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FISHES AT RISK: UNVEILING THE HIDDEN DIVERSITY OF A VULNERABLE LAKE IN THE PERUVIAN AMAZON REGION

Morgan RUIZ-TAFUR[1,*], Edgard Leonardo DÁVILA-PANDURO[2], Ivon CISNEROS-ORTIZ[3], Junior CHUCTAYA[4,5]

[1] Instituto de Investigaciones de la Amazonía Peruana – IIAP, Laboratorio de Taxonomía de Peces, Carretera Iquitos-Nauta Km 4.5, San Juan, Loreto, Perú.

[2] Centro de Rescate Amazónico - CREA, Carretera Iquitos-Nauta, km 13.8, San Juan, Loreto, Perú.

[3] Universidad Nacional de la Amazonia Peruana-UNAP, Facultad de Ciencias Biológicas-FCB, Av. Grau 1072, Iquitos, Perú.

[4] Instituto de Investigaciones de la Amazonia Peruana - IIAP, AQUAREC, Laboratorio de Biología y Genética Molecular, Carretera Iquitos-Nauta km 4.5, San Juan, Loreto, Perú.

[5] Universidad Nacional Mayor de San Marcos, Museo de Historia Natural, Av. Arenales 1256, Jesús María, Lima, Perú.

* Correo electrónico: kruiz@iiap.gob.pe

ABSTRACT

The study focuses on the Huachana lake, a vulnerable ecosystem in the Peruvian Amazon region that receives wastewater from the city of Iquitos. Despite its significance in ichthyology and its role as a type locality for various species, water bodies near Iquitos face threats. While a portion of the ichthyological diversity in the Loreto region is known, the Huachana lake had never been subject to sampling, making this study the first to examine fish diversity in this aquatic environment. A total of 52 fish species from 5 orders, 20 families, and 39 genera were identified. The Characiformes presents he greatest species richness (30 species), followed by Cichliformes (12 species). Cichlidae and Characidae are the families richest in species. No species are endangered according to the IUCN; the majority are considered of least concern. The study also identified ornamental and commercial species, providing crucial information about ichthyofauna in nearby urban areas and

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its potential long-term environmental impact. Preserving Huachana Lake and similar ecosystems in Loreto is crucial. We must monitor urbanization and pollution's potential effects while implementing strong conservation measures to protect the diverse ichthyofauna and the entire ecosystem. This study underscores the need for urgent proactive steps to safeguard the Amazon region's ecologically significant environments and its unique species.

KEY WORDS: freshwater, ichthyofauna, anthropogenic impact, inventory

PECES EN PELIGRO: REVELANDO LA DIVERSIDAD OCULTA DE UNA LAGUNA VULNERABLE EN LA REGIÓN AMAZÓNICA PERUANA

RESUMEN

El estudio se enfoca en la laguna Huachana, un ecosistema vulnerable en la región amazónica peruana, que recibe aguas residuales de la ciudad de Iquitos. A pesar de su importancia en la ictiología y su papel como localidad tipo para diversas especies, los cuerpos de agua cerca de Iquitos enfrentan amenazas. Si bien se conoce parte de la diversidad ictiológica en la región de Loreto, la cocha Huachana nunca había sido objeto de muestreo, lo que hace que este estudio sea el primero en examinar la diversidad de peces en este ambiente acuático. Se identificaron 52 especies de peces de 5 órdenes, 20 familias y 39 géneros. Los Characiformes presentan la mayor riqueza (30 especies), seguido por Cichliformes (12 especies). Cichlidae y Characidae son las familias más ricas en especies. Ninguna especie está en peligro según la IUCN, la mayoría se considera de preocupación menor. El estudio también identificó especies ornamentales y comerciales, proporcionando información crucial sobre la ictiofauna en zonas urbanas cercanas y su posible impacto ambiental a largo plazo. Preservar la laguna Huachana y ecosistemas similares en Loreto es crucial. Debemos monitorear los efectos potenciales de la urbanización y la contaminación mientras implementamos fuertes medidas de conservación para proteger la diversa ictiofauna y todo el ecosistema. Este estudio subraya la necesidad de tomar medidas proactivas urgentes para salvaguardar los entornos ecológicamente significativos de la región amazónica y sus especies únicas.

PALABRAS CLAVE: agua dulce, ictiofauna, impacto antrópico, inventario

INTRODUCTION

The Amazon River holds the distinction of being the world's largest hydrographic basin spanning over eight million km^2 (Sioli, 1984; Goulding *et al*., 2003). The accompanying channels and wetlands exhibit significant primary and secondary productivity (Junk, 2013). Within this intricate landscape lies the highest diversity of freshwater fish on the planet, with 2716 valid species (1696 are endemic), distributed across 529 genera, 60 families, and 18 orders (Dagosta & Pinna, 2019).

The formation of these floodplain areas is closely tied to the annual flood pulse. In this process, the flat topography combined with variations in river and stream discharge gives rise to extensive wetland areas and floodable forests (Junk, 1970). This dynamic system of flooded zones holds significant ecological relevance (Junk *et al*., 2011), and to preserve its biodiversity, it is crucial to implement sustainable management strategies. Conservation of fish assemblages present in the Amazon River floodplain, lakes, and tributaries is essential, and to achieve this, maintaining the biological integrity of the entire system is fundamental (Granado-Lorencio *et al*., 2007). This approach will ensure the proper protection and preservation of this valuable biodiversity.

The spatial patterns of fish biodiversity in the Amazon basin are closely tied to forest cover, and an increase in deforestation within the Amazon River floodplains leads to spatial homogenization of the fish community and a reduction in functional diversity, both at local and regional scales (Arantes *et al*., 2018). The Amazon basin is facing increasing anthropogenic pressures and territorial changes that negatively impact aquatic environments (Castello *et al*., 2013). Consequently, it is estimated that between 4% and 10% of fish species in the Neotropical region are currently at risk of extinction (Reis *et al*., 2016). The main factors that have shown impacts are road construction and expansion (Mäki *et al*., 2001; Ahmed *et al*., 2013; Barber *et al*. 2014; Fonseca *et al*., 2017), deforestation (Pfaff, 1999; Wu *et al*., 2017; Silva *et al*., 2020), pollution (Davidson *et al*., 2012; Castello *et al*., 2013), and overfishing (William, 1998; Tregidgo *et al*., 2021; Prestes *et al*., 2022).

One of the primary impacts in the Amazon basin is the discharge of wastewater into aquatic environments near major cities. This is due to the limited number of households equipped with wastewater collection and treatment facilities, which suggests a significant inflow of waste and wastewater into freshwater ecosystems (Fabregat-Safont *et al*., 2021). Additionally, most monomers used to manufacture plastics, such as ethylene and propylene, are derived from fossil hydrocarbons. None of the commonly used plastics are biodegradable; consequently, they accumulate rather than decompose in landfills or the natural environment (Geyer *et al*., 2017).

Recent findings have demonstrated that many species inhabiting Amazonian aquatic environments exhibit high concentrations of plastics in their gills and internal organs (Rojas *et al*., 2022). Studies conducted in aquatic environments near major cities in Brazil (Manaus, Santarém, Macapá, Belém) have documented the presence of 51 compounds and metabolites in the wastewater, including pharmaceuticals and illicit drugs from the categories of analgesics and antihypertensives, followed by stimulants and antibiotics (Fabregat-Safont *et al*., 2021).

