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Local Ecological Knowledge, Fishing Practices, and Perceived Threats among Kichwa, Cofán, and Siona Fishers in the Ecuadorian Amazon.

Gabriela Echevarría[1]*, Rafael Yunda[2], Fernando Sánchez[1], Blanca Ríos-Touma[1,2] and Francisco Cuesta[3]

ABSTRACT

Fisheries in the Ecuadorian Amazon support subsistence, cultural identity, and local economies, yet face threats from oil extraction, agricultural expansion, and overfishing. This study integrates Local Ecological Knowledge (LEK) and fishing practices from 53 Kichwa, Siona, and Cofán fishers in seven communities across the Napo and Aguarico watersheds. Using structured and open-ended questionnaires, we recorded information on fishing techniques, seasonal patterns, perceived environmental changes, and threats to fisheries. Fishers reported 30-40% decline in abundance, that over 25% of fishers relate to oil extraction. Results show differences in fishing practices among Indigenous groups and communities, and identify key ecological insights including fish migration routes, spawning habitats, and seasonal abundance patterns. Despite high species richness, approximately 15 species dominate catches. Differences in market access and seasonal isolation also risk the food security of the more distant communities. Our results show that LEK in this data-poor region is not only a source of ecological information, but also a foundation for differentiated governance capacities, with some communities already translating knowledge into collective rules. These findings offer a baseline for culturally grounded, participatory co-management and community-based monitoring of Amazonian freshwater fisheries in Ecuador.

Keywords: Environmental threats to fisheries; fishing calendar; fish intakes; indigenous fishing methods; fish agreements.

1 Facultad de Ingenierías y Ciencias Aplicadas, Grupo de Investigación en Biodiversidad Medio Ambiente y Salud –BIOMAS-Universidad de Las Américas, Quito, Ecuador.

2 Colegio de Ciencias Biológicas y Ambientales (COCIBA) and Global Research & Solutions Center, Universidad San Francisco de Quito, Ecuador.

3 Global Solutions & Research Center - Universidad San Francisco de Quito, Quito, Ecuador.

* Corresponding author ✉. E-mail address: GE (gabriela.echevarria@udla.edu.ec), RF (rafael.yunda@wwf.org.ec), FS (fernando.sanchez.orellana@udla.edu.ec), BRT (blanca.rios@udla.edu.ec), FC (fcuesta@usfq.edu.ec)

SIGNIFICANCE STATEMENT

This study presents the first comparative analysis of Local Ecological Knowledge (LEK), fishing practices, and perceived threats among Kichwa, Cofán, and Siona Indigenous nationalities in the northern Ecuadorian Amazon. Drawing on structured interviews with 53 fishers from seven communities across two major watersheds, we document detailed insights into fish migration, spawning habitats, and seasonal abundance. Importantly, we identify how LEK is differentially translated into informal governance rules, including community-led fishing bans and moratoria, revealing key contrasts in adaptive capacity. By integrating ecological observations with social context, this research highlights the role of exposure to extractive industries and collaboration history in shaping local conservation responses. Our findings provide a baseline for culturally grounded co-management strategies and contribute to broader debates on the conditions under which Indigenous knowledge informs biodiversity governance. This work offers a rare interdisciplinary contribution from a data-poor but ecologically and culturally critical region of the Western Amazon.

INTRODUCTION

In recent years, conservation initiatives that incorporate local communities' knowledge and vision have gained traction (Bélisle et al. 2018). Local Ecological Knowledge (LEK) is based on the lived experiences of communities interacting with their environments over generations through observations, practices, and oral transmissions about the ecosystems and the environmental changes they face, as well as about the species' life cycles and behavior (Rai and Mishra 2022). Thus, LEK can support adaptive co-management strategies when integrated with scientific research, build relationships among stakeholders to promote trust, and harness communities' ability to adapt to environmental changes through capacitation and innovation (Olson et al. 2004; Plummer et al. 2013). Beyond ecological data, LEK promotes inclusive governance by recognizing Indigenous communities as legitimate actors in decision-making (Berkes 2009). Its integration into co-management frameworks enhances legitimacy and compliance.

These adaptive and participatory approaches are relevant in tropical inland fisheries, where uncertainty is high and top-down strategies often fail. Inland fisheries operate within complex socio-ecological systems, making it essential to understand human-environment interactions (Ostrom 2009). Tropical inland fisheries face increasing pressures amid limited data and regulatory oversight (Youn et al. 2014). In these data-poor settings, LEK serves as an accessible source of information. It reflects cumulative, place-based observations on fish behavior, habitat use, and reproduction (Berkes et al. 2000). Likewise, LEK has informed management in various aquatic contexts, including marine systems (Zappes et al. 2018; Najera-Medellín et al. 2023), migratory fish tracking and quota systems in Brazil (McGrath and Castello 2015; Nunes et al. 2019), and assessments of river dolphin services (Hallwass et al. 2024). In the Amazon, it has been used to evaluate urban impacts (Griffith et al. 2025), changes in fish communities (Poissant et al. 2024), and mercury pollution (Pereyra et al. 2024). Furthermore, LEK can offer critical insights into fish biology and ecology often overlooked in formal studies, and its integration with scientific knowledge is essential for effective freshwater policymaking (Hoppenreijs et al. 2024). For example, the combination of LEK with scientific studies has contributed to establishing seasonal fishing closures and restricted fishing areas in marine zones, thereby promoting the conservation of fish stocks (Rani et al. 2025).

Amazonian freshwater ecosystems harbor exceptional biodiversity but face threats from oil extraction, mining, agriculture, hydropower, and overfishing (Crespo-López et al. 2021). Despite their ecological and social importance, management is hindered by limited monitoring and baseline data (Castello et al. 2017), especially in the Ecuadorian Amazon, where Indigenous fisheries are vital for food security but poorly documented (Barriga-Salazar 2023). The Ecuadorian Amazon hosts over 725 freshwater fish species (Aguirre et al. 2021), many consumed by Indigenous groups such as the Kichwa, Cofán, and Siona. Fisheries rely on at least 193 species, including 64 heavily exploited ones (Barriga-Salazar 2023), yet biological data, particularly on reproduction, trophic roles, and movements, remain scarce. In addition, there is a lack of official statistics on fisheries yields, hindering the modeling of temporal trends and population viability of the species stocks. Consequently, although some ethnoichthyological studies exist (Jácome-Negrete 2013; Tobes et al. 2022), comprehensive fisheries assessments are lacking.

Thus, to address this gap, we compiled LEK and fisheries practices from 53 Indigenous fishers in seven communities along the Napo, Aguarico, and Cuyabeno rivers, as part of collaborative research with Indigenous communities, aimed at supporting voluntary fisheries agreements and local governance. We gathered information on gear types, seasonal abundance, reproductive cues, and perceived threats. Here, we provide fisheries and LEK baselines to inform academic research and community-based management. Specifically, we asked: Can fisheries and LEK integration identify areas or species under greater pressure or ecological risk? What threats to fish and fisheries do Indigenous fishers perceive? What conservation measures emerge from fishers' knowledge to support future agreements? By examining LEK within differentiated governance contexts, we explored how interest in conservation, market integration, and regulatory experience shape the translation of knowledge into fisheries management. To our knowledge, this is the first systematic documentation of Kichwa, Cofán, and Siona LEK on fisheries in the Ecuadorian Amazon.

MATERIAL AND METHODS

Study Area

This study was conducted in the Northern Ecuadorian Amazon, within the Napo and Aguarico watersheds, in the provinces Subumbíos and Orellana. The Napo River features seasonal flooding and high hydrological connectivity, supporting diverse fish populations and ecological processes. In contrast, the Aguarico River has experienced greater fragmentation and altered flow patterns due to intensified land conversion (Cuesta et al. 2024). Land use patterns also differ: the Napo Basin contains a mosaic of secondary forests, pastures, and palm plantations with denser urban settlements, while the Aguarico Basin faces rapid agricultural expansion and significant loss of successional forests (López and Maldonado 2023). Both watersheds lie within a region of exceptional freshwater fish diversity (Aguirre et al. 2021), where fish are a key protein source for Indigenous peoples (Sirén 2011).

Extractive activities such as oil drilling and illegal mining have impacted both rivers and fisheries, contributing to heavy metal pollution (Echevarría et al. 2024). Our survey included Kichwa communities from Pañacocha, Pompeya, and Limoncocha in the Napo watershed. In the Aguarico watershed, Siona communities from Puerto Bolívar and Sototsiaya, along with the Cofán community of Zábalo and the Kichwa community of Zancudo Cocha, were included (Figure 1).

