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Recreational fishing in the lower basin of the Santa Cruz river (Patagonia, Argentina) in the face of damming scenarios

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Abstract. The Steelhead ecotype (*Oncorhynchus mykiss*) and chinook salmon (*Oncorhynchus tshawytscha*) have promoted a recreational fishery in the Santa Cruz river, the last large free flowing river of Patagonia. However, two dams are being built upstream in the middle course, potentially affecting the life cycle of these anadromous salmonids. The study describes the dynamics of the recreational fishing of the Santa Cruz river around Piedrabuena city and anglers perceptions, discussing its trends according to possible river connectivity scenarios. The fishery was assessed through a monthly year-round field sampling from April 2018 to April 2019, developing instantaneous angler counts, discriminating fishing methods, effort, and catch per unit effort; also, in situ interviews were used to collect information on anglers' motivations and perceptions. In addition, information on fishing tournaments was used. Three fishing zones (FZ) were identified near Piedrabuena city: FZ-1, located downstream where anglers used baited hook and line to catch the native marine Patagonian blenny (*Eleginops maclovinus*); FZ-2, located in the town where baited hook and line, spinning, and fly-cast are used to catch Patagonian blenny and salmonids; FZ-3 located upstream the town, where fishing effort was mainly directed to salmonids employing spinning and fly-cast. Fishing effort showed a seasonal pattern with high values from March to May and September to October, agreeing with Steelhead and Chinook salmon runs, respectively. The most relevant motivations for anglers were nonoriented catch variables. Anglers preferred the capture of salmonids over native species, considering dams to be a major threat to fishery. Although a post-damming scenario could allow the adult salmonids to migrate upstream, the current reproduction grounds of Steelhead will be flooded, and juveniles and adults of both species will be hindered in their downstream migration to sea. These aspects seem to seriously compromise the future of these unique fisheries.

[Keywords: recreational fishing, anadromous salmonids, anglers, Patagonian rivers, dams]

Resumen. La pesca recreativa en la cuenca baja del río Santa Cruz (Patagonia, Argentina) ante escenarios de represamiento. La trucha arco iris en su ecotipo cabeza de acero (*Oncorhynchus mykiss*) y el salmón Chinook (*Oncorhynchus tshawytscha*) han promovido la pesca recreativa en el río Santa Cruz cerca de Piedrabuena, el último gran río de libre caudal de la Patagonia. Aguas arriba se están construyendo dos represas que afectarán al ciclo vital de estos salmónidos anádromos. Este estudio describe la dinámica de la pesca recreativa del río y las percepciones de los pescadores, y analiza sus tendencias según los posibles escenarios de conectividad fluvial. La pesquería se evaluó mensualmente durante un año (abril 2018-abril 2019), realizando conteos de pescadores y discriminando métodos de pesca, esfuerzo y captura por unidad de esfuerzo. Además, se utilizaron entrevistas in situ para conocer sus motivaciones y percepciones. Se identificaron tres zonas de pesca (ZP) cerca de Piedrabuena: ZP-1, localizada río abajo, donde los pescadores utilizan línea y anzuelo encarnado para capturar al róbalo nativo (*Eleginops maclovinus*); ZP-2, localizada en el pueblo, donde se utilizan línea y anzuelo encarnado, spinning y fly-cast para capturar al róbalo y salmónidos, y ZP-3, localizada río arriba, donde el esfuerzo pesquero se dirige a los salmónidos mediante spinning y fly-cast. El esfuerzo mostró un patrón estacional, con picos de marzo a mayo y de septiembre a octubre, coincidiendo con los ascensos de la Steelhead y del salmón Chinook, respectivamente. Las motivaciones más relevantes para los pescadores fueron las variables no orientadas a la captura, prefiriendo la de salmónidos a la de especies autóctonas. Además, consideraron a las represas como una amenaza importante para la pesquería. Aunque las represas permitirían a los salmónidos adultos migrar río arriba, las zonas de reproducción actuales de la Steelhead se inundarán y, además, los juveniles y adultos de ambas especies verán obstaculizada su migración río abajo. Estos aspectos parecen comprometer el futuro de esta pesquería única.

[Palabras clave: pesca deportiva, salmónidos anadromos, pescadores, ríos patagónicos, represas]

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Introduction

Recreational fishing in Patagonian rivers is an activity of recognised relevance boosted by exotic salmonids (Baigún and Quirós 1985; Pascual et al. 2002; Arismendi et al. 2009). These species were introduced in Patagonia at the beginning of the XX century (1904) from North America and Europe (Baigún and Quirós 1985; Pascual et al. 2007; Macchi and Vigliano 2014) to increase the low local fish biodiversity with species with high economical fishing value. A few decades later, salmonids became valuable recreational fisheries (Macchi and Vigliano 2014), enhanced by the capture of trophy-sized anadromous fish in some lakes and rivers (e.g., Vigliano et al. 2000; Arismendi and Nahuelhual 2007; Vigliano and Alonso 2007; Pascual et al. 2009; Casalinuovo et al. 2018; Llompart et al. 2019). Following the growing angler's interest in salmonids as recreational targets, several hatcheries were built in Argentine Patagonia to supplement existing populations or create new fishing opportunities (Pascual et al. 2007). Consequently, national and international fishing tourism has increased, bringing economic benefits to the state (e.g., fishing licenses) and private enterprises (e.g., fishing guides and lodges). Indeed, current recreational fishing regulations in Patagonia, although slightly variable in different water bodies and between the National Park Administration and Patagonian Provinces, promote the conservation of salmonid populations through bag limits, minimum length restrictions, spawning season closures, and fishing tackles used (Continental Patagonia General Sportfishing Rules and Regulations 2021-2022).

