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# Fisheries in a border area of the Moxos Lowlands (Bolivia) after invasion of *Arapaima gigas*

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## Abstract

Fish in the upper Madeira River basin (Bolivian Amazon) are an important source of livelihoods and protein for both rural and urban human populations. We characterised fisheries in the area of the port city of Riberalta, which possesses some of the most important fisheries landing sites bordering the Moxos lowlands, and evaluated the contribution of an invasive species (*Arapaima gigas*) to the landings. We compared the regional economic contribution of urban-based and rural indigenous fisheries. Both fisheries contribute significantly to local food security and livelihoods and take advantage in a different but complementary way of the abundance of the invasive species, avoiding conflicts by partitioning the fish catch and supplying different urban markets. Both fisher groups are involved in a debt peonage system making them dependent on middlemen. *A. gigas* represented 57.6% of the overall economic value of fish in the region. The socioeconomic impact of the invasive species might increase considerably if it would invade and colonise the available habitats in the nuclear area of the Moxos lowlands.

**KEYWORDS**

Amazon, fisheries in developing countries, impact, indigenous people, invasive species

## 1| INTRODUCTION

Fisheries are one of the main productive activities in the Amazon floodplain (Cerdeira et al., 2000; Doria et al., 2018; McGrath et al., 1998, 1999). Bayley & Petrere (1989) estimated an annual fish yield of more than 100,000 tons (t) in the Amazon in 1988, whereas Ruffino & Roubach (2007) estimated an average of 123,000 t/year for the Brazilian Amazon alone, between 1996 and 2006. Based on fish consumption data, actual production figures are likely more than three times higher, due to significant subsistence fisheries whose catch is not registered by the formal data collection systems (Isaac & Almeida, 2011). All these production estimates deal exclusively with native species, as introduced species were not contributing significantly to inland fisheries landings before 2010.

The fish value chains of the Bolivian Amazon, including urban and indigenous fishers, middlemen and retailers, sustain livelihoods for a significant proportion of the local population (Doria et al., 2018). However, the contribution of this food resource to local welfare and food security is still undervalued (Coca Méndez et al., 2012; Van Damme et al., 2022). One of the most important areas in terms of fish production is the northern part of the Bolivian Amazon, a border area of the Moxos lowlands (Figure 1), contributing approximately 30% of the

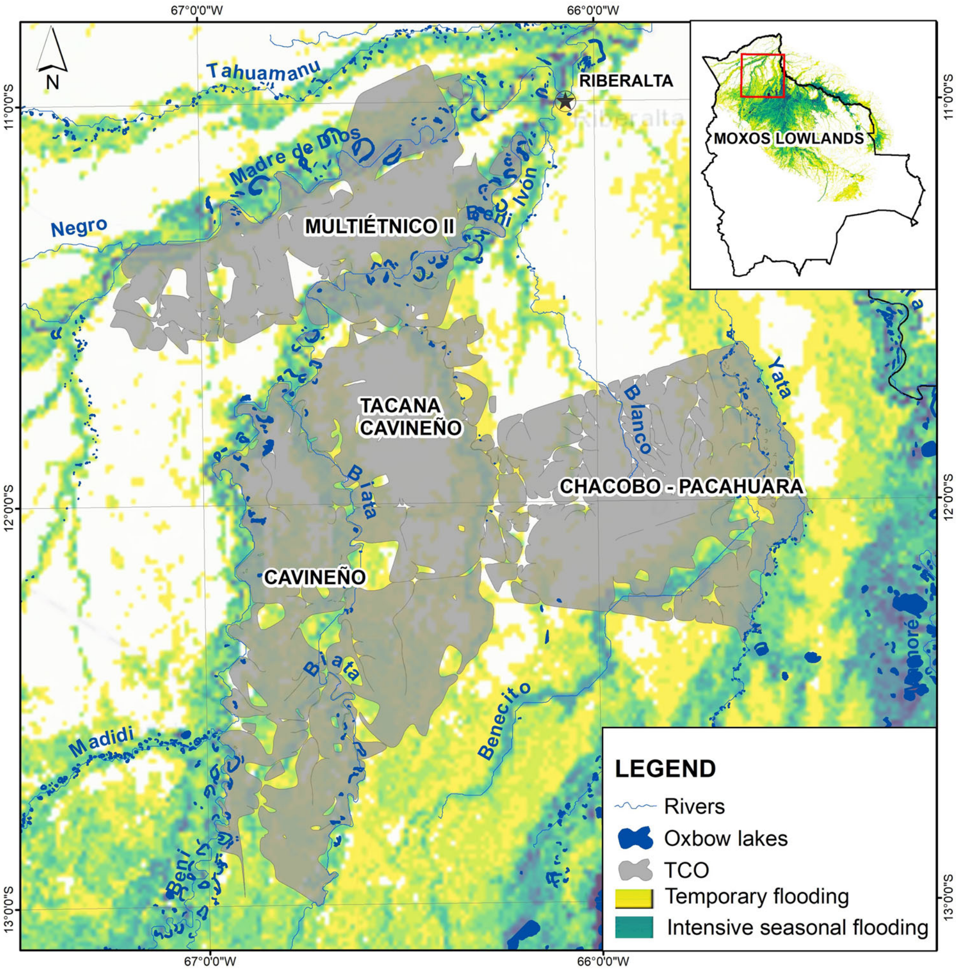


**FIGURE 1** Fishing area in the northern Bolivian Amazon. Commercial fishers use all rivers and oxbow lakes depicted in the study area, whereas indigenous fishers use only oxbow lakes within the TCO. The Bolivia map inserted (Fleischmann et al., 2022) shows the location of the study area in the northwest border of the Moxos lowlands

total fish catch of the river basin (Van Damme et al., 2011). Based on an official population census (INE, 2001) and interviews at landing sites, these authors estimated the presence of more than 400 fishers in this region, most of them affiliated with fisheries associations. The main landing sites are Guayaramerín, Cachuela Esperanza, Villa Bella, Puerto Rico, Rosario del Yata, Porvenir and Riberalta, the latter contributing the major part of the commercial landings (Van Damme et al., 2011). Coca Méndez et al. (2012) estimated that 209 urban-based fishers and 106 indigenous fishers landed fish regularly in Riberalta in August and September of 2011, the latter mainly extracting fish from the indigenous territory (TCO) Territorio Indígena Multiétnico (TIM) II, which is located close to the confluence of the Beni and Madre de Dios rivers (Figure 1).

In the last decade, fish landings in this region have become dominated by the invasive non-native *Arapaima gigas* (local name paiche). Individuals of this species escaped from aquaculture facilities in the southern Peruvian Amazon (upper Madre de Dios basin) in the 1960s (Miranda-Chumacero et al., 2012) and from there invaded northwestern Bolivia in the early 1980s (Carvajal-Vallejos et al., 2017; Macnaughton et al., 2015; Van Damme et al., 2015). The species is one of the largest scaled freshwater fish, with an omnivorous to carnivorous diet (Villafán et al., 2020), reaching a length of 4 m and a weight of 200 kg (Castello, 2004; Castello et al., 2011a). It dwells in slow flowing rivers and shallow floodplain lakes. The species is carnivorous and is suspected to impact the native fish fauna (Macnaughton et al., 2015; Miranda-Chumacero et al., 2013). The species has come to dominate landings in the northern Bolivian Amazon in a relatively short period of time after its first record in commercial catches in 2001 (Farell & Azurduy, 2006).

