributions differed between sexes, with females being the largest in the sample. It is known that some species of Siluriformes may exhibit sexual size dimorphism, in which females are typically larger in standard length and biomass than males (Gomiero and Braga 2007; López-Rodríguez et al. 2019; Segura-Guevara et al. 2021). However, in Heptapteridae species, it is not a well-documented phenomenon (Rapp Py-Daniel and Cox Fernandes 2005; Bockmann and Slobodian 2017). Previous female-biased sexual size dimorphism has been documented in *R. quelen* (Narahara et al. 1985), where females reach a larger size than males, and this pattern may be related to fecundity selection (Gomiero et al. 2007; Benítez 2013), as larger females can produce more eggs and attain higher spawning success, as noted in *R. quelen* (Olaya-Nieto et al. 2010). In contrast, smaller males may use their remaining energy for behaviors such as territorial defense (Lowe-McConnell 1987).

Sexual dimorphism can vary among species and populations due to a range of influences, including abiotic, environmental, ecological, geographical, and phylogenetic factors (Benítez 2013). Sex-specific dietary differences, such as those documented for *R. guatemalensis* (Julián-Caballero et al. 2024), likely play an additional role in dimorphic patterns by influencing growth rate and energy allocation to reproduction (Wootton and Smith 2014). Future studies should test sexual shape differences among species of the genus *Rhamdia* using geometric morphometrics (see Benítez 2013), thereby providing greater insight into the mechanisms underlying this biological phenomenon.

Length at first maturity and fecundity

The L_{m50} and L_{m95} values are described here for the first time for *R. guatemalensis* and *R. laticauda* populations in the Mexican state of Oaxaca. These estimates represent the lengths at which 50% and 95% of

Table 3. Sex ratio (female:male) for species of the genus *Rhamdia* available in the literature. * = indicates significant differences from the expected sex ratio (1:1).

Reference	Species	State or Department, Country	*n*	Female	Male	Sex ratio	Chi-square value
Chávez-Lomelí et al. (1989)	*R. guatemalensis*	Tabasco, Mexico	262	186	76	2.44:1	46.1*
Soto-Galera (2006)	*R. guatemalensis*	Chiapas, Mexico	40	29	11	2.63:1	8.1*
This research	*R. guatemalensis*	Oaxaca, Mexico	81	32	49	0.65:1	3.6
Soto-Galera (2006)	*R. laticauda*	Chiapas, Mexico	60	26	34	0.76:1	1.1
This research	*R. laticauda*	Oaxaca, Mexico	194	93	101	0.92:1	0.3
Narahara et al. (1985)	*R. hilarii* (= *R. quelen*)	São Paulo, Brazil	1490	699	791	0.88:1	5.6*
Olaya-Nieto et al. (2010)	*R. quelen*	Córdoba, Colombia	337	207	130	1.6:1	17.6*

individuals attain sexual maturity and constitute essential reference for fisheries management and conservation planning (King 2007). The L_{m50} estimated for *R. guatemalensis* in this study is consistent with the previously reported range of 80–100 mm from other regions of Mexico (Schmitter-Soto 1998; Soto-Galera 2006). In contrast, the L_{m50} for *R. laticauda* was higher than the 64.5 mm SL stated by Soto-Galera (2006).

Owing to limitations related to sample size and the application of generalized models (Dunn and Smyth 2018), L_{m50} and L_{m95} were estimated for the total sample of both species, which precluded a direct assessment of sexual differences in size at maturity, as previously reported by Chávez-Lomelí et al. (1989) where males of *R. guatemalensis* reached sexual maturity at a smaller size (170 mm TL) than females (215 mm TL) (Table 4). Similar patterns have been documented for wild populations in *R. quelen* where males reach sexual maturity earlier than females (see Table 4) (Narahara et al. 1985; Olaya-Nieto et al. 2010). These differences are probably related to sex-specific energy allocation strategies, where males prioritize energy investment in sperm production and thus attain maturity at smaller body sizes (King 2007; Graeff et al. 2008), while females delay maturation to allocate energy to oocyte production (Narahara et al. 1985). Geographical variation in size at first sexual maturity is therefore expected, even within the same species, and may be influenced by external factors such as temperature, photoperiod, and food availability, as well as internal factors comprising the range of standard lengths examined and the physiological condition of the sample specimens (Narahara et al. 1985).

Our findings indicate that both freshwater fishes exhibited high fecundity, consistent with previous reports (Chávez-Lomelí et al. 1989; Soto-Galera 2006), and that fecundity is significantly correlated with ovary weight. This positive association is consistent with previous research, including those on *R. quelen* (Olaya-Nieto et al. 2010) and *P. yuma* (Segura-Guevara et al. 2021). The fecundity ranges estimated in this study are larger than those previously reported for *R. guatemalensis* (1400–16000 eggs) and *R. laticauda* (950–1100 eggs) by Soto-Galera (2006), but were lower than the values stated for *R. guatemalensis* by Chávez-Lomelí et al. (1989), who documented an average of 51893 eggs in females (n = 15) averaging 287 mm TL.

This pattern supports the general trend within the genus *Rhamdia*, in which larger body size is associated with greater fecundity and, consequently, higher reproductive potential. For example, Gomiero et al. (2007) reported high

Table 4. Size at first sexual maturity (L_{m50}) for species of the genus *Rhamdia* available in the literature. C = Combined, M = Male, F = Female, SL = Standard length, TL = Total length.

