Fishers' knowledge on a large floodplain river in South America. Contributions for sustainable management of inland fisheries

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Abstract This study presents a comparison between fishers' knowledge and fiscal records about the structure of inland fisheries in the Paraná River (Argentina). First of all, we characterized the fishing population according to the main demographic and economic indicators, identifying two different fishing areas: the northern and southern sections in the lower La Plata basin. Secondly, we carried out a comparative analysis of fiscal fishery records (from two commercial sets: 1930–1984 and 2011–2019) and local fishers' knowledge on inland commercial fisheries (frequency of occurrence and abundance). Finally, we contrasted current fishing regulations (allowed meshes and boats, fishing prohibitions, exports) to fishers' effective practices. The study area included 52 sites located along the floodplain of the middle and lower sections of the Paraná River, in the province of Santa Fe. Socioeconomic analyses identified two different groups of fishers throughout the river corridor. Results showed that fishers have detailed knowledge on nomenclature, ecology, reproductive strategy, habitat distribution, and usefulness of commercial fish species. By contrasting fishers' knowledge with fiscal records, we found similar and complementary information about the changes in abundance and frequency of occurrence in fisheries. These results highlight the need of including local knowledge as an outstanding source of information for well-planned management of fishing programs and sustainable policies.
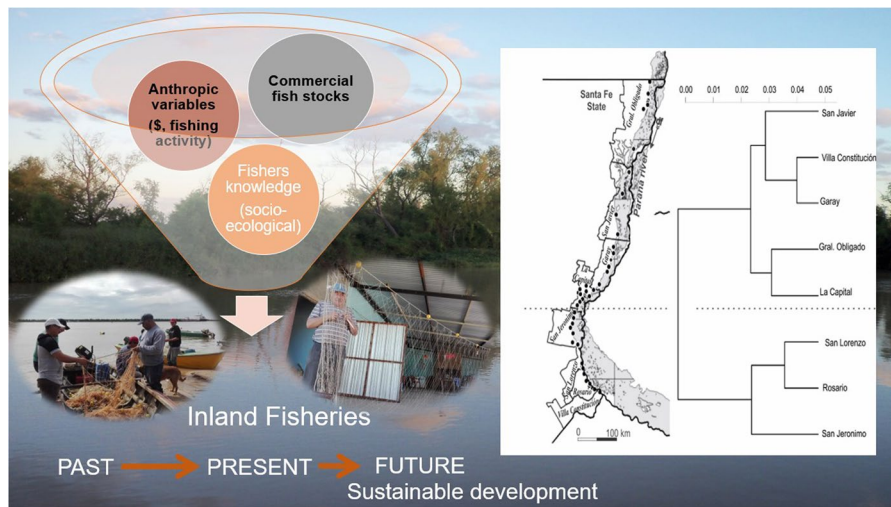
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Graphical abstract

Introduction

Floodplain river systems are highly productive and heterogeneous. They are characterized by extraordinary biodiversity and provide a diverse and generally undervalued set of ecosystem services (Puig et al. 2016), fishing being one of the most important (Fischer et al 2015). Inland fisheries play a critical role in both nutrition -due to the nutritional value of fish- and employment of millions of people. They are crucial for many socially, economically, and nutritionally vulnerable groups of people around the world (Bennett et al 2018; Funge-Smith and Bennett 2019).

Most fisheries of floodplain rivers present low performance; they are small-scale fisheries (SSFs) governed by strongly centralized management under top-down regulations (McClanahan et al. 2009; Castillo et al. 2016). This limits the opportunity to apply the Ecosystem Approach to Fisheries (EAF; FAO 2019). Among other proposals, the EAF has suggested co-management as a new way of governance to overcome the specific limitations of the current legal frameworks of conventional management,

highlighting the role of users in this scheme (Fischer et al 2015; Castillo et al. 2016; 2018; FAO 2019). Under this approach, the value of local fishers' ecological knowledge (FEK) on conservation and management is crucial, mostly in the case of SSF in developing countries, where scientific data or fiscal records are often scarce (Johannes et al. 2000; Fischer et al 2015; Bevilacqua et al 2016; Castillo et al 2018).

About 90% fishers all over the world depend directly on SSFs. The contribution of these SSFs constitute nearly 50% of global fish catches; and inland fisheries, many of which are SSFs, were reported to produce 13% of total capture production in 2014 (Bennett et al 2018). Most inland fisheries are devoted to household consumption and local trade with direct benefits for local food security (Welcomme et al 2014). In South American freshwater fisheries, the number of involved people has increased over the last fifty or sixty years. These SSFs are exposed to different challenges, since floodplain rivers have been severely modified/altered along the twentieth century by the growth of livestock rearing, agriculture, and cities on alluvial plains. This has brought about multiple associated anthropogenic uses (e.g. construction of dams in the Upper Paraná River in Brazil, pollution, etc.; Tucci and Clarke 1998; Barletta et al 2010; Best 2018). In a context of climate change, increased fishing pressure, damming of rivers, deforestation, water pollution, and inadequate practices for managing fisheries are serious challenges to their

sustainability (Barletta et al 2010; Fischer et al 2015). La Plata basin has been affected by these factors (e.g., construction of dams, overfishing, and contamination), leading to possible negative impacts on fish habitats (Agostinho et al 2008; Barletta et al 2010; Baigún et al 2013). The conjunction of changes produced over time in the alluvial plain of the Paraná basin has caused an "artificialization" of the floodplain system (Tucci and Clarke 1998).

In the Paraná River, the floodplain system is dominated by 20 species with significant commercial and sport fishing value, most of them being large specimens that perform periodic and mass breeding migrations (e.g., *Prochilodus lineatus,* Iwaszkiw and Lacoste 2011; Baigún et al 2013). Freshwater fisheries of Argentina generated a significant income estimate of USD 113 million from exports from 2007 to 2013 (FAO 2014). The largest commercial SSFs in Argentina are located along the middle and lower Paraná River and comprise almost the entire continental fish production (~90%) of the country (Baigún et al 2013). Fishing pressure and productive actions changed significantly towards the end of the last century (Iwaszkiw and Lacoste 2011; Baigún et al 2013). Since the nineties, the settling of fish-exporting companies –private investment, several cold storage plants– has brought about the switch from artisanal (subsistence type, low intensity) fishing to commercial artisanal fishing (Iwaszkiw and Lacoste 2011). This change increased the fishing pressure on the resource and produced overexploitation -tripling the catches- at the beginning of the twenty–first century, between 2003 and 2006 (Prol 2008; Baigún et al 2013). The increase in fishing efforts was accompanied by a reduction in the average size of the species caught and a progressive decrease in mesh size (Prol 2008; Iwaszkiw and Lacoste 2011; Baigún et al 2013).

SSFs in the region represent complex socio-ecological systems (McClanahan et al 2009) because of the country's economy: fishers resort to fishing as a way of living and survival through the successive economic recessions that hit Argentina from the 90 s and are still perceived by them (Noceti 2017a). Also, from the ecological point of view, they depend on interactions between the various fish species, their heterogeneous environments (Quirós 1990), the interannual hydrological variability (Welcomme 1985), and different types of fishing communities (Quirós 2003).

Given the extension of the Paraná River, one of the Mega Rivers of the world, laws and activities change throughout the river corridor (that runs along three countries −Brazil, Paraguay and Argentina− and six different provinces in Argentina) without a clear and integrated management of the fishing activity (Quirós 2003). In addition, poverty and weak institutions and management -frequent in our systems- reinforce undesirable results from the feedback between social and ecological processes and unfold poverty traps for fishers (Radosavljevic et al 2021).

The fishing activity is generally carried out by full-time fishers in the main and secondary channels of the river and in floodplain lakes, using small boats, gillnets and line hooks (Iwaszkiw and Lacoste 2011; Baigún et al 2013; Castillo et al. 2016). Several authors pointed out the various fishing practices and types of commercial fisheries along the Paraná River basin (Castillo and Baigún 2020), identifying different limits along the longitudinal gradient of the river. Although the activity involves all family members, the role of women in fishing is generally invisible since their tasks are considered as an extension of their unpaid household responsibilities (Delgado Gustavson 2011; Haslinda et al. 2018). In the same way, children labor (most of them learn to fish during their childhood) is common and also invisible among fishing communities (Noceti 2017b; Funge-Smith and Bennett 2019).