A portion of the headwaters of the Amazon basin originates in Peru, a country recognized as one of the world's 17 megadiverse countries (Noss, 1990). The geological and physiographic history of Peru has led to a remarkable diversity of ecosystems and habitats, enabling the existence of a wide variety of species. Within Peruvian territory, there are 1,141 species of freshwater fish, with over 90% of this richness concentrated in the Amazonian region (MINAM, 2018).

The Loreto region stands out, boasting a diversity of 873 valid species (Meza-Vargas *et al*., 2021). In Loreto, the confluence of the Marañón and Ucayali rivers gives rise to the Amazon River. These basins are renowned for harboring a remarkable diversity of fish, with a recorded richness of 734 valid species in the Ucayali basin (Chuctaya *et al*., 2022). However, it is important to note that the fish diversity in Loreto might be underestimated due to areas lacking sufficient information. With advancements in technology, such as molecular studies, the process of species description, validation, and new records, it is likely that this species richness will increase in the future.

The Huachana lake, situated on the right bank of the lower Nanay River basin, is in close proximity to the Morona Cocha lake, which serves as the main recipient of all wastewaters from the city of Iquitos (Gomez-Garcia, 1998; Cobos *et al*., 2022). Given their degree of connectivity, it is likely that these wastewater effluents could reach the Huachana lake. Moreover, due to their proximity to the city of Iquitos, their risk of threat increases year by year. The high load of contaminants produced daily by the city can jeopardize the survival of fish communities inhabiting these water bodies. With time, it is plausible that these fish communities might experience a drastic decline or even disappear entirely if appropriate conservation and management measures are not implemented. Therefore, conducting detailed studies on the ichthyofauna of these environments and taking concrete actions to protect them and maintain the integrity of their ecosystems are essential.

It is surprising that, despite the well-known high diversity in the Loreto region and the increasing anthropogenic pressures, the environments of the Huachana lake and Morona Cocha lack studies on species composition, and this would be related to the low number of ichthyologists in Peru and the limited budg*et al*located for biodiversity studies. Therefore, the primary objective of this research is to provide a comprehensive inventory with live color information of the ichthyofauna in the Huachana lake. The outcomes of this investigation will hold significant importance, as they will offer the initial scientific evidence regarding the fish species inhabiting an area near a major city that indirectly receives a substantial load of residual contaminants. Furthermore, the acquired information will be important for the implementation of environmental policies aimed at mitigating the impacts affecting aquatic environments close to the major Amazonian cities.

MATERIAL AND METHODS

STUDY AREA

The Loreto region, with its capital city Iquitos, becomes especially significant. Loreto consists of 8 provinces and 53 districts, covering approximately 374,000 km2 (Viceministerio de Gobernanza Territorial, 2017). The city of Iquitos is encompassed by a complex river system that is influenced by the flood pulse of the Amazon River. This city is situated on the left bank of the Itaya River, close to its confluence with the Amazon River. Furthermore, it is located on the right bank of the Nanay River. This area is surrounded by a complex river system that includes streams, channels, and lakes, forming a system of "black" and "white" waters, as well as an extensive area of paleodrainages from the Nanay River, and within this environment is where the Huachana lake is situated. Geographically, the Huachana lake is situated in the district of Iquitos, within the province of Maynas, in the Loreto region of Peru. It is a lake that maintains a consistent water level throughout the year and is interconnected through blackwater with the Morona Cocha lake and the Nanay River.

To conduct sampling in the Huachana lake, three collection sites were chosen. Site 01 is located on the farthest bank of the channel (3°44'7.83"S 73°16'43.10"W). Site 02 is situated in the middle part of the lake (3°43'53.02"S 73°16'42.41"W). Lastly, Site 03 is near the channel (3°43'38.65"S 73°16'38.39"W) (Figure 1 and 2). It is important to note that during the rising water season, the Huachana lake gets completely flooded, making it impossible to obtain representative samples of the species richness present in the environment. For this reason, the sampling period was specifically focused on the falling water season, which occurred in August 2020. The environment was characterized by having blackwater, indicating the influence exerted by the Nanay River in these surroundings. There was an abundant presence of aquatic plants like *Paspalum repens* (gramalote), *Eichornia crassipes* (putu putu), and *Pistia stratiotes* (huama). During the study period, the Huachana lake had a depth of 1.5 meters and a width of 80 meters. Additionally, plastic waste was observed near the lake (Figure 2).

COLLECTION, PRESERVATION, AND DATA ANALYSIS

At the three established sampling sites, fish collections were conducted using a 6-meter-long by 3-meter-high seine net with a mesh opening of 2 mm. The sampling effort was standardized by performing five beach trawls to shore at each collection site. For each captured morphospecies, an individual was selected for live

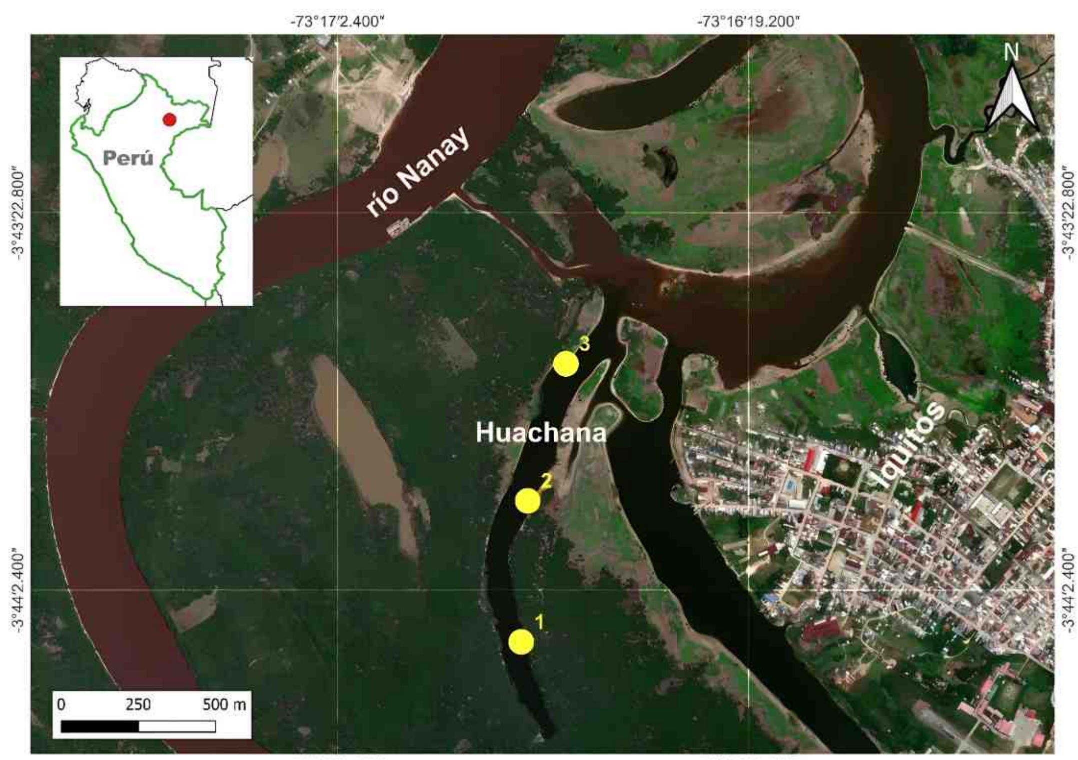

Figure 1. Map of Huachana lake, Loreto, Peru. The yellow circles indicate the collection sites.

