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Cover: Gillneting fishery inside Guaratuba Bay, Parana coast, Brazil. Photo courtesy of Paulo de Tarso da Cunha Chaves.

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ORIGINAL RESEARCH

Juveniles and undersized fish in small-scale fisheries: gillnets are not less implied than trawling

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ABSTRACT. Of particular concern in commercial fishing catch is 'size bycatch', i.e. the death of early stages of resources that would reach a marketable value when they turn into adults. This event is frequently associated with trawling because of the lower size selectivity of this gear as compared to gillnets. However, this is expected when small-scale fisheries (SSF) employ gillnets simultaneously in setnets + driftnets that mix multiple mesh sizes. This work analyzes fishing captures and compares characteristics of fish catch from gillnets and trawlers with respect to size at first maturation, legal size of capture, and expected discards. Data were obtained from 2007-2021 for SSF in Southern Brazil. A total of 112 fish species were represented in the data. Gillnets exploited fewer species than trawlers; however, most of these constitute fishing resources in the study region. Of the 19 species whose maturation size is known, nine occurred in gillnets as juveniles, and of the 14 species for which the legal size of capture is established, seven occurred in gillnets in prohibited sizes. Gillnets and trawlers presented size bycatch and affected different species between them, with four resources that were present in bycatch from both gillnets and trawlers. The broad range of mesh sizes employed by SSF warns of the discarding of undersized captures, and stresses the importance of policies addressing gillnet management.

Key words: Artisanal fisheries, bycatch, fisheries management, Brazil.

Juveniles y peces pequeños en la pesca artesanal: las redes de enmalle no están menos implicadas que la pesca de arrastre

RESUMEN. De particular preocupación en la pesca comercial es el tamaño de los organismos en la captura incidental, es decir, la muerte de las primeras etapas de los recursos que alcanzarían un valor comercial cuando se conviertan en adultos. Este evento se asocia frecuentemente con la pesca de arrastre debido a la menor selectividad de tamaño de este arte en comparación con las redes de enmalle. Sin embargo, esto es esperable cuando en las pesquerías de pequeña escala (PPE) se emplean redes de enmalle simultáneamente en las redes de arrastre + redes de deriva que mezclan varios tamaños de malla. Este trabajo analiza las capturas pesqueras y compara las características de las capturas de peces en las redes de enmalle y en los arrastreros con respecto al tamaño de primera madurez, el tamaño legal de la captura y los descartes esperados. Se obtuvieron datos de 2007-2021 para la PPE en el sur de Brasil. En los datos estuvieron representadas un total de 112 especies de peces. Las redes de enmalle explotaron menos especies que los arrastreros; sin embargo, la mayoría de estos constituyeron recursos pesqueros en la región de estudio. De las 19 especies cuyo tamaño de maduración se conoce, nueve se encontraron en las redes de enmalle como juveniles, y de las 14 especies para las que se establece el tamaño legal de captura, siete se encontraron en redes de enmalle en tamaños prohibidos. Las redes de enmalle y los arrastreros presentaron captura incidental de tamaño y afectaron a diferentes especies en forma conjunta, con cuatro recursos que estuvieron pre-

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sentes en la captura incidental tanto de redes de enmalle como de arrastreros. La amplia gama de tamaños de malla empleados por la PPE es una advertencia sobre el descarte de capturas de tamaño pequeño y enfatiza la importancia de políticas que aborden el manejo de las redes de enmalle.

Palabras clave: Pesquería artesanal, captura incidental, manejo pesquero, Brasil.