The Kichwa, Cofán, and Siona nationalities and the communities of our study

The Kichwa have historical roots in the Amazonian and Andean regions, with their social structures and land-use practices disrupted by colonization and later monoculture systems, such as cacao, rubber, and logging, which led to widespread deforestation (Maldonado-Erazo et al. 2021). Today, their kinship networks extend beyond residential clusters (Reeve et al. 2012). The Kichwa engage in trade and handicraft sales, demonstrating greater integration into market economies than other Indigenous groups, while maintaining subsistence activities such as hunting and fishing (Heredia et al. 2020).

The Cofán and Siona peoples traditionally inhabited the Colombia–Ecuador borderlands, relying on hunting, fishing, and horticulture (Wasserstrom 2014). The Cofán, once centered around the Aguarico River, suffered dramatic population declines due to disease and displacement, but began recovering after the 1930s by reclaiming territory and rebuilding institutions (Wesche et al. 1999). The Siona inhabit areas along the Aguarico and Cuyabeno Rivers. Greater integration into the national economy has increased agricultural and wage labor, reducing reliance on foraging (Vickers 1994). The Siona maintain communal, extended-family structures and collaborate with NGOs on conservation and anti-deforestation initiatives (Solórzano 2021).

The seven communities participating in this study differ in environmental and social contexts. Limoncocha, located within oil block 15, faces water quality degradation from oil exploration (Carrillo et al. 2022). Residents grow coffee and cacao and rely on intensive subsistence fishing (Loomis et al. 2017). Pañacocha is river-accessible only and struggles with poor educational infrastructure; its Kichwa population engages in subsistence and commercial fishing and crop cultivation (Delgado 2020). In Pompeya, road development and oil exploitation have disrupted traditional practices, contributing to bushmeat trade and increased commercial fishing for large catfish (Suárez et al. 2009; Anaguano-Yacha et al. 2022). Zancudo Cocha has undergone socioecological transformation due to colonization and oil activity, combining subsistence farming with commercial cacao production (Madrid Tamayo 2010). The Siona of Puerto Bolívar live within the Cuyabeno Biosphere Reserve and combine ecotourism with fishing and agriculture. Sototsiaya, accessible by road, lies near oil fields and urban areas and participates in conservation initiatives while practicing agriculture and fishing (Wesche et al. 1999). Zábalo, a remote Cofán community at the confluence of the Zábalo and Aguarico rivers, is noted for conservation leadership, including sustainable agriculture and monitoring of *Podocnemis* turtles (Esbach et al. 2024).

Data collection and analysis

Communities were selected based on their collaboration history or interest in sustainable fisheries and future co-management agreements supported by WWF-Ecuador. Prior to fieldwork, we obtained authorization from community presidents and invited fishers to workshops where we explained the study objectives. Participation was voluntary, and individual

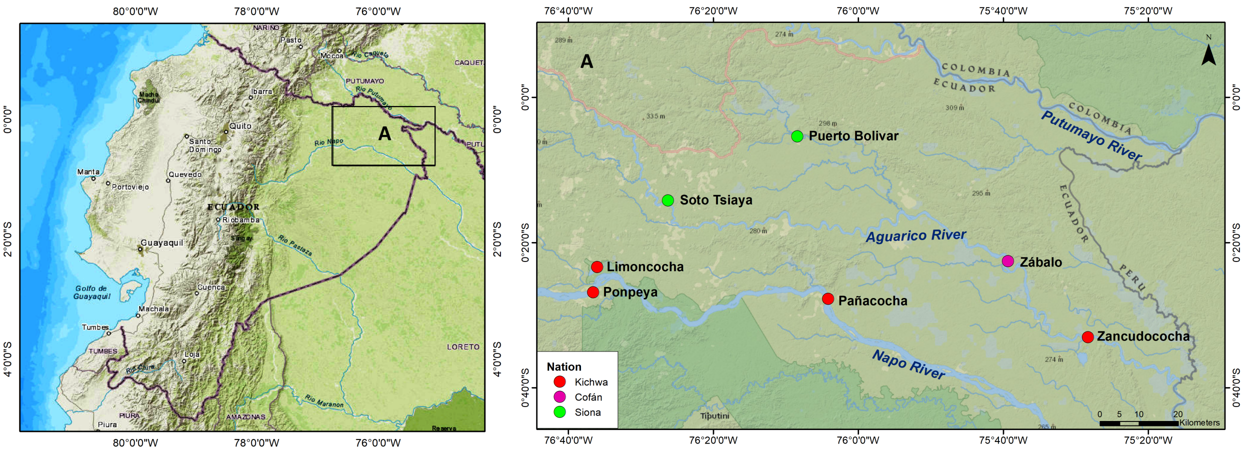

Figure 1. Map of the study area depicting the location of the communities and the respective nations they belong to.

informed verbal consent was obtained with the support of local translators when necessary. Following CEISH–UDLA guidelines, we avoided collecting names or sensitive personal information. Each participant was assigned a unique code based on community initials, date, and survey order. The workshops were designed to both inform participants and foster trust in the context of a broader conservation collaboration. This study was exempted from ethical review by the Research Ethics Committee on Human Beings of Universidad de Las Américas (CEISH–UDLA, 2024-EXC-015).

We used regional fish guides (Jácome-Negrete et al. 2022) to identify species mentioned by fishers. Individual questionnaires (Additional File 1), administered with translation assistance when needed, included open and multiple-choice questions across five themes:

1. Fisher characteristics: age, gender, ethnicity, education, income, and occupation.
2. Fishing practices: type (subsistence, sport, commercial), gear, effort, target species (including biomass, price, location).
3. Fish consumption: daily and weekly intake.
4. Environmental aspects: perceived threats, fish abundance trends, and habitat use.
5. Perceptions: attitudes toward co-management and conservation needs.

To characterize fishers' practices, we estimated fishing effort by multiplying the average number of fishers per trip by monthly fishing hours. Monthly reported catch per unit effort (CPUE) was calculated as:

$$\text{CPUE} = \frac{\text{monthly biomass (kg)}}{\text{fishers} \cdot \text{monthly hours} - 1}$$

The annual CPUE per community was obtained by multiplying the monthly CPUE by fishing months per year. We compared annual CPUEs among communities, water bodies, and watersheds using Kruskal–Wallis tests, with individual fishers reported CPUEs as replicates. Gear use differences among ethnic groups were tested via Chi-square with 1,000 Monte Carlo simulations. Fish consumption frequencies were visualized using Likert plots, and comparisons of daily and weekly intake frequencies among nationalities were made with Chi-square tests. To identify fishing seasons, we built species-specific calendars by tallying the months fishers reported capturing each species. Local Ecological Knowledge (LEK) was categorized into themes (e.g., fish ecology, migration, habitat use) and quantified as percentages. Perceptions of fishery status were grouped into observed population changes and perceived threats. We compared these responses between watersheds using Chi-square tests. Analyses were performed in R V.4.4.3 (R Development Core Team 2025), with the packages forecast V.1.0.1 (Wickham et al. 2025a), reshape2 V.1.4.5 (Wickham 2025), dplyr (Wickham et al. 2025b), tidyverse V.1.3.0 (Wickham et al. 2019), and sjPlot V.2.9.0 (2025). Graphics were created with base R commands and with the package ggplot2 V.4.0.0 Wickham (2016). Representative fishers' quotes on ecology, threats, and management were referenced using participant codes.

RESULTS

The Siona, Cofán, and Kichwa fishers and their practices

We surveyed 53 fishers (ages 27–69). The sample was represented by mostly men (68%), though women comprised 32%, especially in Zábalo, Zancudo Cocha, and Limoncocha. Most participants (62%) were Kichwa, lived along the Aguarico River, and engaged in subsistence fishing. Commercial fishing was reported in Limoncocha, Pañacocha, and Pompeya; sport fishing only in Zancudo Cocha. Tertiary education was limited to Pañacocha, Puerto Bolívar, and Zancudo Cocha (Table 1).

We found significant differences in catch per effort unit (CPUE) among species (F=2.32, p<0.01), communities (F=102.17, p<0.01), water bodies (F=44.77, p<0.01), watersheds (F=5.68, p=0.02), and ethnicities (F=37.03, p<0.01). The highest CPUEs occurred in Pañacocha, followed by Sototsiaya and Zancudo Cocha (Figure 2a). The Shushufindi River, and the lakes Lagartococha, Fanillas, and Pañacocha had the highest yields (Figure 2b). CPUEs were generally greater in the Napo watershed (Figure 2c) and among Kichwa fishers (Figure 2d). Catfish species such as *Zungaro zungaro, Pseudoplatystoma punctifer*, and *Prochilodus nigricans* dominated catches in both watersheds, with some species, such as *Brachyplatystoma tigrinum* and *Potamorhina altamazonica,* caught more intensively in the Napo (Figure 3). Higher CPUEs in the Napo are related to commercial fishing in Pompeya and Pañacocha. Notably, Puerto Bolívar reported the highest fishing effort (Table 2) but had the lowest annual CPUEs, whereas Sototsiaya and Zancudo Cocha showed lower effort but higher CPUEs. Pañacocha combined moderate effort with the highest CPUEs. Fishing effort differed by ethnicity, averaging 46.6 hours/month for Kichwa, 105.3 for Siona, and 50.9 for Cofán. Effort was also higher in the Aguarico watershed (76.4 hours/fisher) compared to Napo (47.4), mainly driven by intensive fishing in Puerto Bolívar.