Fish is an important protein source in the northern Amazon. In the dry season of 2011, more than 70 fish species were sold in the urban markets of Riberalta, with daily sales of at least 450 kg (Coca Méndez et al., 2012). The national fish consumption is estimated at 1.8 kg per capita (Bombin et al., 2009), but fish consumption in Riberalta is higher, approximately 4 kg/person/year (Pérez et al., 2014), still well below the fish consumption in neighbouring countries (FAO, 2020; Pérez et al., 2014). Nevertheless, the demand for fish meat in urban zones is increasing steadily (Van Damme et al., 2022). In the past decade, the arrival of paiche and the increasing demand for fish in Bolivian urban centres has given a boost to the fisheries sector. Fishing has become an increasingly important productive activity, generating employment and supplying protein to national, regional and local markets. However, its real contribution to society has not been studied in detail and most of the information has been obtained through interviews and unreliable fisheries statistics. The present document characterises urban-based and rural indigenous fisheries after paiche invasion, estimates their contribution in terms of provision of fish as food source and estimates overall investments, revenues and profit by the fisheries sector in this border area of the Moxos lowlands. We give special recognition to the role of women in the fish value chain.

## 1 | MATERIAL AND METHODS

### 1.1 | Study area

The study area is situated in the northwestern border of the Moxos lowlands (Bolivian Amazon), upstream of the Madeira rapids. This area comprises rivers south of the town of Riberalta, upstream of the confluences of the Orthon, Madre de Dios and Beni rivers (Figure 1). This zone includes a mosaic of small and large rivers, oxbow lakes and flooded forest. The total surface area of oxbow lakes, which are the main fishing sites in the study area, is approximately 454 $km^2$ (Crespo & Van Damme, 2011).

Urban-based commercial fishers operate both in rivers and, mainly, in lakes. Fishing of native species in rivers is forbidden by the regional government during the high-water season between November and February, coincident with fish spawning migrations. The rivers are mostly used as transportation routes to access floodplain lakes, approximately 70% of which are situated in the communal territories of indigenous people (TCOs): Chacobo Pacahuara, Cavineño and Multiétnico II (Figure 1). Indigenous livelihoods and subsistence in these territories are based on a mixture of small-scale agriculture, fishing, hunting and gathering of forest products (Macnaughton et al., 2015). Although these indigenous communities have territorial ownership, the access rights to the aquatic resources, including fish, are not clearly established, and some lakes are exploited by the urban-based fishers. However, in the last years many indigenous communities have increased commercial exploitation of native fish in their lakes, which are sold to truck drivers or sent by public transport to Riberalta. Fish captured in the area is transported to fish markets in Riberalta by land or water or to national markets by land or airplane.

### 1.2 | Methods

The study was conducted through monitoring of both urban-based commercial fishing and rural (indigenous) commercial fishing from August 2011 to July 2012 in the Madre de Dios and Beni lower river basins. Different methods were used to characterise the fleets and assess the economic value of the landings.

#### 1.2.1 | Fleet characterisation

The fishing fleets were characterised and overall investment costs estimated. An inventory of fixed assets of the fishery units was carried out through interviews with boat owners, during visits at landing sites in Riberalta and during visits of communities in TCO Multiétnico II, during the hours of maximum landings (generally in the morning and the evening). The information on landings was cross-checked with the list of fisheries units provided by the 'Capitanía de Puerto Mayor de Riberalta' and by interviews of leaders of Riberalta fishing and vendor organisations: ASOPESAR (Asociación de Pescadores Amazónicos de Riberalta), ASOPRYC (Asociación de Pescadores, Piscicultores y Comercializadores de Beni y Pando) and MANANTIAL (Asociación Mixta de Comerciantes, Pescadores Manantial Campesino).

The interviews of fish boat owners included questions on the active assets (boat, supplementary boats, motors, ice transportation facilities, fishery equipment, etc.). Also, questions were included on the economic value of the fixed assets, the life expectancy of equipment, the state of the assets and the costs of maintenance. Approximately 90% of urban boat owners were interviewed and 26% of the indigenous fishery units (which are more dispersed in the TCOs).

For facilitating economic analysis and data interpretation, fishery units were classified in categories with similar investment levels (Table 1). In the case of the urban fleet, the classification (in four categories: C1–C4) was based on ice storage capacity; more than 1000 kg, between 501 and 1000 kg, between 201 and 500 kg and less than 201 kg. All of these urban boats operated at least 9 months per year. In the case of indigenous fishing, classification (I1–I3) was based on the length of the period fish is transported to Riberalta: 12 months per year, between 4 and 7 months per year (from March to October) and 3 months per year or less (especially in July and August). This category reflects the extent to which indigenous livelihoods are based almost exclusively on fishing (I1) or also on other seasonal activities, such as small-scale agriculture and Brazil nut harvesting (I2, I3). A fourth indigenous category (I4) included fishers who provided fish to the markets on an irregular basis. Table 1 shows the number of landings registered per year for each of the categories.

#### 1.2.2 | Daily monitoring of landings

Daily monitoring of landings by urban fishers at landing sites in Riberalta was carried out, as were landings and transport of fish catch by rural indigenous fishers. Data collection was done by local technicians from the fishing organisations, assisted by the authors. The forms included questions on the fishing area, the weight of fish caught per species, the final product destination, price per species and the cost of the fishing trip (ice, combustible, oil, payment to fishers, food, maintenance, etc.). In the case of large-sized fish (paiche, surubi), the fish arrived without heads, which is assumed to be 10% lower than their total weight. The rural catch, referred to as 'indigenous fish landings',

**TABLE 1** Number and characterisation of urban-based and rural indigenous fishery units

| | Urban fisheries | | | | | Indigenous fisheries | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | | I1 | I2 | I3 | I4 | |
| | Ice capacity (kg) | | | | | Months of fishing per year | | | | |
| | >1000 | 501–1000 | 201–500 | ≤200 | Total | 8–12 | 4–7 | ≤3 | Sporadic | Total |
| Number of fishery units | 8 | 21 | 15 | 13 | 57 | 25 | 22 | 9 | ** | 56** |
| Number of fishers per unit | 43 | 92 | 47 | 30 | 212 | 50 | 44 | 18 | ** | 112** |
| Total number of landings registered | 75 | 246 | 71 | 51 | 443 | 1167 | 373 | 349 | 74 | 1963 |
| Total weight of landings (t) | 58.2 | 132.2 | 12.4 | 2.6 | 205.3 | 49.1 | 18.3 | 18.4 | 12.9 | 98.7 |
| Mean investment per fishery unit ($US) | 9490 | 5481 | 1793 | 889 | | 1105 | 1200 | 1105* | 2445* | |

*Estimated value: due to high level of dispersion, the number of owners interviewed was not adequate to be confidently representative of the class.
**Total does not include fishers of the I4 category (see text).

was individually labelled, enabling the tracing of the catch origin. In total, 443 landings by urban fisheries were registered: 75, 246, 71 and 51 for the fishery units of categories C1, C2, C3 and C4, respectively (Table 1). Besides, 1,963 indigenous fisheries landings were registered: 1,167, 373 and 349 by fishery units of categories I1, I2 and I3, respectively. Seventy four (74) landings were additionally reported for category I4 (Table 1), but these are not included in the totals, because of the opportunistic nature of their activity and because they transported landings of more than one indigenous fishing unit.