INTRODUCTION

Small-scale fisheries (SSF) differ from large-scale fisheries with respect to several technical, economic, and social attributes. From a conservation perspective, fishing effort in SSF is often more tolerable and catches are less focused on a few stocks. By using passive gears such as hand lines, fish traps, and gillnets, SSF tends to optimize human work and reduce fuel consumption (FAO 2016). These gears show higher capture selectivity with respect to species and individual size as compared to trawl nets (Armstrong et al. 1990; Wolff et al. 2015), another gear employed by SSF fisheries as well as large-scale fisheries (Misund et al. 2002; Santurtún et al. 2014). In comparative studies between gillnets and trawling, Olin and Malinen (2003) found that in South Finland fish smaller than 5 cm corresponded to 51% of trawler captures, while they corresponded to only 1% of gillnet captures; and Huse et al. (2000) found that the mean length of cod caught in gillnets on the Norway coast was approximately 17 cm larger than those caught by trawl nets. Trawling is known to generate bycatch (Silva-Júnior et al. 2015; Cardoso et al. 2021). This promotes design adaptations to reduce the capture and consequent discarding of non-target species and individuals (Alarcón Vélez et al. 2014; Freiría et al. 2014), and strategies as in the penaeid fisheries off Iran, where experiments are being conducted to replace trawl nets with gillnets (Hout et al. 2021).

A particular concern regarding incidental captures is ‘size bycatch’, i.e. the death of juvenile stages of fish, crustaceans, and cephalopods that would reach a satisfactory price for selling as adults. In Southern Brazil, size bycatch from trawlers includes small individuals of marketable species, such as *Micropogonias furnieri* (3% in weight), *Umbrina canosai* (7%), and *Cynoscion guatucupa* (14%) (Cardoso et al. 2021). Apart from the economic loss, discarding resources that are not targeted or are below the permitted capture size constitutes a sensitive problem because of its ecological and ethical implications (Santurtún et al. 2014).

Gillnets incidentally capture charismatic animals, such as turtles, birds, and mammals (Cheng and Tien-Hsi 1997; Cardoso et al. 2011; FAO 2020). These captures do not produce discarding of size bycatch origin (Santurtún et al. 2014), probably because, as verified in the haddock and the Arctic cod fisheries in Finland (Huse et al. 2000), rates of young-adults in catches are lower with gillnets than with trawls and longlines. However, gillnets also show size bycatch that varies between mesh sizes, as observed in a fish assemblage in a Brazilian lake (immature versus mature individuals, Silvano et al. 2016), or with depths of operation, as observed in the whiting fisheries in the Black Sea (Kalayci and Yeşilçiçek 2014).

Each mesh size is selective for a particular morphology (Armstrong et al. 1990; Reis and Pawson 1999). Gillnets mixing different meshes are potentially efficient in capturing a larger spectrum of fish morphologies, widening the range of vulnerable sizes for capture. The use of setnets and driftnets is common in SSF, particularly in tropical waters, where many target resources share a common area (Alves et al. 2012; Wolff et al. 2015). The present work investigates how the employment of multiple mesh sizes in a restricted area results in higher size diversity in the catch, comparatively to trawling. If such heterogeneity includes fish with no marketable value or prohibited species and size classes, they are discarded on board or after landing. Is it plausible to suppose that, in such conditions, gillnets capture juveniles and undersized fish at a not-smaller scale than trawl, and are also harmful for fisheries sustainability?

Along the littoral coast of Southern Brazil, in shallow waters up to 30 m, gillnets and trawl nets are the main fishing gears employed by SSF (Chaves and Robert 2003). Gillnets are deployed from the bottom to the surface and target several teleosts and chondrichthyan species. Trawling is performed on the bottom and targets shrimp. Both gears register incidental captures, mainly fish and invertebrates. While the small meshes used for trawling (1-2 cm) catch an important abundance of benthic fauna, including small fish (Pina and Chaves 2009; Chaves and Silva 2019), the larger meshes used for gillnets (5-20 cm) retain a considerable number of non-target fish (Chaves et al. 2019; Afonso and Chaves 2021). This study analyzes the fish size in trawling and gillnets captures, comparing the two gears with respect to three parameters: legal size of capture, size at first maturation, and expected discards. Does trawling affect more undersized (legal capture and/or first maturation) species than gillnets? With respect to legal capture and first maturation, what is the species performance of each gear? What target resources occur as bycatch in these gears?