The fish fauna of Santa Cruz river includes six exotic salmonid species (Baigún et al. 2022); it is considered the only river in South America where the anadromous rainbow trout or Steelhead ecotype (*Oncorhynchus mykiss*, Walbaum, 1792) has developed a self-sustained population. Steelhead reaches a maximum of 870 mm in total length (TL) due to annual spawning up to eight times, contrasting with the coexisting smaller and strictly resident rainbow trout (Pascual et al. 2001; Riva Rossi et al. 2004, 2007). Until now, Steelhead was the predominant salmonid and the iconic game fish in the Santa Cruz river (Pascual et al. 2001). This unique ecotype in Patagonia has promoted the National Steelhead Trout Festivals in Piedrabuena, which takes place each year in March or April, attracting several hundred participants (Llompart et al. 2019). During the last decades, the increasing presence of Chinook salmon (*Oncorhynchus tshawytscha*, Walbaum 1792) that escaped from farming facilities in Chile and invaded some Patagonian rivers (Ciancio et al. 2005; Correa and Gross 2008; Fernández et al. 2010) has caused both conservation concern and new fishing opportunities (Llompart et al. 2019). Chinook salmon has also become frequent in the Santa Cruz basin (Riva Rossi et al. 2012; Ciancio et al. 2015; Riva Rossi and Quiroga 2020), and unlike Steelhead, this salmon swims up some tributaries in the upper basin for spawning (Ciancio et al. 2005). Not surprisingly, Chinook salmon has aroused considerable interest in the local anglers' community, promoting the Chinook Salmon Festivals in October in Piedrabuena city (Llompart et al. 2019). Currently, the presence of these two anadromous species as recreational targets makes the Santa Cruz fisheries unique in Patagonia. Despite its fishing relevance, salmonid species have generated controversies about their impact on natural environments and native species (e.g., Pascual et al. 2002; Vigliano and Alonso 2007; Cussac et al. 2016). This situation has become a central socio-ecological dilemma since salmonids in Patagonia are considered harmful or beneficial depending on where they are established, for how many times, or the economic benefit they generate (Garcia De Leaniz et al. 2010).

Among native fish that inhabit the Santa Cruz river, only a few attract interest from recreational anglers throughout the basin (Baigún et al. 2022). The Patagonian blenny (*Eleginops maclovinus*, Cuvier, 1830) is a coastal marine species that often enters the lower basin, posing recreational fishing interest along the Patagonian maritime coastline (Gastaldi 2009; Bovcon 2016), but in the studied river, the local fisheries authority allowed its catch for the first time in 2018. Meanwhile, the freshwater Creole perch (*Percichthys trucha*, Cuvier and Valenciennes, 1833) also has recreational fishery relevance in some Patagonian rivers (Baigún et al. 2022). Despite this situation, understanding anglers' perceptions of native species in the Santa Cruz river could be relevant, particularly in potential post-damming scenarios.

The Santa Cruz river represents the last sizeable free flowing river of Patagonia (Tagliaferro et al. 2013), but two large dams (N. Kirchner and J. Cepernic) are being built and will start operating in the next few years. Damming will impound 52% of the main channel (Quiroga

et al. 2015), expecting significant changes in macroinvertebrate assemblages and fish populations (Tagliaferro et al. 2013; 2014; Tagliaferro and Pascual 2017). Reservoirs will promote the loss of rearing habitats and will inundate Steelhead's main spawning grounds (Quiroga et al. 2015). Similar ecological impacts are expected with Chinook salmon, restricting their access to spawning areas in the small streams of the upper basin (Ciancio et al. 2005, 2019). Since river fragmentation and habitat modification are expected to affect the migration of anadromous salmonids and thus reduce their abundance and distribution, management dilemmas have reopened. The impact of these species has formed mixed opinions on the advantage of preserving their population for recreational fisheries, allowing it to rise into the basin or to become extinct to avoid its impact on the aquatic ecosystem. However, the high costs of mitigation measures based on by-pass systems and fishway construction pose challenges that call for a broad vision of social, economic, and environmental demands considering the perspectives of different stakeholders.

Preliminary studies noted that the recreational fisheries in the Santa Cruz river is based on anadromous salmonids, is free to access and practised almost exclusively in the lower basin (Pellanda et al. 2006), near the Piedrabuena city situated 40 km from the Atlantic Ocean. The rest of the river offers poor access from urban centers, and as a result, it is rarely used for recreational fishing. In addition, in the upper basin, recreational fisheries occur in some rivers, the Argentino and Viedma lakes, and related tributaries. However, the overall social relevance of the fishery at a basin scale remains unknown. In this context, better information is required to justify management directions or potential mitigation measurements. Therefore, this study aims to investigate recreational fishing in the lower Santa Cruz river basin through the spatial and temporal distribution patterns of anglers before dams construction. Additionally, based on interviews conducted during fishing festivals, we analyzed anglers' perceptions of the current fishery status, target species and discuss expected trends according to different scenarios of river connectivity.

Materials and Methods

Study area

The Santa Cruz river basin (51° S - 70° W) occupies a total area of 55.000 km² in the Argentinean Patagonia. The main course of this basin, the Santa Cruz river, crosses the Patagonian steppe in a west-east direction, flowing into the Atlantic Ocean and forming an extensive estuary (Figure 1). The river's mainstem has a regular gradient (mean slope 0.6 m/km), and the current flow is derived primarily from melting ice and snow (Quiroga et al. 2015). The average flow is 691 m^3/s with a minimum average of 278.1 m^3/s in September and a maximum average of 1278 m^3/s in March. Annual mean water temperature is 9 °C, with a maximum recorded in January (15 °C) and a minimum in July (3 °C) (Riva Rossi et al. 2004).