The monitoring of the urban fishing units was done at the landing sites of Riberalta, representing close to 100% of all the permissions granted by the 'Capitanía del Puerto Mayor de Riberalta'. Monitoring was a bit less efficient for smaller fishery units because these landed fish close to their riverine houses and did not always arrange permissions. The monitoring of rural indigenous fishery units, which send coolers by river or highway from their communities to Riberalta, was done daily in the home of the receiving fish middlemen or in the Abasto market in Riberalta. The coolers were opened at these sites, and fish were classified and weighted. One filled cooler is considered to be equivalent to one landing, which was confirmed through interviews, except for the I4 category where the coolers contained a mix of individual landings. Overall, approximately 70% of the fish sent by indigenous fishers was monitored.

In both urban and indigenous fishing, the native fish species are classified in three categories, using size and meat quality as criteria. First class native species are mainly the larger Siluriform and Characiform species, the second-class species are large Siluriformes with lower meat quality and the third class are mainly medium-sized species of different orders. The composition of each group and list of scientific names are provided in Annex 1.

### 1.2.3 | Economic analysis

The profit by fishing trip was calculated from the income obtained from selling fish, minus the operating costs during the trip, such as fuel, ice, payment to the crew, food of the crew, equipment maintenance (e.g. boat repair) and equipment depreciation. Fishing effectiveness was calculated as economic efficiency (EE), which is the relationship between gross income and cost per fishing trip and as the return on investment (ROI), which is the relationship between the annual profit and investments (boat, motor and fishing equipment purchase). The results were used for a calculation of the average cost effectiveness for each category.

## 2 | RESULTS

### 2.1 | Fishery fleet characterisation

The fishery fleet of Riberalta consisted of registered urban fishery units (with boat owners living mostly in peri-urban Riberalta) and informal indigenous fishery units (indigenous boat owners) primarily based in rural indigenous territories. The urban-based fleet consisted of 57 units (Table 1): eight possess ice holding capacity of above 1000 kg (C1), 21 have ice holding capacity of between 501 and 1000 kg (C2), 15 have a capacity of between 201 and 500 kg (C3) and 13 have ice capacity of less than 200 kg (C4). On the other hand, there were 56 indigenous fishing units sending fish to Riberalta for months of the year or more (I1, I2). Twenty-five units sent fish more than 7 months of the year (I1), 22 sent fish between 4 and 7 months of the year (I2) and nine sent fish during 3 months or less (I3). These units sent fish to Riberalta with a relatively constant periodicity. Additionally, an unknown number of units send fish sporadically and irregularly throughout the year (I4) (Table 1).

The urban fishery units of the different commercial categories (C1–C4) varied in terms of type, size and number of boats, motors, ice boxes and fishing material. Two types of boat are used in the area: larger boats locally called ‘santarem’ (weighing on average 7.8 t) and chalupa boats, a local name used for the traditional canoe. A typical unit consists of one santarem and one or two accompanying chalupas, one motor (capacity between 16 and 18 hp), one wooden or aluminium ice box cooler and an average of six fishing nets for the capture of paiche and 15 nets for the capture of native species. The smaller units use only one chalupa boat (approximately 0.9 t) equipped with a small motor (capacity between 5 and 13 hp), with a second-hand freezer used as the ice box cooler and an average of three fishing nets used exclusively for native fish species. Based on interviews with boat owners, the mean investment per urban fishery unit was between $US 889 (C4) and $US 9490 (C1) (Table 1). There are also marked differences in how the fishing was organised amongst the different categories. The fishery units of the two largest categories (C1, C2) travelled on average 13 days per trip and used a boat crew of four fishers, including the captain, whereas the intermediate-sized units (C3) travelled on average of 9 days, with a crew of two fishers. The smallest units (C4) travelled on average 3 days and generally operated with two fishers (Table 2).

In comparison, the indigenous fishing units generally consisted of chalupa-type boats less than 1 t in weight, constructed with local wood, such as cedro, palo maria or ochoo. These carried a wooden ice box cooler, two oars, hooks, one fishing line, eight fishing nets for the capture of native species, a large knife (machete), a smaller knife, lead weights, rope and a torch. They possessed one or two coolers for ice and fish transport, with an ice capacity of 50–200 kg. Some units possessed an outboard motor (between 5.5 and 6.5 hp), one or two nets for the capture of paiche and a second-hand freezer. The indigenous fishery units were less specialised, with the boats often used for other purposes besides fishing, such as the transport of passengers and goods. The investment in this type of fishery unit was between $US 1105 and $US 1200. The I4 category is not considered in this analysis, as this investment included multifunctional boats that send fish sporadically throughout the year (Table 1). The logistics of indigenous fisheries is complex due to the large distance (on average 200 km) between the communities and Riberalta. Transport was mainly by motorcycle or by river. A fishing cycle generally started with the trip of the fisher (mostly the boat owner) by river to the closest crossing point with a highway or road to receive the ice box (of between 50 and 200 kg ice capacity) sent by truck by a middleman, together with other supplies, such as food for

**TABLE 2** Fisheries landings and trip characteristics in urban and indigenous fisheries. Description of the categories are provided in Table 1. Values are mean ± standard deviation

| | Urban fisheries | | | | Indigenous fisheries | | | |
|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | I1 | I2 | I3 | I4 |
| Mean weight of landings (kg) | 776 (±362) | 537 (±261) | 174 (±107) | 51 (±36) | 42 (±24) | 49 (±28) | 53 (±43) | 174 (±114) |
| Mean duration of fishing trips (days) | 13 (±4) | 13 (±3) | 8 (±4) | 3 (±2) | 3* | 3* | 3* | ** |
| Mean number of fishers per fishing trip | 4 (±2) | 4 (±2) | 2 (±1) | 2 (±1) | 2* | 2* | 2* | ** |
| Mean landing per unit effort (CPUE) (kg/day/fisher) | 18 (±12) | 13 (±8) | 15 (±13) | 10 (±8) | 13* | 14* | ** | ** |
| Total weight landed per fishery unit along study period (t) | 6.3 (±4.2) | 6.4 (±4.5) | ** | ** | 2.0 (±1.5) | 0.8 (±0.4) | ** | ** |
| % Paiche | 73 | 78 | 43 | 15 | 17 | 13 | 31 | 30 |
| % Native species | 27 | 22 | 57 | 85 | 83 | 87 | 69 | 70 |

*Estimated value based on interviews with boat owners.
**Insufficient data.

