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Length-weight relationships for 119 fish species of socioeconomic value in the fresh and coastal-estuarine waters of Costa Rica

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ABSTRACT

Introduction: Length-weight (L-W) relationships are essential in ichthyology and fisheries science, providing a basis for estimating biomass, evaluating fish condition, and modeling growth. Such information currently is scarce for Costa Rican freshwater and coastal-estuarine fishes.

Objectives: To estimate L-W relationships of 119 fish species with socioeconomic value in Costa Rica, evaluating the potential influence of specimen preservation on these estimates.

Methods: A total of 22 219 individuals representing 119 species (23 families) were analyzed. Fresh specimens ($n = 17\,988$; 111 species) were collected during field surveys conducted between 2009 and 2024 across 306 localities throughout the country. Preserved specimens ($n = 4\,231$; 114 species), collected between 1966 and 2009, were obtained from the Ichthyological Collection of the University of Costa Rica. Standard length (L; cm) and body weight (W; g) were recorded following standard ichthyological protocols. Length-weight relationships were modeled as $W = aL^b$, using least-squares regression of log-transformed data. Differences in linear regression slopes between fresh and preserved specimens were tested through ANCOVA.

Results: Differences between fresh and preserved specimens were evaluated for each species. For 96 species (80.7%), no significant differences were detected; therefore, both datasets were combined and a single L-W relationship was estimated using all available individuals. All regressions were significant ($p < 0.001$), with $r^2 \geq 0.91$. Most species (101; 84.9%) exhibited positive allometry ($b > 3$), whereas nine species showed negative allometry ($b < 3$) and seven displayed isometric growth ($b \approx 3$).

Conclusions: This study represents the most comprehensive assessment of L-W relationships for Costa Rican fishes to date, generating new parameters for 83 species lacking previous records. Results confirm the utility of preserved specimens for L-W studies, while also indicating that preservation effects may vary among species and may require separate analyses for fresh and preserved specimens in some cases. The dataset provides an essential



baseline for fisheries management, ecological monitoring, and conservation of the Ichthyological resource in Costa Rica and the broader Neotropical region.

Key words: biometric parameters; fish morphometrics; fisheries management; museum specimens; neotropical ichthyofauna.

RESUMEN

Relaciones longitud-peso para 119 especies de peces con valor socio-económico en las aguas dulces y costero-estuarinas de Costa Rica

Introducción: Las relaciones longitud-peso (L-P) son fundamentales en ictiología y en ciencias pesqueras, ya que proporcionan una base para estimar biomasa, evaluar la condición de los peces y modelar su crecimiento. Este tipo de información actualmente es escasa para los peces de aguas continentales y ambientes costero-estuarinos de Costa Rica.

Objetivos: Estimar las relaciones L-P de 119 especies de peces de importancia socioeconómica en Costa Rica, evaluando la posible influencia de la preservación de los especímenes sobre tales estimaciones.

Métodos: Se analizaron un total de 22 219 individuos correspondientes a 119 especies (23 familias). Los especímenes frescos ($n = 17\,988$; 111 especies) fueron recolectados durante muestreos de campo en 306 localidades a lo largo de todo el país entre 2009 y 2024. Los especímenes preservados ($n = 4\,231$; 114 especies), recolectados entre 1966 y 2009, fueron obtenidos de la Colección Ictiológica de la Universidad de Costa Rica. La longitud estándar (L; cm) y el peso corporal (P; g) se registraron siguiendo protocolos ictiológicos estándar. Las relaciones longitud-peso se modelaron como $W = aL^b$, mediante regresión de mínimos cuadrados utilizando datos transformados logarítmicamente. Las diferencias en las pendientes de las regresiones lineales entre especímenes frescos y preservados se evaluaron mediante un análisis de covarianza (ANCOVA).

Resultados: Las diferencias entre especímenes frescos y preservados se evaluaron para cada especie. En 96 especies (80.7%) no se detectaron diferencias significativas; por lo tanto, ambos conjuntos de datos fueron combinados y se estimó una única relación L-P utilizando todos los individuos disponibles. Todas las regresiones fueron significativas ($p < 0.001$), con $r^2 \geq 0.91$. La mayoría de las especies (101; 84.9%) presentó alometría positiva ($b > 3$), mientras que nueve especies mostraron alometría negativa ($b < 3$) y siete presentaron crecimiento isométrico ($b \approx 3$).

Conclusiones: Este estudio representa la evaluación más completa de las relaciones L-P para peces de Costa Rica, generando nuevos parámetros para 83 especies que carecían de registros previos. Los resultados confirman la utilidad de los especímenes preservados para estudios de relaciones L-P, aunque también indican que los efectos de la preservación pueden variar entre especies y que, en algunos casos, puede ser necesario analizar por separado los especímenes frescos y preservados. El conjunto de datos generado proporciona una base fundamental para el manejo pesquero, el monitoreo ecológico y la conservación del recurso ictiológico en Costa Rica y en la región neotropical en general.

Palabras clave: parámetros biométricos; morfometría de peces; gestión pesquera; ejemplares de museo; ictiofauna neotropical.

INTRODUCTION

Length-weight (L-W) relationships are widely recognized as fundamental descriptors in ichthyology and fisheries science since they provide a practical means of linking length data with estimates of body weight (Bagley et al., 2022; Barragán et al., 2024; Froese, 2006; Hay et al., 2020). They are essential for estimating population biomass, assessing fish health and condition, and modeling growth

patterns across different environments (Bagley et al., 2022; Barragán et al., 2024; Froese, 2006). Length-weight relationships are also used to derive comparative indicators that inform stock assessments, ecological monitoring, and biodiversity conservation, thereby serving both applied and basic research purposes (Bagley et al., 2022; Froese, 2006).

Costa Rica hosts a relatively rich ichthyofauna, with more than 270 recognized species across its freshwater and coastal-estuarine

environments, shaped by diverse habitats and different biogeographical processes (Angulo, 2021; Angulo et al., 2013; Bussing, 1998; Bussing & López, 2009; Murase et al., 2014). Many species sustain recreational, artisanal, and subsistence fisheries, while others hold potential value in ornamental trade (Allen et al., 2017; Angulo, 2021; Bussing, 1998; Murase et al., 2014; Villalobos-Rojas et al., 2014). Despite its importance, biometric information remains scarce, with few species studied in detail. Relatively recent work in Central America, such as Bagley et al. (2022), has provided L-W data for several Neotropical freshwater fishes, underscoring the relevance of such studies for the region. However, comprehensive analyses that encompass a broad range of socioeconomically important species in Costa Rica remain unavailable.

Scientific collections can provide an additional source of morphometric and meristic data, particularly when access to fresh specimens is limited (Barragán et al., 2024; Hay et al., 2020). Although preservation may alter body weight or proportions to some extent, comparisons with fresh material indicate that reliable L-W parameters can often be derived from museum specimens when appropriate methodological care is taken (Barragán et al., 2024; Froese, 2006; Hay et al., 2020; Le Cren, 1951). Thus, preserved material has the potential to complement field sampling, adding value to existing ichthyological collections while broadening the range of species that can be evaluated (Barragán et al., 2024; Hay et al., 2020).

The objective of this study is to estimate length-weight relationships (LWRs) and associated parameters for a suite of socioeconomically important fish species from the fresh and coastal-estuarine waters of Costa Rica, including those relevant to recreational, artisanal, and subsistence fisheries, as well as the aquarium trade. In addition, potential differences between fresh and preserved specimens are evaluated to determine whether both data sources can be reliably combined when estimating LWRs and to assess the usefulness of museum collections for these analyses. By addressing

these aspects, this study helps fill important gaps in the biological knowledge of Costa Rica's ichthyofauna while also providing a methodological framework that can strengthen fisheries research, ecological monitoring, and biodiversity conservation in the region.

MATERIALS AND METHODS

Fresh specimens were obtained during field surveys conducted, between 2009 and 2024, at approximately 306 localities across the entire country; detailed information on some of these sampling efforts is available in Angulo & Garita-Alvarado (2013), Angulo et al. (2017); Angulo et al. (2020), Scholten (2024), and Tonella et al. (2022). Fishes were sampled using several methods, including seines, cast nets, electrofishing, and centipede nets. A total of 17 988 individuals, representing 111 species, were measured and weighed in the field (i.e., fresh specimens). In addition, between 2022 and 2025, 4 231 preserved specimens, representing 114 species, were measured and weighed in the laboratory. The preserved material was collected between 1966 and 2009 and is deposited in the Ichthyological Collection of the Museum of Zoology, University of Costa Rica (UCR); see Angulo et al. (2016) for details. Altogether, the dataset comprised 22 219 specimens, including both fresh and preserved material from Costa Rican freshwater and coastal-estuarine species.