MATERIALS AND METHODS

The study area is located in Southern Brazil, on the coasts of Parana and Santa Catarina states, 25° 30′ S-26° 10′ S; 48° 10′ S-48° 40′ W. This corresponds to the fishing area of three SSF communities: Matinhos, Itapoa, and São Francisco do Sul (Figure 1). The fishing fleet consists of between 30 and 50 fiberglass canoes in each

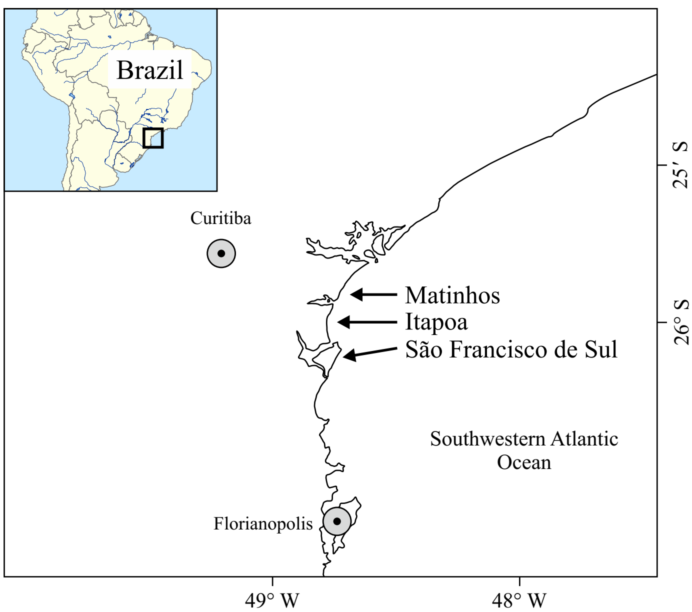

Figure 1. Study area (small square) on Southern Brazilian coast and location of fishing communities of Matinhos, Itapoa, and São Francisco do Sul (arrows).

community, measuring 8-12 m, all motorized with < 60 HP. They are equipped with a gillnet and/or with bottom trawling gear. Fishers perform one-day trip, but gillnets fish for up to six days continuously. In trawling, two nets are simultaneously pulled by canoes at depths of 8-15 m in successive hauls during 6-8 h per day. The mesh size at the codend is 1-2 cm between opposite knots, and the target resource is the seabob shrimp *Xiphopenaeus kroyeri*. Gillnets have a height of up to 20 m and a length of a few hundred to four thousand meters. They are fixed to the bottom or drifting at depths of 10-30 m. Mesh sizes are diverse, typically 5, 7, 9, 11, 12, and 20 cm between opposite knots, depending on the target resource, sharks and teleosts. The latter primarily belong to Mugilidae, Scombridae, Pomatomidae, Sciaenidae, and Pleuronectiformes. Technical specifications of trawl nets and gillnets used in the study area, target resources, and modes of operation are described by Chaves and Robert (2003), Nogueira et al. (2011), Chaves et al. (2019), and Afonso and Chaves (2021).

The range of total length (TL) by species and the minimum and maximum TL values were linked with gillnets or shrimp trawling. The sources used were: (i) previous works carried out in the study area from 2007-2016; fish were obtained by monitoring landings in the cited communities, or experimental cruises for academic research using boats and fishing gears routinely employed by them; and (ii) original data obtained by monitoring landings of the Matinhos fleet during 2020-2021. In experimental cruises, all individuals were measured, while in monitored landings individuals were accessed by chance. Because most of the sources did not discriminate between the mesh size of gillnets, they were considered as a single entity.

For each species, the largest TL landed by trawlers (Max. TL T) and/or the smallest TL landed by gillnetters (Min. TL G) were identified. These data were compared with two other specific TL values: the minimum size of legal capture (TL C), and the average size at first maturation (TL_{50}), preferentially in this area or, when not available, in Brazil. When TL_{50} differed between sexes, the largest value was adopted. Values of TL C came from federal rules MMA 53/05 (MMA 2005) and IBAMA 83/06 (MMA 2006), while those of TL_{50} came from the literature.

Species of commercial interest in the study area were recognized after the findings of Chaves and Robert (2003), Chaves et al. (2019), and Afonso and Chaves (2021), and designated as fishing resources. *Carcharhinus* sp., *Diplectrum* sp., *Paralichthys* sp., and *Sphyrna* sp. refer to two or more species occurring in the study area and are not always recognized at species level. To simplify the representation of results, each genus was considered a single species.