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photography. To accomplish this, a Nikon D3100 camera and a glass aquarium measuring 20 x 6 x 15 cm were utilized. Before taking photographs, all specimens were anesthetized with 3% eugenol (Lucena *et al*., 2013). Subsequently, the fish were fixed in a 10% formalin solution for 48 hours and then preserved in 70% ethanol for subsequent taxonomic identification. After identification was completed, the specimens were deposited in the ichthyological collection of the Instituto de Investigaciones de la Amazonía Peruana (CIIAP), located at kilometer 4.5 of the Iquitos-Nauta Road. The taxonomic nomenclature and classification of families and higher levels used in this study follow the proposal by Fricke *et al*. (2023). However, due to incongruences between morphological and molecular phylogenetic proposals, the classification of families is presented in alphabetical order.

For species-level identification, various bibliographic sources were utilized, including books and scientific articles by the following authors: Weitzman & Kanazawa (1976); Menezes & Géry (1983); Kullander (1986); Vari (1992); Géry (1997); Castro & Vari (2004); Galvis *et al*., (2006); Mautari & Menezes (2006); Toledo-Piza (2007); Benine *et al*., (2010); Sidlauskas *et al*., (2011); Beltrão & Zuanon (2012); Slobodian (2017); Van Der Sleen & Albert (2017); Silva-Oliveira *et al*., (2019); Soares *et al*., (2020); as well as reviews of original descriptions.

The designation of resource use (ornamental or consumption) was based on the work of García-Dávila *et al*., (2018, 2021). To assess the threat level of the captured species, the review by the International Union for Conservation of Nature (IUCN) conducted in 2023 was followed. During sampling, all collected fish species and

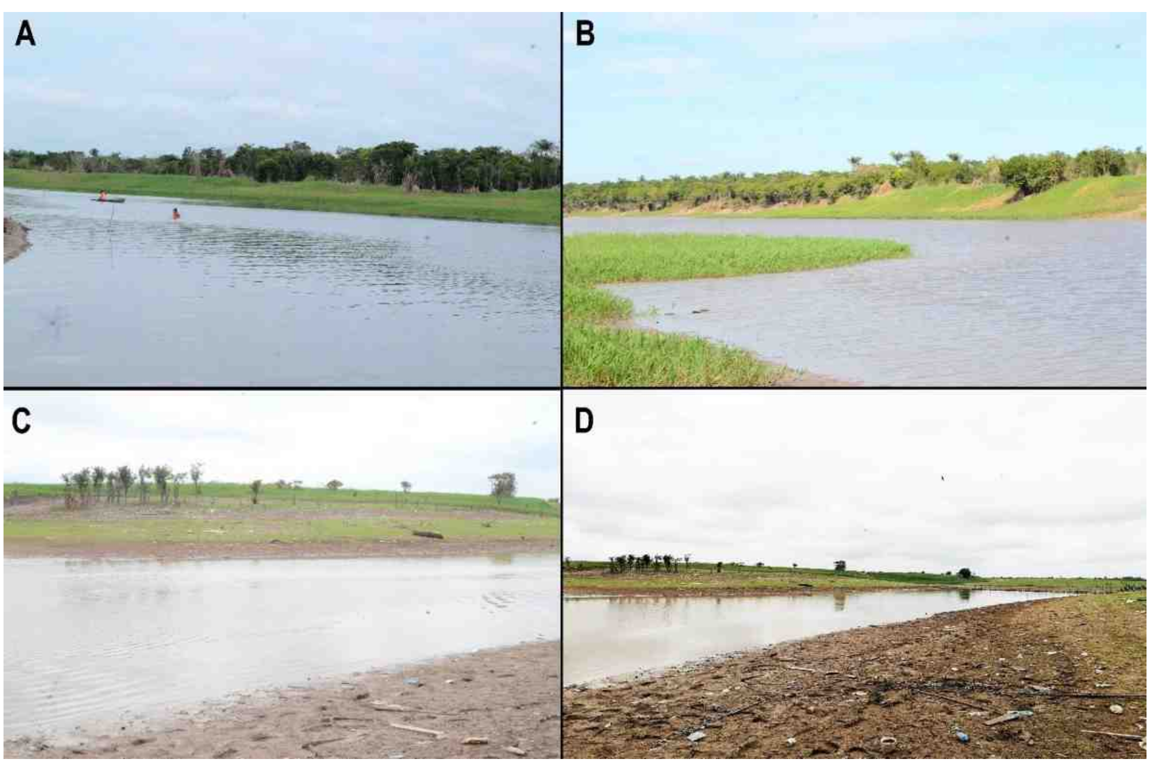

Figure 2. Sampling sites in Cocha Huachana. A) site 1, B) site 2, C) site 3, D) presence of contamination by plastic waste.

the number of individuals of each species were recorded and quantified for each collection site. To obtain relative abundance in percentage, an estimation was performed at the family and order levels, allowing for a general view of the species composition and distribution within the Huachana lake.

RESULTS

A total of 1326 individuals were collected, representing 52 species, 39 genera, 20 families, and 5 orders (Table 1, Figure 3-5). The orders with the highest number of species were Characiformes (59%, 30 species) and Cichliformes (24%, 12 species) (Figure 6). The most prominent families in the Huachana lake were Cichlidae (25.4%, 13 species) and Characidae (17.6%, nine species) (Figure 7).

In the Huachana lake, several fish species were identified, and some of them were particularly common across all sampling sites. The most frequent species included *Cyphocharax spiluropsis, Laemolyta taeniata, Moenkhausia ceros, Bryconops melanurus, Iguanodectes purusii,* and *Mesonauta mirificus*.

Among the collected species, there were some that were exclusively of ornamental importance, such as *Anchoviella jamesi, Hemiodus unimaculatus, Laemolyta taeniata, Chilodus punctatus, Nannostomus eques, Carnegiella schereri, Ctenobrycon hauxwellianus, Hemigrammus hyanuary, H. levis, H. pulcher, Hyphessobrycon copelandi, Moenkhausia ceros, M. collettii, M. lepidura, Thayeria obliqua, Iguanodectes purusii, Chalceus epakros, Eigenmannia limbata, Steatogenys elegans, Brachyhypopomus brevirostris, Anadoras grypus, Oxyropsis wrightiana, Acarichthys heckelii, Acaronia nassa, Aequidens tetramerus, Biotodoma cupido, Cichlasoma amazonarum, Mesonauta mirificus*, and *Pterophyllum scalare.*

Additionally, species of commercial importance were found, including *Cyphocharax festivus, C. spiluropsis, C. spilurus, Semaprochilodus insignis, Acestrorhynchus falcirostris, A. heterolepis,* and *Serrasalmus sanchezi.*

Species used as ornamentals in their juvenile stages and as food in their adult stages were also collected. These include *Leporinus niceforoi, L. fasciatus, L. agassizii, L. parae, Erythrinus erythrinus, Hoplias malabaricus, Boulengerella maculata, Bryconops melanurus, Pimelodella cristata, Sexatilia* cf. *proteus, Lugubria cincta, L. Johanna, Heros efasciatus,* and *Satanoperca jurupari*. It is important to note that a species of genus *Sexatilia* was tentatively identified as *Sexatilia* cf. *proteus,* since it was a juvenile, which made its identification difficult in this study.