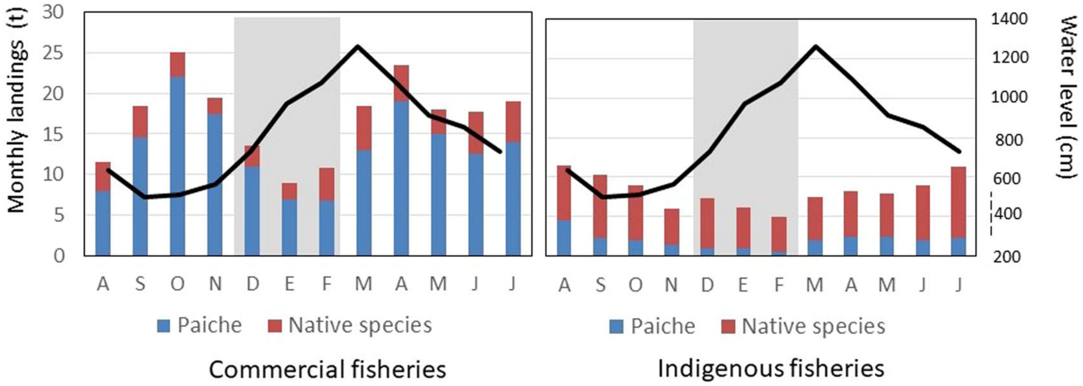


**FIGURE 2** Monthly fish landings by urban and indigenous fishers in the Riberalta area over a hydrological cycle (2011–12). The grey bar in the background shows the period during which fisheries of native species (but not of paiche) is formally closed by regional authorities (December–February). The black line represents the water level

the fisher's family. From this moment on, the fisher and aide had a maximum of 3 days to fill the box with fish, before the ice all melted. Fishing started generally with the nets placed in the evening (from 5:00 p.m. to 10:00 p.m.) and checked in the morning (6:00 a.m.), followed by the cleaning and icing of the fish (7:00 a.m.–9:00 a.m.). In general, a crew of two fishers needed two nights and 2 days for a catch of approximately 50 kg, after which the fisher transported the fish box to the same meeting point with the truck, from where it was transported to the middleperson's house.

The debt peonage system, which is the system of dependence of fishers on middlemen or middlewomen, locally called *habilito* (Macnaughton et al., 2015), consists of the middleman or woman providing credit for operational costs of fishing in return for exclusive rights to market the fish caught. This system is in place for both indigenous (90% of interviewed fishers) and urban fishers (68%). However, whereas in urban fisheries the middlemen primarily provide only ice, in indigenous fisheries they provide fuel, food and fishing supplies in addition to ice.

## 2.2 | Fish landings

In the year sampled (2011–12), fishing in the Riberalta area provided the national and local markets with 304 tons of fish, 67.5% (205.3 t) of which was landed by urban fishers and 32.5% (98.8 t) by indigenous fishers. Lowest overall monthly landings were reported from December to February, coinciding with the rainy season, during which fishing of native species is prohibited by regional authorities to protect spawning schools. This prohibition is only partly followed by fishers, as landings of native fish actually continue (Figure 2). As also indicated in this figure, paiche catches declined during the highwater period in both the urban and indigenous fisheries. Reduced paiche landings were also observed in August in the urban-based fisheries.

Intermediate-sized urban fishery units (C2) were responsible for 43.5% of the total landings, whereas the larger units, with ice capacity above 1000 kg (C1), contributed 19.1%. Indigenous fishery units

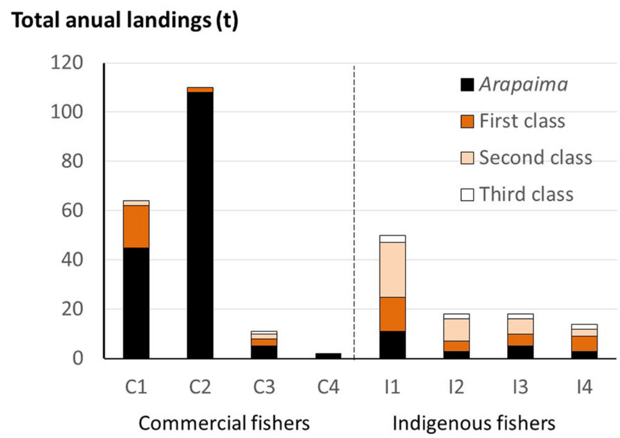


**FIGURE 3** Annual landings by urban and indigenous fishery units in the lower Beni and Madre de Dios tiver basins. See Annex 1 for native fish classification

I1 contributed 16.1%. Approximately 84% of paiche were captured by urban C1 and C2 fishers (Figure 3). Paiche contributed 60% to total landings, and the remaining 40% consisted of a range of native species, a list of which is provided in Annex 1. Of the 205.3 t landed by urban fishers, 78.3% was composed of paiche and 21.7% by native species. On the other hand, of the 98.8 t landed by indigenous fishers, 23.3% was composed of paiche and 76.7% of native species.

Urban fishing was mainly dedicated to the fishing of paiche (160.7 t) and first-class native species 35.5 t (17.3%), with a low contribution of second-class (7.3 t; 3.6%) and third-class species (1.7 t; 1.7%) (Figure 3). On the other hand, the indigenous fishery was mainly dedicated to the fishing of native fish species, with 46.6 t of second-rated fish (41.1%), 28.7 t of first-rated (29.0%) and 6.5 t of third-rated fish (6.6%), compared to 23.0 t of paiche.

The duration of the fishing trip depended on the size of the units. The indigenous fishery unit and the small urban units (C4) made fishing trips of 3 days, on average, while the medium (C3) and largest urban fishing units (C1) undertook average trips of 8 and 13 days, respectively

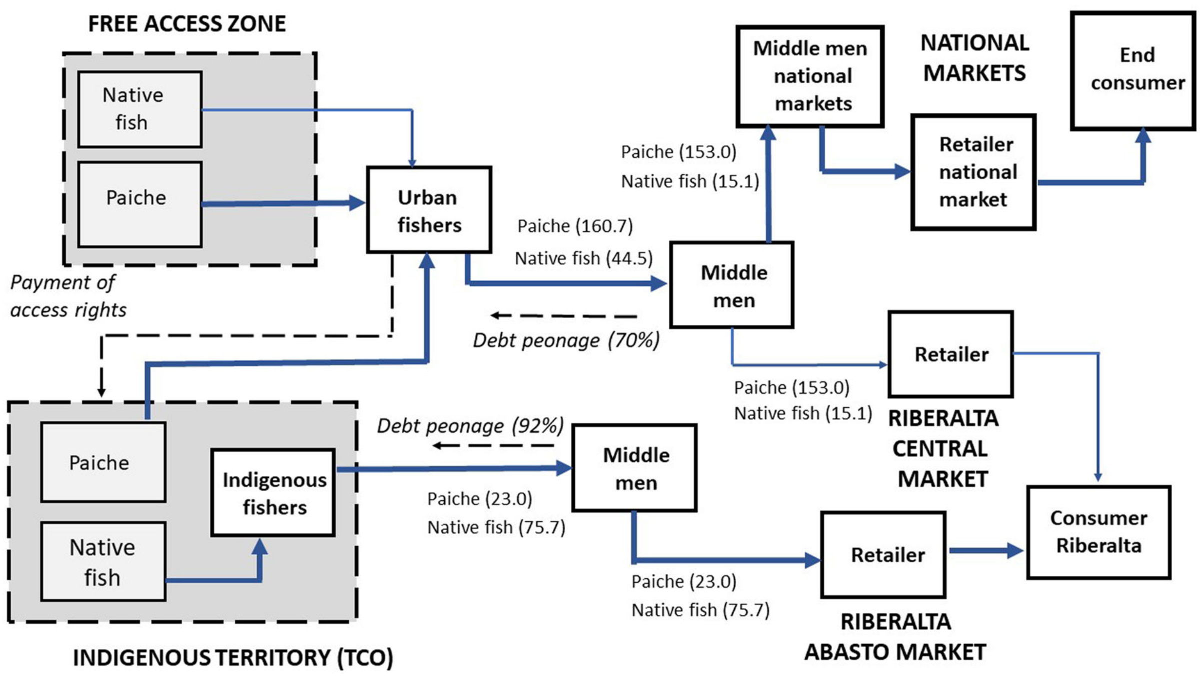


**FIGURE 4** Simplified fish value chain in the study area. The dark arrows show main flow of fish meat, the narrow arrows show minor flow. Total annual fish weight commercialised (in t) is indicated between brackets. Debt peonage is in % of fishers with debts. Brazilian markets are small and are not shown