Roving creel survey design

Fisheries assessment focused on the lower basin and was performed through a monthly year-round field sampling from April 2018 to April 2019 (Figure 1). For fieldwork, a stratified random sampling without replacement was selected according to Pollock et al. (1994). Because of the disparity in fishing efforts throughout the year (Pellanda et al. 2006), one stratum was split into high season (November-April, eight days per month) and low season (May-October, four days per month). The other stratum was a type of day (weekdays and weekend days). During the high season, the fishery was visited during four days in each secondary stratum per month, while two sampling days were done during the low season (Table 1). Two instantaneous angler counts were performed on each working day (12 h): one during the morning (8:00 a.m. to 2:00 p.m.) and the other in the afternoon (2:00 to 8:00 p.m.). Night fishing was not sampled because it is banned by the Patagonian fishing regulations (Continental Patagonia General Sportfishing Rules and Regulations 2022). Each angler count took around 30 minutes to traverse the overall fishery (20 km) using a four-wheel vehicle along a parallel route to the river. Each angler was georeferenced (decimal latitude and longitude), and their fishing methods were recorded using binoculars and categorised as spinning, fly-casting, or baited hook and line.

Fishery zonation, fishing effort, and catch per unit effort

Following anglers' georeferencing and their fishing method, we tested the existence of different fishing zones using canonical analysis of principal coordinates (CAP) (Anderson and Willis 2003). The resemblance matrix was based on Euclidean distance, and

Table 1. Distribution of eighty sampling workdays from March 2018 to October 2019 to assess the recreational fishery of Santa Cruz in the lower basin.

Tabla 1. Distribución de ochenta jornadas de muestreo desde marzo de 2018 a octubre de 2019 para evaluar la pesquería recreativa de Santa Cruz en la cuenca baja.

Year	Month	WD[1]	%Coverage total month	%Coverage WW[2]	%Coverage WWD[3]
2018	March	2		National Steelhead Festival-1	
2018	April	8	27	19	44
2018	May	4	13	9	25
2018	June	4	13	10	22
2018	July	4	13	9	22
2018	August	4	13	9	22
2018	September	4	13	10	20
2018	October	4	13	9	25
2018	October	2		Chinook Salmon Festival-1	
2018	November	8	26	17	50
2018	December	8	26	19	40
2019	January	8	26	17	50
2019	February	8	25	20	37.5
2019	March	8	22	14	40
2019	April	4	13	9	25
2019	April	2		National Steelhead Festival-2	
2019	October	2		Chinook Salmon Festival-2	

[1-] Working days (WD); [2-] Working Weekdays (WW); [3-] Working Weekend Days (WWD)

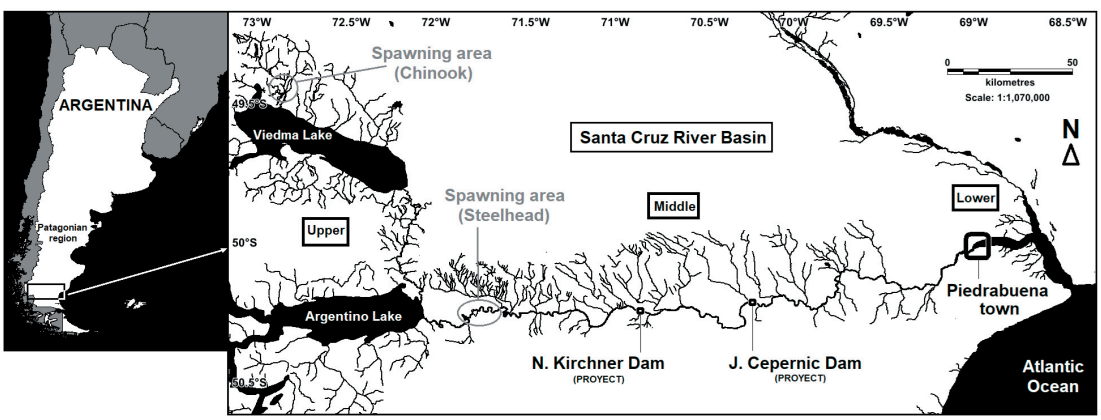

Figure 1. Basin location (left panel) indicating its different portions (right panel). Main recreational fishery area at Piedrabuena city (lower part), the future location of and J. Cepernic dams (middle portion), and spawning areas of Steelhead and Chinook salmon (upper portion).

Figura 1. Localización de la cuenca (panel izquierdo) indicando diferentes porciones del río Santa Cruz (panel derecho). Principales áreas de pesca en Piedrabuena (cuenca baja), la futura localización de las represas N. Kirchner y J. Cepernic (cuenca media) y áreas de desove de trucha cabeza de acero y salmón Chinook (cuenca alta).

CAP was constrained to classify samples in 1 to 6 groups, with the intention of determining which number of groups (=fishing zones) best explain the number of anglers with the three fishing gears (spinning, fly-casting or baited hook and line). The fishing zones obtained were plotted on a map showing the total number of anglers counted and the fishing method used. From the Patagonian fishing regulations (Continental Patagonia General Sportfishing Rules and Regulations, 2021-2022), we assumed that spinning and fly-casting were used for salmonids and baited-hook was used for Patagonian blenny.

Fishing effort was calculated monthly and by fishing zone, following the procedure reported by Pollock et al. (1994), employing the formulas presented by Llompart et al. (2012). The monthly fishing effort was plotted by the fishing zone obtained with CAP.

The catch per unit effort (CPUE) was calculated for the Steelhead Festival (StF) and Chinook Festival (ChF) as the number of

catch and release fish per hour, considering both spinning and fly-cast angling methods.