Fishes were identified/re-identified, in the field/laboratory, using the taxonomic keys and descriptions of Angulo et al. (2017); Angulo et al. (2021), Angulo & San Gil-León (2022), Bussing (1998), Robertson & Allen (2024) and Robertson & Van Tassell (2023). Taxonomy and geographic distributions (Table 1), follow Angulo (2021), Robertson & Allen (2024) and Robertson & Van Tassell (2023); except for *Astyanax aeneus*, *Poecilia gillii* and *Poecilia mexicana*, which are listed according to Bussing (1998).

For each specimen, standard length (L, to the nearest 0.1 cm) and body weight (W, to the nearest 0.1 g for fresh material and 0.01 g for preserved specimens) were recorded following

**Table 1**

List of fish species (n = 119) from the fresh and coastal-estuarine waters of Costa Rica examined in this study, organized by family, including their geographical distribution and current state of knowledge of their length-weight (L-W) relationships (i.e., the number of L-W records/references available for the species on FishBase; superscripts identify the corresponding references as detailed in the table footnotes). Species highlighted in gray indicate those of socioeconomic relevance to recreational, artisanal, or subsistence fisheries.

Family/Species	Geographical distribution	References*
Anablepidae		
<i>Oxyzygonectes dovii</i>	Middle America (MA); from northern Nicaragua to western Panama, Pacific drainages	None
Ariidae		
<i>Ariopsis seemanni</i>	Eastern Pacific Ocean (EPO); from the Gulf of California, Mexico, to northern Peru, entering estuaries and littoral lagoons and ascending river courses	2 ^{2, 5}
<i>Sciades dowii</i>	EPO; from southern Mexico to northern Peru, entering estuaries and littoral lagoons and ascending river courses.	1 ⁵
Atherinopsidae		
<i>Atherinella argentea</i>	EPO; from Guatemala to western Panama, entering estuaries and littoral lagoons and ascending river courses	None
Bryconidae		
<i>Brycon behrae</i>	MA; from southwestern Costa Rica to central Panama, Pacific drainages	1 ¹⁷
<i>Brycon costaricensis</i>	MA; from northern Nicaragua to northeastern Costa Rica, Atlantic drainages	None
Carangidae		
<i>Caranx caninus</i>	EPO; from Southern California, USA, to Peru (including Revillagigedos, Galápagos, Cocos and Malpelo), entering estuaries and littoral lagoons and ascending river courses	5 ^{2, 7, 9, 15, 32}
Centropomidae		
<i>Centropomus medius</i>	EPO; from southern Baja California and the central Gulf of California, Mexico, to northern Peru, entering estuaries and littoral lagoons and ascending river courses	3 ^{2, 7, 15}
<i>Centropomus robalito</i>	EPO; from the southern Gulf of California, Mexico, to Ecuador, entering estuaries and littoral lagoons and ascending river courses	6 ^{2, 5, 12, 15, 24, 32}
<i>Centropomus unionensis</i>	EPO; from the southeastern Gulf of California, Mexico, to Peru, entering estuaries and littoral lagoons and ascending river courses	1 ⁵
Characidae		
<i>Astyanax "aeneus"</i>	From southern Mexico to Panama, Atlantic and Pacific drainages	2 ^{32, 33}
<i>Astyanax anai</i>	MA; from eastern Costa Rica to western Panama, Atlantic drainages	None
<i>Astyanax bransfordii</i>	MA; from southwestern Nicaragua to northern Costa Rica, Atlantic drainages	None
<i>Carlana eigenmanni</i>	MA; from southern Nicaragua to northern Costa Rica, Atlantic drainages	None
<i>Eretmobrycon scleroparius</i>	MA; from southern Nicaragua to western Colombia, Atlantic and Pacific drainages	None
<i>Eretmobrycon terrabensis</i>	MA; southwestern Costa Rica, Pacific drainages	None
<i>Hyphessobrycon bussingi</i>	MA; from eastern Costa Rica to western Panama, Atlantic drainages	None
<i>Hyphessobrycon savagei</i>	MA; southwestern and southern Costa Rica, Pacific drainages	None
<i>Hyphessobrycon tortuguerae</i>	MA; from central and eastern Honduras to northern Costa Rica, Atlantic drainages	None
<i>Odontostilbe dialeptura</i>	MA; from southern Costa Rica to eastern Panama, Pacific drainages	None
<i>Pseudochirodon terrabae</i>	MA; southern Costa Rica, Pacific drainages	None
<i>Pterobrycon myrnae</i>	MA; southern Costa Rica, Pacific drainages	None
<i>Roeboides bouchellei</i>	MA; from southern Mexico to northern Costa Rica, Atlantic and Pacific drainages	None
<i>Roeboides bussingi</i>	MA; from southeastern Costa Rica to western Panama, Pacific drainages	None
<i>Roeboides ilseae</i>	MA; southern Costa Rica, Pacific drainages	None
Cichlidae		
<i>Amatitlania kanna</i>	MA; from eastern Costa Rica to western Panama, Atlantic drainages	None
<i>Amatitlania myrnae</i>	MA; from eastern Costa Rica to (probably) western Panama, Atlantic drainages	None
<i>Amatitlania sajica</i>	MA; southeastern Costa Rica, Pacific drainages	None
<i>Amatitlania septemfasciata</i>	MA; from southern Nicaragua to central Costa Rica, Atlantic drainages	None

Family/Species	Geographical distribution	References*
<i>Amatitlania siquia</i>	MA; from eastern Honduras to central Costa Rica, Atlantic and Pacific drainages	None
<i>Amphilophus citrinellus</i>	MA; from central Nicaragua to northern Costa Rica, Atlantic drainages	1 ¹⁷
<i>Amphilophus labiatus</i>	MA; from southern Nicaragua to northern Costa Rica, Atlantic drainages	4 ²⁵
<i>Andinoacara coeruleopunctatus</i>	MA; from southern Costa Rica to central Panama, Atlantic and Pacific drainages	None
<i>Archocentrus centrarchus</i>	MA; from northern Honduras to northern Costa Rica, Atlantic and Pacific drainages	None
<i>Cribroheros alfari</i>	MA; from northern Honduras to central and eastern Costa Rica, Atlantic and Pacific drainages	None
<i>Cribroheros altifrons</i>	MA; from southern Costa Rica to western Panama, Pacific drainages	None
<i>Cribroheros bussingi</i>	MA; from eastern Costa Rica to (probably) western Panama, Atlantic drainages	None
<i>Cribroheros diquis</i>	MA; southeastern Costa Rica, Pacific drainages	None
<i>Cribroheros longimanus</i>	MA; from eastern Guatemala to northern Costa Rica, Atlantic and Pacific drainages	None
<i>Cribroheros rhytisma</i>	MA; from eastern Costa Rica to western Panama, Atlantic drainages	None
<i>Cribroheros rostratus</i>	MA; from southern Nicaragua to northeastern Costa Rica, Atlantic drainages	None
<i>Herotilapia multispinosa</i>	MA; from eastern Honduras to northeastern Costa Rica, Atlantic and Pacific drainages	None
<i>Hypsophrys nicaraguensis</i>	MA; from southern Nicaragua to northeastern Costa Rica, Atlantic and Pacific drainages	None
<i>Neotroplus nematopus</i>	MA; from southern Nicaragua to northern Costa Rica, Atlantic and Pacific drainages	None
<i>Parachromis dovii</i>	MA; from eastern Honduras to northeastern Costa Rica, Atlantic and Pacific drainages	2 ^{1, 7}
<i>Parachromis friedrichsthalii</i>	MA; from eastern Honduras to western Panama, Atlantic and Pacific drainages	None
<i>Parachromis managuensis</i>	MA; from eastern Honduras to northeastern Costa Rica, Atlantic and Pacific drainages	4 ^{1, 17, 25, 33}
<i>Talamancaheros underwoodi</i>	MA; from southwestern Costa Rica to (probably) western Panama, Pacific drainages	None
<i>Tomocichla tuba</i>	MA; from eastern Nicaragua to western Panama, Atlantic drainages	None
<i>Vieja maculicauda</i>	MA; from southern Belize to central Panama, Atlantic and Pacific drainages	None
Eleotridae		
<i>Dormitator latifrons</i>	EPO; from southern California, USA, to northern Peru; entering estuaries and littoral lagoons and ascending river courses	9 ^{2, 4, 11, 29, 32, 34}
<i>Dormitator maculatus</i>	Western Atlantic Ocean (WAO); from North Carolina, USA, to southeastern Brazil; entering estuaries and littoral lagoons and ascending river courses	None
<i>Eleotris amblyopsis</i>	WAO; from North Carolina, USA, to southeastern Brazil; entering estuaries and littoral lagoons and ascending river courses	None
<i>Eleotris perniger</i>	WAO; from Bermuda, Bahamas, South Carolina and northern Gulf of Mexico, USA, to southeastern Brazil; entering estuaries and littoral lagoons and ascending river courses	None
<i>Eleotris picta</i>	EPO; from the mouth of the Gulf of California, Mexico, to northern Peru, as well as Cocos and the Galapagos Islands; entering estuaries and littoral lagoons and ascending river courses	2 ^{2, 29}
<i>Eleotris tubularis</i>	EPO; Cocos Island; entering estuaries and ascending river courses	None
<i>Gobiomorus dormitor</i>	WAO; from Bermuda and southern Florida, USA, to southeastern Brazil; entering estuaries and littoral lagoons and ascending river courses	125
<i>Gobiomorus maculatus</i>	EPO; from Baja California and the mouth of the Gulf of California, Mexico, to northern Peru, as well as the Galapagos and Cocos Islands; entering estuaries and ascending river courses	3 ^{18, 29, 32}
<i>Gobiomorus polylepis</i>	EPO; from central Mexico to southern Costa Rica; entering estuaries and ascending river courses	None
<i>Hemieleotris latifasciata</i>	EPO; from southern Mexico to Ecuador; entering estuaries and ascending river courses	None
Engraulidae		
<i>Anchoa chamensis</i>	EPO; from central Costa Rica to eastern Panama, entering estuaries and littoral lagoons and ascending river courses	None
<i>Anchoa lucida</i>	EPO; from central Baja California, Mexico, to northern Peru, entering estuaries and littoral lagoons and ascending river courses	2 ^{13, 32}
<i>Anchoa nasus</i>	EPO; from the Gulf of California, Mexico, to Chile, entering estuaries and littoral lagoons and ascending river courses	2 ^{14, 23}
<i>Anchoa panamensis</i>	EPO; from southern Mexico to Ecuador, entering estuaries and littoral lagoons and ascending river courses	2 ^{12, 34}