RESULTS

Values of Max. TL T were compiled from 100 species and those of Min. TL G from 32 species. Overall, data on 112 species were compiled with more than 30% (42) constituting fishing resources in the study area (Table 1).

The number and weight of catches were not quantified, but data indicate that, all species considered, individuals < 100 mm were vulnerable almost exclusively to trawling, while those in the range of 100-300 mm were vulnerable to both trawling and gillnets. A few species were represented in trawl nets by individuals > 500 mm or occur in gillnets with individuals not smaller than 500 mm (Figure 2). Gears partially shared the ranges 36-940 mm for Max. TL T, and 110-720 mm for Min. TL G (Table 1). Most representative size classes corresponding to > 10% of frequency of occurrence confirmed significant captures by both gears of species within TLs 100-300 mm: Max. TL T at classes 110-230 mm, and Min. TL G at classes 110-270 mm (Figure 2).

Table 1. Fish species caught by small-scale fisheries in Parana and Santa Catarina littoral, Southern Brazil. Part of them (*) constitute fishing resources in this area. Max. TL T, Min. TL G: maximum and minimum total length (TL) in trawling or gillnets, respectively. TL C: minimum TL of legal capture. TL_{50}: average TL at first maturation. Ref.: references see below. Code applies to species of Figure 6.

	Max. TL T (mm)	Ref.	Min. TL G (mm)	Ref.	TL C (mm)	Ref.	TL_{50} (mm)	Ref.	Code
Achirus declivis Chabanaud, 1940	190	1, 2, 3							
Achirus lineatus (Linnaeus, 1758)	112	1							
Anchoa januaria (Steindachner, 1879)	139	1					65	17	ANJA
Anchoa lyolepis (Evermann and Marsh, 1980)	87	3							
Anchoa spinifera Valenciennes, 1840	177	1, 3							
Anchoa tricolor Spix and Agassiz, 1829	113	1, 3							
Anchovia clupeoides (Swaison, 1839)	156	3							
Anchoviella brevirostris (Günther, 1868)	136	3							
Anchoviella lepidentostole (Fowler, 1911)	119	2					94	17	ANLE
Anisotremus surinamensis (Bloch, 1791)	277	2							
Aluterus monoceros (Linnaeus, 1758)	477	1							
Aspistor luniscutis (Valenciennes, 1840)	256	2							
Astroscopus y-graecum (Cuvier, 1829)	65	3							
Bairdiella ronchus (Cuvier, 1830)	180	1, 2, 3					158	17	BARO
Carcharhinus sp.*			455	7	1,150				
Cathorops spixii (Agassiz, 1829)*	273	1, 3							
Centropomus parallelus Poey, 1860*	347	2, 3	210	8	300	10	200	11	CEPA
Centropomus undecimalis Bloch, 1792*	267	2, 3			500	10			
Cetengraulis edentulus (Cuvier, 1829)	131	2					137	17	CEED
Chaetodipterus faber (Broussonet, 1782)	114	1, 3	305	7					
Chilomycterus spinosus (Linnaeus, 1758)	80	1, 3							
Chirocentrodon bleekerianus (Poey, 1867)	141	1, 3					76	17	CHBL
Chloroscombrus chrysurus (Linnaeus, 1766)*	159	1, 2, 3	200	7	120	10	124	17	CHCH
Citharichthys arenaceus Evermann and Marsh, 1900	186	1, 3							
Citharichthys spilopterus Günther, 1862	173	1, 2, 3							
Conodon nobilis (Linnaeus, 1758)	193	1, 2, 3							
Ctenosciaena gracilicirrhus (Metzelaar, 1919)	148	2, 3							
Cynoscion acoupa (Lacepède, 1801)*			300	8			427	17	CYAC

Table 1. Continued.