Angler's interviews

A semi-structured questionnaire (Sudman and Bradburn 1982; Robson 1993) was designed to collect information on anglers' preferences, demands, and attitudes in Piedrabuena city in April 2018 and 2019 during StF and October 2018 and 2019 in ChF. Interviews were developed on-site to gather information on key questions: a) perception of fishing quality (five ordinal answers [very good, good, regular, bad, very bad]; b) motivation for fishing (thirteen variables and three ordinal answers [very important, indifferent, not important]). These variables were divided into catch-oriented groups (i.e., those options focused on fish capture and fishing equipment) and noncatch-oriented (i.e., those options focused on enjoying nature environment with relatives) groups; c) preferred fish target (five nominal answers [Steelhead, Chinook salmon, resident rainbow trout, Patagonian blenny, Creole perch]); d) fishing deterioration factors or threats (four variables with three ordinal answers [high importance, low importance, no importance]), and e) fishing success according to different target species (one ordinal variable [no interest, no catch, low success, high success]). The percentage values for each ordinal answer were estimated by question and plotted separately.

Results

Spatio-temporal distribution of fishing effort

A total of 704 anglers were counted during the sampling period, of which 38% were recorded on weekdays and 62% on weekends. The CAP analysis showed that three different fishing zones (FZ) was the best grouping method of the samples (total correct classification 93%, m=2). In the FZ located downstream (I) (see Figure 2), all anglers used baited hook and line, trying to catch Patagonian blenny. The FZ, located in Piedrabuena city (II), was a mixed zone where the native Patagonian blenny and salmonids were the main target species. In the FZ located upstream of Piedrabuena city (III), all fishing methods were detected, but most were directed to salmonids.

The fishing effort showed a clear seasonality pattern (Figure 3). After the first two austral summer months with low fishing effort, a high increase was evident during March with a predominance in FZ-III. During April and May, fishing efforts remained moderately high, but with increased fishing efforts in FZ-

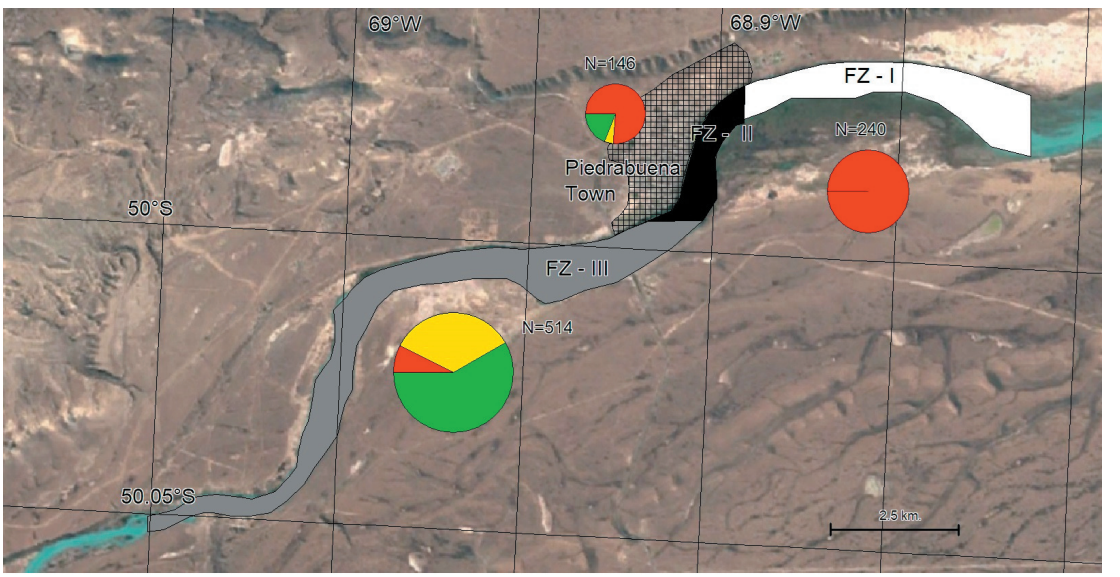

Figure 2. Fishing zones (FZ, with Roman numbers from I to III) in the lower basin of Santa Cruz river. Piedrabuena city is shown as a reference. The total number of anglers in each fishing zone yearly (April 2018 - April 2019) and the fishing methods used are indicated as color pies (red: baited hook and line; yellow: spinning; green: fly-cast). Fishing zones are represented with the same colour as in Figure 3.

Figura 2. Zonas de pesca (FZ, con números romanos del I al III) en la cuenca baja del río Santa Cruz. Piedrabuena se muestra como referencia. Se indica el número total de pescadores en cada zona de pesca en un año (abril 2018 a abril 2019) y los métodos de pesca como gráficos de torta (rojo: carnada y anzuelo; amarillo: spinning; verde: mosca). Los colores de las FZ se corresponden con los de la Figura 3.

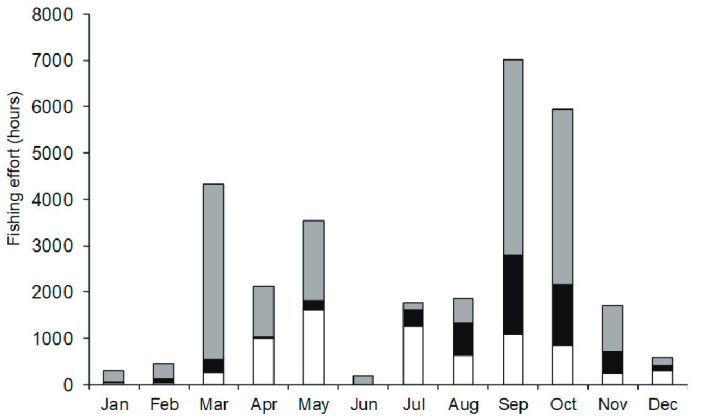

Figure 3. Spatio-temporal distribution of the fishing effort in the lower basin of the Santa Cruz river. Fisheries zones (FZ) along the river according to the fishing method-species target, indicating FZ-I as white bars, FZ-II as black bars and FZ-III as grey bars (see locations in Figure 2).