Family/Species	Geographical distribution	References*
<i>Anchoa starksii</i>	EPO; from southern Mexico to northern Peru, entering estuaries and littoral lagoons and ascending river courses.	None
Erythrinidae		
<i>Hoplias microlepis</i>	Central and northwestern South America: from southern Costa Rica to Ecuador, Atlantic and Pacific drainages	None
Gerreidae		
<i>Diapterus brevirostris</i>	EPO; from southern Baja California and the lower two-thirds of the Gulf of California, Mexico, to Peru (including Galápagos and Revillagigedo), entering estuaries and littoral lagoons and ascending river courses	4 ⁶ , 23, 24
<i>Eucinostomus currani</i>	EPO; from California and the Gulf of California, Mexico, to northern Peru (including Galápagos and Cocos), entering estuaries and littoral lagoons and ascending river courses	9 ⁶ , 8, 13, 15, 23, 24, 28, 29, 32
Gobiidae		
<i>Awaous banana</i>	North, Central and South America; from northern Florida, USA, southward through the Greater and Lesser Antilles to Trinidad and Tobago and Venezuela, Atlantic drainages	1 ²⁹
<i>Awaous transandeanus</i>	North, Central and South America; from central Baja California Sur and Sonora, Mexico, to Tumbes, Peru, Pacific drainages	None
<i>Sicydium adelum</i>	WAO; from eastern Costa Rica to (probably) western Panama; entering estuaries and littoral lagoons and ascending river courses	None
<i>Sicydium altum</i>	WAO; from northern Costa Rica to (probably) western Panama; entering estuaries and littoral lagoons and ascending river courses	None
<i>Sicydium cocoense</i>	EPO; Cocos Island; entering estuaries and ascending river courses	None
<i>Sicydium salvini</i>	EPO; from El Salvador to Ecuador; entering estuaries and littoral lagoons and ascending river courses	None
Gymnotidae		
<i>Gymnotus cylindricus</i>	MA; from central Guatemala to eastern Costa Rica, Atlantic and Pacific drainages	None
<i>Gymnotus maculosus</i>	North America; from southern Mexico to central Costa Rica, Atlantic and Pacific drainages	None
Heptapteridae		
<i>Imparfinis lineatus</i>	MA; southern Costa Rica, Pacific drainages	None
<i>Pimelodella chagresi</i>	Central and South America; from southern Costa Rica to Colombia and Venezuela, Atlantic and Pacific drainages	None
<i>Rhamdia guatemalensis</i>	North, Central and South America; from southern Mexico to eastern Colombia, Atlantic and Pacific drainages	1 ²⁷
<i>Rhamdia laticauda</i>	North America; from central Mexico to western Panama, Atlantic and Pacific drainages	1 ³³
<i>Rhamdia nicaraguensis</i>	MA; from northern Nicaragua to Central Costa Rica, Atlantic and Pacific drainages	None
Lebiasinidae		
<i>Lebiasina boruca</i>	MA; southern Costa Rica, Pacific drainages	None
Lutjanidae		
<i>Lutjanus argentiventris</i>	EPO; from southern California, USA, and the Gulf of California, Mexico, to Peru (including oceanic islands except Clipperton), entering estuaries and littoral lagoons and ascending river courses	10 ² , 3, 6, 7, 13, 15, 23, 32
Mugilidae		
<i>Mugil setosus</i>	EPO; from Baja California and the Gulf of California, Mexico, to Peru (including Revillagigedo, Cocos and Galápagos), entering estuaries and littoral lagoons and ascending river courses	None
Poeciliidae		
<i>Alfaro cultratus</i>	MA; from eastern Honduras to western Panama, Atlantic and Pacific drainages	1 ¹
<i>Belonesox belizanus</i>	North America; from southern Mexico to northern Costa Rica, Atlantic drainages	1 ²⁰
<i>Brachyrhaphis holdridgei</i>	MA; from southern Nicaragua to northern Costa Rica, Atlantic drainages	None
<i>Brachyrhaphis olomina</i>	MA; from (probably) southern Nicaragua to central Costa Rica, Atlantic and Pacific drainages	None
<i>Brachyrhaphis rhabdophora</i>	MA; southwestern Costa Rica, Pacific drainages	None
<i>Brachyrhaphis roseni</i>	MA; from southeastern Costa Rica to western Panama, Pacific drainages	None
<i>Brachyrhaphis terrabensis</i>	MA; from southeastern Costa Rica to western Panama, Pacific drainages	None