(Table 2). Landing volumes were very different between urban groups, ranging from an average of 51 (C4) to 776 kg per trip (C1). There was little difference in the average landed volumes of the different indigenous categories, between 42 (I1) and 53 kg (I3). The fishers belonging to the I4 category, only occasionally transporting fish to town, land on average 174 kg, probably combining landings of several indigenous fishing units. Overall, payments to the crew were higher in the larger urban fishery units (Table 2).

Commercial strategies differed between fishery units. Of the total landings of urban units, 96% of paiche (153.6t) was exported to other cities in Bolivia ('national markets') and the remaining 4% was sold in Riberalta ('local markets'). 34% of the native species were sent to other cities in Bolivia and 66% was sold in Riberalta. On the other hand, of the landings of the indigenous fishing units, 100% of the paiche (23 t) and of native species (75.7 t) were sold in Riberalta (Figure 4).

## 2.3 | Economic analysis

Paiche represented 57.6% of the overall economic value of fish in the region. About 89% of this value was contributed by urban fishers. On the other hand, the largest part (56.7%) of the economic value of native fish was contributed by indigenous fishers.

Fish prices show high variability throughout the year, with higher prices recorded in the months with high water levels (December–April) and reaching a peak around Holy Week (March–April), when demand increases. Meanwhile, during the low water season (August–November), fish supply is higher and prices fall. Some fishers (especially urban fishers) temporarily leave fisheries activity due to the low prices paid per unit weight, leading to a drop in the capture of paiche, especially notorious in August (Figure 2). The first-rated native species (*Colossoma macropomum*, *Brycon amazonicus*, *Brachyplatystoma rousseauxii*) presented better and more stable prices in comparison with second-rated and third-rated native species (Figure 5) (see scientific names and price classes for all species in Annex 1). Urban fishers generally received higher income per weight than indigenous fishers. The price of paiche obtained by commercial fishers ranged between 1.5 and 2.6 US$/kg, higher than the price obtained by indigenous fishers, which ranged between 1.0 and 2.4 US$/kg (Figure 5). The price received by indigenous fishers for native species was on average 30% lower than the price received by urban fishers.

The average income per indigenous landing was between $US 1586 for the large urban units (C1) and $US 112 for the small fishing units (C4) (Figure 6). The larger units (C1, C2) obtained the majority of this income from the sale of paiche, whereas the small fishing units (C3, C4) obtained this income mostly selling native fish species (Table 3). On the other hand, indigenous fishing units had an average income per landing of $US 90 (I2) to $US 87 (I3), mainly from the sale of native species of fish (Table 3). Fuel costs were a distinctively lower component of cost in indigenous fisheries, as fewer of the boats were motorised.

Urban fishers had higher total annual profits than indigenous fishers. For example, the C2 urban fishers, travelling an average of 13 days with 4 crew members per fishing trip, generated a profit per trip of $US 364 and an annual profit of approximately $US 4261, equivalent to 2.5 times the national minimum salary. Indigenous I1 fishers on the other hand, travelled an average of 3 days with two crew

**TABLE 3** Costs, average income and economic efficiency per landing in urban and indigenous fisheries. Description of the categories are provided in Table 1

| | Urban fisheries | | | | Indigenous fisheries | | | |
|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | I1 | I2 | I3 | I4 |
| Payment to crew | | | | | | | | |
| Total number of fishers | 43 | 92 | 47 | 30 | 50 | 44 | 18 | ** |
| Mean number of annual landings per fishery unit | 9 (±6) | 12 (±7) | ** | ** | 47 (±23) | 17 (±7) | ** | ** |
| Total number of fisher working days per year | 3963 | 11,194 | 1307 | 282 | 4668 | 1492 | 444* | ** |
| Average payment to fishers per fishing trip ($US) | 114 (±67) | 82 (±57) | 25 (±21) | 8 (±7) | 14 (±5) | 14 (±5) | 14 (±5) | ** |
| Average payment to fishers per fishing day ($US) | 10 (±7) | 7 (±6) | 3 (±4) | 3 (±3) | 5* | 5* | 5* | ** |
| Income | | | | | | | | |
| Average income per weight ($US/kg) | 2.0 (±0.4) | 2.0 (±0.4) | 2.1 (±0.4) | 2.3 (±0.4) | 1.9 (±0.4) | 1.9 (±0.4) | 1.7 (±0.4) | 1.9 (±0.5) |
| Average income per landing ($US) | 1586 (±802) | 1091 (±634) | 364 (±237) | 112 (±85) | 79 (±48) | 90 (±53) | 87 (±64) | 337 (±267) |
| Indicators of economic efficiency | | | | | | | | |
| Average profit per landing ($US) | 485 (±422) | 364 (±368) | 142 (±164) | 60 (±71) | 28 (±34) | 29 (±33) | 22 (±43) | ** |
| Economic efficiency (gross income/costs) | 1.4 | 1.5 | 1.6 | 2.1 | 1.5 | 1.4 | 1.2 | ** |
| Total annual profit per fishery unit ($US) | 4517 (±3456) | 4261 (±3636) | ** | ** | 1313 (±1131) | 489 (±286) | ** | ** |
| Profit in relation to income per landing | 31% | 33% | 39% | 53% | 36% | 32% | ** | ** |
| Return on Investment (annual profit/investment) | 48% | 78% | ** | ** | 119% | 41% | ** | ** |

*Estimated value based on interviews with boat owners.
**Insufficient data.