Figura 3. Distribución espacio-temporal del esfuerzo de pesca en la cuenca baja del río Santa Cruz. Zonas de pesca a lo largo del río de acuerdo con el método de pesca y las principales especies blanco, indicando la FZ-I con barras blancas, la FZ-II con barras negras y la FZ-III con barras grises (ver ubicación en la Figura 2).

I. After the austral winter season with low fishing effort, a maximum was found during September and October due to an increase in FZ-II, and especially in FZ-III. During late spring and early summer, the fishing effort decreased.

Angler's interviews

A total of 265 in situ interviews were done during the StF (n=153) and ChF (n=112), 70% of which corresponded to resident anglers. Regarding motivations for fishing, more anglers chose 'very important' within the non-catch variables than those related to catch-oriented ones (Figure 4). Notably, spending free time in a riverine natural environment near urban areas (easy access) was most widely selected as 'very important'. Within the catch-oriented variables, their preference for a few large fish instead of many small ones and for tested fishing equipment and techniques was the greatest motivation. In contrast, fishing economic reasons, such as selling and eating the fish caught, were seen by anglers as 'not important'.

Steelhead and Chinook salmon were selected as the preferred target species, and resident rainbow trout received intermediate ratings

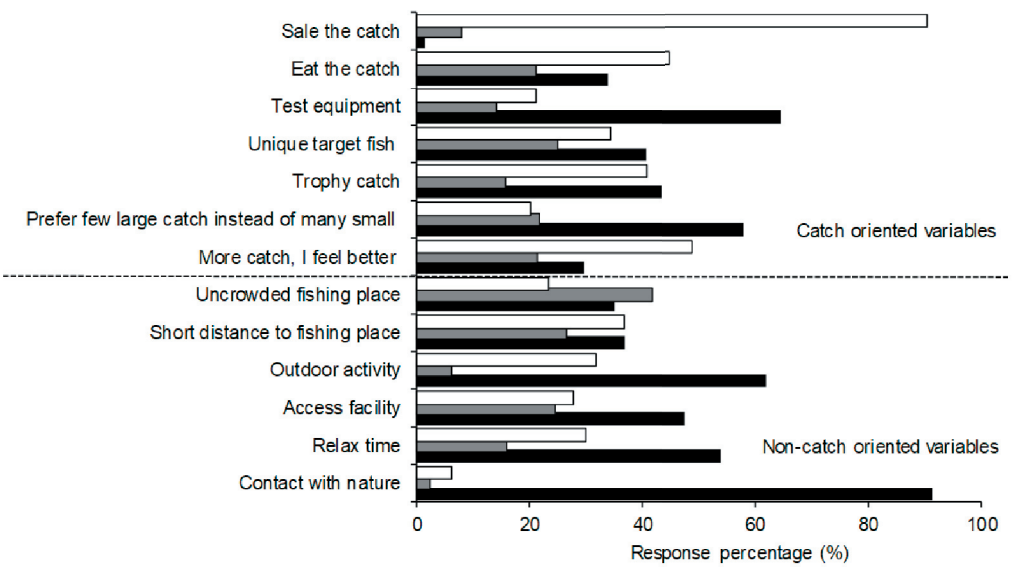

Figure 4. Anglers' responses from the interviews performed during National Steelhead Trout Festivals and Chinook Salmon Festival. Above the dotted line: catch-oriented variables. Below the dotted line: non-catch-oriented variables. White bars refer to 'not important'. Grey bars refer to 'indifferent'. Black bars refer to 'very important' variables according to anglers.

Figura 4. Respuesta de los pescadores entrevistados durante la Fiesta Nacional de la Trucha Cabeza de Acero y la Fiesta del Salmón Chinook. Por encima de la línea punteada: variables asociadas a la captura. Por debajo de la línea punteada: variables no asociadas a la captura. Las barras blancas se refieren a las variables 'poco importantes'. Las barras grises se refieren a las 'indiferentes'. Las barras negras se refieren a las 'muy importantes' según el criterio de los pescadores.

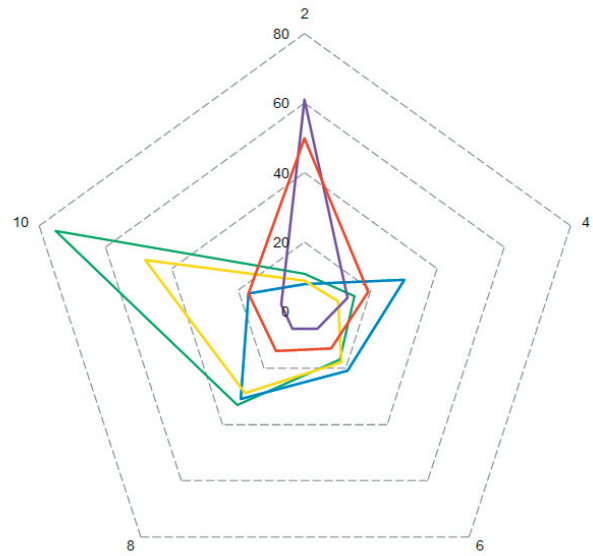

Figure 5. Radar plot showing the frequency (0 to 80) of species scoring (2=lowest preferences; 10=highest preferences) according to anglers interviewed in the Santa Cruz river during the National Steelhead Trout Festivals and Chinook Salmon Festivals. The green line refers to anadromous rainbow trout (Steelhead). The blue line refers to resident rainbow trout. The yellow line refers to Chinook salmon. The purple line refers to Creole perch and the red line to Patagonian blenny.