Family/Species	Geographical distribution	References*
<i>Gambusia nicaraguensis</i>	MA; from southern Belize to central Panama, Atlantic drainages	None
<i>Hiathirhaphis parismina</i>	MA; from southern Nicaragua to northeastern Costa Rica, Atlantic drainages	None
<i>Phallichthys amates</i>	MA; from eastern Guatemala to western Panama, Atlantic and Pacific drainages	1 ¹
<i>Phallichthys quadripunctatus</i>	MA; from eastern Costa Rica to (probably) western Panama, Atlantic drainages	None
<i>Phallichthys tico</i>	MA; from southern Nicaragua to northern Costa Rica, Atlantic drainages	None
<i>Poecilia gillii</i>	MA; from central Costa Rica to eastern Panama, Atlantic and Pacific drainages	2 ^{1, 18}
<i>Poecilia mexicana</i>	North America; from eastern Mexico to western Panama, Atlantic and Pacific drainages	3 ^{22, 33}
<i>Poecilia reticulata</i>	Northern South America and Western Atlantic; coastal (Atlantic) drainages of Venezuela, Guyana, Suriname, Trinidad and Tobago and the Brazilian states of Amapá and Pará	5 ^{10, 16, 26, 30, 31}
<i>Poeciliopsis elongata</i>	MA; from northwestern Costa Rica to eastern Panama (also recorded in Colombia), Pacific drainages	None
<i>Poeciliopsis paucimaculata</i>	MA; from southern Costa Rica to (probably) western Panama, Pacific drainages	None
<i>Poeciliopsis retropinna</i>	MA; from southern Costa Rica to western Panama, Pacific drainages	None
<i>Poeciliopsis santaelena</i>	MA; northwestern Costa Rica, Pacific drainages	None
<i>Poeciliopsis turrrubarensis</i>	North, Central and South America: from central Mexico to southwestern Colombia, Pacific drainages	1 ¹⁵
<i>Priapichthys annectens</i>	MA; from northern Costa Rica to (probably) western Panama, Atlantic and Pacific drainages	1 ¹
<i>Priapichthys panamensis</i>	MA; from northern Costa Rica to central Panama, Pacific drainages	None
<i>Xenophallus umbratilis</i>	MA; from southern Nicaragua to northern Costa Rica, Atlantic drainages	None
Rivulidae		
<i>Cynodonichthys fuscolineatus</i>	MA; northwestern Costa Rica, Atlantic and Pacific drainages	None
<i>Cynodonichthys glaucus</i>	MA; southeastern Costa Rica, Pacific drainages	None
<i>Cynodonichthys hildebrandi</i>	MA; from southeastern Costa Rica to western Panama, Pacific drainages	None
<i>Cynodonichthys isthmensis</i>	MA; from central Nicaragua to eastern Costa Rica, Atlantic and Pacific drainages	None
<i>Cynodonichthys rubripunctatus</i>	MA; from eastern Costa Rica to (probably) western Panama, Atlantic drainages	None
<i>Cynodonichthys siegfriedi</i>	MA; southeastern Costa Rica, Pacific drainages	None
<i>Cynodonichthys uroflammeus</i>	MA; from southeastern Costa Rica to (probably) western Panama, Pacific drainages	None
Sciaenidae		
<i>Bairdiella armata</i>	EPO; from the lower Gulf of California, Mexico, to Colombia, entering estuaries and littoral lagoons and ascending river courses	None
<i>Cynoscion albus</i>	EPO; from the southeastern Gulf of Mexico to Peru, entering estuaries and littoral lagoons and ascending river courses	2 ^{5, 21}
<i>Stellifer mancorensis</i>	EPO; from El Salvador to Peru, entering estuaries and littoral lagoons and ascending river courses	1 ⁵
<i>Stellifer oscitans</i>	EPO; from El Salvador to Ecuador, entering estuaries and littoral lagoons and ascending river courses	1 ⁵
Trichomycteridae		
<i>Trichomycterus striatus</i>	MA; from southern Costa Rica to eastern Panama, Atlantic and Pacific drainages	None

*Indicates the number of L-W records/references available for the species on FishBase (Froese & Pauly, 2024) before this study; 1: Bagley et al. (2022), 2: Bautista-Romero et al. (2012), 3: Bonilla-Gómez et al. (2014), 4: Chang & Navas (1984), 5: Coello et al. (2020), 6: Cota-Gómez et al. (2013), 7: Crawford (1993), 8: De La Cruz Agüero et al. (2011), 9: Espino-Barr et al. (2008), 10: Faustino-Fuster et al. (2017), 11: Florencio & Serrano (1981), 12: Flores-Ortega et al. (2016), 13: González-Acosta et al. (2004), 14: González-Acosta et al. (2024), 15: González-Sansón et al. (2014), 16: Gurgel-Lourenço et al. (2017), 17: IGFA (2001), 17: IGFA (2009), 18: Jiménez-Prado et al. (2018), 20: Klassen et al. (2014), 21: Lai et al. (1992), 22: Miranda et al. (2009), 23: Moreno-Sánchez et al. (2012), 24: Nieto-Navarro et al. (2010), 25: Prchalová et al. (2020), 26: Ribeiro et al. (2017), 27: Rodríguez-Olarte et al. (2018), 28: Ruiz-Ramírez et al. (1997), 29: Sandoval-Huerta et al. (2015), 30: Severo-Neto et al. (2018), 31: Terra et al. (2017), 32: Velázquez-Velázquez et al. (2009), 33: Velázquez-Velázquez et al. (2015), and 34: Warburton (1979).



standard ichthyological protocols (Anderson & Neumann, 1996; Barragán et al., 2024; Froese, 2006; Hay et al., 2020). Length-weight relationships were described for each species (pooling data across sexes and years) using the power function $W = aL^b$, where a is the intercept and b is the allometric growth exponent (Bagley et al., 2022; Froese, 2006; Le Cren, 1951). The parameters a and b were estimated separately for fresh and preserved specimens by applying least-squares linear regression to log-transformed data, according to the equation $\log(W) = \log(a) + b \log(L)$. This transformation linearizes the power relationship and helps reduce heteroscedasticity commonly observed in L-W data. To ensure data quality, outliers were identified and excluded using both visual inspection of log-log scatterplots and the standardized residual method (values $> |3|$), following Froese (2006) and Bagley et al. (2022). Both approaches yielded consistent results, providing a double validation for outlier removal. All analyses were implemented in PAST v. 4.14 (Hammer et al., 2001).

Differences in linear regression slopes (b) between fresh and preserved specimens, by species, were tested using the “Compare regressions” routine in PAST. This tool applies an analysis of covariance (ANCOVA) framework to test for the homogeneity of slopes between groups/treatments (Hammer et al., 2001; Warton et al., 2006; Zar, 1999). The null hypothesis of this test is that the slopes are equal across treatments (Hammer et al., 2001; Warton et al., 2006; Zar, 1999). When no significant difference was detected ($p > 0.05$), datasets (fresh and preserved) were combined, and a single linear L-W equation was recalculated. For species showing significant differences ($p < 0.05$), parameters were reported separately for fresh and preserved specimens.

Finally, the parameter b was used to evaluate growth patterns (Froese, 2006; Le Cren, 1951; Ricker, 1975). Growth was considered isometric when the value $b = 3$ fell within the 95% confidence interval of the estimated slope. Conversely, when the value 3 was outside the 95% confidence interval,

growth was interpreted as allometric (positive allometry for $b > 3$ and negative allometry for $b < 3$) (Froese, 2006; Le Cren, 1951; Ricker, 1975).

RESULTS

A total of 119 species, belonging to 23 families (Table 1) and 21 701 individuals were analyzed (i.e., data from 518 individuals were excluded as outliers), of which 17 488 specimens were fresh and 4 213 specimens were preserved. Species relevant to recreational, artisanal, and subsistence fisheries are noted in Table 1. For 106 species, data were obtained from both fresh and preserved specimens, whereas for five species (i.e., *Anchoa lucida*, *Atherinella argentea*, *Bairdiella armata*, *Lutjanus argentiventris*, and *Sciades dowii*) only fresh material was analyzed. For eight species (i.e., *Cynodonichthys siegfriedi*, *Cynodonichthys rubripunctatus*, *Cynodonichthys uroflammeus*, *Eleotris tubularis*, *Phallichthys tico*, *Poecilia reticulata*, *Pterobrycon myrnae*, and *Sicydium cocoense*) only preserved specimens were considered. Sample sizes per species ranged from five to 1 408 fresh individuals (mean: 159.0), and five to 76 preserved individuals (mean: 37.0). The species analyzed included both freshwater and coastal-estuarine taxa, representing groups of relevance to recreational (e.g., *Brycon* spp., *Caranx caninus*, *Centropomus* spp., and *Parachromis* spp.), artisanal/subsistence (e.g., *Atherinella argentea*, *Ariopsis seemanni*, *Sciades dowii*, *Astyanax* spp., *Amphilophus* spp., *Cribroheros* spp., *Tomocichla tuba*, *Vieja maculicauda*, *Dormitator* spp., *Eleotris* spp., *Gobiomorus* spp., *Anchoa* spp., among others; see Table 1), and ornamental fisheries (e.g., *Hyphessobrycon* spp., *Pterobrycon myrnae*, *Amatitlania* spp., *Andinoacara coeruleopunctatus*, *Archocentrus centrarchus*, *Cribroheros* spp., *Herotilapia multispinosa*, *Hypsophrys nicaraguensis*, *Neetroplus nematopus*, *Talamancaheros underwoodi*, *Gymnotus* spp., *Brachyrhaphis* spp., *Poecilia* spp., and *Cynodonichthys* spp., among others).

The inferred L-W relationships for all 119 species are presented in Table 2. For all species, linear L-W regressions were significant

Table 2

Inferred L-W relationships for 119 fish species of socioeconomic value in the fresh and coastal-estuarine waters of Costa Rica. Species are listed alphabetically; sample types/treatments [S; Fresh (F), Preserved (P) or Combined (C)], sample sizes (NT = Total; NR = Reduced, i.e., after removal of outliers), size ranges (in cm), L-W parameters [i.e., the log(a) and b estimates, plus their respective 95% bootstrapped confidence intervals (CIs; n = 1 999 permutations)], the r^2 values, and the inferred growth pattern [GT; i.e., Isometric (I) or Allometric (A), + indicates positive allometry and – negative allometry] are indicated. Regression parameters were estimated using the reduced sample size (NR). Species highlighted in gray showed differences in b values between treatments and are therefore presented with separate regressions by treatment.