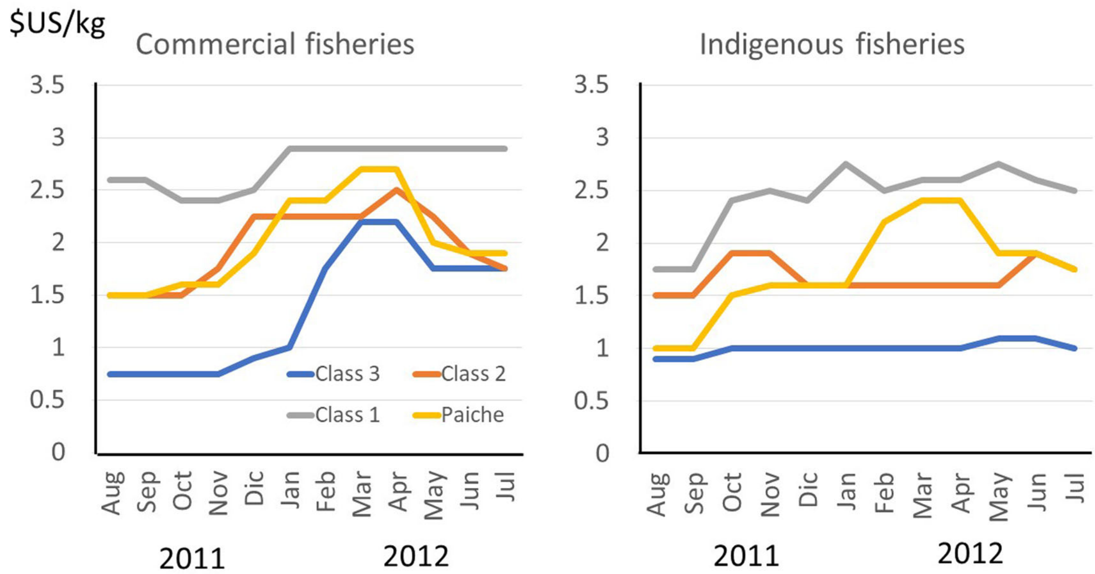


**FIGURE 5** Average price range of fish meat belonging to different categories paid to urban and indigenous fishers in Riberalta (2011–2012)

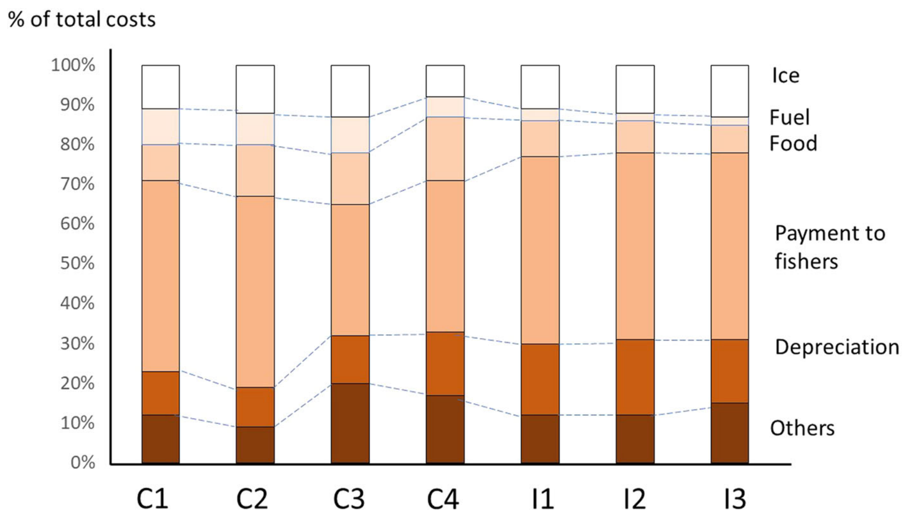


**FIGURE 6** Cost structure of urban and indigenous fisheries

members per trip, generating a profit per landing of $US 28 and an annual profit of approximately $US 1313, equivalent to 0.75 times the national minimum salary (Table 3). In terms of payment to the crew, each fisher of medium-sized urban-based fishing units receives approximately $US 114 and $US 82 per fishing trip (on average 10 and 7$US/day), whereas indigenous fishers regularly landing fish only receive $US 14 per landing (on average 5$US/day) (Table 3).

In the urban fisheries, small vessels were economically more efficient than larger ones. Small boats (C4) had an EE of approximately 2.1, which means that on average for each $US 1 spent during fishing, a gross income of $US 2.1 was generated. Units with larger ice capacity (C3) generated $US 1.6 for each dollar spent, C2 boats generated $US 1.5 for every dollar spent, and the largest units (C1) generated $US 1.4 for every dollar spent. Analysing the relationship between the annual profit and the investment of the fishing units (ROI), it is concluded that medium-sized urban fishing units were more economically efficient than those of greater size: C2 boats presented an annual profit of 77% in relation to investment, while the largest C1 boats had an annual profit of 47% in relation to investment.

In the indigenous fishery, it is estimated that for every dollar spent on fishing, a gross income was generated of between $US 1.4 and $US 1.5, for I2 and I1 boats respectively. If the profitability is analysed in relation to the annual profit and the investment, it is concluded that the I1 boats had an annual profit of 118% in relation to the investment, while the I2 boats have an annual profit of 40% in relation to the investment. The urban and indigenous fishing units generated a profit in relation to income per fishing trip between 31 and 39%, except for the small urban units (53%) that had lower operating costs.

## 2.4 | Gender structure

The urban fishing fleet generated 214 jobs during the year of study, representing a total of 16,820 working days, of which 566 were for female fishers (3.4%). The study registered 144 indigenous fishers landing fish in Riberalta during the study year, of which 23 were women (16%). Out of a total of 1963 landings, 261 (13.3%) were registered for women. Six out of seven middlemen in Riberalta were men. Female participation was higher in the marketing link of the value chain: in the central (urban) market and in the (indigenous) market, the participation of women retailers was, respectively, 75% (out of 20) and 62.5% (out of 24).

# 3 | DISCUSSION

Fishing is a significant source of livelihoods and healthy protein in the Amazon basin. The present study describes how an invasive species is contributing to the local fisheries economy in the northern Bolivian Amazon, and how commercial and indigenous fishers use this new resource in different ways. The presence of *A. gigas* determines fishers' behaviour and income (Doria et al., 2020), value chains (Coca Mendez et al., 2012), fisheries policies (Carvajal-Vallejos et al., 2018) and intersectoral arrangements and resource partitioning (this study).

In a recent review, Doria et al. (2021) established an Amazon Non-Native Fish database, which compiles data on the introduction of fish species in the Amazon basin. The review identifies few examples of invasions that have affected a large geographical scale and had a profound impact on fisheries value chains. The paiche is a noteworthy exception, having successfully invaded a wide geographic area in the upper (Bolivian and Perú) and middle Madeira (Brasil) basin, replacing native species in fisheries landings and inducing an economic boom. This species has come to dominate production of the northern Bolivian Amazon fisheries, more than 50 years after its introduction in Bolivia (Van Damme et al. 2015), but only two decades since first appearing in commercial catches. Whereas in its native range in Brazil and Peru, the paiche has been historically overfished (Castello et al., 2011b, 2015, Ruffino & Roubach, 2007) and now only represents a small proportion of the fisheries catches, in the study area it now predominates in the commercial catches. The significant social and economic importance of this species is comparable with other dominant freshwater fish invaders, such as the Nile perch in Africa (Goudswaard et al., 2008; Marshall, 2018) and tilapia in many parts of the world (Canonico et al., 2005).

Before paiche invasion, the fish markets of Riberalta were supplied by registered, urban-based commercial fishers operating in the Madre de Dios, Beni and Orthon river channels, capturing exclusively higher valued native species such as the surubí (*Pseudoplatystoma* spp.), pacú (*C. macropomum*) and pirahiba (*Brachyplatystoma filamentosum*) (Farrell & Azurduy 2006). These were sold both locally in Riberalta and exported to Brazilian cities. However, two decades later, these same fishers focus mostly on the invasive paiche caught in oxbow and floodplain lakes, most of which are in indigenous territories, using a variety of fishing material and techniques.