Fishing is a traditional income-generating activity which affects the ichthyofauna of the system. Even though the Paraná River is subject to national, provincial, and international jurisdictions, it is still managed by the provinces –states- (Castillo et al. 2016), creating different social conflicts (e.g., with catch bans, considering different species, establishing different periods by species or, even worse, valid only for some states). Although fisheries are relevant as an economic activity in the middle and lower Paraná River, most studies focused only on fishery data (Baigun et al. 2013). Little research has been focused on the social and economic dimensions of artisanal fishery (Ferrero and Arizpe Ramos 2015), analyzing the legal framework (Castillo et al. 2016) and identifying fishing territories and related conflicts (Castillo and Baigún 2020). This brings up the lack of regulations and control of SSFs, since fiscal fishing statistics are only available in some ports of the province, together

with national data on exports of a few commercial species. As in most inland fisheries, there are no records for other variables such as extraction volume, plant income, fishing activity -gears being used, type of boats, sale prices-, fishing population size, and fishers' social profile.

Therefore the main objectives of this study are, (1) characterize the fishing population according to the main demographic and economic indicators; (2) identify different fishing areas (analysing updated and quali-quantitative data of fisheries and the fishing activity) in the lower La Plata basin; (3) compare fishers' knowledge (FEK) with the statistical information –fiscal landing records of SSF- regarding changes in fisheries of the middle and lower Paraná River (abundance and frequency of occurrence for commercial species in space and time); (4) contrast the current regulations on fishing activities (e.g. fish size limits, allowed fishing gears, boats, and fishing prohibitions) to fishers' effective practices, seeking to integrate knowledge to build a participatory management of fisheries.

Material and methods

Study area

The Paraná River, the main fluvial system of the La Plata Basin, is a mega river ranked ninth among the largest rivers in the world according to its mean annual discharge (18,000 m^3s^{-1}) with a huge drainage area of 2,400,000 km^2. It runs along a diversity of landscapes and climatic regions in Brazil, Bolivia, Paraguay and Argentina (Latrubesse 2008). The middle reach of the Paraná River –from the Paraná-Paraguay rivers confluence to the south of Rosario City (delta, 27°25′S to 33°S)- presents a large floodplain. The study area included all fishing ports (total of 52 points) in the province of Santa Fe, crossing more than 800 km of the middle and lower -from the tip of the delta to the La Plata delta- reaches of the Paraná River (Fig. 1). The floodplain presents an anabranching pattern, that is, an intricate drainage network of high connectivity, a system of numerous channels –comprising a complex mosaic of large secondary channels and minor channels and fluvial lakes, swamps and residual floodplain

channels- characterized by vegetated or otherwise stable alluvial islands that divide flows at discharges up to bankfull. The channels are relatively small (around 50 m in width) but deeply and fast flowing, maintaining permanent connections with the parent river and its floodplain (Abrial et al. 2019).

Data collection

Fishers-based surveys

A total of 49 sites (set FK, Fig. 1) where fishers usually land and store their products were visited. The minimum number of interviews to be conducted was Nmin = 94, based on the number of commercial fishers registered in the last published payroll data by Santa Fe state (in 2014; total of 3305 fishers). We were able to conduct a total of 111 surveys, which is equivalent to 3.36% of the real population -with a 95% confidence level and 10% margin of error- (Badii et al. 2008). One interview per fisher was conducted, reaching a total of 1–3 surveys –individuals- per site –ports– (depending on the available time). Anonymous semi structured fisher surveys (qualitative and quantitative, open and closed questions; Table 1; Appendix S1 –questionnaire-) were carried out among the fishing population during the fishing licence-issuing process (Ministry of Production, province of Santa Fe; Fig. 2).
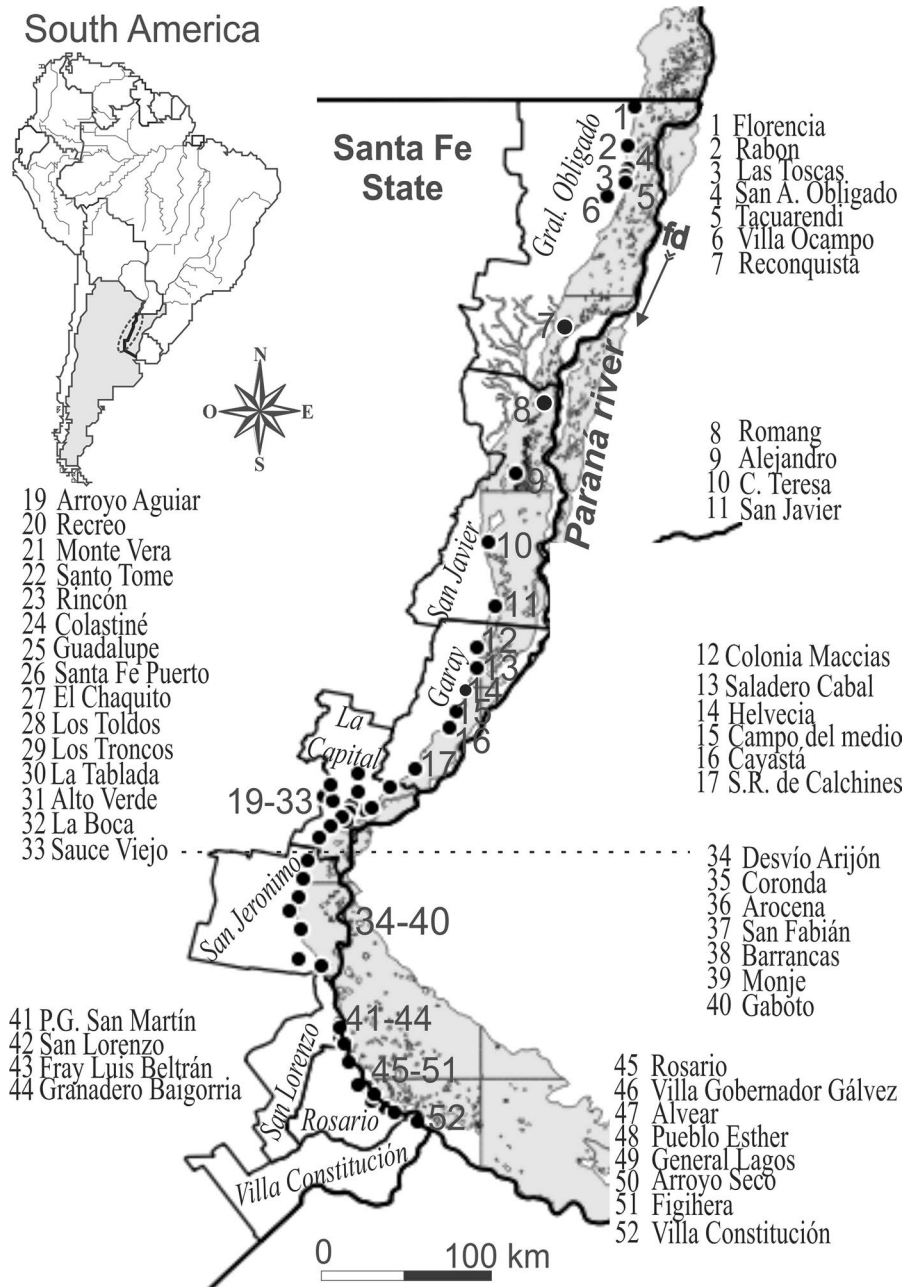
These fisher-based surveys had the aim of collecting data on the artisanal fishing activity in the region, such as fishing gears and methods being used, species caught, trading modes, living conditions of fishers and their households, role of women in the sector, and personal knowledge about the evolution and features of the fishery resource in their activity area. The research was conducted from October to December 2018.