Species	S	NT	NR	L (cm)	Log(a) [95% CI]	b [95% CI]	r ²	GT
<i>Alfaro cultratus</i>	C	303	292	0.64–6.63	0.0100 [0.0095–0.0106]	3.2517 [3.2019–3.3001]	0.9792	A+
<i>Amatitlania kanna</i>	C	194	186	1.59–8.70	0.0197 [0.0182–0.0210]	3.4582 [3.4105–3.5088]	0.9886	A+
<i>Amatitlania myrnae</i>	C	168	162	1.72–9.11	0.0319 [0.0288–0.0350]	3.0259 [2.9643–3.0880]	0.9844	A+
<i>Amatitlania sajica</i>	C	101	98	1.53–8.62	0.0238 [0.0210–0.0268]	3.2945 [3.2248–3.3670]	0.9909	A+
<i>Amatitlania septemfasciata</i>	C	188	179	1.57–9.44	0.0293 [0.0265–0.0323]	3.1690 [3.1110–3.2290]	0.9940	A+
<i>Amatitlania siquia</i>	C	245	233	1.81–7.43	0.0326 [0.0303–0.0353]	3.1191 [3.0678–3.1698]	0.9844	A+
<i>Amphilophus citrinellus</i>	C	168	160	1.87–21.80	0.0290 [0.0266–0.0318]	3.1059 [3.0645–3.1447]	0.9925	A+
<i>Amphilophus labiatus</i>	C	71	70	1.63–22.50	0.0303 [0.0272–0.0333]	3.0609 [3.0166–3.1112]	0.9972	A+
<i>Anchoa chamensis</i>	C	93	93	1.80–14.20	0.0055 [0.0050–0.0061]	3.3490 [3.2997–3.4118]	0.9846	A+
<i>Anchoa lucida</i>	F	66	66	1.10–12.10	0.0076 [0.0063–0.0093]	3.1870 [3.0639–3.3127]	0.9731	A+
<i>Anchoa nasus</i>	C	33	33	5.20–11.30	0.0072 [0.0055–0.0095]	3.1390 [3.0113–3.2710]	0.9851	A+
<i>Anchoa panamensis</i>	C	550	550	0.90–16.10	0.0103 [0.0095–0.0112]	3.0035 [2.9621–3.0430]	0.9856	A+
<i>Anchoa starksii</i>	C	1 043	1 038	2.00–26.40	0.0071 [0.0066–0.0077]	3.2995 [3.2583–3.3399]	0.9559	A+
<i>Andinoacara coeruleopunctatus</i>	C	108	104	2.07–12.44	0.0332 [0.0289–0.0375]	3.1619 [3.0947–3.2352]	0.9884	A+
<i>Archocentrus centrarchus</i>	C	164	158	1.92–11.05	0.0248 [0.0232–0.0264]	3.2062 [3.1650–3.2493]	0.9914	A+
<i>Ariopsis seemanni</i>	C	1 445	1 440	4.50–29.00	0.0164 [0.0155–0.0173]	2.9918 [2.9674–3.0162]	0.9898	A+
<i>Astyanax "aeneus"</i>	F	610	588	1.01–10.44	0.0119 [0.0112–0.0126]	3.3518 [3.3162–3.3875]	0.9872	A+
<i>Astyanax "aeneus"</i>	P	40	40	3.13–9.58	0.0081 [0.0068–0.0101]	3.5304 [3.4169–3.6234]	0.9927	A+
<i>Astyanax anai</i>	C	163	160	1.86–9.90	0.0188 [0.0180–0.0196]	3.0942 [3.0587–3.1295]	0.9964	A+
<i>Astyanax bransfordii</i>	F	152	143	1.99–13.07	0.0103 [0.0095–0.0111]	3.3253 [3.2728–3.3859]	0.9929	A+
<i>Astyanax bransfordii</i>	P	40	40	2.33–13.50	0.0123 [0.0105–0.0148]	3.1874 [3.0795–3.2801]	0.9870	A+
<i>Atherinella argentea</i>	F	220	220	2.00–12.60	0.0081 [0.0073–0.0090]	3.1120 [3.0645–3.1550]	0.9873	A+
<i>Awaous banana</i>	F	168	161	1.36–19.28	0.0136 [0.0128–0.0146]	3.0816 [3.0443–3.1154]	0.9917	A+
<i>Awaous banana</i>	P	40	40	1.55–19.80	0.0098 [0.0089–0.0107]	3.2286 [3.1849–3.2756]	0.9983	A+
<i>Awaous transandeanus</i>	C	172	166	1.35–21.98	0.0079 [0.0071–0.0088]	3.3134 [3.2482–3.3727]	0.9879	A+
<i>Bairdiella armata</i>	F	42	42	8.60–23.5	0.0261 [0.0142–0.0362]	2.9216 [2.7864–3.1581]	0.9455	I
<i>Belonesox belizanus</i>	C	124	120	1.14–12.02	0.0048 [0.0041–0.0056]	3.2948 [3.2078–3.3780]	0.9853	A+
<i>Brachyrhaphis holdridgei</i>	C	75	74	1.14–12.10	0.0141 [0.0130–0.0155]	3.4067 [3.3270–3.4837]	0.9774	A+
<i>Brachyrhaphis olomina</i>	C	283	271	1.11–4.74	0.0143 [0.0138–0.0148]	3.2643 [3.2341–3.2987]	0.9902	A+
<i>Brachyrhaphis rhabdophora</i>	C	356	339	0.99–5.20	0.0179 [0.0174–0.0183]	3.2236 [3.1931–3.2557]	0.9919	A+
<i>Brachyrhaphis roseni</i>	P	40	40	1.01–4.03	0.0127 [0.0111–0.0148]	3.6912 [3.5527–3.8255]	0.9837	A+
<i>Brachyrhaphis roseni</i>	F	120	114	0.91–5.47	0.0172 [0.0160–0.0185]	3.2740 [3.1942–3.3614]	0.9706	A+
<i>Brachyrhaphis terrabensis</i>	C	140	138	1.62–4.72	0.0102 [0.0090–0.0114]	3.5863 [3.4905–3.6852]	0.9673	A+
<i>Brycon behrae</i>	C	321	303	1.38–24.87	0.0099 [0.0095–0.0103]	3.1941 [3.1737–3.2150]	0.9971	A+
<i>Brycon costaricensis</i>	F	745	712	1.12–29.54	0.0151 [0.0146–0.0157]	3.0290 [3.0112–3.0458]	0.9946	A+
<i>Brycon costaricensis</i>	P	40	40	2.10–21.90	0.0101 [0.0079–0.0118]	3.2140 [3.1491–3.3138]	0.9962	A+
<i>Caranx caninus</i>	C	58	58	2.60–15.60	0.0124 [0.0077–0.0206]	3.3437 [3.0849–3.5695]	0.9551	A+
<i>Carlana eigenmanni</i>	C	127	119	1.29–7.53	0.0125 [0.0116–0.0132]	3.2376 [3.1956–3.2892]	0.9966	A+
<i>Centropomus medius</i>	C	45	45	3.42–18.30	0.0173 [0.0148–0.0207]	2.9632 [2.8593–3.0414]	0.9734	A+
<i>Centropomus robalito</i>	C	27	27	5.60–15.10	0.0133 [0.0100–0.0173]	3.1151 [2.9970–3.2322]	0.9908	A+
<i>Centropomus unionensis</i>	C	86	86	3.40–23.50	0.0262 [0.0204–0.0340]	2.8558 [2.7459–2.9582]	0.9866	A–
<i>Cribroheros alfari</i>	C	286	275	1.64–13.85	0.0271 [0.0256–0.0287]	3.1177 [3.0853–3.1508]	0.9904	A+