Fishing by indigenous communities prior to the arrival of paiche was exclusively for household consumption and local trade within and between communities (Herrera Sarmiento, 2015). However, thanks to improved road access to Riberalta, the arrival of paiche and reduced availability of native fish from urban-based fishers, an increasing number of communities now sells fish in Riberalta markets (Coca Méndez et al., 2012, Macnaughton et al., 2015, 2017). Utilisation of paiche by indigenous fishers varies significantly between communities, but the fish is not yet generally targeted, even though it may be abundant in the oxbow lakes within their territories. This is likely due to a preference for native fish by the Riberalta consumer, lack of adequate technology (gear and knowledge), low connectivity to paiche markets and competition with other livelihood activities (Macnaughton et al., 2015). However, the interest by indigenous fishers to fish paiche is growing steadily (Coca Méndez et al., 2012). Some indigenous leaders, supported by non-governmental organisations, have tried to set up indigenous paiche production chains with market connectivity, but their efforts have not been successful so far (Roxana Salas, personal communication).

There is a marked seasonality in fish landings. Paiche is mainly caught in the dry season and becomes harder to catch during the high-water season, as they disperse in the flooded forest. Whereas fishing of native species during the latter season is formally closed, but poorly enforced, paiche fishing is not prohibited, which is part of a population control strategy implemented by regional authorities.

The economic structure for urban and indigenous fishing is markedly different. In terms of profitability, each owner of a medium-sized urban-based fishing unit receives lower annual profits than owners of indigenous fishing units. Indigenous fishers receive also lower wages than fishers on urban fishing boats, a situation also encountered in the lower Brazilian Amazon (Almeida et al., 2001). For the smaller commercial and indigenous units, fishing represents necessarily an economic activity complementary to other activities, such as the collection of Brazilian nut, wood, cocoa and others, rather than fully supporting a family on its own. Generally, the owners of small scale fishing units (both urban-based and indigenous) are short of capital, with fishing profits used for family support rather than investing in the fishing enterprise. The *habilito* peonage system still in place in the study area additionally limits the profitability of these smaller scale fisheries, with fishers in this system receiving up to 40% less than market value.

Historically, *habilito* is linked to a labour control strategy during the rubber and Brazil nut estate eras, though now functionally adapted to conditions of agrarian reforms (Cano Cardona et al., 2014; Stoian & Henkemans, 2000). While the mechanism is generally considered exploitive, maximising profits of the traders at the expense of those of the fishers, it persists as it has a strong social precedence, at times reinforced by family ties, and provides stable links between rural communities and urban centres (Cano Cardona et al., 2014). Most indigenous fishers do not have access to refrigerators, and if marketing directly would need to invest in ice until the fish is sold, which in many cases occurs several days later (especially when supply exceeds local demand). Additionally, food, fishing supplies and fuel may be challenging to obtain in the distant rural setting. The fish trader arranges, sells and ships these supplies with the ice. This prompts fishers to sell the largest fish and paiche to the traders, at a price lower than that of the local market, but providing immediate income and supplies to support their families. The debt peonage system is one of the main causes for the inequitable prices in the fish value chain. In the study area, the system has not yet evolved to more equitable commercial links, in contrast to the local Brazilian nut resources, where a government-led buying company now regulates the market (Cano Cardona et al., 2014). Uncertainty in the ownership and access rights to the paiche, as well as the limited capacity of indigenous fishers to negotiate favourable terms for the sale of their fish resources, also contributes to the ongoing inequity in profits from fish. Thus, while *habilito* may provide a socially established stability to remote resource extraction, it helps to keep smaller scale fishers on the edge of poverty, limits improved methodologies and effectively dictates aspects of fisheries management.

Efficiency of fishing, calculated as Catch per Unit Effort, was greater for larger boats (18 kg/day/fisher on average) than for smaller boats (10 kg). This may be due to the enablement of more effective fishing methods, ability to reach richer fishing areas or increased ratio of fishing days/travel days. Further analysis of this factor, and changes over time should provide information on the status of fish stocks, though predictable advances in fishing technology of large boats, that have access to investment capital, will affect their capture per effort.

There have also been policy components of the paiche fishery. Paiche live primarily in floodplain lakes, 70% of which are in indigenous territories, leading to conflict between urban-based fishers and indigenous communities. The constitutional law of the Bolivian Plurinational State (2009) recognises that indigenous people have the exclusive right to administer and manage their territory, but the aquatic resources in lakes, such as fish and other aquatic animals, remain state property and access to these hydrobiological resources is allowed for all Bolivian citizens, unless the State assigns specific rights. However, resolutions promulgated by the environmental authorities in 2015 (RA VMABC-CGDE No. 13/2015) and 2017 (RA SERNAP No. 060/2017), supported by regulations by regional authorities, also state that within indigenous territories, paiche fishing can be done without any restriction or closed seasons (December–February for native species), according to local traditions and based on decisions taken by the indigenous authorities (see Carvajal-Vallejos et al., 2018). These resolutions officially declared paiche an invasive species and consider commercial fishing as a way to control its populations and protect native fish species important in subsistence fishing. These resolutions had two consequences: they transferred decision making on fisheries management to indigenous fishers (which is a milestone in Bolivian fisheries legislation), but also opened the opportunity for commercial fishers to enter indigenous territories without seasonal restrictions. The lack of a governmental follow-up on these resolutions strengthened the strategic position of the commercial sector and debilitated even more the indigenous rights to use the aquatic resources in their lands. Indigenous organisations are weak and do not have capacity to take advantage of their implicit user rights (López Flores, 2017; Reyes-Garcia et al., 2017). The recently promulgated Fisheries Law (No. 938, May 2017) did not resolve this issue, which has led to conflicts. At times, indigenous communities prohibit the entry of commercial fishing boats into the oxbow lakes of their territory, but more often access rights are sold to commercial fishers on a case-by-case basis.

Basurto et al. (2013) discuss factors that push remote fishing communities in Mexico to either the patrón-client strategy (like *habilito*) or a more equitable sales cooperative approach, as in Santarem, in the Brazilian Amazon (Almeida et al., 2001). In the Mexican situation, more remote communities have tended to a cooperative approach, whereas those with more development pressures tend towards patron–client systems. They postulate that the social cost of a collaborative arrangement is higher and success depends very much on local history of cooperation. In the study area, in the absence of governmental incentives and state regulation, and due to the presence of powerful salesmen, the patron–client relationship and the *habilito* remain the dominant systems, making it difficult the consolidation of efficient rural or peri-urban cooperative frameworks and governance structures for fishers.

With respect to the role of women in the fisheries, the average of the low participation in fishing and the high participation in marketing approximates the published global average of 47% of women in the fish value chain workforce (Harper et al., 2013; Swathi Lekshmi et al., 2022). While the contribution of urban-based women to the post-harvest sector in the study area is long-standing, the role of women in indigenous communities has changed significantly with the development of commercial fisheries, occupying now key positions in the fish value chain, added to their original occupations in households and subsistence activities (Macnaughton et al., 2016). Increasing market access, introduced species, lack of governmental support and extreme climate variability put pressure on indigenous households, and in particular on their female members (Macnaughton et al., 2017). According to these authors, increasing household participation in the fish value chain is an adaptive strategy to keep sustaining their livelihoods and cover deficits in income. This illustrates that future fisheries policies should not only address lake fisheries management but also promote livelihood diversification strategies, addressing gender-related issues and promoting better decision-making by women.