Fiscal records

The fiscal catch data was obtained from two sources:

(1) National Directorate for Inland Fisheries of Argentina: generated the historical set of fiscal statistics (commercial catches: Fig. 1) of Argen-

Fig. 1 Studied area in the floodplain of the Paraná River (Argentina). Sites where commercial fisheries data were obtained: set of fiscal statistics of Argentine Inland Fishery Production (PPARG, for its Spanish initials) (1,7,11,14,16,26,35,40,42,45,50,52), set of fiscal fishing records of Santa Fe (PPSF, for its Spanish initials) (3,7–8,11–14,16–17,35–36,38,40,44,46,48,50–52), set of fishers knowledge (FK) (1–6,9–13,15–52). The dotted line shows the division between north and south sections collected from Results. fd: flow direction

South America

Santa Fe State

1 Florencia
2 Rabon
3 Las Toscas
4 San A. Obligado
5 Tacuarendi
6 Villa Ocampo
7 Reconquista

8 Romang
9 Alejandro
10 C. Teresa
11 San Javier

12 Colonia Maccias
13 Saladero Cabal
14 Helvecia
15 Campo del medio
16 Cayastá
17 S.R. de Calchines

19 Arroyo Aguiar
20 Recreo
21 Monte Vera
22 Santo Tome
23 Rincón
24 Colastiné
25 Guadalupe
26 Santa Fe Puerto
27 El Chaquito
28 Los Toldos
29 Los Troncos
30 La Tablada
31 Alto Verde
32 La Boca
33 Sauce Viejo

34 Desvío Arijón
35 Coronda
36 Arocena
37 San Fabián
38 Barrancas
39 Monje
40 Gaboto

41 P.G. San Martín
42 San Lorenzo
43 Fray Luis Beltrán
44 Granadero Baigorria

45 Rosario
46 Villa Gobernador Gálvez
47 Alvear
48 Pueblo Esther
49 General Lagos
50 Arroyo Seco
51 Figihera
52 Villa Constitución

0   100 km

tine Inland Fishery Production (PPARG, for its Spanish initials, in the past: 1935–1981).

(2) Ministry of Production, Science and Technology, General Sub Directorate of Ecology of Santa Fe: provided a dataset of fiscal fishing records (commercial catches: Fig. 1) of Santa Fe (PPSF, for its Spanish initials, in the present: 2011–2019).

These sets formed a long-term series of more than 50 years of information on commercial fish species (catches in tons, biomass). The largest gaps in the data sets are concentrated in the 1950s and in the period between 1997 and 2008. Details and descriptions regarding the structure of those datasets, the analyses carried out to select sites/ports and species in the same area, and the sampling methods and

Table 1 Components and variables selected to characterize fishing activity and fishers knowledge (FK) on the floodplain of the Paraná River, Santa Fe

	Components	Variables
Questions with factual answers	Personal information	Self-perceived gender; age; civil status; education; household members; others works; fishing licence
	Economic composition of the family unit	Social plans; medical assistance –insurance-
	Fishing boats	Quantity; property; type and Hp of engines (when they have)
	Fishing gears	Types; mesh size and meters –length-; hook and line; property; effort
	Fishing uses and practices	Fishing areas; travel distance (km); costs per day; fishing shifts; number of hours fishing; preferred times/seasons
	Commercialization	Fish processing and conservation; sale, storage (processing plant), added value (processed, filleted, smoked); value of target species –per kilogramme and piece– (after processing); salary
Questions about perceptions, knowledge, ideas, opinions of fishers	Commercial catches	Freshwater species that occur in the sections. Frequency and abundance of catches and temporal changes in frequency and abundance of the most important commercial –native and non-native– species (manguruyú, surubí, dorado, sábalo, pacú, tararira, carpa, esturión; Table S1)
	Fishing prohibition	Knowledge about catch ban, prohibition and restrictions on fishing (permanent, temporal, seasonal) by species

Fig. 2 Encounters with fishers of the Paraná River, working into the port -their boats- during a day of fishing, and repairing fishing arts that were manually knitted

efforts applied per dataset are described in Rabuffetti et al (2020; see Methodology sections). Each database was analysed separately since they resulted from different efforts and sampling methods.

Data analysis

To identify different fishing areas in the lower La Plata basin, we compare characteristics of the fishing activity and socioeconomic and sociodemographic conditions of fishers (e.g., economic income, educational level, fishing gears, Table 1) by districts, conducting a cluster analysis (Ward method, Ward's algorithm; with cluster and FactoMineR packages; Lê et al 2008) using Euclidean distance. Based on the results obtained we described structure of fishers by river sections and characterized demographic (socio-family) and fishing activity issues -fishing gears, uses and practices-. The same spatial segmentation criterion was applied in the rest of the analyses.

The approach used in this study was EAF, considering fishers' ecological knowledge (FEK) crucial to practical application in management plans (Leite and Gasalla 2013; Fischer et al 2015). FEK comprises experimental and experience based knowledge, of ecosystems and fisheries and changes in dynamics of fisheries -spatial and temporal issues related to SSF, on the status of population, exploitation and trends of resources-, fishing practices, communities, and the livelihoods (Bevilacqua et al 2016; Lima et al 2017; Castillo et al 2018). This proved to be useful for the definition of fishing grounds, fish habitats, to design conservation strategies for vulnerable species, and mitigating environmental conflicts (Castello et al 2009; Truchet and Noceti 2021; Truchet et al 2022). We considered Ecological epistemology (EE), which refers to the repositioning of human beings in the symmetrical network of mutually determined relations. EE seeks to merge the human and natural histories considering all, nonhumans and humans, coresidents, and "co-citizens" of the same world (Carvalho 2016).

In order to analyse the evolution of structure and composition of SSF over time, we first identified the species that were registered in each dataset (PPARG, PPSF and FK; presence/absence). Then we evaluated the set FK, analysing abundance of fish species (local names) caught in each section of the river, based on fishers accounts on which species they normally

catch/trade (mention). On the other hand, changes in fish abundance (commercial catches in tons) of the most abundant and frequent species over time were analysed for each period and by river sections. Percentages (%) of catches by species of sets PPARG (1936–1969 and 1973–1981) and PPSF (2011–2019) along the river corridor were contrasted. Changes in total catches are used to equated with changes in the fish community biomass in the ecosystem over time (Fuentes and Quirós 1988; Rabuffetti et al 2016).

Looking to contrast the observed changes in commercial data records (PPARG and PPSF) and fishers knowledge (FK), the latter were asked about the capture of the most commercialized native fish species both at present and in the past and about the incorporation of non-native species that had been detected in the study area (dataset FK). We referred to each species separately by local names (manguruyú, surubí, dorado, sábalo, pacú, tararira, carpa, esturión; Table 1; popular names frequently used in region, Castillo et al 2018) and asked about catch frequency (abundant, infrequent, absent). As regards abundance (more, less, or same frequency) of fish captures, we asked about temporal changes observed in these populations, comparing current and past −previous century− status. All this information was based on their personal experience, considering the beginning of their activity and based on oral history shared by co-workers/older relatives. In both cases, responses were analysed considering the division by river sections, namely North and South. Statistical analyses were carried out using R statistical software (R Development Core Team 2014).

Finally, we analysed the current regulations for the fishing activity (allowed mesh sizes and boats, fishing prohibitions –temporal prohibition, in summer: surubí; permanent prohibition: manguruyú, pacú, dorado; established by provincial laws; Table 2) in relation to the fishing practices reported by fishers (set FK, Table 1).

Results

Characterization of the fishing population

The cluster analysis of the main sociodemographic and socioeconomic characteristics of the fishing activity developed by the interviewed fishing population

Table 2 Commercial fish species caught by artisanal fishers (FK) and recorded per dataset (PPARG and PPSF). FP: Fishing prohibition; ToP: total catch ban, permanent (Law 12,722, Exp. N°33,329; Res. N° 027/82 and N° 011/83). TeP: temporary –catch ban- prohibition (in summer, 1/11 to 31/12; Res. N°168/05). RS: reproductive strategy (PC: parental care, sedentary, with external fertilization; IF: internal fertilization, sedentary or short-distance migrators, without parental care; LM: long-distance migrators with external fertilization, without parental care; SM: short-distance migrators with external fertilization, without parental care)