The most abundant species in the Huachana lake were *Moenkhausia lepidura* (17.7%, 235 individuals), *M. ceros* (12.1%, 161 individuals), *Mesonauta merificus* (11.3%, 150 individuals), *Hemigrammus pulcher* (10.9%, 145 individuals), and *H. levis* (7.5%, 100 individuals). Among the less abundant or incidental species, which were found with a record of only one or two individuals at a sampling site, are *Hemiodus unimaculatus, Cyphocharax spilurus, Semaprochilodus insignis, Leporinus amazonicus, Erythrinus erythrinus, Nannostomus eques, Acestrorhynchus heterolepis, Thayeria obliqua, Steatogenys elegans, Oxyropsis wrightiana, Rineloricaria morrowi,* and *Biotodoma cupido*.

In terms of species richness, the three evaluated sampling sites recorded similar values, ranging between 25 and 28 species. However, in terms of abundance, site 02 had the lowest values with 273 individuals, representing 21% of the total.

When evaluating the threat level of the collected species in the Huachana lake, it was found that 58.8% of the species do not have an

Table 1. List of species collected in the Huachana lake, Loreto, Perú.

Order/family/species	Common name	Sampling areas				Use	IUCN	Voucher
		Site 01	Site 02	Site 03	Total			
Clupeiformes								
Engraulidae								
Anchoviella jamesi (Jordan & Seale 1926)	sardina	0	0	34	34	O	LC	CIIAP 863
Characiformes								
Hemiodontidae								
Hemiodus unimaculatus (Bloch 1794)	yulilla	0	0	2	2	O	NE	CIIAP 861
Curimatidae								
Cyphocharax festivus Vari 1992	chio chio	0	0	8	8	C	NE	CIIAP 782
Cyphocharax spiluropsis (Eigenmann & Eigenmann 1889)	chio chio	5	7	12	24	C	NE	CIIAP 804, 818, 837, 847
Cyphocharax spilurus (Günther 1864)	chio chio	0	1	0	1	C	NE	CIIAP 817
Prochilodontidae								
Semaprochilodus insignis (Jardine 1841)	yaraqui	0	0	1	1	C	NE	CIIAP 839
Anostomidae								
Laemolyta taeniata (Kner 1858)	lisa	16	14	1	31	O	LC	CIIAP 798, 819, 858
Leporinus niceforoi Fowler 1943	lisa	0	0	2	2	O, C	LC	CIIAP 835
Leporinus fasciatus (Bloch 1794)	lisa	2	6	0	8	O, C	LC	CIIAP 796, 820
Leporinus agassizii Steindachner 1876	lisa	0	3	0	3	O, C	LC	CIIAP 824
Leporinus parae Eigenmann 1907	lisa	0	6	0	6	O, C	LC	CIIAP 813
Chilodontidae								
Chilodus punctatus Müller & Troschel 1844	lisa	0	2	5	7	O	NE	CIIAP 811, 842
Erythrinidae								
Erythrinus erythrinus (Bloch & Schneider 1801)	shuyo	1	0	0	1	O, C	NE	CIIAP 781
Hoplias malabaricus (Bloch 1794)	fasaco	2	1	0	3	O, C	LC	CIIAP 792, 808
Lebiasinidae								
Nannostomus eques Steindachner 1876	pez lápiz	2	0	0	2	O	NE	CIIAP 789
Gasteropelecidae								
Carnegiella schereri Fernández Yépez 1950	pechito	19	0	0	19	O	NE	CIIAP 791
Ctenoluciidae								
Boulengerella maculata (Valenciennes 1850)	picudo	3	0	0	3	O, C	NE	CIIAP 785
Acestrorhynchidae								
Acestrorhynchus falcirostris (Cuvier 1819)	pez zorro	2	0	0	2	C	LC	CIIAP 783
Acestrorhynchus heterolepis (Cope 1878)	pez zorro	0	1	0	1	C	LC	CIIAP 816
Serrasalmidae								
Serrasalmus sanchezi (Géry 1964)	paña	1	0	1	2	C	NE	CIIAP 794, 860
Characidae								
Ctenobrycon hauxwellianus (Cope 1870)	mojara	3	0	14	17	O	NE	CIIAP 787, 843
Hemigrammus hyanuary Durbin 1918	mojara	0	25	28	53	O	LC	CIIAP 833, 857
Hemigrammus levis Durbin 1908	mojara	0	0	100	100	O	LC	CIIAP 856
Hemigrammus pulcher Ladiges 1938	mojara	139	6	0	145	O	LC	CIIAP 786, 807

Hyphessobrycon copelandi Durbin 1908	mojara	0	0	43	43	O	NE	CIIAP 864
Moenkhausia ceros Eigenmann 1908	mojara	56	56	49	161	O	NE	CIIAP 788, 834, 853
Moenkhausia collettii (Steindachner 1882)	mojara	0	0	20	20	O	NE	CIIAP 848
Moenkhausia lepidura (Kner 1858)	mojara	53	0	182	235	O	NE	CIIAP 803, 838, 854, 855
Thayeria obliqua Eigenmann 1908	mojara	0	2	0	2	O	NE	CIIAP 832
Iguanodectidae								
Bryconops melanurus (Bloch 1794)	mojara	6	20	6	32	O, C	NE	CIIAP 797, 814, 862
Iguanodectes purusii (Steindachner 1908)	mojara	18	48	26	92	O	NE	CIIAP 784, 810, 846
Chalceidae								
Chalceus epakros Zanata & Toledo-Piza 2004	sardina, san pedrito	8	2	0	10	O	NE	CIIAP 800, 815
Gymnotiformes								
Sternopygidae								
Eigenmannia limbata (Schreiner & Miranda Ribeiro 1903)	macana	0	0	24	24	O	NE	CIIAP 852
Rhamphichthyidae								
Steatogenys elegans (Steindachner 1880)	macana	0	1	0	1	O	LC	CIIAP 831
Hypopomidae								
Brachyhypopomus brevirostris (Steindachner 1868)	macana	3	1	0	4	O	LC	CIIAP 799, 830
Siluriformes								
Doradidae								
Anadoras grypus (Cope 1872)	pirillo	0	0	11	11	O	LC	CIIAP 836
Heptapteridae								
Pimelodella cristata (Müller & Troschel 1848)	cunchi, bagre	0	5	0	5	O, C	LC	CIIAP 828
Loricariidae								
Oxyropsis wrightiana Eigenmann & Eigenmann 1889	carachamita	1	0	0	1	O	LC	CIIAP 801
Rineloricaria morrowi Fowler 1940	shitari	1	0	0	1	O	LC	CIIAP 802
Cichliformes								
Cichlidae								
Acarichthys heckelii (Müller & Troschel 1849)	bujurqui	1	0	0	1	O	NE	CIIAP 780
Acaronia nassa (Heckel 1840)	bujurqui	4	12	0	16	O	NE	CIIAP 795, 806, 825
Aequidens tetramerus (Heckel 1840)	bujurqui	1	3	0	4	O	NE	CIIAP 779, 827
Biotodoma cupido (Heckel 1840)	bujurqui	0	0	1	1	O	NE	CIIAP 844
Cichlasoma amazonarum Kullander 1983	bujurqui	1	5	0	6	O	NE	CIIAP 790, 826
Cichla monoculus Spix & Agassiz 1831	tucunare	0	1	0	1	O, C	NE	photo
Sexatilia cf. *proteus* (cope 1872)	añashua	1	0	1	2	O, C	NE	CIIAP 793, 859
Lugubria cincta (Regan 1905)	añashua	0	1	0	1	O, C	LC	CIIAP 822
Lugubria johanna (Heckel 1840)	añashua	0	4	0	4	O, C	LC	CIIAP 821
Heros efasciatus Heckel 1840	bujurqui hacha vieja	4	0	1	5	O, C	NE	CIIAP 778, 841
Mesonauta mirificus Kullander & Silfvergrip 1991	bujurqui	98	36	16	150	O	LC	CIIAP 776, 829, 845
Pterophyllum scalare (Schultze 1823)	pez angel	3	1	0	4	O	NE	CIIAP 777, 809
Satanoperca jurupari (Heckel 1840)	bujurqui punta shimi	0	4	10	14	O, C	NE	CIIAP 823, 840
Abundance		454	274	598	1326			