Species	S	NT	NR	L (cm)	Log(a) [95% CI]	b [95% CI]	r2	GT
<i>Cribroheros altifrons</i>	C	119	117	1.45–13.57	0.0311 [0.0273–0.0360]	3.0111 [2.9358–3.0743]	0.9889	I
<i>Cribroheros bussingi</i>	C	119	115	1.35–17.80	0.0286 [0.0258–0.0317]	3.0163 [2.9604–3.0744]	0.9887	I
<i>Cribroheros diquis</i>	C	121	119	1.78–14.12	0.0365 [0.0323–0.0409]	2.9591 [2.8989–3.0195]	0.9861	A–
<i>Cribroheros longimanus</i>	C	230	224	1.76–17.89	0.0297 [0.0274–0.0318]	3.1069 [3.0732–3.1466]	0.9927	A+
<i>Cribroheros rhytisma</i>	C	46	46	1.50–13.50	0.0260 [0.0233–0.0289]	3.1218 [3.0620–3.1841]	0.9955	A+
<i>Cribroheros rostratus</i>	C	181	179	1.39–18.10	0.0248 [0.0231–0.0265]	3.1284 [3.0959–3.1610]	0.9956	A+
<i>Cynodonichthys fuscolineatus</i>	C	70	69	1.30–5.38	0.0172 [0.0148–0.0196]	2.9885 [2.8903–3.1066]	0.9863	I
<i>Cynodonichthys glaucus</i>	C	49	48	1.30–4.78	0.0127 [0.0109–0.0144]	3.1821 [3.0752–3.3074]	0.9879	A+
<i>Cynodonichthys hildebrandi</i>	C	82	79	2.21–6.49	0.0190 [0.0166–0.0221]	2.8530 [2.7435–2.9550]	0.9741	A–
<i>Cynodonichthys isthmensis</i>	C	106	105	1.88–5.70	0.0151 [0.0135–0.0168]	3.0718 [2.9926–3.1523]	0.9850	A+
<i>Cynodonichthys rubripunctatus</i>	P	40	40	1.49–6.68	0.0157 [0.0139–0.0178]	3.0457 [2.9352–3.1527]	0.9906	A+
<i>Cynodonichthys siegfriedi</i>	P	16	16	1.96–3.32	0.0085 [0.0052–0.0123]	3.6881 [3.2554–4.2404]	0.9328	A+
<i>Cynodonichthys uroflammeus</i>	P	31	31	0.27–3.85	0.0130 [0.0100–0.0168]	3.2562 [3.0133–3.4914]	0.9720	A+
<i>Cynoscion albus</i>	F	30	30	3.80–20.50	0.0325 [0.0213–0.0579]	2.6816 [2.4457–2.8510]	0.9644	A–
<i>Cynoscion albus</i>	P	8	8	6.20–20.70	0.0066 [0.0010–0.0254]	3.2758 [2.7374–3.9398]	0.9814	A+
<i>Diapterus brevirostris</i>	C	419	419	0.90–16.10	0.0219 [0.0201–0.0239]	3.1008 [3.0182–3.1292]	0.9439	A+
<i>Dormitator latifrons</i>	C	230	225	1.87–21.79	0.0164 [0.0154–0.0174]	3.2956 [3.2643–3.3292]	0.9942	A+
<i>Dormitator maculatus</i>	C	181	175	1.80–12.00	0.0159 [0.0149–0.0171]	3.2231 [3.1828–3.2596]	0.9928	A+
<i>Eleotris amblyopsis</i>	C	124	121	2.05–9.74	0.0084 [0.0075–0.0094]	3.5805 [3.5042–3.6536]	0.9879	A+
<i>Eleotris perniger</i>	C	150	146	1.17–12.96	0.0086 [0.0079–0.0093]	3.4206 [3.3776–3.4641]	0.9957	A+
<i>Eleotris picta</i>	C	182	176	1.89–31.37	0.0112 [0.0104–0.0120]	3.2297 [3.1853–3.2725]	0.9954	A+
<i>Eleotris tubularis</i>	P	16	16	2.68–9.17	0.0090 [0.0063–0.0156]	3.4681 [3.0526–3.6871]	0.9840	A+
<i>Eretmobycon scleroparius</i>	C	276	270	2.04–9.42	0.0153 [0.0147–0.0160]	3.2136 [3.1854–3.2404]	0.9968	A+
<i>Eretmobycon terrabensis</i>	C	121	119	2.49–7.68	0.0186 [0.0166–0.0209]	3.0639 [2.9907–3.1325]	0.9801	A+
<i>Eucinostomus currani</i>	C	332	332	1.10–13.80	0.0241 [0.0218–0.0263]	2.9113 [2.8581–2.9718]	0.9624	A–
<i>Gambusia nicaraguensis</i>	C	107	106	1.21–2.92	0.0146 [0.0133–0.0160]	3.1693 [3.0414–3.2992]	0.9543	A+
<i>Gobiomorus dormitor</i>	C	182	174	1.10–21.00	0.0094 [0.0087–0.0102]	3.1096 [3.0720–3.1470]	0.9962	A+
<i>Gobiomorus maculatus</i>	C	154	151	2.50–19.90	0.0145 [0.0135–0.0154]	3.0310 [2.9970–3.0664]	0.9957	A+
<i>Gobiomorus polylepis</i>	C	30	29	2.07–17.10	0.0108 [0.0085–0.0136]	3.1753 [3.0439–3.2974]	0.9937	A+
<i>Gymnotus cylindricus</i>	C	148	144	3.50–26.78	0.0031 [0.0026–0.0036]	2.9245 [2.8685–2.9844]	0.9858	A–
<i>Gymnotus maculosus</i>	C	41	39	2.52–24.50	0.0007 [0.0005–0.0009]	3.3008 [3.1742–3.3779]	0.9931	A+
<i>Hemieleotris latifasciata</i>	C	150	147	1.84–6.03	0.0130 [0.0117–0.0145]	3.2361 [3.1633–3.3048]	0.9885	A+
<i>Herotilapia multispinosa</i>	C	265	258	2.53–12.13	0.0320 [0.0297–0.0346]	3.2338 [3.1863–3.2810]	0.9869	A+
<i>Hiatirhaphis parismina</i>	C	155	153	1.46–4.46	0.0102 [0.0093–0.0113]	3.3402 [3.2634–3.4177]	0.9768	A+
<i>Hoplias microlepis</i>	C	36	35	4.19–24.80	0.0112 [0.0089–0.0134]	3.1862 [3.1084–3.2813]	0.9947	A+
<i>Hyphessobrycon bussingi</i>	C	110	108	1.30–4.34	0.0129 [0.0120–0.0139]	3.4146 [3.3477–3.4814]	0.9891	A+
<i>Hyphessobrycon savagei</i>	C	149	146	1.32–3.92	0.0157 [0.0146–0.0170]	3.3676 [3.2972–3.4316]	0.9895	A+
<i>Hyphessobrycon tortuguerae</i>	C	113	110	1.46–5.96	0.0126 [0.0111–0.0145]	3.3289 [3.2080–3.4543]	0.9598	A+
<i>Hypsophrys nicaraguensis</i>	F	114	111	1.74–16.84	0.0121 [0.0109–0.0135]	3.3788 [3.3231–3.4341]	0.9904	A+
<i>Hypsophrys nicaraguensis</i>	P	40	40	1.73–16.20	0.0180 [0.0156–0.0200]	3.2720 [3.2181–3.3391]	0.9967	A+
<i>Imparfinis lineatus</i>	C	18	18	2.79–6.99	0.0032 [0.0010–0.0057]	3.7188 [3.3582–4.4010]	0.9614	A+
<i>Lebiasina boruca</i>	C	157	155	2.23–13.38	0.0148 [0.0135–0.0163]	3.1249 [3.0776–3.1723]	0.9910	A+
<i>Lutjanus argentiventris</i>	F	30	30	5.00–14.40	0.0273 [0.0147–0.0573]	2.9790 [2.6247–3.3036]	0.92977	I
<i>Mugil setosus</i>	C	620	620	2.00–31.50	0.0167 [0.0158–0.0177]	3.0205 [2.9922–3.0486]	0.98559	A+
<i>Neotroplus nematopus</i>	C	244	236	1.90–13.29	0.0266 [0.0237–0.0301]	3.0823 [3.0204–3.1402]	0.9882	A+
<i>Odontostilbe dialeptura</i>	C	152	140	1.25–3.65	0.0062 [0.0054–0.0071]	4.0289 [3.8719–4.1919]	0.9435	A+
<i>Oxyzygonectes dovii</i>	C	150	145	1.95–14.67	0.0069 [0.0064–0.0076]	3.3676 [3.3214–3.4112]	0.9931	A+
<i>Parachromis dovii</i>	C	379	362	1.81–28.20	0.0178 [0.0170–0.0188]	3.2253 [3.1983–3.2506]	0.9957	A+
<i>Parachromis friedrichsthalii</i>	C	115	112	1.83–17.90	0.0335 [0.0312–0.0362]	3.0699 [3.0228–3.1112]	0.9949	A+