Local name	Scientific name	FP	RS	PPARG (1935–1981)	PPSF (2011–2019)	FK (2018)
Anchoíta de río	*Lycengraulis grossidens*		LM	X	X	–
Anguila criolla	*Synbranchus marmoratus*		PC	X	X	–
Armado común	*Pterodoras granulosus*		LM	X	X	X
Bagre amarillo	*Pimelodus maculatus*		LM	X	X	X
Bagres (otros)	*Pimelodus* spp.		LM	–	X	X
Bagre sapo	*Rhamdia* sp.		SM	X	–	X
Blanquillo	*Potamorhina* sp.		SM	–	X	–
Banderita	*Eigenmannia trilineata*		SM	X	–	–
Boga	*Megaleporinus obtusidens*		LM	X	X	X
Cárapo, morena	*Gymnotus inaequilabiatus*		PC	–	X	–
Carpa*	*Cyprinus carpio*		SM	–	X	X
Cascarudo	*Hoplosternum littorale*		PC	–	X	–
Corvina de río	*Plagioscion ternetzi*		PC	–	X	–
Dientudo	*Oligosarcus jenynsii*		SM	–	X	–
Dorado	*Salminus brasiliensis*	ToP	LM	X	–	X
Esturión*	*Acipenser* sp.		LM	-	-	X
Golondrina	*Triportheus nematurus*		SM	–	X	–
Manduvé	*Ageneiosus* spp. + *Sorubim* sp.		IF	X	X	–
Manguruyú	*Paulicea lutkeni* + *Zungaro* sp.	ToP	LM	X	–	X
Moncholo	*Pimelodus albicans*		LM	X	X	X
Mojarra	*Astyanax* spp.		SM	X	–	–
Pacú	*Piaractus mesopotamicus*	ToP	LM	X	–	X
Palometa	*Serrasalmus* spp. + *Pygocentrus* sp.		PC	X	X	–
Patí	*Luciopimelodus pati*		LM	X	X	X
Pejerrey	*Odontesthes bonariensis*		LM	X	–	–
Raya	*Potamotrygon* sp.		IF	X	X	X
Salmón (de río)	*Brycon orbignyanus*		LM	X	X	–
Surubí	*Pseudoplatystoma* spp.	TeP	LM	X	X	X
Sábalo	*Prochilodus lineatus*		LM	X	X	X
Tararira	*Hoplias argentinensis*		PC	X	X	X

*Non-native (introduced/established) fish species. *Acipenser* sp. is not commercialized; it comes from aquaculture but was registered by some fishers at fishing sites

resulted in a distinction between two groups (Fig. 3), although dissimilarity is little. Showing a consistent spatial arrangement in a longitudinal direction throughout the river corridor. Group 1 includes sites of the Southern section (San Geronimo, Rosario, San Lorenzo, Figs. 1 and 3), except for Villa Constitución, which was included in the second group (La Capital, San Javier, Garay, Gral. Obligado), which consists of the remaining sites located in the Northern section, the Middle Paraná River. It is worth noting that only one city was visited in this department −Villa Constitución− (Fig. 1).

Based on these results -cluster analysis-, the study area was subdivided into two sections (Fig. 1): the North section, from Florencia to Sauce Viejo (55 interviews), where there is a predominance of drift

Fig. 3 Cluster analysis of the main sociodemographic and socioeconomic characteristics of fisher population by district using the Euclidian dissimilarity coefficient. Dotted line indicates the spatial division between sectors, north/south
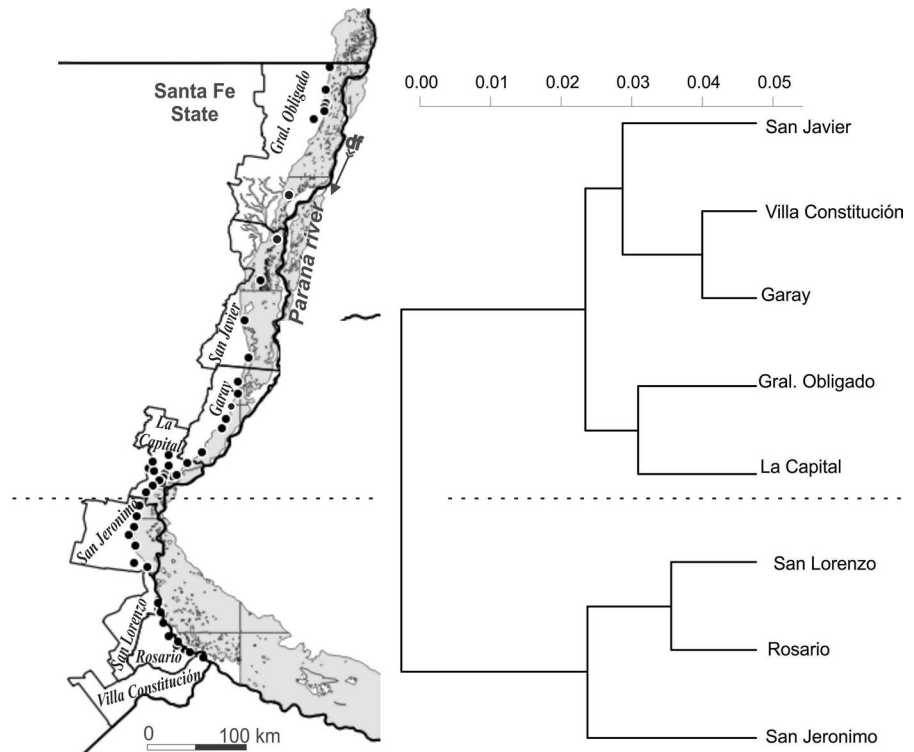
gillnets and hook and line; and the South section, from Desvio Arijón to Villa Constitución (56 interviews), where the trawl nets was the most common fishing gear.

With respect to sociodemographic structure, the interviewed fishers were aged from 19 to 70 years old. In both North and South sections, more than 95% of the interviewed fishing population is represented by men, 66.7% of them are older than 50 years old, and more than 61% have been more than 21 years in the fishing trade. Values of variance, standard deviation and coefficient of variation of the fishers responses by age ranges, respect to changes in the dynamics of fisheries (frequency and abundance of species) over time, are summarized in Table S2. As regards household composition, 66% of households are composed of four or more people. This trait is even more prevailing in the northern section where this number reaches 75% (3–4 children per family on average, respectively), representing 20% more than in the South (57%). Moreover, most men considered they are head of household (84.7%). At the same time, the educational level of these heads of household is comparatively low in relation to the national average (11.2 years of time in the classroom is the average

-3rd/4th year of high school-; in 2018 more than 60% of adults had completed high school). Results show that over 90% of the fishermen have attended only elementary school. The same information is registered regarding the educational level of their partners (85%) in both sections. Moreover, 72.5% of fishermen's partners are housewives and only one out of ten partners are involved in fishery activities (post-harvest: cleaning, cutting, filleting; table S1).

In general, the fishing activity remains artisanal and independent work, carried out by two fishers per 5 to 6-m boat, in the north and south sections respectively (table S1). As regards the engines being used, there is a noticeable difference between sections (in the south everyone has, while in the north the 70%), with an average of 14 Hp (range 2.5–40, SD8.9) in the north and 27 in the south (range 3–90, SD16.62). Another notorious difference is observed in fishing gears: nylon meshes predominate in both sections, but 230 m (range 50–700, SD166) of 16 cm mesh (range 10–20, SD1.6) are used in the north, while 314 m (range 100–900, SD163) of 15 cm mesh (range 13–19, SD1.1) is used in the south. On the other hand, a slightly greater use of hook and line is reported in the north section. It is important to highlight that

more than 80% of fishers indicate changes in mesh sizes over time that correlate with a decrease in abundance/size of fish species populations.