Table 1. Fishers' socioeconomic aspects for indigenous communities in the Napo and Aguarico watersheds of the Ecuadorian Amazon.

Variable	N	%
Sex		
Men	36	67.92
Women	17	32.08
Nationality		
Siona	9	16.98
Cofán	11	20.75
Kichwa	33	62.26
Education level		
None	2	3.77
Primary	25	47.17
Secondary	23	43.40
Tertiary	3	5.66
Watershed		
Napo	15	28.30
Aguarico	38	71.70
Community		
Limoncocha	4	7.55
Pañacocha	4	7.55
Pompeya	7	13.21
Puerto Bolívar	4	7.55
Sototsiaya	5	9.43
Zábalo	11	20.75
Zancudo Cocha	18	33.96
Fisheries type		
Subsistence	43	81.13
Commercial	9	16.98
Sport fishing	1	1.89

Fishing gear use differed significantly by ethnicity (Chi^2=43.9, p < 0.0001). In Limoncocha, Kichwa mainly used gill nets; in Pompeya, gill nets and hooks were equally common, with some cast nets. Pañacocha Kichwa used cast nets, hooks, and gill nets. Harpoons were exclusive to Siona in Sototsiaya and Puerto Bolívar, while Cofán in Zábalo relied on cast nets. Characiformes were caught mostly with small-medium hooks, gill nets, and cast nets; Siluriformes with large hooks and gill nets. Harpoons targeted medium-large fish (Additional File 2).

Fishing was mainly for subsistence, but 34 species were sold locally to USD 1.5–2.5/lb (Additional File 3). Commercial fishing focused on Pañacocha and Pompeya, supplying markets in El Coca. Zábalo and Puerto Bolívar fishers fished only for subsistence. Napo communities sold more species, with Pompeya trading up to 17 species. Estimated annual fisher income ranged from USD 841 in Limoncocha to USD 147 in Pompeya.

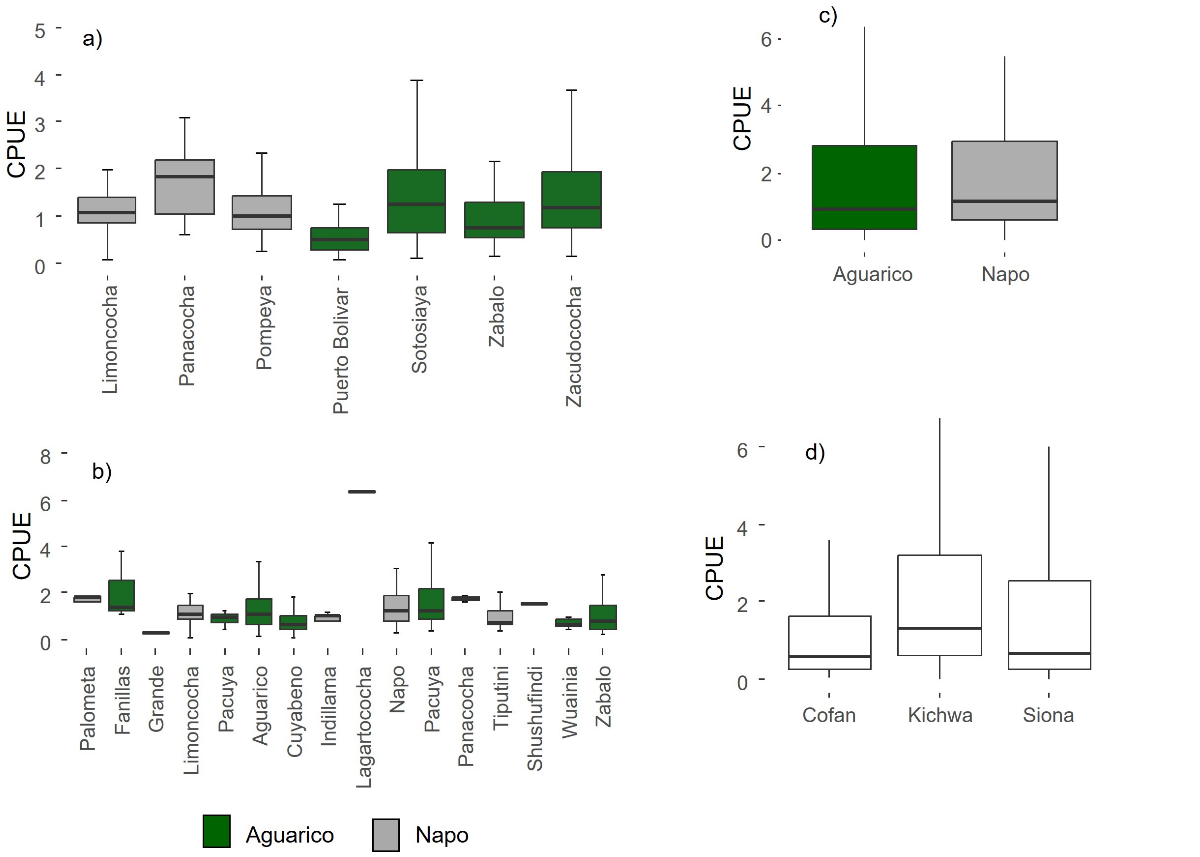

Figure 2. Yearly captures per unit effort in each indigenous community (a), by water body, (b) watershed (c), and nationality (d). Horizontal lines within boxes indicate means, and vertical lines indicate standard deviations.

Table 2. Fishing effort in terms of the number of hours and the number of fishers by fishing event in the indigenous communities of the study area.

Watershed	Community	Number of hours by month		Number of fishers by fishing event		Effort (Number of hours * number of fishers)
		Mean	SD	Mean	SD	
Napo	Limoncocha	29.08	12.15	2	0	58.17
	Pañacocha	27.25	13.94	2	0	54.5
	Pompeya	14.75	5.12	2	0	29.5
Aguarico	Zábalo	11.14	7.38	4.57	1.45	50.94
	Zancudo Cocha	23.26	24.31	1.89	0.46	44.08
	Puerto Bolivar	39.2	9.96	4.6	1.34	180.32
	Sototsiaya	15.17	7.28	2	0.63	30.33

Fish daily and weekly intake

Most Indigenous fishers consume fish one to two times per week (62%), while 38% eat fish three to four times weekly (Figure 4). Daily, 72% eat fish once, and none more than three times. Kichwa and Siona eat fish more frequently than Cofán, who consume it once

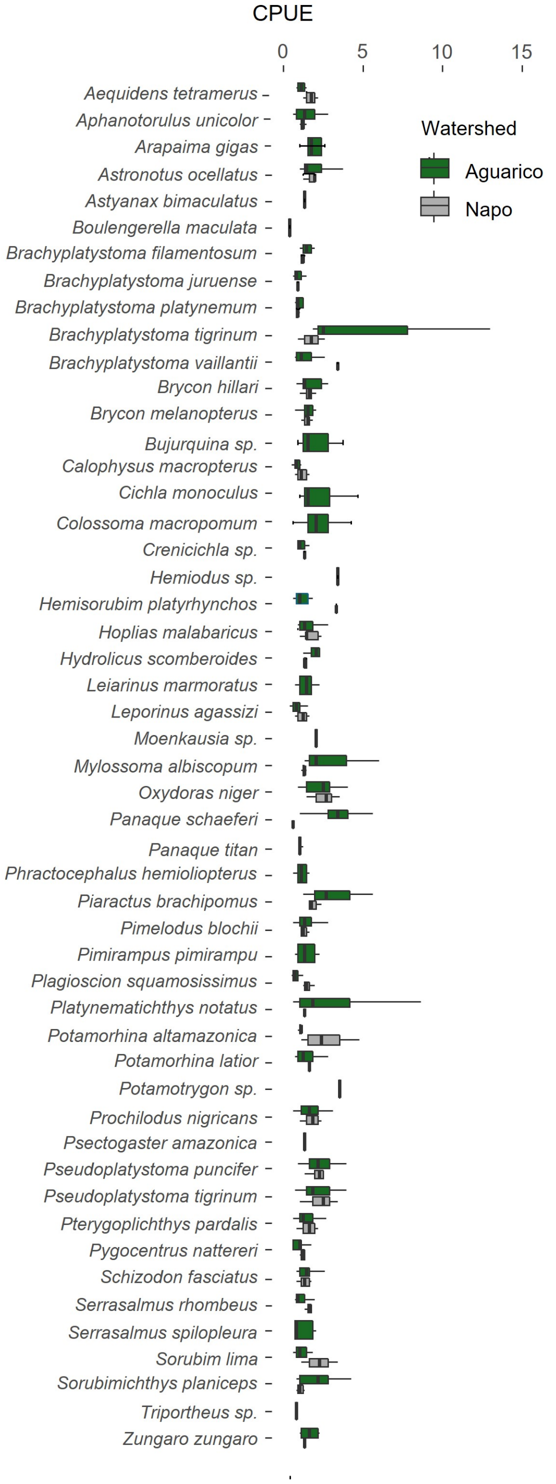

Figure 3. Yearly captures per effort unit by fish species (Square root-transformed) in the Napo and Aguarico Watersheds. Horizontal lines within boxes indicate means and vertical lines indicate standard deviations.