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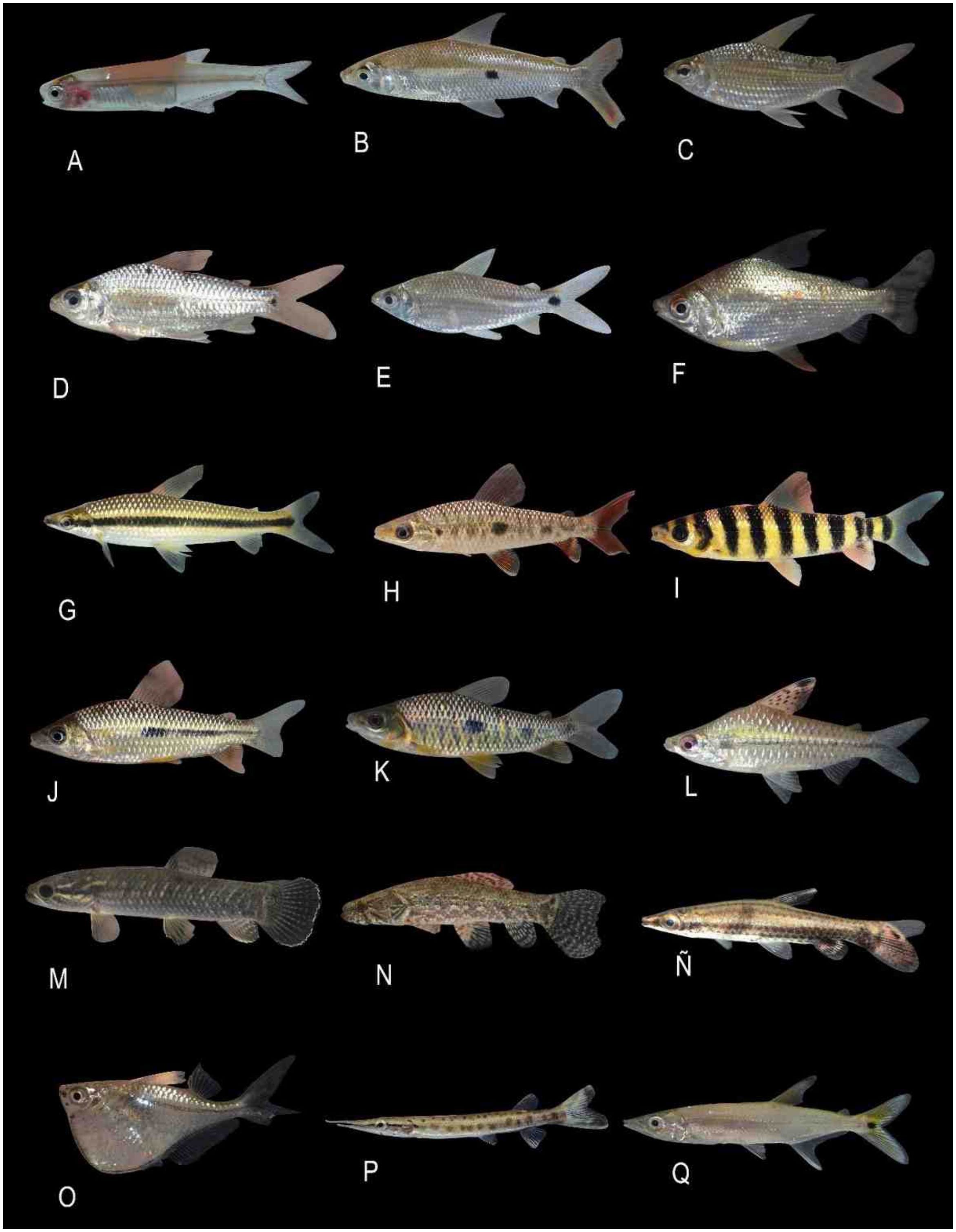

Figure 3. Huachana lake fish species. (A) *Anchoviella jamesi*, (B) *Hemiodus unimaculatus*, (C) *Cyphocharax festivus*, (D) *Cyphocharax spiluropsis*, (E) *Cyphocharax spilurus*, (F) *Semaprochilodus insignis*, (G) *Laemolyta taeniata*, (H) *Leporinus niceforoi*, (I) *Leporinus fasciatus*, (J) *Leporinus agassizii*, (K) *Leporinus parae*, (L) *Chilodus punctatus*, (M) *Erythrinus erythrinus*, (N) *Hoplias malabaricus*, (Ñ) *Nannostomus eques*, (O) *Carnegiella schereri*, (P) *Boullengerella maculata*, (Q) *Acestrorhynchus falcirostris.*