Figura 5. Gráfico de arañas mostrando la frecuencia (0 a 80) de la valoración de especies (2=menor preferencia; 10=mayor preferencia) de acuerdo con los pescadores entrevistados durante la Fiesta Nacional de la Trucha Cabeza de Acero y la Fiesta del Salmón Chinook. La línea verde se refiere a la trucha arco iris anádroma (Steelhead). La línea azul se refiere a la trucha arco iris residente. La línea amarilla se refiere al salmón Chinook. La línea púrpura se refiere a la perca criolla y la roja al róbalo patagónico.

(Figure 5). Although native species were poorly valued, local anglers opted for the Patagonian blenny over the Creole perch.

The fishing success of Steelhead and Chinook salmon was considered low (Figure 6). Similarly, more than half of the anglers stated that there were either low success or no catches at all of Creole perch. Moreover, this species was also the most widely selected as arousing 'no interest' from anglers. In turn, the Patagonian blenny and resident rainbow trout showed seemingly contradictory patterns since, at the same time, low and high success were chosen.

In view of the anglers' perceptions, river damming is the major threat posed to fishing performance (Figure 7), followed by excessive non-release recreational fishing, artisanal fishing near the river mouth, and the introduction of new species in decreasing order of importance.

There was an average of 147.5 anglers in the StF festivals, where the CPUE value was 0.008 fish per hour. For ChF festivals, the average

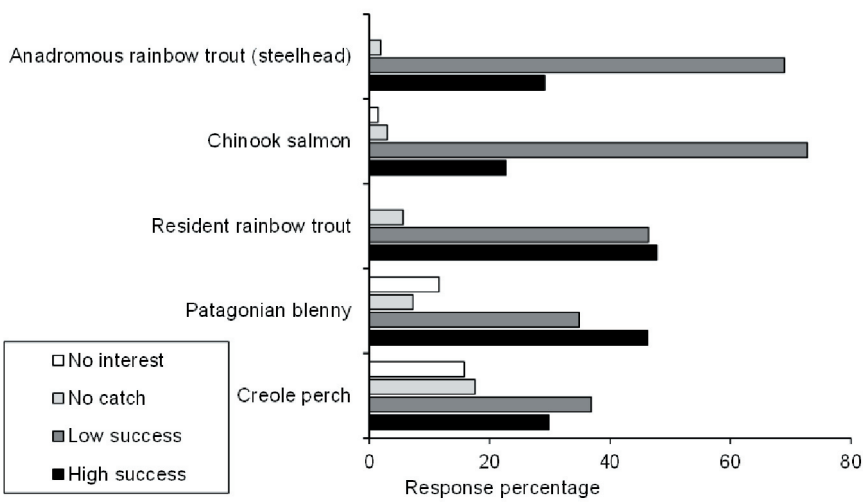

Figure 6. Fishing success, according to anglers, in selected target species in the Santa Cruz river during the National Steelhead Trout Festivals and Chinook Salmon Festivals. White bars refer to 'no interest'. Light grey bars refer to 'no catch'. Dark grey bars refer to 'low success'. Black bars refer to 'high success'.

Figura 6. Éxito de captura, según pescadores, para determinadas especies blanco en la cuenca del río Santa Cruz obtenidas de encuestas realizadas durante la Fiesta Nacional de la Trucha Cabeza de Acero y la Fiesta del Salmón Chinook. Las barras blancas se refieren a 'ningún interés'. Las barras gris claro se refieren a 'ninguna captura'. Las barras gris oscuro se refieren a 'poco éxito'. Las barras negras se refieren a 'mucho éxito'.

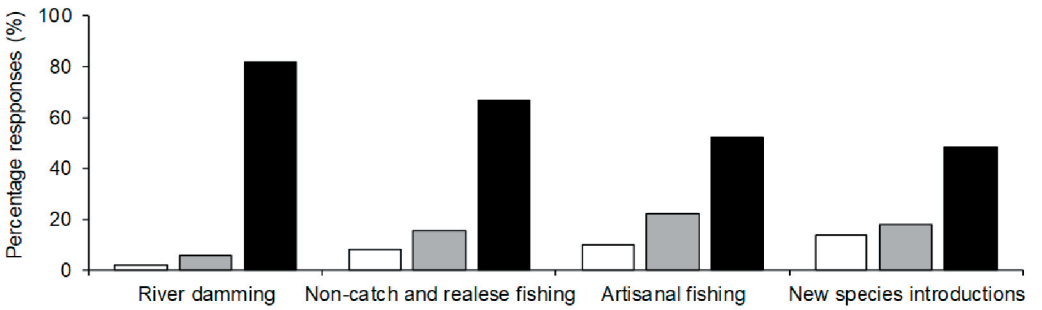

Figure 7. Angler's perceptions of fishing threats in the Santa Cruz river during the National Steelhead Trout Festivals and Chinook Salmon Festivals. White bars refer to 'no importance'. Light grey bars refer to 'low importance'. Black bars refer to 'high importance'.

Figura 7. Percepción de amenaza según los pescadores encuestados durante la Fiesta Nacional de la Trucha Cabeza de Acero y la Fiesta del Salmón Chinook. Las barras blancas se refieren a 'ninguna importancia'. Las barras color gris claro se refieren a 'poca importancia'. Las barras negras se refieren a 'mucha importancia'.

number of participants was 91, but no salmon were caught.