Finally, in relation to the economic characterization, some important differences between both sectors were observed (table S1). More than 55% of the interviewed people in both sectors revealed that they perform multiple occupations. In the north section fishery is more artisanal -larger subsistence

component- than in the south, since household consumption of fish products is higher than the amount to be stored (50 *vs.* 75%), with a predominance of direct sale to the public (60 *vs.* 32%) and higher added value. In addition, the pay per kilogram in general is higher in the north (e.g., the average sale price of sábalo is $13 vs. $11, armado $51 vs $32, surubí $110 vs $57, boga is $34 vs. $53, respectively). This produces differential income by sections, being higher

Fig. 4 Temporal variation of fish catches of the main commercial species, recorded by commercial fishing statistics (% of catches; in the past PPARG: a, b; and present PPSF: c) and fishers interviewed (catch rates; FK: d), by sections of the river corridor. Dotted line in c (PPSF) separate *P. lineatus,* since it alone represents more than 90% of the catches (upper axis); so, it had to be removed in a second analysis to be able to observe the representation of the rest of the spp catches (lower axis without *P. lineatus*). Data is % of biomass of catches
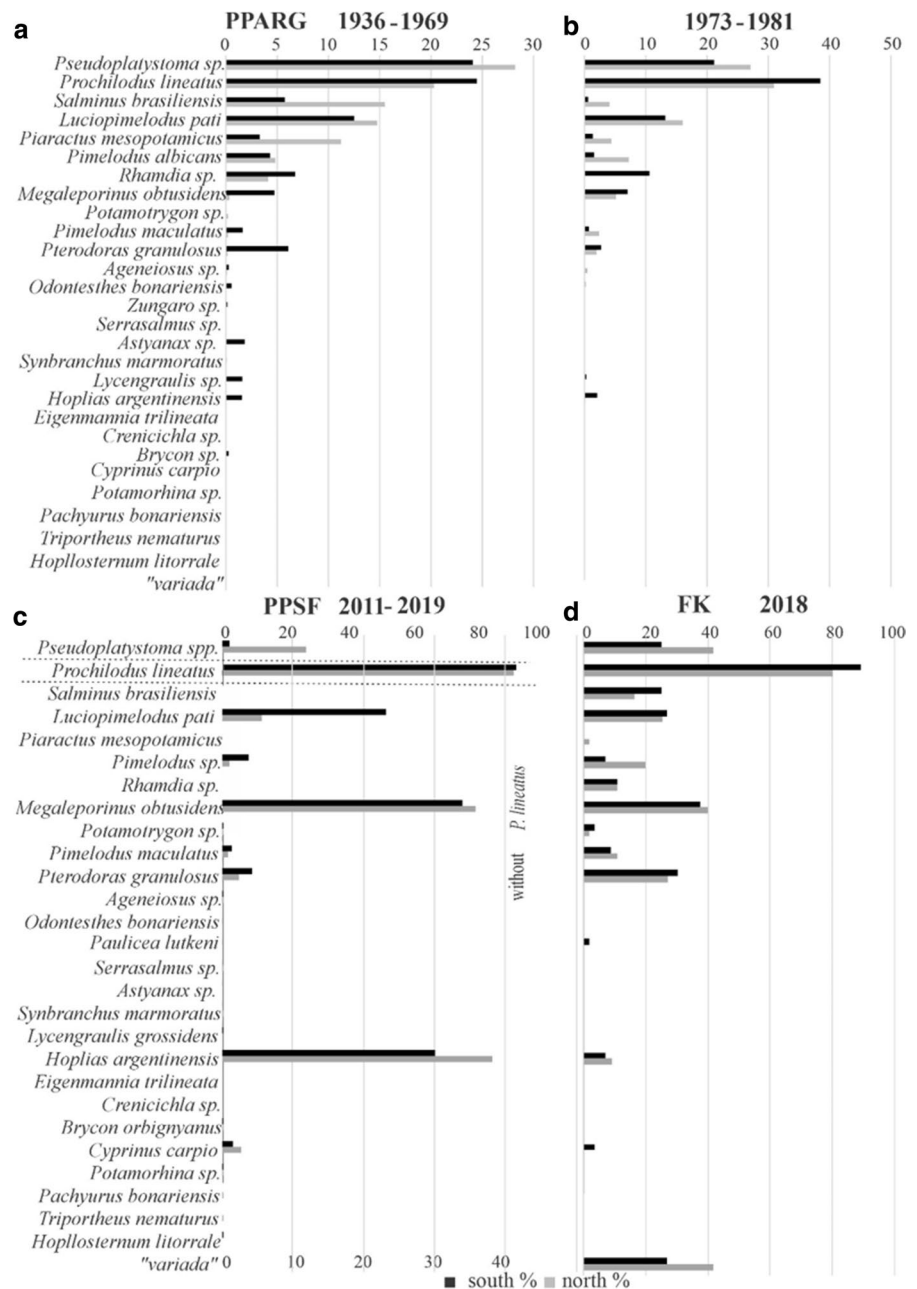
in the northern section (\$9872 *vs* \$9400 per month, Table S1).

Fishers ecological knowledge (FEK)

When contrasting fisheries composition of the catch in the past (PPARG) and present (PPSF), and even among sets in present (PPSF vs FK), a remarkable change in composition is observed (Table 2). Between 1935 and 1981 (PPARG), approximately 22 species were recorded (considering that more than one species could be included within the same genus). In the current period (2011–2019, PPSF) 23 commercial fish species were registered, and 15 were identified by the interviewed fishers (2018, FK) as the most frequently caught in the Paraná River floodplain (Table 2). A total set of 30 species referred to local names was recorded considering the three sources (Table 2).

The structure of commercial fish assemblage changed notably over time and along the river corridor in a north–south direction (Fig. 4). *Pseudoplatystoma* sp. (surubí), *P. mesopotamicus* (pacú) and *S. brasiliensis* (dorado) depicted a marked decrease since 1970 (Fig. 4b), whereas they had been among the most frequent and abundant species before that period. *H. argentinensis* and *M. obtusidens* on the other hand, showed a progressive increase over time, and the non-native fish *C. carpio* became a frequent incorporation into the commercial stock of the Paraná River, at least in the province of Santa Fe (Fig. 4c and d). *P. lineatus*, which had been always present and dominant in the commercial stock, showed a progressive increase in captures over time, currently representing more than 91% of the total commercial biomass (Fig. 4c).

The analysis by sections showed different patterns over time. In the past, catches of the largest migratory species like *Pseudoplatystoma* sp*., S. brasiliensis, L. pati* and *P. mesopotamicus* were more abundant in the north section, while *H. argentinensis, P. granulosus, Rhamdia* sp. and *P. lineatus* were more frequently and abundantly caught in the south section, the latter being the main target species (Fig. 4). Currently, this relationship remains but in a smaller proportion in the case of *P. lineatus* and in a higher proportion for *H. argentinensis*. On the other hand, some species are only commercialized in one of the two sections, e.g.

H. littorale and *L. grossidens* only in the south while *T. nematurus, P. bonariensis, S. marmoratus* and *Serrasalmus* sp. were only registered in the north section. In addition, species such as *Pseudoplatystoma* sp. were more frequent in the north, while others such as *L. patti, P. granulosus* and bagres (*Pimelodus* spp*.*) were more frequently and abundantly captured in the south.

The interviewed fishing population (FK) −considering the whole province as a single assemblage− identified *P. lineatus* as the main target species with a central role from San Javier to the south. When considering analyses by sections, however, the set differs in species abundance and frequency of occurrence (Fig. 4d). In the northern area, *Pseudoplatystoma* sp., *Pimelodus* sp*., P. mesopotamicus* and 'la variada' (i.e., several catfish of the genera *Pimelodus, Ageneiosus* and *Sorubim*) were more frequently reported. In the southern area, *P. lineatus* is the main caught species according to the fishing population, followed by other species such as *P. granulosus*, the exotic non-native species *C. carpio,* and the native and banned specie *S. brasiliensis* (Fig. 4d). It should be noted that *S. brasiliensis*, like pacú and manguruyú, is captured and commercialized by fishers, but not considered in the fiscal statistics in the province of Santa Fe (PPSF, Fig. 4c, Table 2).

The analysis of capture frequency (abundant, not frequent, absent) reported by fishers (FK) showed differences between sections (Fig. 5). *H. argentinensis*, *P. lineatus*, *S. brasilinesis* and *Pseudoplatystoma* sp. turned out to be predominant in the north with a few records of *P. mesopotamicus* and *P. lutkeni*, both being absent in the south. In the southern section, *P. lineatus* was the most captured species, followed by *H. argentinensis* and −to a lesser extent− the carp (*C. carpio*, a non-native species). *Acipenser* sp. is a non-native fish species that has been more frequently registered in the system over the last years.

As regards changes observed by fishers (FK) in catches (frequency and abundance) over time, more than 60% of the interviewed population -in both sections- highlighted a decrease in the abundance (and subsequent frequency, Table S1) of surubí (70–84%), dorado (73–84%)*,* pacú (67–79%) and manguruyú (56–78%).