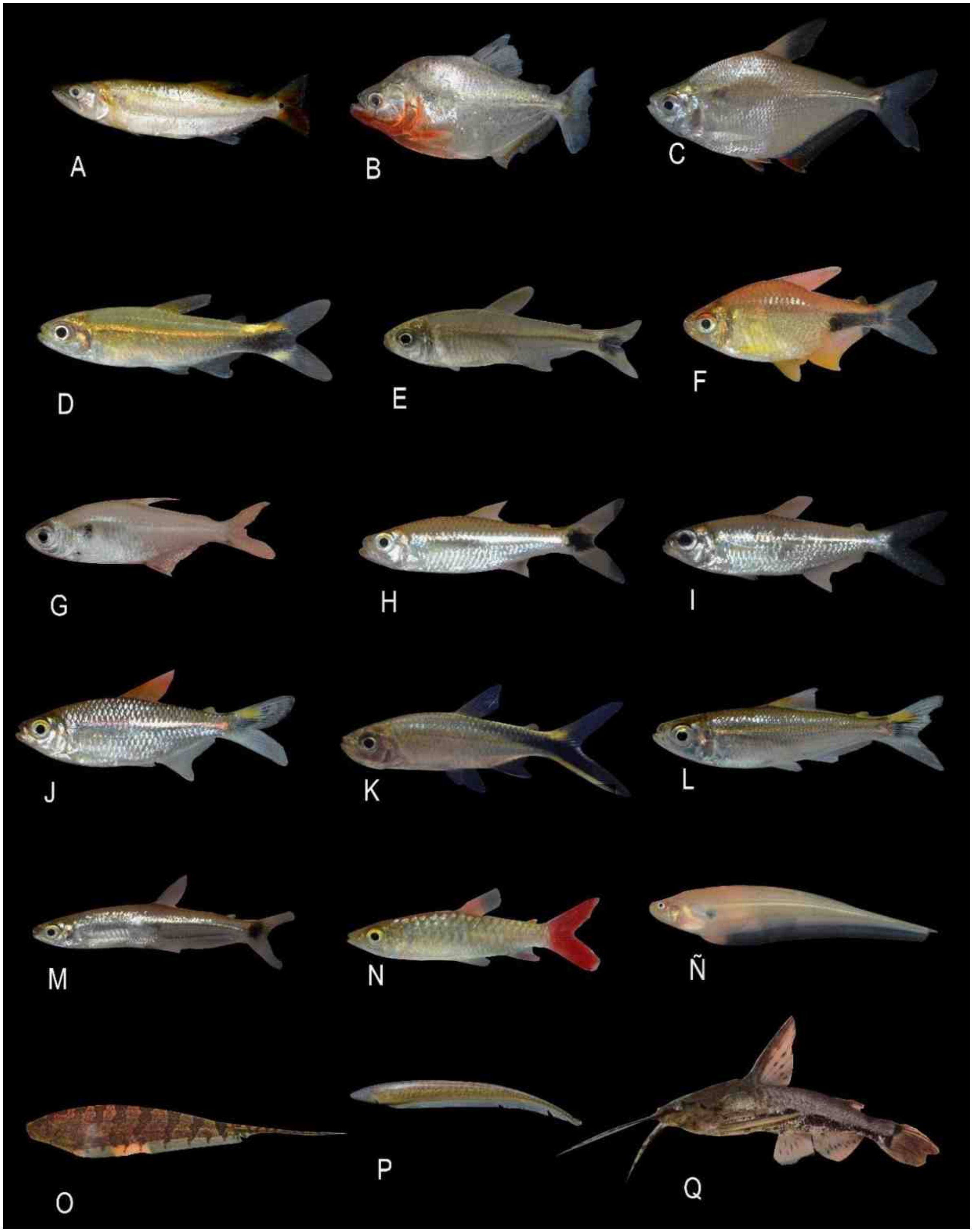

Figure 4. Huachana lake fish species. (A) *Acestrorhynchus heterolepis*, (B) *Serrasalmus sanchezi*, (C) *Ctenobrycon hauxwellianus*, (D) *Hemigrammus hyanuary*, (E) *Hemigrammus levis*, (F) *Hemigrammus pulcher*, (G) *Hyphessobrycon copelandi*, (H) *Moenkhausia ceros*, (I) *Moenkhausia collettii*, (J) *Moenkhausia lepidura*, (K) *Thayeria obliqua*, (L) *Bryconops melanurus,* (M) *Iguanodectes purusi*, (N) *Chalceus epackros*, (Ñ) *Eingenmania limbata*, (O) *Steatogenys elegans*, (P) *Brachyhypopomus brevirostris*, (Q) *Anadoras gryphus*.

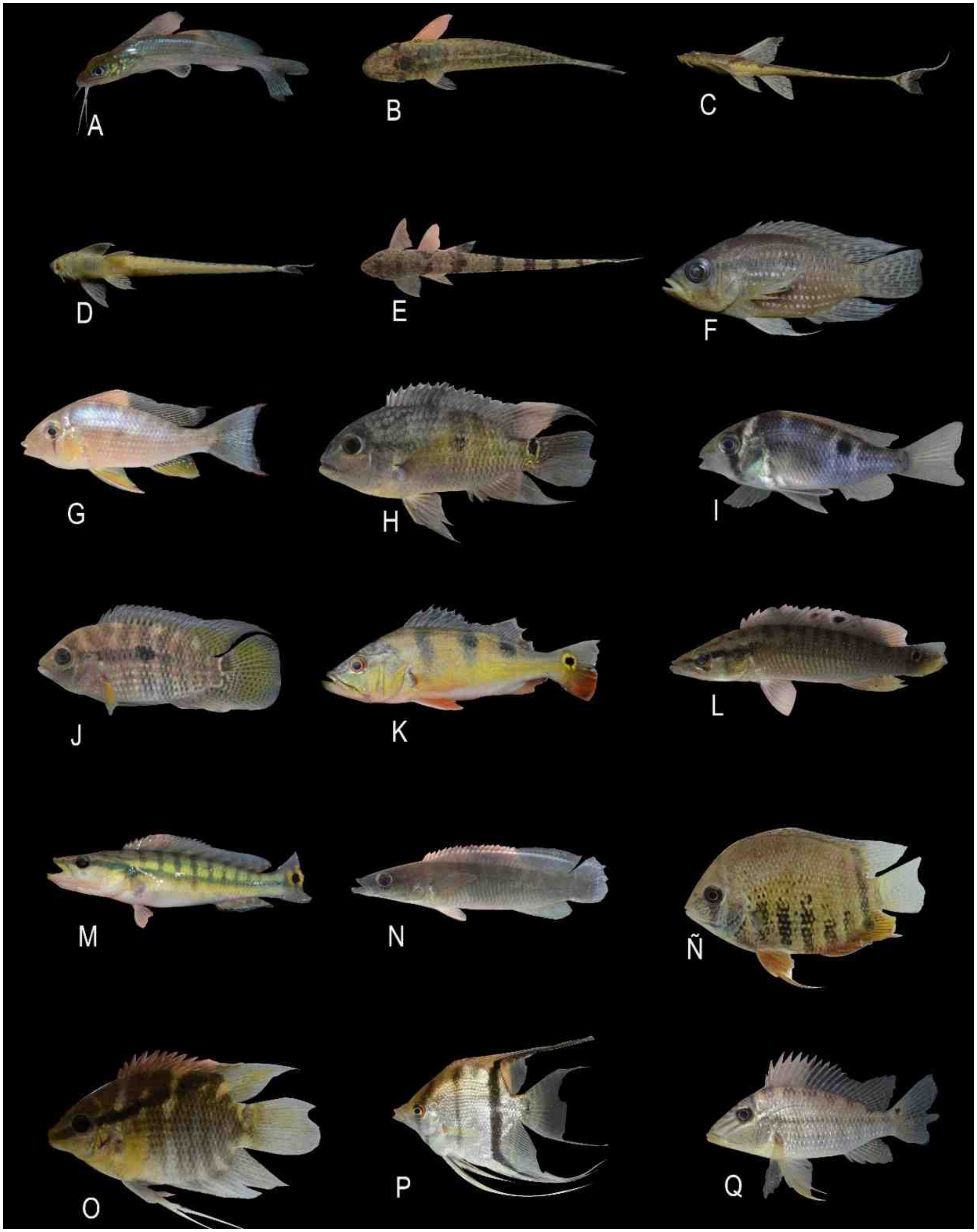

Figure 5. Huachana lake fish species. (A) *Pimelodella cristata,* (B) *Oxyropsis wrightiana*, (C-E) *Rineloricaria morrowi*, (F) *Acaronia nassa*, (G) *Acarichthys heckelii*, (H) *Aequidens tetramerus*, (I) *Biotodoma cupido*, (J) *Cichlasoma amazonarum*, (K) *Cichla monoculus*, (L) *Sexatilia* cf. *proteus*, (M) *Lugubria cincta*, (N) *Lugubria johanna*, (Ñ) *Heros efasciatus*, (O) *Mesonauta mirificus*, (P) *Pterophyllum scalare*, (Q) *Satanoperca jurupari*.

assessment of their threat level according to the criteria of the IUCN (International Union for Conservation of Nature). These species were coded as NE (Not Evaluated). On the other hand, 41.2% of the collected species are categorized as Least Concern (LC) according to the IUCN criteria. This means that these species are not immediately endangered and are considered relatively safe in their current conservation status.