or twice per day (Table 3). All groups mostly eat fish twice weekly, but many Cofán and Kichwa eat fish more often, with 18% of Kichwa eating fish nearly daily, indicating higher intake. Chi^2 tests indicated significant differences among nationalities in daily fish intake (Chi^2=17.02, 4 df, p=0.0019), and weekly intakes (Chi^2=56.29, 8 df, p=0.001).

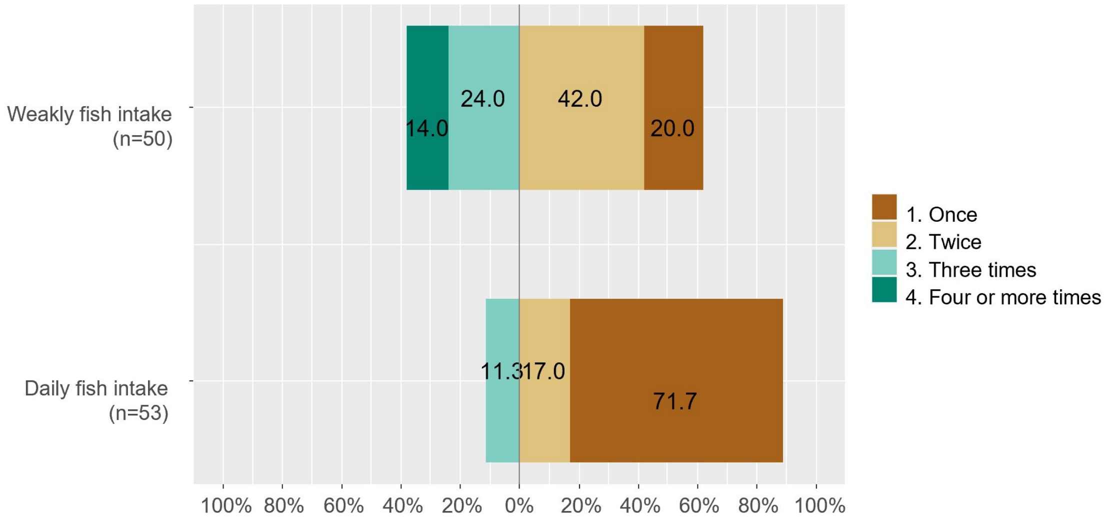

Figure 4. Likert plot of weekly and daily fish intake by fishers and their families.

Table 3. Distribution of fishers by their daily and weekly fish intake frequencies.

Frequency	**Kichwa (%)**	**Cofán (%)**	**Siona (%)**
Daily Fish Intake			
Once	69.70	81.82	66.67
Twice	15.15	18.18	22.22
Three times	15.15	0.00	11.11
Weekly Fish Intake			
Once	21.21	18.18	11.11
Twice	36.36	36.36	55.56
Three times	21.21	27.27	22.22
Four times	3.03	18.18	11.11
Five to all week	18.18	0.00	0.00

Local Ecological Knowledge in the Napo and Aguarico Watersheds

Fishers identified 52 fish species across five orders: Myliobatiformes (1), Osteoglossiformes (1), Characiformes (21), Siluriformes (22), and Perciformes (6). The richest families were Pimelodidae (17), Serrasalmidae (6), and Cichlidae (5). Fishing locations varied by community: Pompeya fishers used multiple rivers (Napo, Indillama, Palometas, Tiputini), Pañacocha fishers targeted Napo and Pañacocha Rivers and Pañacocha Lake, Limoncocha fishers used Limoncocha Lake, Puerto Bolívar fishers fished Grande Lake and Cuyabeno River, Sototsiaya fishers used Aguarico, Wainia, and Shushufindi rivers, Zábalo fishers used Pacuya, Zábalo, and Aguarico rivers, and Zancudo Cocha fishers fished lakes Zancudo Cocha and Fanillas plus Pacuya and Aguarico rivers.

Fishers' Local Ecological Knowledge (LEK) focused on fish migration (100%), reproduction (90%), waterbody importance (100%), natural phenomena (6%), and habitat use (50%). They noted migratory fish move from main channels to lakes for refuge and feeding; e.g., "*Bocachicos move to Zábalo River in October and March*" [P-16-ZAB] (Additional File 4). Fish populations drop in December and May–June but rise in March during upstream spawning migrations. Smaller species sustain fishing during high waters. Two migrations occur yearly: upstream in March for reproduction, and downstream in September–November for feeding.

LEK helped identify fishing seasons and species abundance, forming fishing calendars for 43 species, focused mainly on August–November, the falling and low-water period (Figure 5).

Fishers identified spawning habitats for various species: Cichlidae (viejas), *Hoplias malabaricus, Pterigoplichthys multiradiatus,* and *Pygocentrus nattereri* reproduce in lakes (e.g., "Viejas lay eggs and raise young in Zancudococha Lake" [P-33-ZAN]). Large Pimelodid catfish and some Characiformes like *Prochilodus nigricans* and *Brycon* spp. spawn in the main channels of the upper Napo River. One fisher noted *Arapaima gigas* spawn in Zancudococha Lake in December (Additional File 4).

Fishers view rivers and water bodies as vital for food, mobility, and transport: *"Cuyabeno River is everything for my community"* [P-53-PB], *"Fish can act as bioindicators"* (e.g., Aguarico River [P-53-ZAN]). An elder linked a volcanic eruption and landslide to the disappearance of *Sorubimichthys planiceps* from the Aguarico River, possibly signaling loss of migratory routes. Regarding habitat use, rivers serve mainly as spawning and nursery sites, while lakes like Limoncocha and Pañacocha provide refuge from predators and feeding grounds (Table 4). Among fishers, 9.4% emphasized breeding habitats, 32% refugia, 58% feeding sites, and 34% spawning sites.

Communities in Zancudo Cocha, Zábalo, Sototsiaya, and Puerto Bolívar apply LEK-based social-ecological practices, including bans on commercial fishing, barbasco, and blast fishing. Zábalo prohibits commercial fishing and sets fish quotas. Zancudo Cocha also bans commercial fishing and enforces two-year fishing moratoriums in Zancudo Cocha and Pacuya Lakes. Fishers in Puerto Bolívar were less aware of such rules compared to those in Zábalo and Zancudo Cocha: "We need to regulate catch sizes and quotas in Zancudo Cocha" [P-38-ZAN]. No regulations exist in Pompeya (Additional File 4).

Fishers' perceptions on the current state of fisheries in the study area

Fishers reported declines in fish abundance and size over the past five years, noting that fishing once required less effort and yielded larger catches (Additional File 4). Species replacement was noted only in Sototsiaya and Zancudo Cocha (Additional File 5). Perceptions of changes in fish populations did not differ significantly between watersheds (Figure 6a), but perceptions of threats did (Figure 6b). Oil extraction, solid waste pollution, and barbasco use were the top threats. Solid waste was more often reported in the Napo watershed, while barbasco use was more common in the Aguarico. Many Aguarico fishers reported no threats, unlike nearly all in Napo who identified at least one. Oil extraction was equally cited in both and was the most frequent threat overall (Additional File 5). Blast fishing appeared only in Limoncocha, and agrochemical use was reported only in Sototsiaya, where one fisher linked fish deaths to palm crop fumigation: *"When palm crops are fumigated, dead fish appear near my community"* [P-49-SO] (Additional File 4).

Ninety-four percent of fishers supported fisheries co-management. While a few (2%) suggested alternatives like pisciculture, most favored regulations: banning commercial fishing (28.3%), catch quotas (2%), restricted fishing areas (2%), limits on fish size and gear (7.5%), and patrolling/monitoring (9.4%) (Additional File 4). One fisher said, *"We need bans and to prohibit blast fishing in Limoncocha"* [P-02-LI]. Fishers who were opposed to or indifferent to co-management were mainly from Pompeya, where no fisheries regulations exist.