Finally, we compared FK about the change in frequency and abundance of seven commercial species since the 1970–80 with the commercial records

Fig. 5 FK (2018) of, **a** current fish species abundance and catch frequency (abundant, not frequent, absent). **b** Temporal contrast of fish abundance (less, more or equal) by commercial species and by sections in relation to the past: filled bars −north section, 55 fishers−, empty bars −south section, 56 fishers−
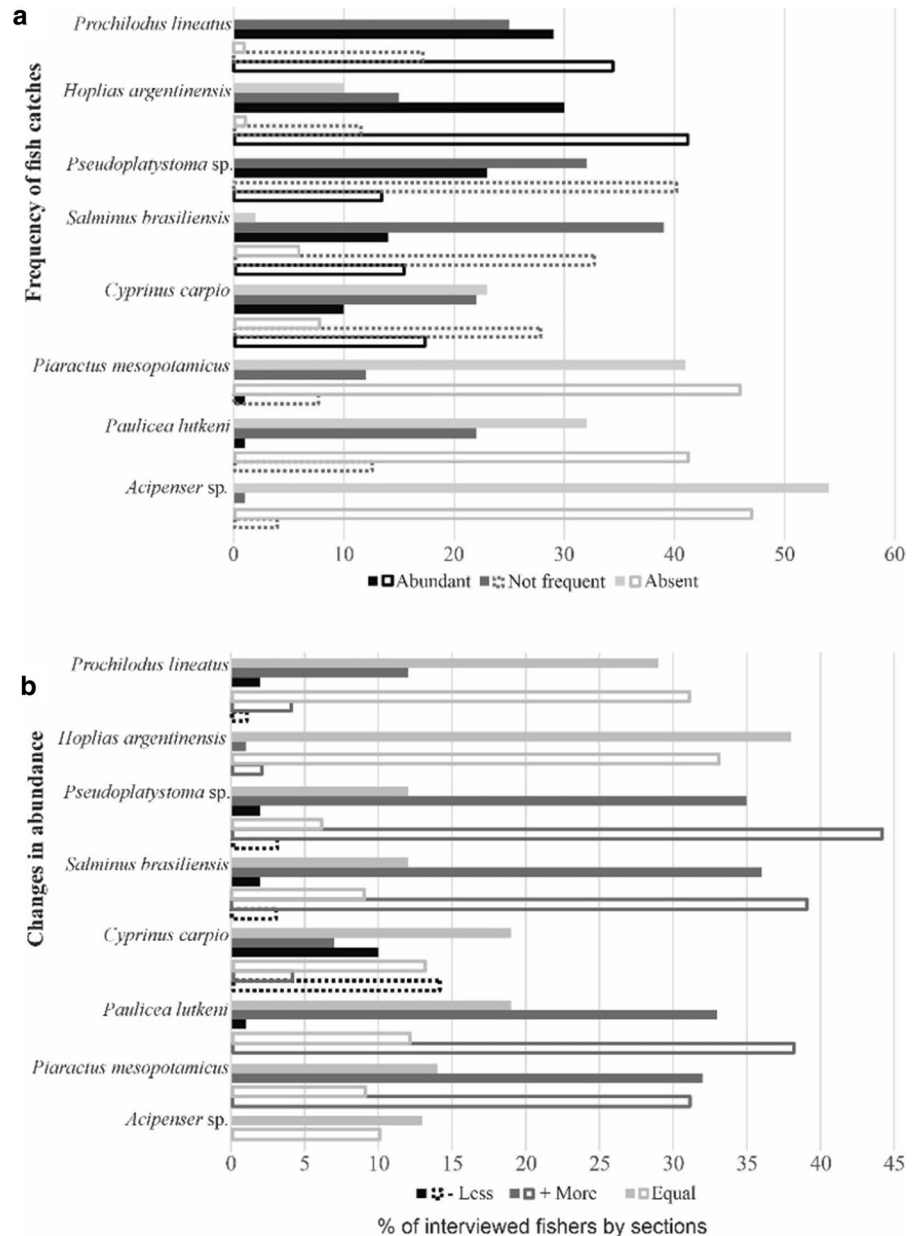

(Fig. 6). This loss of commercial catches of *Pseudoplatystoma* spp., *S. brasiliensis*, *P. mesopotamicus* and *P. luetkeni* over time was also noted by fishers in a real reduction -or even loss- of these species in the river. In the same way, the increase in catches of *C. carpio* was supported by FK. While, on the other hand, the increased commercial catches of *P. lineatus*, *H. argentinensis* over time was not supported by the fishers' perception. They generally perceived equal frequency and abundance of these species from the

1970s onward, showing that the increase in commercial catches may possibly be rather related to a change in commercial fishery strategy than to an increase in the abundance of these species.

Fishing activity and regulations

By contrasting practical aspects of the fishing activity performed by fishers (table S1) in freshwater systems and the current regulatory measures established

Fig. 6 Interannual fluctuations (smoothed line) of the commercial catches in the past (PPARG, 1936–1981) and present (PPSF, 2011–2019) and fishers perception about these temporal changes (black arrows, more, less or equal abundance as in the past). Dotted line (.....) shows periods and/or beginning of total catch ban, permanent by species (—) show beginning of temporary catch ban (Table 2)
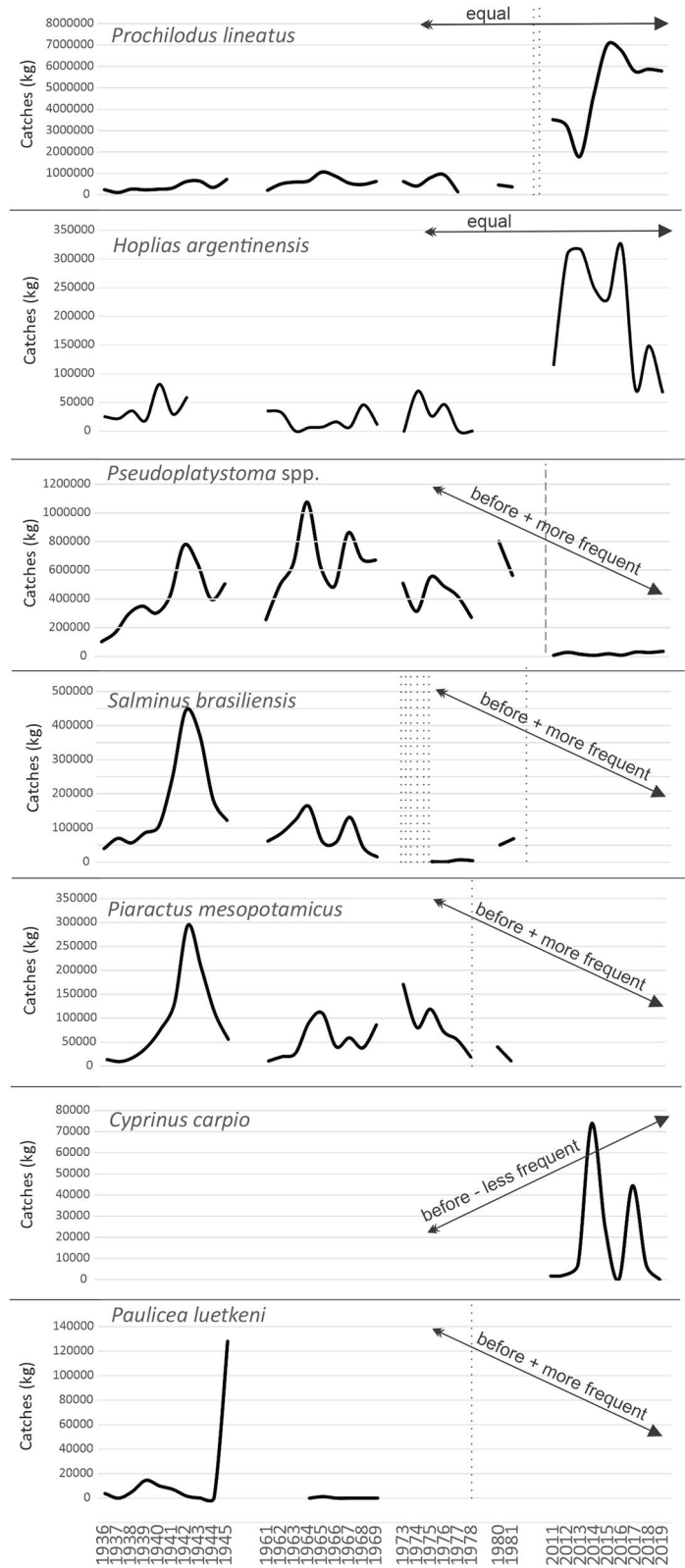
for the province, we observed clear differences. The engine power values used in fishing boats (average 14 Hp in the north and 27 Hp in the south) are within the allowed limits (up to 55 Hp for commercial fishing). However, more than 5% of the engines used by those interviewed in the southern sector exceeded the power limit (who in addition, earn above the monthly average registered on the sector, between $20,000–14,000 thousand; Table S1). As regards regulations for fishing gears (minimum mesh size: 16 cm between opposite knots; maximum length: 250 m), we found greater compliance in the northern sector (average mesh size: 16 cm; average length: 230 m). On the contrary, in the southern section, 46% of the interviewed fishers (25 of 56) had fishing gears that exceeded the allowed (average length: 314 m; average mesh size: 15 cm, Table S1).