Discussion

Spatio-temporal dynamics of fishery

Recreational fishery in the lower Santa Cruz river basin exhibited a clear spatio-temporal pattern throughout the year. Three fishing zones (FZ) and angling methods were identified. From January to February, fishing effort was low, followed by a peak in March. During this period, the highest contributions from the FZ-III were represented by spinning and fly-casting due both, the river FZ extension and to the presence of prime fishing spots for salmonids. Such a peak in fishing effort reflected the upstream migration of Steelhead for reproductive purposes in the late winter and early spring (Pascual et al. 2001; Riva Rossi et al. 2003). The importance of this run for fishing is also seen in the development of the National Steelhead Trout Festival in Piedrabuena city. This event rewards the largest Steelhead specimen and gathers primarily local people and, to a lesser extent, anglers from other Patagonian provinces (Llompart et al. 2019). Subsequently, in April and May, the fishing effort remains relatively high, yet it is associated with the FZ-I, where Patagonian blenny fishing is carried out using baited hooks. This native species is frequent in the estuarial-marine environment, reaching the lower portion of the Santa Cruz river following the entrance of the tide up to Piedrabuena city. In September and October, the highest fishing effort of the year was recorded in FZ-III and, to a lesser extent, in FZ-II, where anglers preferentially used spinning and fly-casting to catch Chinook salmon. This anadromous species migrates upstream between mid-August and December to reach the spawning ground in the upper basin (Ciancio et al. 2005). The local authority has fostered such a fishing effort pattern, organising the Chinook Salmon Festivals from 2017 onwards.

These findings show that the dynamics of the recreational fishery are highly influenced by the delayed upstream migration of two species of anadromous salmonids and the consequent fishing promotion of these exotic species by governmental agencies. Except for the period corresponding to salmonid migrations, the fishery of anadromous species during the rest of the year is negligible and low for native species and resident salmonids. As a result, fishery is seasonally sustained mainly by two species, thus highly dependent on them.

Anglers' preferences

Anglers represent a vital component of the fishery socio-ecological system, and as heterogeneous groups, they often seek distinct experiences and outcomes by participating in recreational fisheries (Haab et al. 2012; Llompart et al. 2012; Beardmore et al. 2015). Therefore, failing to account for their expectations and demands can lead to inaccurate management guidelines. Previous findings suggest that recreational anglers rank non-oriented catch motivations as more critical than oriented ones. (e.g., Fedler and Ditton 1994; Fedler and Ditton 1986; Birdsong et al. 2021). Such a statement is particularly true

in the lower Santa Cruz river basin, where fishermen emphasise that it is 'very important' to enjoy nature alone or with family and friends. It is worth noting that anglers exercise direct control over the most non-oriented catch variables that are, therefore, relatively easier to satisfy, such as selecting a location that meets the expectations of experiencing nature or choosing the right fishing partners (Beardmore et al. 2011). In contrast, achieving satisfactory oriented catch results takes more work to control by anglers (Arlinghaus 2006). Indeed, our results show that anglers indicated that the probabilities of catching the two anadromous species were low and proportionally higher for the resident rainbow trout and the two native species. This opinion is reinforced by the low catch-per-unit-effort values documented for both fishing tournaments. Nevertheless, anglers preferred the capture of anadromous salmonids over native species. However, we recognize that information from anglers who participate in tournaments may differ from those who do not. For example, Falk et al. (1989) found that tournament anglers fish more assiduously, are members of fishing clubs and consume specialized fishing literature, and therefore consider themselves to be more knowledgeable about fishing. This could then influence their opinions on the state and management of the resources that may diverge from non-tournament anglers. Also, Wilde et al. (1998) suggested that tournament anglers exhibit similar behaviors, motives, attitudes and preferences that are independent of geographic area or species, thus representing a different fishing profile.

Steelhead has been traditionally the main target species in the recreational fishery of the lower Santa Cruz river basin (Pascual et al. 2001). However, their presence, especially in the middle and upper reaches, has declined drastically in recent years, probably displaced by the highly invasive Chinook salmon and due to the expansion of brown trout (*Salmon trutta*) (Baigún et al. 2022; Clarke 2021). In turn, although Chinook salmon spawning events in the Santa Cruz river basin have been recorded for more than 40 years (Ciancio et al. 2005; Riva Rossi et al. 2012; Ciancio et al. 2015), their relevance for the fishery in the upper basin is relatively recent (Ciancio et al. 2019; Clarke 2021). This species has held second place among the species preferred by anglers in the lower Santa Cruz river (Llompart et al. 2019). In 2017, recreational fishing regulations for catching Chinook salmon were recently modified in Piedrabuena city, thus reflecting its growing fishing interest while invasion continues in the Patagonian basins (Avigliano et al. 2023). On the other hand, the Patagonian blenny was ranked slightly favourably only by half of the respondents. Still, their fishery is identified with a different view and is perceived as a much easier species to catch. Indeed, this fishery has specific regulations allowing up to five fish to catch in the bag using up to three hooks per line and natural baits. Nowadays, local fishing enforcement agencies authorise a brief fishing season between October and November, yet they require extending the fishing season until May. This highlights the attempt to promote the recreational capture of the Patagonian blenny. On the other hand, the Creole perch does not arouse interest from Santa Cruz river's anglers. This species is also not abundant in the lower basin (Baigún et al. 2022).