DISCUSSION

Potential of LEK in management practices in the Ecuadorian Amazon

Fishers demonstrated a detailed understanding of migration, habitat use, and reproduction. For instance, some identify spawning mesohabitats and distinguish species that reproduce in rivers versus lakes (Table 4), following patterns similar to Brazilian Amazon fishers (Pereira et al. 2021), though in our study, fishers showed less knowledge about migration routes than their Brazilian counterparts (Nunes et al. 2019). In contrast, Indigenous fishers in the Colombian Amazon distinguish habitat use only at the mesohabitat scale, possibly due to lower environmental heterogeneity (Bogota-Gregory et al. 2024).

Local ecological knowledge (LEK) from communities in both watersheds provides valuable insights for ecosystem-based co-management, including information for establishing closed seasons, gear restrictions, or protected areas, some of which are already practiced in Aguarico communities. Yet, LEK does not always translate into sustainable practices (Diamond 1993). In Pompeya, for example, fisheries face high pressure due to weak local regulation and strong ties to the oil industry, both of which undermine community co-management.

Several species with the highest reported CPUEs: *Brachyplatystoma tigrinum*, *B. vaillantii*, *Pseudoplatystoma* spp., *Colossoma macropomum*, *Hemiodus* sp., *Panaque schaeferi*, *Potamorhina altamazonica*, and *Hemisorubim platyrhynchos*, may require co-management measures to ensure their long-term conservation. LEK about migration, reproductive periods, and spawning habitats can support participatory rulemaking and legitimize local agreements (Plummer et al. 2013). Additionally, the fishing calendars presented here (Figure 5) could guide communities in determining periods of the hydrological cycle when regulation should be applied. Our findings also highlight the need for closer monitoring in the Napo watershed, where CPUEs were higher.

Socioecological variability of fisheries practices, fish intake patterns, and market integration

Communities exploit diverse species, but fishing pressure concentrates on some 15 species of ecologically sensitive taxa such as large Pimelodidae and Characiformes. Reported CPUEs were lower in the Aguarico than in the Napo, despite stronger governance in the former, where bans and gear regulations are enforced. Differences reflect contrasting exploitation patterns among nationalities. For in-

Table 4. Fished water bodies by each community and their importance for fish according to the fishers.

Community	Fished water body	Importance for fish
Limoncocha	Limoncocha Lake	Breeding of larvae and fry Refugia, against predators Feeding
Pompeya	Indillama and Napo Rivers	Spawning Feeding
	Tiputini River and Palometa Creek	None
Pañacocha	Pañacocha and Napo Rivers	Spawning
	Pañacocha Lake	Breeding of larvae and fry Refugia against predators
Zábalo	Zábalo and Aguarico Rivers	Spawning Breeding of larvae and fry Refugia against predators Feeding
	Pacuya River and Fanillas Lake	None
Zancudo Cocha	Aguarico River	Spawning Breeding of larvae and fry Refugia against predators Feeding
	Pacuya River and Fanillas Lake	None
Sototsiaya	Aguarico and Shushufindi Rivers	Spawning Feeding
	Cuyabeno and Wainia Rivers	None
Puerto Bolívar	Cuyabeno River	Feeding
	Grande Lake	None

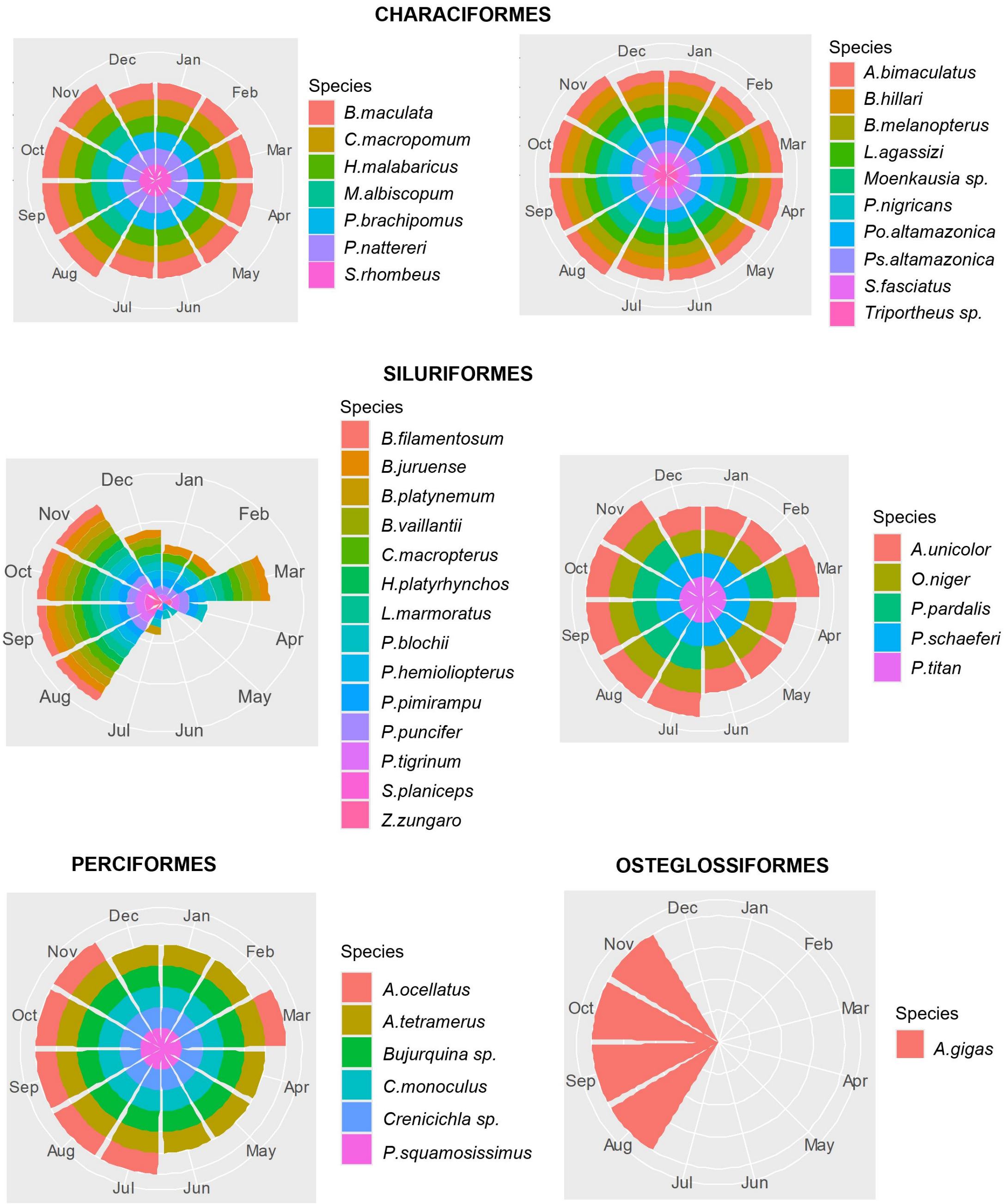

Figure 5. Fishing calendar of the species that are part of the commercial and subsistence fisheries in the study area. Colors indicate the presence of the species in the respective month.

stance, Kichwas from Pompeya reported the highest captures, consistent with stronger commercial engagement and proximity to El Coca. Similar drivers, including market access and habitat availability, shape capture patterns elsewhere in the Amazon (Poissant et al. 2023; Castello et al. 2012). Cultural practices also matter: Siona fishers use harpoons and fruit bait, whereas Kichwa fishers more often use gill nets (Jácome-Negrete 2013). At the waterbody scale, Lagartococha showed the highest CPUEs, suggesting that its community-imposed bans are effective. Gender roles were also evident, with women in Cofán communities using small hooks and gill nets.