Partitioning of the fishing fleet into larger boats for ‘export’ products and smaller boats for local markets is also common throughout the world, at different scales. Development proposals for small scale fisheries commonly focus on the interface of the two, promoting the access to ‘global’ markets as a beneficial opportunity for economic development. Examples of this partitioning based on fisheries of high-value introduced species, is less common, with the Nile perch fishery perhaps the best known (Goudswaard et al., 2008). Despite early predictions of the many potential positive impacts on local small scale fishing communities, benefits have generally accrued to large scale fisheries, to the detriment of the smaller scale fisheries. The Bolivian paiche fishery described here is likely the most recent example of such a fishery, in the middle of a dynamic evolution. Predictions on how the fishery may develop in other parts of the country as the range of paiche expands (such as to the nuclear area of the Moxos lowlands), and policies to guide its socioeconomic impact, need to draw on the information presented in this study and the experience of examples such as the Nile Perch.

Fishing in this border area of the Moxos lowlands contributes $US 472,854 of landed value annually to the regional economy. This resource also contributes significantly to food security and livelihoods for both urban-based and rural indigenous fishers. Additional economic value is added through the processing and marketing. The largest part of the catch consists of paiche, which is subject to a considerable fishing pressure and, being a vulnerable species to overfishing (Castello et al., 2015), possibly it will become over-exploited at some point, and may put in risk an established value chain which provides income and employment, as has occurred with other invasive species (see, for example, Mkuna & Baiyegunhi, 2020). However, some authors argue that the paiche inhabits a large number of lakes located in more remote unfished areas in the indigenous territories (Macnaughton et al., 2017; Montellano et al., 2017). To date there are no studies to verify this hypothesis, making it difficult to structure management plans balancing between the economic benefits generated by a sustainable exploitation and the mitigation of impacts on native species.

This study provides information to predict impacts on fisheries resulting from further expansion of the paiche, specifically into the nuclear area of the Moxos lowlands. The species has recently been reported both in the Mamoré and Iténez River basins (Carvajal-Vallejos et al., 2017; Lizarro et al., 2017) and is currently in full expansion to the headwaters of the lowlands, taking advantage of fishers lacking the adequate fishing methods to catch it efficiently (Van Damme et al., 2015). It recently entered in the commercial fish landings in Santa Ana de Yacuma, in the heart of the Moxos lowlands (Coca Méndez, unpublished data). These lowlands are a vast floodplain of between 100,000 and 150,000 km$^2$ (Fleischmann et al., 2022; Hamilton et al., 2004; Ovando et al., 2015) and have a multitude of river tributaries and oxbow lakes which are intensively fished by a similar conglomeration of urban-based fisher organisations and indigenous fishers. The oxbow lakes occupy a surface area of 4409 km$^2$, nine times the lake surface of the present study area (Crespo & Van Damme, 2011), and have a potentially high *Arapaima* production capacity. The future exploitation of this species may evoke a chain of socioeconomic impacts in the Moxos lowlands, generating a value chain as presented in this paper. These upcoming changes will need a proper planning and a policy framework which balances between mitigating the ecological impacts of the invasive species, safeguarding rural livelihoods and preventing social conflicts.

## AUTHOR CONTRIBUTIONS

Gabriela Rico Lopez collected the data, elaborated the figures and tables and wrote the first version of the manuscript. Claudia Coca Méndez provided technical assistance during data collection. Joachim Carolsfeld and Oriana Almeida provided support for economic data analysis and interpretation and reviewed the manuscript. Paul A. Van Damme supervised the research and edited the manuscript. All authors have contributed to the manuscript and have approved the final submission to Aquaculture, Fish and Fisheries.

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## CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

## DATA AVAILABILITY STATEMENT

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

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## PEER REVIEW

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## ETHICS STATEMENT

All animal capture and fisheries data processing was done complying with Bolivian fisheries legislation (Sustainable Fisheries and Aquaculture Law No. 938). The authors certify that this publication is original scientific research work, and it has not been submitted or published elsewhere.

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**TABLE A1** Fish species landed in Riberalta and distribution in price classes

| Scientific name | Local name | Clas |
|---|---|---|
| OSTEOGLOSSIFORMES | | |
| *Arapaima giga* s | Paiche | 0 |
| CHARACIFORMES | | |
| *Brycon amazonicus* | Yatorana | 1 |
| *Colossoma macropomum* | Pacú | 1 |
| *Piaractus brachypomus* | Tambaqui | 1 |
| Cichla pleiozona | Tucunaré | 2 |
| *Hoplias malabaricus* | Bentón | 2 |
| *Schizodon fasciatus* | Pacusillo, Lisa | 2 |
| *Potamorhina altamazonica* | Llorona, Sabalina | 2 |
| *Prochilodus nigricans* | Sábalo | 2 |
| *Psectrogaster* sp. | Sardina | 2 |
| *Pygocentrus nattereri* | Palometa | 2 |
| *Serrasalmus* spp. | Piraña | 2 |
| *Serrasalmus maculatus* | Piraña amarilla | 2 |
| *Anodus elongatus* | Salmón | 2 |
| *Mylossoma* sp. | Pacupeba | 3 |
| *Hoplerythrinus* sp. | Yeyu | 3 |
| *Hydrolycus scomberoides* | Cachorro | 3 |
| *Triportheus* spp. | Menudo, Sardina | 3 |
| SILURIFORMES | | |
| *Brachyplatystoma rousseauxii* | Dorado | 1 |
| *Hemisorubim platyrhynchos* | Brazo de moza | 1 |
| *Hoplosternum littorale* | Buchere | 1 |
| *Leiarius marmoratus* | Tujuno | 1 |
| *Pseudoplatystoma fasciatum* | Surubí | 1 |
| *Pseudoplatystoma tigrinum* | Pintado | 1 |
| *Ageneiosus* spp. | Seferino, Bocacho | 2 |
| *Brachyplatystoma filamentosum* | Pirahiba | 2 |
| *Sorubimichthys planiceps* | Paleta | 2 |
| *Sorubim lima* | Pico de pato | 2 |
| *Zungaro zungaro* | Chanana | 2 |
| *Pimelodus* spp. | Bagre | 2 |
| *Phractocephalus hemioliopterus* | Coronel, General | 2 |
| *Trachelyopterus galeatus* | Torito | 2 |
| *Pinirampus pirinampu* | Blanquillo | 3 |
| *Pterodoras granulosus* | Tachacá | 3 |
| *Pterygoplichthys* spp. | Carrancho, Zapato | 3 |
| PERCIFORMES | | |
| *Astronotus crassipinis* | Serepapa real | 1 |
| *Satanoperca jurupari* | Serepapa | 2 |
| *Plagioscion squamosissimus* | Curvina | 3 |
| CLUPEIFORMES | 2 | |
| *Pellona* spp. | Sardinón | 2 |