Although anglers' profiles and preferences were obtained only from surveys carried out during the fishing tournaments for the two salmonids, we claim that the angler's profiles linked to salmonid fishing differ from those who fish for the Patagonian blenny. Accordingly, note that the fishing gear used for salmonids and the Patagonian blenny distinguishes not only the target species but the fishing practice itself. The degree of specialisation of fishermen is reflected by the fishing tackle and their fishing skills (Bryan 1977). According to that author, as the level of specialisation grows, dependence on specific resources also increases, such as preferred target species and the importance of non-oriented catch motivations in the value of the fishery (Ditton et al. 1992). Therefore, most fishermen in the lower Santa Cruz river basin can be considered to have a high level of specialisation, tending to opt for capturing anadromous salmonids during the seasons when they enter the basin.

Post-damming scenarios end expected fishery trends

The construction of N. Kirchner (NK, 70 m height) and J. Cepernic (JC, 40 m height) dams will affect and modify the current functioning of the recreational fishery of the lower portion of Santa Cruz river. Moreover, in such projects, constructing fish by-passes for the upper dam in NK is highly unlikely, even though fish ladders were initially planned (EsIA 2017). However, the current review of the environmental impact assessment comprises other transfer alternatives considering

the height of the dams. These alternatives allow predicting two fishery scenarios: a) recovering the effective reconnection of the river, which would allow the successful transfer of migratory fish upstream, and b) assuming loss of river connection, with dam(s) being impassable blockages to reproductive migration. This second scenario appeared to be reflected in the angler's opinion since they identified damming as the most potential damage for future fishing development.

In an effective reconnection scenario of the river, Steelhead could overcome the barrier of both dams in their upstream migration; however, their main spawning and rearing habitat, currently located around the future NK reservoir, will disappear (Riva Rossi et al. 2003). The species could, however, use secondary spawning areas downstream JC. In this case, even if the species could find new breeding sites upstream of the NK reservoir or even in the upper basin, mortality, physical damage, and stress should be expected during downstream migrations, as adults and smolts should pass through turbines. These damages will occur several times during its life cycle as this is an iteroparous species (Pascual et al. 2005). Similarly, resident rainbow trout and brown trout are expected to suffer effects like those of the anadromous form (Pascual et al. 2005). This traditional fishery resource in the lower basin will thus depend, in part, on the recruitment levels that may be provided by secondary spawning sites located downstream JC or in other streams of the basin. Likewise, the possibility of supplementing rainbow trout based on stocking practices is open, yet it is uncertain whether these captive-reared juveniles will develop the anadromous ecotype.

In the process of expansion (Correa and Gross 2008; Ciancio et al. 2019), Chinook salmon could maintain their reproductive migrations to reach spawning bottoms located in the tributaries of the upper basin. However, turbines will also impact on smolts during their return to sea. Unlike Steelhead, it will not be directly affected by the formation of the NK reservoir because its reproductive areas are in the upper Santa Cruz and the Río de las Vueltas basins.

The impact of dams should not affect the Patagonian blenny since the same flow that enters from the Argentino Lake to the Santa Cruz river is expected to be discharged (ESiA 2017). At the same time, other species adapted to lentic environments, such as the Creole perch (Pascual et al. 2005; Baigún et al. 2022), the lake trout (*Salvelinus namaycush*), although currently having a limited presence in the basin, may be benefited from the development of reservoirs and could raise new recreational fishing interests. Moreover, the Patagonian silverside (*Odontesthes hatcheri*) has been successfully translocated into other dams in Argentina (Cussac 2023), where it is considered a valuable fish for recreational anglers. However, the possibility of a transition to new anglers' profiles, shifting from one specialised in salmonids to another that allows the incorporation of non-traditional species and new fishing motivations, is a complex, dynamic and multifaceted process.

In a non-effective reconnection scenario, river blockage in NK due to a lack of fish passage or low efficiency of fishways would limit the availability of alternative spawning sites to only the river's lower reaches for Steelhead. The future development of the fishery will depend on the success of restocking through aquaculture and/or implementation and maintenance of alternative transfer practices over time. In the case of Chinook salmon, dams will prevent upstream migration and, therefore, access to the main spawning sites. However, there are few records of post-spawned Chinook Salmon being caught near Piedrabuena city (Hudson personal communication) and thus new spawning sites should be possible in the lower Santa Cruz river. If it cannot reproduce, it will only be possible to maintain the fishery through the occasional entry of strayed specimens from other Patagonian rivers. Stocking downstream JC appears as an alternative, although no optimum habitat conditions for rearing are evident. It should be noted that dams have been a major cause in the decline of the Chinook salmon population in some Northern Hemisphere rivers, even where investment in infrastructure and research to optimise fish passage systems have been high (Raymond et al. 1979; Keefer et al. 2010). In the short term, this would affect the sustainability of Chinook fishery in the lower basin.

The described potential scenarios pose a genuine dilemma for the management of anadromous exotic species, varying from strong interest in eliminating these salmonids to benefit the conservation of native species (vision supported by ONG and National Park Administration) to their preservation as a critical support of recreational fisheries in

the lower basin due to socio-economical value and supported by local authorities and anglers (Machi and Vigliano 2014). Both positions are unified under a biocentric conservation perspective, yet serving diverging purposes since the objective of maintaining current fisheries introduces a socio-centric vision (Cid-Aguayo et al. 2020). The results of this study show that fishery exhibits local relevance, with a clear seasonal pattern of activity modulated by the upstream migration of two exotic anadromous salmonids followed by a native estuarine species, which gives the Santa Cruz river unique characteristics in Patagonia. Considering this, it is imperative to discuss in the short-term costs and benefits of preserving anadromous salmonid populations. This involves significant investments in hydraulic infrastructure, with no guarantee of their long-term sustainability. However, these populations also serve as a main attraction for local anglers and fishing-related tourism in the lower Santa Cruz river.

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