Species	S	NT	NR	L (cm)	Log(a) [95% CI]	b [95% CI]	r ²	GT
<i>Parachromis managuensis</i>	C	138	135	1.88–20.60	0.0264 [0.0252–0.0277]	3.0727 [3.0455–3.0994]	0.9968	A+
<i>Phallichthys amates</i>	C	237	231	0.78–5.47	0.0159 [0.0147–0.0170]	3.5308 [3.4794–3.5879]	0.9941	A+
<i>Phallichthys quadripunctatus</i>	C	64	63	0.88–3.16	0.0177 [0.0145–0.0221]	3.6412 [3.2545–3.9668]	0.9135	A+
<i>Phallichthys tico</i>	P	40	40	0.97–2.55	0.0187 [0.0167–0.0212]	3.3160 [3.0760–3.5624]	0.9499	A+
<i>Pimelodella chagresi</i>	C	101	99	3.35–10.34	0.0110 [0.0097–0.0127]	3.1571 [3.0766–3.2315]	0.9859	A+
<i>Poecilia gillii</i>	C	794	760	1.79–10.99	0.0221 [0.0215–0.0228]	3.1622 [3.1421–3.1829]	0.9924	A+
<i>Poecilia mexicana</i>	C	259	247	1.18–12.05	0.0200 [0.0189–0.0210]	3.1405 [3.1087–3.1729]	0.9950	A+
<i>Poecilia reticulata</i>	P	40	40	1.41–3.61	0.0222 [0.0173–0.0286]	3.3700 [3.0909–3.6338]	0.9423	A+
<i>Poeciliopsis elongata</i>	C	183	179	1.85–12.12	0.0277 [0.0262–0.0294]	2.8760 [2.8403–2.9108]	0.9917	A–
<i>Poeciliopsis paucimaculata</i>	C	118	112	1.47–6.10	0.0246 [0.0173–0.0306]	3.0291 [2.8689–3.2804]	0.9718	I
<i>Poeciliopsis retropinna</i>	C	159	155	1.19–7.07	0.0191 [0.0180–0.0204]	3.0803 [3.0386–3.1194]	0.9956	A+
<i>Poeciliopsis santaelena</i>	P	40	40	0.93–4.60	0.0167 [0.0136–0.0195]	3.1443 [2.9959–3.3262]	0.9768	A+
<i>Poeciliopsis turrubarensis</i>	C	156	153	1.36–6.64	0.0147 [0.0137–0.0157]	3.2308 [3.1858–3.2747]	0.9950	A+
<i>Priapichthys annectens</i>	C	287	283	1.36–7.03	0.0183 [0.0172–0.0193]	3.1181 [3.0745–3.1618]	0.9903	A+
<i>Priapichthys panamensis</i>	C	94	92	1.07–3.57	0.0177 [0.0168–0.0189]	3.3224 [3.2508–3.3903]	0.9878	A+
<i>Pseudocheirodon terrabae</i>	C	67	66	2.32–5.20	0.0147 [0.0123–0.0176]	3.2721 [3.1340–3.4109]	0.9778	A+
<i>Pterobrycon myrnae</i>	P	40	40	2.13–3.95	0.0107 [0.0068–0.0156]	3.3244 [3.0105–3.7051]	0.9280	A+
<i>Rhamdia guatemalensis</i>	F	149	143	2.51–24.99	0.0073 [0.0063–0.0083]	3.2132 [3.1555–3.2784]	0.9793	A+
<i>Rhamdia guatemalensis</i>	P	40	40	3.35–24.50	0.0057 [0.0041–0.0069]	3.4400 [3.3537–3.5616]	0.9921	A+
<i>Rhamdia laticauda</i>	C	230	221	2.57–20.80	0.0185 [0.0214–0.0214]	2.8374 [2.7968–2.8772]	0.9853	A–
<i>Rhamdia nicaraguensis</i>	C	147	143	2.25–22.66	0.0132 [0.0119–0.0146]	2.9677 [2.9207–3.0143]	0.9927	I
<i>Roeboides bouchellei</i>	C	272	264	2.23–10.49	0.0081 [0.0076–0.0086]	3.2525 [3.2134–3.2914]	0.9946	A+
<i>Roeboides bussingi</i>	F	115	113	2.49–8.97	0.0064 [0.0056–0.0072]	3.4034 [3.3367–3.4774]	0.9892	A+
<i>Roeboides bussingi</i>	P	40	40	2.81–8.95	0.0103 [0.0066–0.0143]	3.1355 [2.9410–3.3810]	0.9777	A+
<i>Roeboides ilseae</i>	C	187	183	2.61–10.99	0.0118 [0.0107–0.0130]	3.0984 [3.0383–3.1550]	0.9880	A+
<i>Sciades dowii</i>	F	158	158	7.00–24.20	0.0072 [0.0059–0.0086]	3.1171 [3.0515–3.1873]	0.9773	A+
<i>Sicydium adelum</i>	C	153	150	0.76–9.96	0.0070 [0.0062–0.0078]	3.4624 [3.4048–3.5255]	0.9901	A+
<i>Sicydium altum</i>	C	128	127	1.97–13.74	0.0059 [0.0048–0.0070]	3.4976 [3.4074–3.5987]	0.9845	A+
<i>Sicydium cocoense</i>	P	22	22	1.60–7.98	0.0080 [0.0055–0.0099]	3.4865 [3.3511–3.7125]	0.9872	A+
<i>Sicydium salvini</i>	C	198	196	2.23–10.75	0.0096 [0.0082–0.0114]	3.2914 [3.2028–3.3767]	0.9859	A+
<i>Stellifer mancorensis</i>	F	101	100	2.00–11.30	0.0119 [0.0063–0.0226]	3.2828 [2.9960–3.5682]	0.9695	A+
<i>Stellifer mancorensis</i>	P	27	26	7.90–12.21	0.0253 [0.0229–0.0282]	2.9015 [2.8407–2.9558]	0.9842	A–
<i>Stellifer oscitans</i>	C	121	119	2.4–14.4	0.0227 [0.0196–0.0263]	2.9628 [2.8864–3.0416]	0.9747	A–
<i>Talamancaheros underwoodi</i>	C	263	260	1.87–16.48	0.0253 [0.0240–0.0267]	3.1181 [3.0865–3.1487]	0.9922	A+
<i>Tomocichla tuba</i>	C	175	171	2.14–22.42	0.0354 [0.0331–0.0376]	2.8981 [2.8664–2.9299]	0.9908	A–
<i>Trichomycterus striatus</i>	C	52	52	2.79–11.97	0.0085 [0.0068–0.0104]	3.1477 [3.0449–3.2568]	0.9874	A+
<i>Vieja maculicauda</i>	C	201	198	1.82–22.15	0.0241 [0.0218–0.0269]	3.2267 [3.1794–3.2753]	0.9914	A+
<i>Xenophallus umbratilis</i>	C	225	223	1.43–4.75	0.0144 [0.0129–0.0159]	3.3238 [3.2377–3.4109]	0.9881	A+

($p < 0.001$), with r^2 values greater than or equal to 0.9135 (mean: 0.9829).

Comparisons of linear regression slopes showed no significant difference ($p > 0.05$) between fresh and preserved specimens of 96 species (80.7%); with all non-significant p values ranging from 0.094 to 0.996. In contrast, ten species (8.4%; i.e., *Astyanax "aeneus"*, *Astyanax*

bransfordii, *Awaous banana*, *Brachyrhaphis roseni*, *Brycon costaricensis*, *Cynoscion albus*, *Hypsophrys nicaraguensis*, *Rhamdia guatemalensis*, *Roeboides bussingi*, and *Stellifer mancorensis*) exhibited significant differences in slope values between those treatments ($p < 0.05$).

Growth patterns varied among species. Across all taxa analyzed, most species



(101; 84.9%) showed positive allometry ($b > 3$), whereas nine species (7.6%; *Centropomus unionensis*, *Cribroheros diquis*, *Cynodonichthys hildebrandi*, *Eucinostomus currani*, *Gymnotus cylindricus*, *Poeciliopsis elongata*, *Rhamdia laticauda*, *Stellifer oscitans*, and *Tomocichla tuba*) showed negative allometry ($b < 3$), and seven species (5.9%; *Bairdiella armata*, *Cribroheros altifrons*, *Cribroheros bussingi*, *Cynodonichthys fuscolineatus*, *Lutjanus argentiventris*, *Poeciliopsis paucimaculata*, *Rhamdia nicaraguensis*) exhibited isometric growth ($b \approx 3$). The remaining two species (*Cynoscion albus* and *Stellifer mancorensis*) were the only ones that exhibited significantly different slopes between fresh and preserved individuals, and differences in allometry between these treatments. In *C. albus*, fresh individuals showed negative allometry ($b = 2.6816$), whereas preserved material presented positive allometry ($b = 3.2758$). In contrast, *S. mancorensis* exhibited the opposite pattern: fresh individuals showed positive allometry ($b = 3.2828$), while preserved specimens presented negative allometry ($b = 2.9015$).