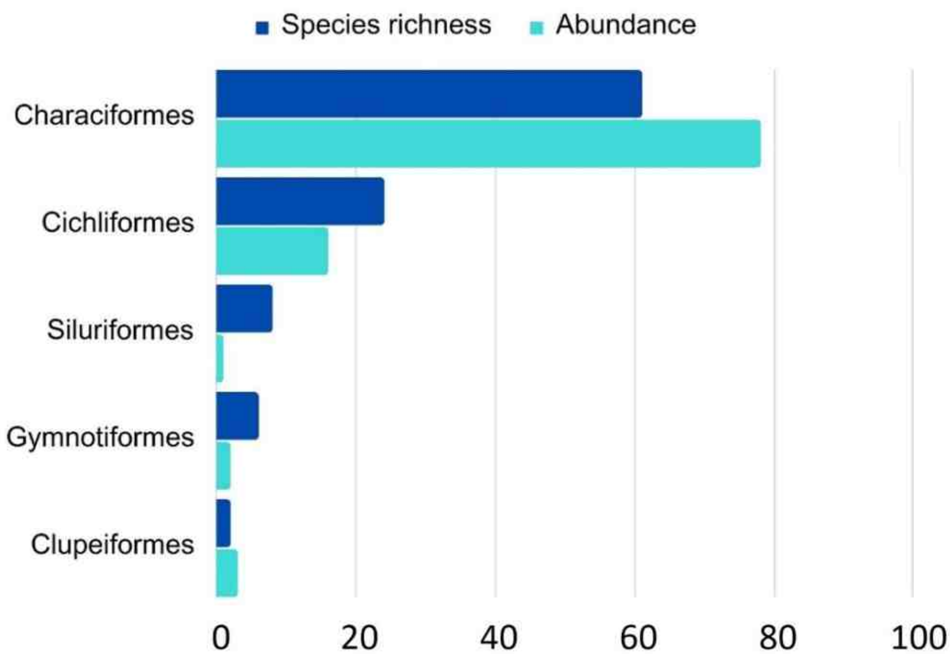

Figure 6. Percentage of Species richness and abundance by order of the species collected in the Huachana lake.

DISCUSSION

The predominance of Characiformes in the Huachana lake aligns with patterns observed in other studies of fish inventories in the Peruvian Amazon, reflects the high diversity of this order in the region (Aylas *et al*., 2022; Chuctaya *et al*., 2022). However, there is a difference compared to these studies, instead of a high diversity of Siluriformes, the dominance of Cichliformes stands out, primarily represented by the family Cichlidae. This family was the most diverse in terms of the number of species, comprising 24% of the entire fish richness recorded in the Huachana lake.

Cichlidae are widely recognized as a family with high species richness, naturally distributed across Africa and America, and it is introduced to all continents around the world (Fricke *et al*., 2023). This family has demonstrated a strong capacity for reproductive success in anthropogenic environments (Oliveira & Bennemann, 2005).

Some species within the Cichlidae family, such as those in the *Oreochromis* genus (tilapia), hold great significance in aquaculture due to their adaptability and reproductive capabilities. Furthermore, most Cichlidae species exhibit an opportunistic diet, which enables them to with stand environmental disturbances that may occur in aquatic habitats. This gives them a competitive advantage over other species that might be more sensitive to environmental changes (Santos & Ferreira, 1999; Oliveira & Benne-

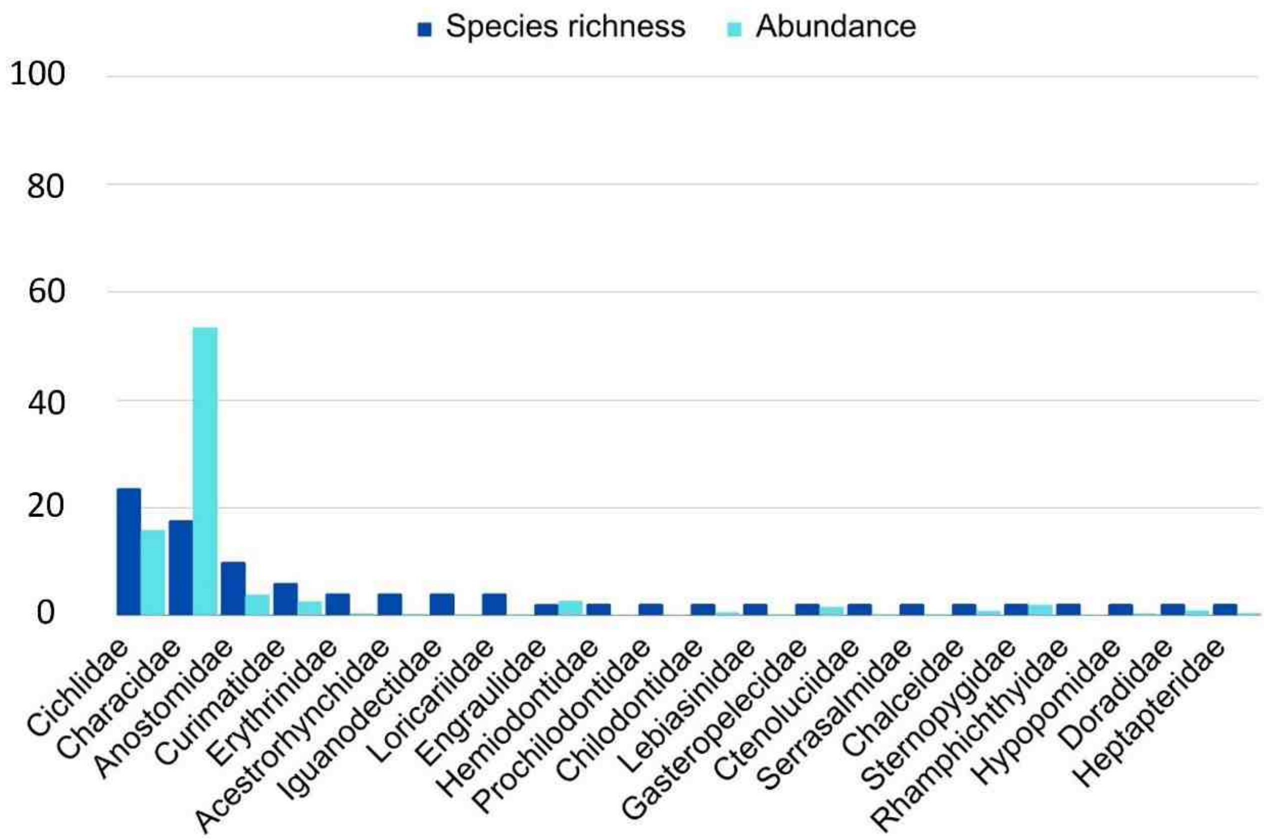

Figure 7. Percentage of richness and abundance by families of the species collected in the Huachana lake.

mann, 2005). These findings are pertinent for understanding the composition and ecology of the fish community in the Huachana lake and identifying species with higher adaptability to environmental and human-induced changes in the region.