	Max. TL T (mm)	Ref.	Min. TL G (mm)	Ref.	TL C (mm)	Ref.	TL_{50} (mm)	Ref.	Code
Cynoscion guatucupa (Cuvier, 1830)*			240	8			346	17	CYGU
Cynoscion leiarchus (Cuvier, 1830)*			200	7, 8					
Cynoscion virescens (Cuvier, 1830)*	142	2							
Dactylopterus volitans (Linnaeus, 1758)	230	1, 3							
Dactylopterus auratus Ranzani, 1842*	171	3							
Diapterus rhombeus (Cuvier, 1829)*	197	1, 2, 3					150	13	DIRH
Diplectrum radiale (Quoy and Gaimard, 1824)	184	1, 3							
Diplectrum sp. (*D. radiale* or *D. formosum*)			190	8					
Engraulis anchoita Hubbs and Marini, 1835	108	1							
Etropus crossotus Jordan and Gilbert, 1822	174	1, 3					85	17	ETCR
Eucinostomus gula (Cuvier, 1830)*	180	3			150	13	110	17	EUGU
Eucinostomus. melanopterus (Bleeker, 1863)*	234	1, 3							
Eugerres brasilianus (Cuvier, 1830)*	263	2	200	8	170		150	17	EUBR
Genidens barbus (Lacepède, 1830)*	171	1	410	7	400	10	415	17	GEBA
Genidens genidens (Cuvier, 1829)*	194	1					118	17	GEGE
Gempylus serpens Cuvier, 1829	106	1							
Gobiesox barbatulus Starks, 1913	53	3							
Gymnothorax ocellatus Agassiz, 1834	495	1, 3							
Harengula clupeola (Cuvier, 1829)	166	2, 3							
Hemicaranx amblyrhynchus (Cuvier, 1833)	210	2, 3							
Isopisthus parvipinnis (Cuvier, 1830) *	194	1, 2, 3	180	8			159	12	ISPA
Lagocephalus laevigatus (Linnaeus, 1766)	173	2, 3							
Larimus breviceps Cuvier, 1830*	256	1, 2	110	8			135	14	LABR
Lycengraulis grossidens (Agassiz, 1829)	150	1, 3							
Macrodon ancylodon (Bloch and Schneider, 1891)*	224	1, 3	190	7, 8	250	10	237	17	MAAN
Menticirrhus americanus (Linnaeus, 1758)*	261	1, 2, 3, 4					177	17	MEAM
Menticirrhus littoralis (Holbrook, 1860)*	229	1			200	10	230	15	MELI
Micropogonias furnieri (Desmarest, 1823)*	274	1, 2, 3	190	7, 8	250	10	306	17	MIFU
Mugil liza Valenciennes, 1836*			450	7, 8	350	10	350	17	MULI
Myrophis punctatus Lütken, 1852	510	3							

Table 1. Continued.

	Max. TL T (mm)	Ref.	Min. TL G (mm)	Ref.	TL C (mm)	Ref.	TL_{50} (mm)	Ref.	Code
Narcine brasiliensis (Olfers, 1831)	202	1, 2					288	17	NABR
Nebris microps Cuvier, 1830	331	1, 2	270	8					
Ophichthus gomesii (Castelnau, 1855)	595	1, 3							
Ophichthus parilis (Richardson, 1848)	471	3							
Oligoplites saliens (Bloch, 1793)			270	7, 8					
Oligoplites saurus (Bloch and Schneider, 1801)	213	1							
Ophidium holbrooki (Putnam, 1874)	225	1, 3							
Ophioscion punctatissimus Meek and Hildebrand, 1925	155	1, 3							
Opisthonema oglinum (Lesueur, 1817)*	185	1, 3	208	8	150	10	115	17	OPOG
Orthopristis ruber (Cuvier, 1830)	275	1, 2, 3					156	17	ORRU
Paralichthys sp. (*P. brasiliensis* or *P. patagonicus*)*			300	7	350	10			
Paralonchurus brasiliensis (Steindachner, 1875)*	250	1, 2, 3, 5	160	8			149	14	PABR
Pellona harroweri (Fowler, 1917)	246	1, 2, 3							
Peprilus paru (Linnaeus, 1758)*	185	1, 3	200	8	150	10	120	17	PEPA
Peprilus xanthurus (Quoy and Gaimard, 1825)*			210	7					
Platanichthys platana (Regan, 1917)	124	3							
Polydactylus oligodon (Günther, 1860)	214	1							
Polydactylus virginicus (Linnaeus, 1758)	190	2, 3							
Pomadasys corvinaeformis (Steindachner, 1868)*	214	1, 2, 3	175	8					
Porichthys porosissimus (Cuvier, 1829)	265	1, 3							
Priacanthus arenatus Cuvier, 1829			270	7					
Prionotus punctatus (Bloch, 1797)*	272	1, 3	180	7	180	10	262	17	PRPU
Prionotus nudigula Ginsburg, 1950*	111	2							
Pseudobatos percellens (Walbaum, 1792)	645	1, 2	430	7			583	17	PSPE
Rypticus randalli Courtenay, 1967	176	1, 3							
Sardinella janeiro (Eigenmann, 1894)	149	3					192	17	SAJA
Scomberomorus brasiliensis Collette, Russo and Zavala-Camin, 1978*	206	1	210	7, 9	370		446	9	SCBR
Selene setapinnis (Mitchill, 1815) *	195	1, 3					205	17	SESE