Differences in attitudes towards monitoring and co-management were marked. Aguarico communities showed stronger interest, likely due to greater social cohesion and longer governance experience (Vickers 1994). In contrast, heterogeneous Kichwa commu-

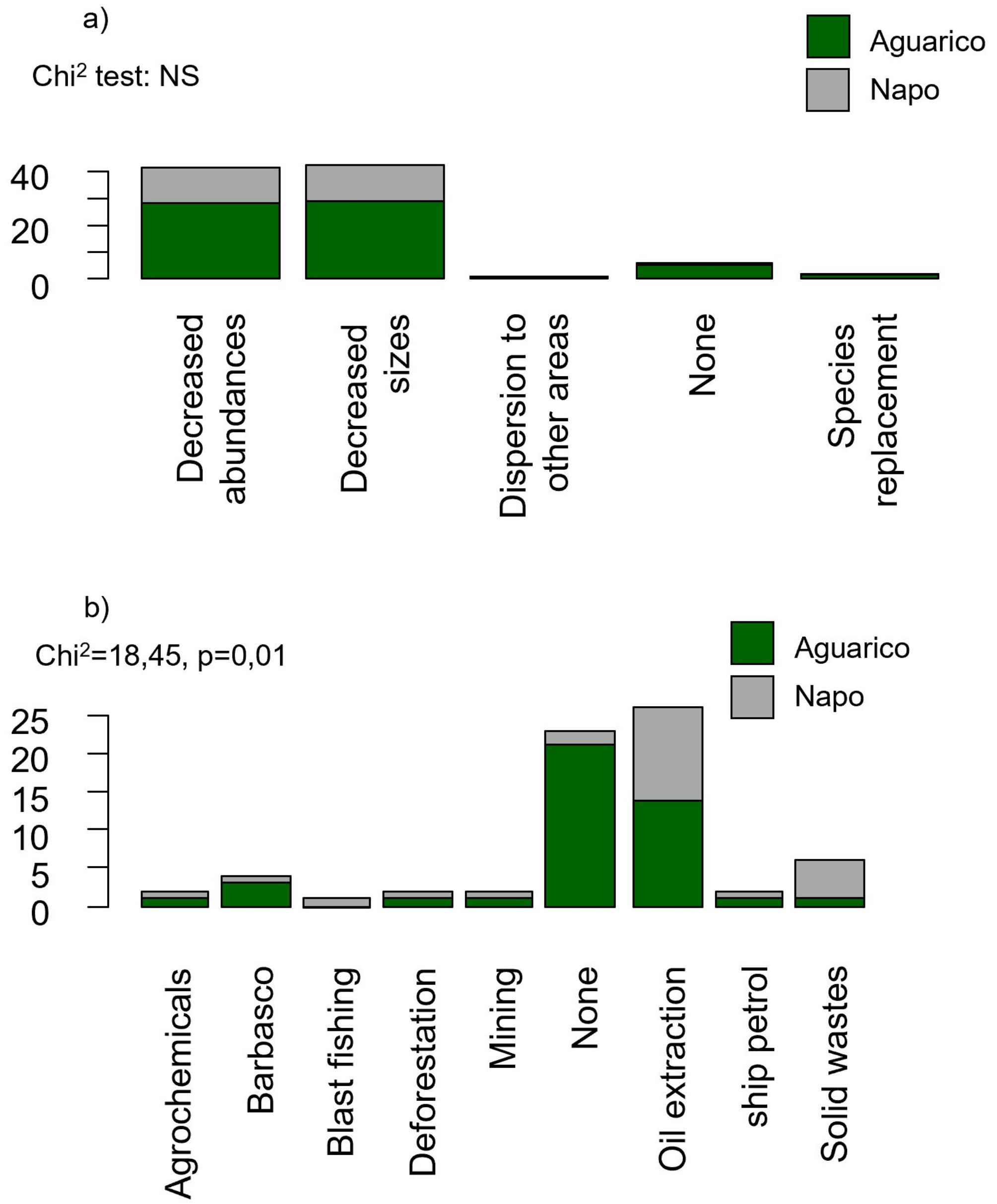

Figure 6. Bar plots and Chi2 test results of comparisons between watersheds of perceived changes in fish populations in the last five years (a) and threats to fisheries (b).

nities from the Napo River, which have experienced intense industrial development (Pellegrini and Arsel 2018), reported lower involvement in collective management and a growing orientation towards tourism and agriculture (Unda and Llanos 2022). These patterns indicate the need for tailored approaches and recognition of each community as a distinct management unit.

On the other hand, fish remains central to local diets, with most households consuming it at least twice a week. Kichwas showed higher and more uniform intake, reflecting their reliance on fish protein but also their vulnerability to overfishing and contamination from extractive activities (Rondoni 2022). Diets varied by ethnicity and socioeconomic factors, shaping exposure to contaminants and nutritional reliance, which can be driven by income, occupation, or population density (Escobar-Camacho et al. 2024; Vasco and Sirén 2018; Isaac et al. 2015). Such heterogeneity may exacerbate nutritional inequalities (Dufour et al. 2016). Policies must therefore balance food security with environmental health, especially where alternatives to wild fish are limited.

Market access also varied significantly. Kichwa communities near El Coca (Pañacocha, Pompeya) can commercialize fish more easily, whereas remote Siona communities like Puerto Bolívar lack market outlets and face seasonal isolation, increasing their vulnerability. Similar dynamics have been documented in the Central Amazon, where communities with lower market access depend more on wild meat as a source of protein than communities located near urban areas, a pattern that also correlates with lower income and labor diversification in the former (Chaves et al. 2017). Access to markets can also determine the composition of catches, as evidenced in the Purus River, where communities nearer to Manaus specialized in a few species of higher commercial value, such as large Serrasalmids and Pimelodids (Tregido et al. 2021). Thus, market constraints, including low prices, high transport costs, and intermediary control, limit livelihood diversification and sustainability (Bartkus et al. 2022). While fisheries agreements could support ecological recovery and new livelihood opportunities, they require enabling conditions, including market access (Fernandes et al. 2024) and strong internal cohesion to adopt and enforce local governance instruments such as fisheries agreements.

Implications for co-management and food security

Fishers reported declines in fish abundance and size over the last five years, attributed to population pressure and environmental degradation from oil activities in the Napo and upper Aguarico (Lessmann et al. 2016). Similar LEK-based observations have been reported in the Colombian and Peruvian Amazon (Bogotá-Gregory et al. 2024; Poissant et al. 2024), particularly for large-bodied species (Hallwass et al. 2020). Threat perceptions differed between watersheds: 30% of Aguarico fishers reported no threats, versus only 4% in the Napo. While barbasco use and tourism were mentioned locally, oil contamination was the predominant concern, with implications for both ecosystem health and human health.

Nevertheless, fishers proposed practical measures, including size limits, bans on blast fishing, seasonal closures, and stricter barbasco regulation (Table S3). Communities with experience in co-management (e.g., Zábalo, Zancudo Cocha) showed the strongest support for formal agreements, highlighting the potential for community-led conservation. Comparable measures have supported population recovery of *Arapaima gigas* and *Osteoglossum bicirrhosum* in Colombia (Mora et al. 2017), although recommended measures differed, since gillnet restrictions were absent in our study.

Adaptive management is particularly important in tropical rivers, where ecological variability complicates sustainability (Berkes et al. 2000). Integrating LEK supports ecosystems resilience, biodiversity protection, and food security through culturally grounded strategies. Experiences from Zancudo Cocha and Zábalo illustrate how LEK can underpin effective community-based governance and could be shared with other Indigenous communities.

On the other hand, given the importance of fish in local diets, further research is needed to evaluate nutritional outcomes and to examine how environmental and social factors affect community health. Management measures such as closed seasons and protected habitats must ensure access to protein sources. LEK can support this balance by identifying species or areas that can be fished without jeopardizing reproductive cycles.

Furthermore, our results contribute to a growing body of evidence that positions Local Ecological Knowledge as central to the sustainability of tropical freshwater fisheries of the Amazon Drainage. Specifically, we show that LEK is not only a source of ecological insights but also reflects diverse governance capacities and market integration, with some communities actively transforming knowledge into localized conservation rules. This challenges the notion of uniform Indigenous environmentalism and highlights the need for context-specific engagement strategies. Thus, while previous research in the Amazon emphasized the descriptive value of LEK for identifying species or ecological patterns (Silvano and Begossi 2012; Campos-Silva and Peres 2016), our findings highlight its normative dimensions, informing on how knowledge is translated into community rules such as seasonal bans, and informal enforcement systems. By comparing Kichwa, Siona, and Cofán communities, this work reveals the diversity of governance pathways shaped by historical exposure to extractive industries, market integration, and collective action experiences.

Limitations and future research directions

This study documented LEK, fishing practices, and perceived threats across seven communities, enabling comparisons between watersheds but limiting depth on life history traits (e.g., trophic interactions, ontogenetic shifts) relevant to species distribution (Pereira et al. 2021). We did not include socioeconomic variables such as purchasing power or ice availability, which affect fishing intensity and sustainability. Our sample was male-biased (68%), so practices more common among women may be underrepresented. Translation during some interviews could also have introduced interpretive bias, as subtle nuances or culturally specific expressions may have been lost or altered in the process.