DISCUSSION

This study provides the most comprehensive assessment to date of L-W relationships for freshwater and coastal-estuarine fishes in Costa Rica, encompassing 119 species (across 23 families) of socioeconomic importance. The taxonomic and ecological breadth of this dataset substantially exceeds that of previous contributions from Central America (Bagley et al., 2022), and other portions of tropical America (Coello et al., 2020; Faustino-Fuster et al., 2017; González-Acosta et al., 2024). Hence, this study fills a critical gap in regional ichthyological knowledge by providing essential baselines for fisheries evaluation, ecological monitoring, and conservation.

The L-W relationships presented here had b values within the expected range of 2.5–3.5 for fishes (Bagley et al., 2022; Froese, 2006). Moreover, such values revealed clear trends consistent with those reported in other studies from the Neotropics (Coello et al., 2020; Bagley

et al., 2022; Faustino-Fuster et al., 2017). Positive allometry, for example, was predominant, characterizing more than 80% of the species analyzed, whereas only a handful exhibited isometry or negative allometry. Similar overall patterns have been reported in other studies from tropical freshwater and coastal systems, where positive allometry ($b > 3$) predominates in most species examined (Bagley et al., 2022; González-Acosta et al., 2024; Ribeiro et al., 2017; Severo-Neto et al., 2018). This trend has been documented across diverse taxonomic groups, habitats, and sampling designs, suggesting that increases in body mass often outpace increases in length in many fish species. Such patterns have been associated with factors such as trophic strategies, reproductive investment, and habitat-related adaptations (Froese, 2006; Le Cren, 1951; Ricker, 1975). Conversely, cases of negative allometry ($b < 3$) may reflect environmental constraints, food availability, or ontogenetic shifts in body proportions (Froese, 2006; Warton et al., 2006).

Isometric growth ($b \approx 3$), reported in seven species in this study, indicates that body weight increases proportionally with length, suggesting relatively constant body proportions across the size range examined (Froese, 2006; Ricker, 1975). This pattern is often associated with stable environmental conditions and consistent resource availability, which allow for “ideal” growth without significant morphological changes. Furthermore, isometry can be an adaptive trait in species that must maintain a specific hydrodynamic or functional shape throughout their ontogeny to optimize swimming efficiency or prey capture, particularly when there are no major shifts in diet or habitat during the life stages analyzed (Karachle & Stergiou, 2012).

From a fisheries management perspective, the predominance of positive allometry observed in this study (84.9% of the species) has practical implications for the establishment of minimum catch sizes in artisanal fisheries. In species exhibiting $b > 3$, body mass increases disproportionately faster than length, meaning that relatively small increases in length can

translate into substantially larger gains in biomass (Froese, 2006; Ricker, 1975). As a result, allowing individuals to reach slightly larger sizes before capture could considerably increase biomass yield per recruit while also enhancing reproductive output, given that larger individuals typically contribute disproportionately to spawning potential (Froese, 2006; Le Cren, 1951; Ricker, 1975). In this context, the L-W parameters reported here provide an essential quantitative basis for evaluating size-based management measures and for refining species-specific minimum landing sizes for Costa Rican artisanal fisheries and size limits for retention in recreational fisheries.

A key contribution of this study is the explicit comparison of fresh versus preserved specimens. In most cases (> 80% of the species), no significant differences were detected in regression slopes between treatments, supporting the use of museum material as a reliable source of biometric data (Barragán et al., 2024; Hay et al., 2020). Although factors such as sample size may influence the statistical power to detect differences (Froese, 2006), the overall consistency of these results across species suggests that preserved specimens can often provide robust estimates of length-weight parameters. Nevertheless, a small subset of species showed differences in regression slopes between treatments, in some cases reversing the direction of growth allometry (i.e., shifting from positive to negative allometry, or vice versa; e.g., *Cynoscion albus* and *Stellifer mancorensis*). Such discrepancies highlight the need for caution when interpreting L-W relationships derived from preserved material.

Preservation processes can affect body mass through dehydration, lipid loss, or structural changes in tissues, which may vary among species depending on body composition, lipid content, musculature, and overall body morphology (Barragán et al., 2024; Hay et al., 2020). Species with higher lipid reserves or more delicate tissues may be particularly susceptible to preservation-induced changes in mass, potentially altering the slope of the L-W relationship (Barragán et al., 2024; Hay et al., 2020). In

addition, differences in body shape and skeletal structure may influence how preservation affects body dimensions and weight (Barragán et al., 2024; Hay et al., 2020). Although the proportion of species showing such effects was relatively small in our dataset, these results suggest that preservation effects may not be uniform across taxa and should be considered when interpreting biometric data derived from museum specimens. Future studies could further explore these differences experimentally, thereby refining correction factors for species that are most susceptible to preservation-induced bias.

From an applied perspective, the availability of L-W relationship parameters for species supporting recreational, artisanal, and subsistence fisheries, such as *Brycon* spp., *Caranx caninus*, *Centropomus* spp., *Gobiomorus* spp., and *Parachromis* spp., among others, enhances the capacity to estimate biomass in the absence of direct weight measurements, which is particularly valuable for rapid field assessments (Froese, 2006; Ricker, 1975). L-W parameters are also of critical importance to conduct stock assessments with limited data (Canales et al., 2021). Likewise, the inclusion of ornamental taxa (e.g., *Amatitlania* spp., *Amphilophus citrinellus*, *Andinoacara coeruleopunctatus*, *Cribroheros* spp., *Cynodonichthys* spp., *Brachyrhaphis* spp., *Poecilia* spp., *Hyphessobrycon* spp., and *Gymnotus* spp., among others) extends the utility of this dataset to an emerging economic sector in Costa Rica, with implications for sustainable management of the aquarium trade (Allen et al., 2017; Angulo & San Gil-León, 2022).

Of the 119 species analyzed in this study, 83 (69.7%) lacked any available L-W relationship records in open-access databases such as FishBase (Froese & Pauly, 2024), underscoring the novelty and relevance of our contribution. For the remaining 36 (30.3%) species, L-W relationship information was available in FishBase, though often limited in scope: 15 species were represented by a single literature record, nine by two records, three by three records, three by four records, two by five records, one by



six records, two by nine records, and only one species by ten records (Table 1). Importantly, in most cases where comparative data existed from other regions/countries, our estimates of the a and b parameters fell within the ranges previously reported in FishBase (Froese & Pauly, 2024), confirming their reliability. However, the present dataset provides a critical advancement by generating locally derived parameters for Costa Rican populations, thereby enhancing their applicability to local and regional fisheries management, ecological assessments, and conservation planning.

Methodologically, this study demonstrates the benefits of integrating field sampling with curated ichthyological collections, thereby maximizing taxonomic and temporal coverage. This approach increases the representation of rare, endemic, and/or cryptic species and adds scientific value to national collections, in line with recent calls to better incorporate preserved material into population dynamics and biodiversity studies (Barragán et al., 2024; Hay et al., 2020). Such integration not only supports fisheries and ecological research but also contributes to global information systems, such as FishBase, which rely on local data to improve representation and applicability (Froese & Pauly, 2024).

Finally, it is important to acknowledge that a variety of biological and ecological factors can influence fish growth and L-W relationships, including sex, body condition, gonad maturity, seasonal fluctuations in resource availability, stomach fullness, and/or sample size (Bagley et al., 2022; Froese, 2006; Le Cren, 1951). These factors were not explicitly addressed in our analyses, as specimens were pooled across sexes, years, and localities. Consequently, the L-W relationship parameters reported here should be interpreted as mean species-level estimates. Nonetheless, our approach followed the standardized recommendations proposed by Froese (2006) for the estimation and reporting of L-W relationship, thereby ensuring comparability with other studies and facilitating integration into broader regional and global databases.

In summary, the findings of this study provide a robust baseline for advancing fisheries biology and ecological research in Costa Rica and across the Neotropics. By generating comprehensive L-W relationship parameters for a broad set of species, this work strengthens the foundation for stock assessments, biodiversity monitoring, and conservation planning, while underscoring the complementary value of museum collections for ichthyological and fisheries science.

Author contribution statement: AA conceived, designed, and proposed the study. All authors recorded data from fresh and/or preserved specimens, contributed to the analysis and interpretation of the data, and to the preparation of the manuscript.

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