Studies on African cichlids have revealed that these species exhibit a facultative diet, which means they can adapt their feeding habits based on food availability. This characteristic contributes to the success of the Cichlidae family, enabling them to survive in various environmental conditions and during food scarcity situations (Mckaye & Marsh, 1983). Additionally, African cichlids have been utilized as study models in research investigating the impact of water pollution (Ruas *et al*., 2008; Meyer & Salzburger, 2012), these studies have analyzed biomarkers of oxidative stress in the blood of these species to assess the effects of environmental pollution.

The results have demonstrated that there is considerable variation in the responses of cichlids to pollution, as well as differences in their sensitivity to contaminants present in the water (Ruas *et al*., 2008). These investigations provide valuable insights into the adaptability and responsiveness of cichlids to stressful environmental factors such as reduced food availability and pollution. This dietary flexibility and response to pollution may partially explain the success of the Cichlidae family in various habitats and the diversity of species found within this family, both in Africa and the Americas, as well as other continents. Furthermore, these findings can be instrumental in understanding how fish in general, and cichlids in particular, adapt and confront challenges in ever-changing environments, carrying significant implications for the conservation and management of aquatic resources. It is noteworthy that *Oreochromis niloticus*, a widely distributed cichlid species known for its ability to persist in highly polluted environments, has been regarded as a biological indicator of water contamination (dos Santos *et al*., 2012).

Due to its resilience to adverse conditions, this species has been assessed in studies examining its defense response to oxidative stress and liver damage, as the liver plays a crucial role in vital functions such as the accumulation, biotransformation, and excretion of contaminants (Dos Santos *et al*., 2012).

In the study conducted in Huachana lake, it was recorded that the species *Mesonauta mirificus* was found in all sampling stations with high abundance. This species exhibited a significant presence and is adapted to the local environmesnt, it's suggested that it could be a potential candidate for future studies on oxidative stress induced by water contamination. The utilization of species as biological indicators is crucial for comprehending the effects of pollution on aquatic ecosystems.

While the results of the study in Cocha Huachana suggest that Cichlidae, like *Mesonauta mirificus*, may be showing a greater ability to withstand the effects of water pollution compared to other fish groups, such as Siluriformes, Cichlidae seem to have adaptations that enable them to cope with challenging conditions and tolerate certain levels of contamination.

On the other hand, Siluriformes, which are often benthic fish, could be more susceptible to the accumulation of contaminants in the water and substrate. Their closer interaction with the substrate could expose them to higher concentrations of pollutants than pelagic fish, such as Characiformes, which are mainly found within the body of water.

It's important to note that, although Cichlidae may be showing greater resistance to pollution in this study, it doesn't imply they are entirely immune to negative impacts. The presence of contaminants in the water remains concerning for all species, and it's crucial to continue monitoring and assessing the long-term effects on Huachana lake and its fish communities.

Out of the total species collected in Huachana lake, 41% are species intended for human consumption. However, due to the connection with areas with high levels of environmental contaminants, such as the nearby Morona Cocha lake, it's crucial for people to exercise caution when regularly consuming fish from these waters. Previous studies have shown that levels of contaminant residues can be significantly higher in fish collected from environments near landfills or polluted areas compared to farm-raised fish (Minh *et al*., 2006). Therefore, consuming fish from areas affected by pollution could entail risks to human health.

Fish can also serve as indicators of pollution in an aquatic environment. For instance, the proportion of fish that are not feeding may increase with higher pollution levels. This means that when the source of contamination is in direct contact with sediments, an increase in the occurrence of empty stomachs in species can be observed (Gregg *et al*., 1997). These findings underscore the significance of environmental monitoring and responsible consumption of fishery resources from potentially contaminated areas.

The Huachana lake harbors a significant diversity of ornamental fish, accounting for 58% of the total. This remarkable diversity is attributed to the fact that the Huachana lagoon is part of the aquatic ecosystems that drain into the Nanay River, renowned in the aquarium community for its abundance of ornamental species.

During the 1980s, the Nanay River basin established itself as the primary region for the export of ornamental fish in Peru. However, this situation changed between 2000 and 2010 when it lost its top position to the Ucayali basin (García *et al*., 2011). Currently, while the Nanay River basin remains one of the most important regions for ornamental fish exports, it has fallen to the second position, this time behind the Tapiche River basin (García-Dávila *et al*., 2021).

A significant portion of the fish extracted from the Nanay River basin is exported to China and the USA. China has become the leading destination for exports in terms of quantity, while the United States generates the highest economic income (García *et al*., 2011). Furthermore, within the basin, management plans have been proposed for the conservation and sustainable use of ornamental species. Among the selected species are the cichlids Pterophyllum scalare, which are collected in the Huachana lake, and Symphysodon aequifasciatus Pellegrin 1904, which is not found in the same lake (Juvonen & Salo, 2004).

In recent years, there has been a decline in the demand for fish captured in natural environments in the ornamental market. Instead, European and American aquarium enthusiasts are giving preference to those produced in captivity (García-Dávila *et al*., 2021)

The increasing pollution in aquatic environments, particularly the concentration of heavy metals and the presence of microplastics, is indeed concerning. Studies have demonstrated that the presence of heavy metals in water from wastewater can lead to the bioaccumulation of these metals in fish tissues (Rani, 2000; Malik *et al*., 2010; Arantes *et al*., 2016; Ali *et al*., 2020; Mehouel & Fowler 2022). This can have negative consequences for fish health, as the formation of micronuclei and DNA fragmentation has been observed, suggesting genotoxic damage and increased vulnerability to diseases (Ali *et al*., 2020).

On the other hand, pollution from microplastics is another serious issue that has been escalating in recent years (Rojas *et al*., 2023). Studies have shown that the presence of microplastics in the stomachs of fish has significantly increased from the mid-century to the present, correlating with the rise in plastic concentration in the environment (Hou *et al*., 2021). The presence of plastic fragments on the shores of Huachana lake during the sampling is a concerning indicator of the potential presence of microplastics in the aquatic environment of the lake (Figure 2).

Another point to highlight is the difference in abundance between sampling sites. Site 02 (Figure 2B), located at the center of the lake, records the lowest number of individuals. It is an area with less vegetation coverage, fewer shelter zones, and a higher likelihood of predator presence. Site 03 (Figure 2C) is situated in the channel connecting Huachana Lake with the Nanay River, facilitating an exchange of individuals between the river and the lake. These channels, serving as connection points between the river and the lake, exhibit a high species abundance. Site 01 (Figure 2A) is in the area farthest from the lake channel, featuring a high concentration of macrophytes and an environment that offers a wide variety of shelter zones, allowing for a greater abundance of species (Lobón-Cerviá *et al*., 2015). Local fishers take advantage of these characteristics when placing their fishing nets.

En summary, Huachana lake stands out as an ecosystem with significant species richness of fish, which are valuable resources for the local community. However, these resources are vulnerable to threats such as pollution. Our study plays a key role in enriching the knowledge about the ichthyofauna of Huachana lake, an aquatic environment near a major city. This can serve as a starting point to promote the conservation and sustainable management of this aquatic environment over time. Preserving Huachana Lake and similar ecosystems in Loreto is crucial. We must monitor urbanization and pollution's potential effects while implementing strong conservation measures to protect the diverse ichthyofauna and the entire ecosystem. This study underscores the need for urgent proactive steps to safeguard the Amazon region's ecologically significant environments and its unique species.

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