Moreover, some LEK elements, such as species identification or perceptions of threats, may be influenced by local narratives or incomplete information. While relying on self-reported CPUE introduces uncertainty, previous work shows strong alignment between fishers' reports and formal statistics (Poissant et al. 2024; Santos and Pelicice 2025), supporting LEK as a cost-effective monitoring tool in data-poor contexts, logistical and financially challenging settings. Unequal sample sizes among communities should also be considered when interpreting results.

Several communities, particularly Zábalo and Zancudo Cocha, are already using LEK to shape local governance through bans, quotas, and seasonal moratoria. However, formal integration of LEK into public policy in the Ecuadorian Amazon remains limited. This suggests that while LEK can inform adaptive governance, enabling mechanisms such as NGO partnerships, codeveloped management plans, and intercultural dialogues with state institutions are essential for translating knowledge into action.

Considering our results, future research on LEK and fisheries in the Western Amazon should prioritize participatory monitoring frameworks that engage Indigenous fishers as active co-researchers in documenting ecological change, rather than as just informants. In particular, trends in populations, capture sizes, and average maturation sizes of the most important species for fisheries are urgently needed, and could be gathered by community fisheries monitors. These collaborative approaches can contribute to data continuity, validate LEK across temporal scales, and enhance local ownership of conservation outcomes. Longitudinal studies that track shifts in fishing practices and governance norms over time would be particularly valuable for understanding how communities adapt to socioenvironmental pressures, including extractive activities and climate change. Integrating these participatory perspectives in the long term will promote the robustness of fish stocks and aquatic ecosystems assessments and foster more equitable and resilient models of co-management in the Amazon.

CONCLUSION

This study highlights the central role of Indigenous fishers' Local Ecological Knowledge (LEK) in understanding the ecological and social dynamics of Amazonian fisheries. Across the Napo and Aguarico watersheds, Kichwa, Cofán, and Siona fishers provided detailed insights into species behavior, seasonal abundance, spawning habitats, and migratory patterns, knowledge that is essential for sustainable management in data-poor contexts. While LEK was present in all communities, its translation into local rules and practices varied, shaped by factors such as social cohesion, market exposure, distance to cities, and history of collaboration with NGOs. These findings highlight that effective integration of LEK into conservation requires not only documenting knowledge but also strengthening the social and institutional conditions that support collective action. Adaptive co-management rooted in LEK can promote ecologically and culturally grounded governance, particularly through measures such as seasonal closures, gear restrictions, and lake-specific protections. Sharing results with participating communities supports local autonomy and co-produced fisheries agreements, contributing to both biodiversity conservation and Indigenous self-determination.

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DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

CONTRIBUTION STATEMENT

FUNDING DECLARATION

DISCLOSURE OF AI USE

The authors used ChatGPT and Grammarly to assist in improving language clarity and grammar. The content was reviewed and edited by the authors to ensure accuracy and appropriateness.

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Additional Files

Add File 2. Fish species harvested in commercial and subsistence fisheries, fishing gear employed to capture them and habitats where they are found according to the indigenous fishers.

Order	Family	Species	Fishing gear	Habitat
Myliobatiformes	Potamotrygonidae	*Potamotrygon* spp.	Hooks	Lakes and rivers
Osteoglossiformes	Arapaimidae	*Arapaima gigas*	Hooks, harpoon	Rivers
Characiformes	Anostomidae	*Leporinus agassizi*	Gill nets, cast nets, small hooks	Lakes and rivers
		Schizodon fasciatus	Gill nets, cast nets, small hooks, harpoon	Lakes and rivers
	Bryconidae	*Brycon hillarii*	Gill nets, cast nets, medium hooks	Rivers with deep channels
		Brycon melanopterus	Gill net, cast nets, medium hooks	Rivers with deep channels
	Curimatidae	*Potamorhina altamazonica*	Gill nets, cast nets, medium hooks	Lakes and rivers
		Potamorhina latior	Gill net, cast nets	Rivers
	Erythrynidae	*Hoplias malabaricus*	Gill nets, hooks, cast net, harpoon	Lakes, creeks, swamps and rivers
	Prochilodontidae	*Prochilodus nigricans*	Gill nets, cast nets	Lakes and rivers
	Scinodontidae	*Hydrolicus scomberoides*	Gill nets, small to medium hooks	Rivers
	Serrasalmidae	*Colossoma macropomum*	Hooks, gill nets, cast net	Lakes and rivers
		Mylossoma albiscopum	Gill nets, cast net, hooks, harpoon	Rivers
		Piaractus brachipomus	Gill nets, hooks, cast net	Lakes and rivers
		Pygocentrus nattereri	Gill nets, cast nets, small to medium hooks	Lakes and rivers
		Serrasalmus rhombeus	Gill nets, cast nets, small to medium hooks	Lakes and rivers
Siluriformes	Doradidae	*Oxydoras niger*	Gill nets, cast net, harpoon	Lakes and rivers
	Loricariidae	*Panaque schaeferi*	Gill nets, cast net, hooks, harpoon	Rivers
		Panaque titan	Gill nets, cast net, hooks, harpoon	Rivers
	Pimelodidae	*Brachyplatystoma filamentosum*	Large hook	Rivers with deep channels

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Order	**Family**	**Species**	**Fishing gear**	**Habitat**
		Brachyplatystoma juruense	Large hook	Rivers with deep channels
		Brachyplatystoma platynemum	Large hook, gill nets	Rivers with deep channels
		Brachyplatystoma punctifer	Cast net, gill nets, large hooks	Rivers with deep channels
		Brachyplatystoma tigrinum	Large hook, gill nets	Rivers with deep channels
		Brachyplatystoma vaillantii	Large hook	Rivers with deep channels
		Calophysus macropterus	Medium hooks, harpoon, gill nets, cast net	Rivers
		Hemisorubim platyrhynchos	Medium hooks, gill nets	Rivers
		Leiarius marmoratus	Medium hooks	Rivers
		Phractocephalus hemioliopterus	Large hook	Rivers
		Pimelodus blochii	Gill nets, cast nets, small hooks	Rivers
		Pinirampus pirinampu	Large hook	Rivers
		Platynematichthys notatus	Large hook	Rivers
		Pseudoplatystoma punctifer	Gill nets, large hooks	Rivers with deep channels
		Pseudoplatystoma tigrinum	Gill nets, cast nets, large hooks	Rivers with deep channels
		Sorubimichthys planiceps	Large hook	Rivers
		Zungaro zungaro	Large hooks, harpoon	Rivers
Perciformes	Cichlidae	*Cichla monoculus*	Medium hook	Lakes and rivers
	Sciaenidae	*Plagioscion squamosissimus*	Gill nets, medium hooks	Lakes and rivers
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Add File 3: Sale price by fish species in the indigenous communities of the study area.

Species	Fishing site	Price/pound $
Limoncocha		
Aequidens tetramerus		2.5
Astronotus ocellatus		2.5
Hoplias malabaricus		2
Hydrolicus scomberoides		2–2.5
Oxidoras niger		2–2.5
Plagioscion squamosissimus		2.5
Potamorhina altamazonica	Limoncocha Lake	2.5
Prochilodus nigricans		2–2.5
Pterygoplichthys pardalis		1.5–2
Pygocentrus nattereri		2–2.5
Schizodon fasciatus		2
Serrasalmus rhombeus		2
Pañacocha		
Aphanotorulus unicolor		1.5
Astronotus ocellatus		1.5
Brachyplatystoma punctifer		2
Calophysus macropterus		1.5
Hemisorubim platyrhynchos		1.5
Mylossoma albiscopum		1.5
Piaractus brachipomus	Napo and Pañacocha Rivers	1.5
Potamorhina altamazonica		1.5
Prochilodus nigricans		1.5
Pseudoplatystoma tigrinum		2
Pseudoplatystoma vaillantii		2
Pterygoplichthys pardalis		1.5
Sorubim lima		1.5
Pompeya		
Pimelodus blochii		1.5
Plagioscion squamosissimus		1.5
Prochilodus nigricans		1.5
Pseudoplatystoma tigrinum		1.5
Schizodon fasciatus		1.5
Brycon melanopterus		1.5
Calophysus macropterus		1.5
Mylossoma albiscopum		1.5
Platynematichthys notatus	Indillama and Tiputini Rivers	1.5
Pseudoplatystoma punctifer		1.5
Zungaro zungaro		1.5
Aphanotorulus unicolor		1.5
Hoplias malabaricus		1.5
Leporinus agassizi		1.5
Pterygoplichthys pardalis		1.5
Serrasalmus rhombeus		1.5
Sorubim lima		1.5
Sotosiaya		
Arapaima gigas	Cuyabeno River	2.5
Zancudo Cocha		
Brachyplatystoma tigrinum		1.5
Leiarinus marmoratus		1.5

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Species	Fishing site	Price/pound $
Pimirampus pimirampu		1.5
Platynematichthys notatus		1.5
Pseudoplatystoma punctifer		1.5
Pseudoplatystoma tigrinum		1.5
Cichla monoculus	Lagartococha River	1.5
Bujurquina sp.		1.5
Mylossoma albiscopum	Pacuya River	1.5
Piaractus brachipomus		1.5

Add File 4. Compilation of fishers quotes on fish LEK, perceptions on the state on fisheries and ideas on necessary regulations.