We also found that fishers in the north had broader knowledge about current fishing regulations (species and fishing periods, Table S1) (87%) than those in the south (50%). With respect to the species that are permanently banned for commercial fishing (ToP, Table 2), only 1% of the interviewed fishers reported catching pacú (*P. mesopotamicus*) and manguruyú (*P. lutkeni*), while 21% of them admitted fishing and trading dorado (*S. brasiliensis,* Fig. 4d), whose capture is permanently banned in the province of Santa Fe. The same degree of non-compliance, as a result of unawareness, is observed with the capture of temporarily banned species such as surubí.

Discussion

These socioeconomic, demographic and fishery analyses by sites and districts in the province of Santa Fe showed a spatial division throughout the river corridor of the Paraná River (Figs. 1 and 3). The contrast between spatial–temporal structures of commercial catches shows a fishing stock made up of 30 species (Table 2), which has substantially changed over time and throughout the floodplain system (Fig. 4), losing species of great commercial value. The analysis of FK about changes in the frequency and abundance of commercial fishery stocks (Fig. 5) shows clear coincidences with the commercial data collected from fiscal records (Fig. 6).

Characterization of the floodplain fishers

Fishing as a subsistence activity involves all family members (Araya et al 2009) and constitutes their only job (Del Barco et al. 2016). Further, if we consider that more than 60% of these male heads of household usually stay the entire week away from home, the investment of time and work is probably higher than in other economic sectors. Several studies highlighted the significant role of fishermen's wives in improving their household economy/welfare. Around the world, female fishers' work is not remunerated and reproduces domestic work. Although they represent nearly 50% of the fishing population (Bennett et al. 2018) they are frequently overlooked and disregarded in the practices and decision-making. They should be considered as active participants in the sector, engaged in post-harvest activities such as processing and selling fish (Delgado Gustavson 2011; Haslinda et al. 2018). Most domestic chores are usually invisible to occupational survey categories, but this unpaid labour is crucial to sustaining the household (Federici 2018; Funge-Smith and Bennett 2019). A more equitable and participatory fisheries management must incorporate gender approaches, recognize existing inequalities, and that both men and women play different but complementary roles in fishing (Mangubhai and Lawless 2021).

As regards socioeconomic characterization, the average monthly income of fishers is 247$D ($9655). Considering fishing as the only one income in the household (40% of fishers interviewed), half of them (48.6%) live under the indigence threshold and 86.5% under the poverty threshold. These data correspond to the values of the Basic Food Products (CBA, for its Spanish initials; 199$D = $7.750) and the Total Basic Products (CBT, for its Spanish initials; 494$D = $19.298) published in October 2018 by the Argentine Institute of Statistics and Census (INDEC, for its Spanish initials). If we considered the benefits paid by the government to low-income families (social plans), these percentages of poverty would decrease. However, labor conditions of these unregistered workers expose them to not accessing the set of social protections that bind workers to a system of guarantees such as medical insurance (Table S1) and labour rights (Dalle and Stiberman 2017). These aspects make these families more vulnerable to falling below the poverty threshold

(Radosavljevic et al. 2021). In general, is observed low social status of SSF and widespread poverty within communities (Drammeh 2000), because of restricted access to adequate nutrition, clean water, healthcare, education (Table S1), housing, and other rights and services required to sustain livelihoods (Misturelli and Heffeman 2010). In addition, the low education level registered would be covertly related with child-labour, often overlooked in assessments of employment, given the informal and re-mote nature of inland fisheries (Noceti 2017b; Funge-Smith and Bennett 2019; Truchet et al. 2022).

Despite the evident vulnerability of this social group, there is no updated official data about their living conditions, labour and income characteristics. The national household survey −Permanent Household Survey– (EPH, for its Spanish initials) carried out by INDEC includes the fishing activity in this National Occupational Classifier (CNO, for its Spanish initials), but no fisher was officially surveyed in the main agglomerates in the province of Santa Fe. This lack of official published data has two important consequences: on the one hand, problems related to validating and comparing data, for example, about the socioeconomic conditions of fishers; and on the other hand, the impossibility of formulating specific public policies for this neglected sector.

Fishers' knowledge of commercial fishery changes

Between 1930 and 2019, 30 species referred to local names were recorded as the most frequent and abundant in commercial catches. The fishing activity is multi-specific, composed of about 20 species (Iwaskiw and Lacoste 2011) which vary over time and in a north–south direction. Comparative analyses among fiscal fishery records and FK in the middle and lower Paraná River showed some matching patterns but highlighted interesting data that are not observed in fiscal records. Fishers detected temporal changes in fish abundance and distribution (Fig. 5), as well as the appearance of new exotic species in the area (e.g. *Acipenser* sp.), which is not revealed by fiscal sources. In addition, they mentioned the capture and commercialization of species that do not appear in the statistics records because their capture is prohibited for commercial purposes (e.g. *S. brasiliensis*). This shows the importance needs to incorporate FEK

in fishing research and management, since allows identified changes in fish stock due anthropic activities, arts of fishing used, the increase of non-native species, thereby incorporating crucial knowledge of fish ecobiology (Leite and Gasalla 2013; Fischer et al 2015; Bevilacqua et al 2016; Lima et al 2017; Castillo et al 2018; Truchet and Noceti 2021; Truchet et al 2022).

Although obtaining information from fishers (FK) by recalling past catches have many drawbacks (Verweij et al 2010), it is worth considering data, since it shows the great knowledge they have about the state of the resource and its dynamics –spatial–temporal patterns- (Lima et al 2017; Castillo et al 2018). Despite the age disparity of the interviewees, more than 60% have been engaged in that trade for more than 21 years (Table S1). Therefore, their contributions based on their own and direct experience provide information that dates from the late '90 s. However, considering that this is generally an inherited practice (˜50%; Araya et al 2009), part of the knowledge arises from constructions based on oral transmission of colleagues and older relatives (also fishers). All this knowledge could fill the gaps in scientific and fiscal records for river systems and contribute to the conservation of social and ecological resources (Johannes et al 2000). In the face of this lack of clear fishery management, the EAF arises as a necessary strategy to consider all intervening actors (government, private parties, fishers, civil society organizations) and all approaches (ecological, fishing, social, economic, institutional, legal; FAO 2019).

Commercial fisheries in the lower La Plata Basin started in the 1930s (Prol 2008). Since then, a progressive increase in catches of *P. lineatus* was registered (PPARG; Fig. 4a). By the 70 s, this species had already appeared as dominant in commercial stocks representing more than 60% of total catches (Sverlij and Espinach Ros 1986, Fig. 4b). Nowadays, *P. lineatus* represents more than 90% of the total commercial catches in the Santa Fe state (Fig. 4c). It was reported by fishers as clearly abundant and frequent in both sections (Fig. 4d). The constant increase could be explained by the opening of new external markets –international demand− focused on this species towards the end of the 1980s (Prol 2008). The change in the commercial assemblage composition over time was noted by fishers. Species of high commercial value (e.g., *P. mesopotamicus, S. brasiliensis,*

P. lutkeni) were replaced by others of minor value (e.g., *H. argentinensis, P. granulosus, C. carpio*). *P. mesopotamicus –Colossoma* sp.–*,* as well as large catfish (Quiros 1990, 2003), also show signs of overexploitation in the Brazilian Amazon basin since 1980 (Bayley and Petrere 1989; Quiros 2003). It is also worth mentioning the variations (decrease/increase) in frequency and abundance of other species such as *Pseudoplatystoma* spp. and *P. lineatus,* respectively (Fuentes and Espinach Ros 1998) observed in both datasets (Figs. 4 and 6). Until the 1980s in the northern section, the capture of *Pseudoplatystoma* spp. and *S. brasiliensis* represented around 80% of the catches (Fig. 4a-b). Since the year 2000, exports of both species showed a pronounced decrease (Iwaszkiw and Lacoste 2011), which is consistent with the data observed in this study. The reduction of migratory species (LM, Table 2) is considered as an indicator of environmental problems linked to anthropogenic impacts, since these species are very susceptible to environmental changes and fragmentation of the basin (Winemiller 2004; Baigún et al 2013), causing an impoverishment of inland commercial fisheries.