Reference	Species	State and Country	L_{m50}
Chávez-Lomelí et al. (1989)	*R. guatemalensis*	Tabasco, Mexico	M = 170 mm TL; F = 215 mm TL
Schmitter-Soto (1998)	*R. guatemalensis*	Quintana Roo, Mexico	C = 90–100 mm SL
Soto-Galera (2006)	*R. guatemalensis*	Chiapas, Mexico	C = 80 mm SL
This research	*R. guatemalensis*	Oaxaca, Mexico	C = 97.6 mm SL
Soto-Galera (2006)	*R. laticauda*	Chiapas, Mexico	C = 64.5 mm SL
This research	*R. laticauda*	Oaxaca, Mexico	C = 79 mm SL
Narahara et al. (1985)	*R. hilarii* (= *R. quelen*)	São Paulo, Brazil	M = 134 mm TL; F = 140 mm TL
Olaya-Nieto et al. (2010)	*R. quelen*	Córdoba, Colombia	M = 236 mm TL; F = 241 mm TL

fecundity in *R. quelen*, one of the largest species in the genus, with ranges of 14775–69440 eggs in the Paraiba River and 9120–54080 eggs in the Grande River, Brazil. Similarly, Olaya-Nieto et al. (2010) estimated a mean fecundity of 26305 eggs in *R. quelen* (184–350 mm TL) in Colombia. Overall, these comparisons indicate that within the genus *Rhamdia*, fecundity can vary considerably even within the same species, largely as a function of female body size, ovary weight, and local environmental conditions (Gomiero et al. 2007; Olaya-Nieto et al. 2010). Geographic differences in temperature, hydrological regime, habitat productivity and food availability can directly influence reproductive investment and, consequently, the fecundity in *Rhamdia* species (Gomiero et al. 2007; Olaya-Nieto et al. 2010).

The results of this study suggest that the catfishes examined apparently follow a seasonal strategy according to Winemiller (2005), characterized by females generally larger than males, little or no sexual difference in coloration (CCJC, pers. obs.), and high fecundity. In addition, the species studied exhibit an insectivorous diet, as previously reported in the same area (Julián-Caballero et al. 2024). This seasonal strategy suggests that these fishes tend to exploit the most abundant trophic resources available according to seasonal conditions and geographic region and further indicates that members of the genus *Rhamdia* may exhibit synchronization of the reproductive season with periods of highest precipitation (Narahara et al. 1985; Gomiero et al. 2007; Olaya-Nieto et al. 2010). Knowledge of reproductive strategies is crucial for guiding management and conservation measures of ichthyofauna in the face of impacts caused by anthropogenic activities, such as fishing and the reduction or loss of spawning and nursery habitats for fish species (Winemiller and Rose 1992; Winemiller 2005).

In the present study, only sexual size dimorphism (SL and BM) was evaluated, whereas sexual shape dimorphism (see Benítez 2013) was not assessed and will be investigated in the following work. In addition, size at first maturation was estimated using the total sample for each species, indicating that further research is needed to determine whether these catfish exhibit sexual differences in this reproductive trait. Another limitation of this study is that total fecundity was estimated using a small sample size and a gravimetric method. Therefore, the positive association between fecundity and ovary weight may partly reflect methodological dependence between these variables and should be interpreted with caution. Future studies should include monthly sampling over the course of a year to determine the reproductive period and spawning type, as well as to measure egg size in these Neotropical catfishes. Such information would provide a more comprehensive understanding of their reproductive strategies.

Conclusion

We provide updated distribution data and new information on the reproductive biology of two native catfish species within a Biosphere Reserve. These fishes share the same sub-basins (Río Quiotepec and Río Salado) and occur across similar altitudinal ranges. Our findings revealed an equal sex ratio and female-biased sexual size dimorphism in standard length and biomass. Standard length frequency distributions differed between sexes,

with females representing the largest individuals in the samples. Sexual maturity in standard length was reached at 97.6 mm in *R. guatemalensis* and 79 mm in *R. laticauda*. The Pale catfish and the Filespin chulín exhibited high fecundity, with mean numbers of eggs per female of 9647 and 1457, respectively, with fecundity showing a positive association with ovary weight in both species. These results improve our understanding of the reproductive biology of these key components of the food webs and provide valuable baseline information to support future conservation and fisheries management strategies in the TCBR.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.
No AI tools were used in the preparation of this manuscript.

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Author contributions

Conceptualization: CCJC, ECA, EMR, GICR. Data curation: CCJC, EMR, ECA, GICR. Formal analysis: CCJC. Funding acquisition: EMR. Investigation: CCJC, ECA. Methodology: CCJC, EMR, ECA, GICR. Project administration: EMR. Resources: EMR. Software: CCJC. Super vision: ECA, EMR, RMGU, GICR. Validation: EMR, CCJC, RMGU, ECA, GICR. Visualization: RMGU, CCJC, EMR, ECA, GICR. Writing – original draft: CCJC. Writing – review and editing: RMGU, ECA, GICR, EMR, CCJC.

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Data availability

Data of measurements and fecundity are available in tableA1 and tableA2, respectively at Zenodo: https://doi.org/10.5281/zenodo.18378004.