Topic	Example statement
FISHERS ECOLOGICAL KNOWLEDGE	
Fish movements and migration patterns	"Fish such as bocachico and pirañas access Limoncocha Lake from the Napo River to find refuge against predators". (Bocachico is the common name of the migratory fish *Prochilodus nigricans*, pirañas refer to species of Serrasalmidae of the genera *Serrasalmus* as well as *Pygocentrus nattereri*). [P-01-LI].
	"Bocachicos move to Zábalo River during October and March to feed". (Bocachico is the common name of the migratory fish *Prochilodus nigricans*). [P-16-ZAB].
Fish reproduction	"Viejas reproduce in Zabalo River". (Viejas is the common name to refer to Cichlidae species). [P-24-ZAB].
	"Viejas put their eggs and raise in Zancudococha Lake. Large catfish reproduce in the upper Aguarico". (Viejas is the common name of Cichlids and large catfishes refer to Pimelodidae species). [P-33-ZAN].
	"Paiches reproduce during december in Zancudococha Lake". (Paiche is the common name of *Arapaima gigas*). [P-35-ZAN].
	"Fishes don't put their eggs in the Indillama River". [P-06-POM].
	"Arawanas, viejas and carachamas breed in Pañacocha Lake". (Arawana is the common name for *Osteoglossum bichirrhosum*, viejas refers to Cichlids and carachamas are catfishes of the family Loricariidae, mainly *Pterygoplichthys multiradiatus* in Pañacocha Lake). [P-15-PA].
Importance of water bodies and fish	"Cuyabeno River is everything for my community, food, mobility and transportation". [P-53-PB].
	"Fish could be used as bioindicators in the Aguarico River". [P-53-ZAN].
	"In Puerto Bolívar, we have the cultural party of the paiche". [P-51-PB].
Natural phenomena affecting fish populations	"Achacaspi disappeared from the Aguarico River after a landslide caused by an eruption of the Reventador Vulcano". (Achacaspi is the common name of the catfish *Sorubimichthys planiceps*). [P-39-ZAN].
FISHERS' KNOWLEDGE ABOUT THE STATE OF FISHERIES	
Changes in fish populations	"Before in Pañacocha, one threw the hooks and catch fish immediately, now you have to invest a lot of time". [P-12-PA].
	"Years ago, when we fished in the Aguarico we captured larger fish, and more". [P-40-ZAN].
Threats to fisheries	"nocturnal blast fish with dynamite and barbasco are threatening Limoncocha". [P-01-LI].
	"In the last five years there's been three oil spills in the Napo River, threatening fish. Besides, norms about fisheries are not respected". [P-15-PA].
	"Waves from ships make fishing in the Aguarico River harder". [P-17-ZAB].

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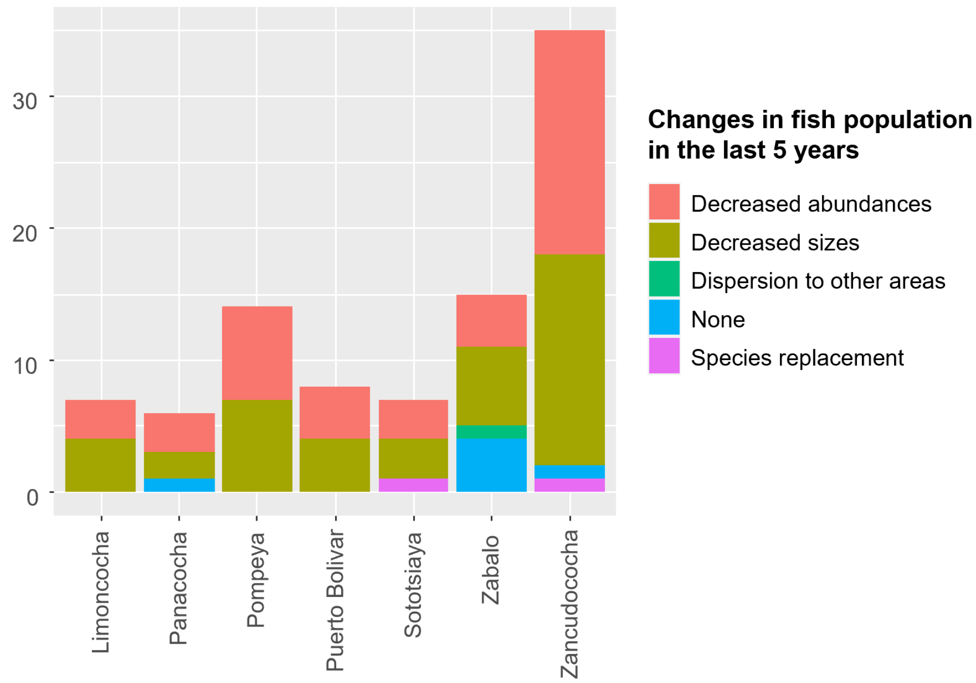
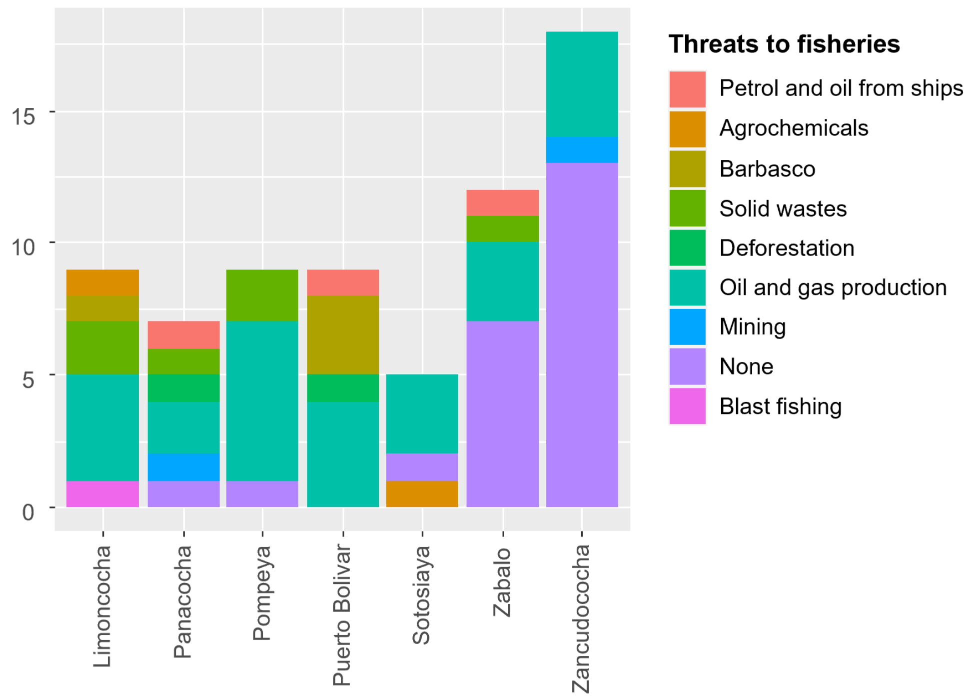
Topic	Example statement
	"When palm crops are fumigated dead fish appear in the Aguarico, near my community". [P-49-SO].
FISHERS' THOUGHTS ABOUT NECESSARY REGULATIONS	
Alternative activities to fisheries	"We could catch fish from Limoncocha Lake and raise them in pools". [P-03-LI].
Fisheries management	"We need bans and to prohibit blast fishing in Limoncocha". [P-02-LI].
	"We should not catch in excess. If the community agrees, I would accept regulations". [P-05-POM].
	"I would like to patrol Napo River. We need norms to preserve fish". [P-14-PA].
	"We should use nets with large holes to catch only large fish in Pañacocha". [P-15-PA].
	"We should have maximum and minimum catch sizes in Zancudococha". [P-34-ZAN].
	"My community (Zancudococha) wants to establish controls to fishing and that all people living in the community participate". [P-35-ZAN].
	"We need to regulate catch sizes and establish quotas in Zancudococha". [P-38-ZAN].
	"In Zábalo, only people from the community should fish". [P-39-ZAB].
	"I would like to be monitor of fisheries in Zábalo". [P-16-ZAB].





Add File 5. Fishers' perceived changes in fish populations in the last five years (top) and perceived threats to fisheries (bottom) in the seven communities involved in this study.