Qualitative data provided by fishers can complement scientific information from conventional biological and ichthyological research (Johannes et al 2000). This kind of information allows addressing issues related to the localized practices that lead to the exploitation of this resource (Preste-Carnneiro and Béarez 2017), and it thus becomes relevant for the assessment and management of fisheries in the various large rivers of South America (Barletta et al 2010). According to Verweij et al (2010), integrating different types of knowledge -from fishers, scientists, stakeholders, policy makers and environmental NGOs- about the temporal patterns of fish stocks is required to avoid controversy in sustainable fisheries management.

Fishing activity and regulations

Considering the characteristics of fishing practices described by the interviewed fishers, we are dealing with a commercial but artisanal fishing population. Thus, fishing gears, efforts and capture frequency vary within two large groups (north–south sections) throughout the river corridor (Fig. 3). This distinction by sections was previously marked by Iwaszkiw (2001), who postulated that the studied area could

be divided into three sectors (north, south, and centre of the province) according to the various fishing techniques. Regarding the distribution, we considered that data mismatches –maybe as a result of the disparity in the number of points visited per department- could cause the unclear location of Villa Constitución in cluster analysis. Our field observations and previous bibliographical contributions show that the fishing activity there is similar in other ports near Rosario (south section). The northern section is a SSF characterized by being a family activity, where handling, conservation and commercialization of fish is mainly carried out by fishermen and their family groups (Araya et al 2009; Iwaszkiw and Lacoste 2011). The southern section shows a more commercial activity, with little use of hook and line, higher power engines in fishing boats (Hp), and longer mesh with smaller size (Table S1). The non-compliance of current regulations, which is much more noticeable in the south (50% vs 12% in south, of the fishers interviewed totally unaware about the current prohibitions of catches) (Ferrero and Arizpe Ramos 2015), threatening the health and viability of the fish assemblage. This change observed in the south section, evading regulations, might be caused by the lower payment of cold stores to fishers -they need to increase catches to get better profits-. This crisis in SSF, where fishers avoid regulations, and governments do not control fisheries, they just increase the vulnerability of the sector. The lack of regulations and gaps in control, called illegal, unreported and unregulated –IUU- fishing (Drammeh Ousman 2000), is a common patron observed in South American fisheries (Quirós 2003; Salas et al 2011; Chiaravalloti 2016; Truchet and Noceti 2021); and all over the world in SSF (Welcomme et al 2014). This IUU fishing is one of the greatest threats to inland fisheries sustainably. Our results reinforce this idea for freshwater fisheries in Argentina in the Paraná River.

There are very few official sources that systematically publish analyses of the sector, except for some projects focused on the study of the fishing activity and biological evolution of species of commercial/ sports interest (EBIPES, Arrieta et al 2017) and for some provincial trade and technical reports on inland fishing in the basin (e.g., Del Barco et al 2016). These studies are usually sporadic and present little specific statistics, with scarce/null socioeconomic data.

Provincial entities (Ministry of Production of Santa Fe) oversee the registration, inspection and census of fishers and they do generally, not publish information referring to socio-economic aspects (Del Barco et al. 2016), productivity, and characteristics of the activity.

As described in the results section, there is a gap between official regulations of the activity and the actual fishing practices of the population. As an example, species like *P. mesopotamicus* and *P. lutkeni* have been completely depleted since the 1980s (Fig. 4, Quirós 1990) and their capture for commercial purposes has been totally banned since the 1990s. Population of *S. brasiliensis* showed a notorious decline since the 1940s, disappearing from commercial stock –at least in fiscal records– (PPARG *vs.* PPSF), and is still more frequent and larger in the northern section of the middle reach (Fig. 5, Vargas 2014). Although the capture of this species has been totally and permanently prohibited for commercial purposes for decades, fishers interviews showed that its capture and commercialization still occur (Fig. 4d) without being included in the statistical fishing records (Fig. 4c). The information gaps in commercial records (e.g., between 1985–1994) make analyses and interpretations even more difficult.

The lack of adaptation and updating of fishing legal frameworks (provincial and national) for the studied area was previously analysed by Castillo et al. (2016), highlighting most of the needs, gaps, and weaknesses. In this sense, our study proves that the use of tighter and longer meshes than those dictated by the government, and the illegal capture of certain species are common practices among artisanal fishers in La Plata basin. This phenomenon could be related to the lack of awareness of regulations, as shown in our study: only 27% of the surveyed individuals (Table S1) had a precise awareness of the duration of summer prohibitions that protect the spawning period of some species. The specific reasons for this situation need to be further studied. However, it is undeniable that this activity is undertaken without regulations concerning both ecosystem protection strategies and working conditions of the involved population.

Conclusions

The results presented in this study constitute a first attempt to characterize the context ‒based on the main demographic and economic indicators‒ situation and state of the art of the fishing population in the province of Santa Fe. Fishers' lack of social security and labour protection and the inefficient fishing prohibitions are two sides of the same coin: the absence of state regulations for this sector. This research makes an important contribution by analyzing updated data of fisheries and fishing activities, identifying two different fishing areas in the lower La Plata basin: a more artisanal fishery in the north and more commercial in the south; the knowledge fishers have about species abundance, catch frequency and temporal changes; the fact that fiscal records (PPSF) fail to fully reflect commercial captures in the system (FK); and a great lack of awareness/breach of regulations in force (although legislation and regulations exist for SSF, they are ineffective and are hardly enforced), potentially threatening fish stock. This integrated analysis of knowledge provided by fishing statistics (PPAR and PPSF) and FK shows consensus and differences in information, highlighting their complementarity and the importance of including FEK in monitoring plans, laws, decrees or resolutions referred to the fishing activity. Sustainable fishery management must contemplate the integration of different actors' knowledge: scientists, fishers, and decision-makers. Finally, the COVID-19 pandemic, which occurred simultaneously with an extraordinary drought (lasting more than two years) of the Paraná River, meant a change of scenario for the SSF: limiting activity, eliminating monitoring and controls -absence of the state-, further marginalizing the sector; introducing new questions and challenges for fishery management.

Recommendations

As regards recommendations, we suggest a greater emphasis on studies that focus on the relationship between human senses and practices and traditional ecological studies. Those studies supply crucial information for developing programs that aim to improve living conditions of large portions of the population that subsist on natural resources. Our study calls for strengthened collaboration among institutions, higher efforts to implement development and monitoring

plans, and joint data collection in riparian sites of the middle and lower Paraná River. It is essential to unify guiding criteria for regulations and measures on fishing activities at basin level. In addition, it is necessary to expand government capacity for controlling captures (species and sizes), warehousing, the purchase of fish from processing plants, and fish commercialization/exports. Another suggestion is to establish a reference price −minimum sale value− for the various commercial fish species in the market, promoting a sustainable management of fishery resources and an improvement in fishers' life quality. In addition, the increase in abundance of non-native species within the commercial stock (such as *C. carpio*) warns us about the need to intensify studies on the invasiveness of non-native fish species in the basin to improve the quality of national/provincial laws that regulate their introduction and production.

Availability of data and materials   Data sources and their supplemental material used in this review are provided in the manuscript. In addition, data is available upon request to the corresponding author. Informed consent was obtained from each interviewed fisher; privacy rights of human subjects were observed.

Declarations

Informed consent   Informed consent was obtained from each interviewed fisher; privacy rights of human subjects were observed.

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