Table 1. Continued.

	Max. TL T (mm)	Ref.	Min. TL G (mm)	Ref.	TL C (mm)	Ref.	TL_{50} (mm)	Ref.	Code
Selene vomer (Linnaeus, 1758) *	110	1, 3	305	7,8					
Serranus phoebe Poey, 1851	112	1							
Sphoeroides greeleyi (Gilbert, 1900)	124	1, 3					70	17	SPGR
Sphoeroides testudineus (Linnaeus, 1758)	260	1, 3					108	17	SPTE
Sphyraena guachancho Cuvier, 1829	331	3							
Sphyrna sp. (*S. lewini* or *S. zygaena*)*			720	7	600	10			
Stellifer brasiliensis (Schultz, 1945)*	190	1, 2, 3					73	17	STBR
Stellifer rastrifer (Jordan, 1889)*	215	1, 2, 3					98	17	STRA
Stellifer sp. (species not described)*	124	1, 2, 3							
Stellifer stellifer (Bloch, 1790)*	175	1, 2, 3					75	17	STST
Stephanolepis hispidus (Linnaeus, 1766)	202	3					139	17	STHI
Syacium micrurum Ranzani, 1842	175	3							
Syacium papillosum (Linnaeus, 1758)	239	3							
Symphurus jenynsi (Evermann, 1906)	158	3							
Symphurus plagusia (Bloch and Schneider, 1801)	168	2							
Symphurus tessellatus (Quoy and Gaimard, 1824)	200	1, 2, 3							
Syngnathus folletti Herald, 1942	130	2							
Synodus foetens (Linnaeus, 1766)	224	3							
Thalassophryne nattereri Steindachner, 1876	36	1							
Trichiurus lepturus Linnaeus, 1758*	940	1, 2, 3, 6	550	7, 8	700	10	506	17	TRLE
Trinectes microphthalmus (Chabanaud, 1928)	165	2, 3							
Trinectes paulistanus (Ribeiro, 1915)	165	1, 3							
Umbrina coroides Cuvier, 1830*	200	3							
Urophycis brasiliensis (Kaup, 1858)*	265	1, 2, 3							
Zapteryx brevirostris (Müller and Henle, 1841)	551	1, 2	380	7			506	16	ZABR

Ref.: 1: Pina and Chaves (2009); 2: Pinheiro (2016); 3: Souza and Chaves (2007); 4: Muniz and Chaves (2008); 5: Robert et al. (2007); 6: Del Puente and Chaves (2009); 7: Afonso and Chaves (2021); 8: original data; 9: Chaves et al. (2021); 10: MMA (2005); 11: Chaves and Nogueira (2018); 12: Romero et al. (2008); 13: MMA (2006); 14: Silva-Júnior et al. (2015); 15: Braun and Fontoura (2004); 16: Colonello and Menni (2011); 17: Froese and Pauly (2021).

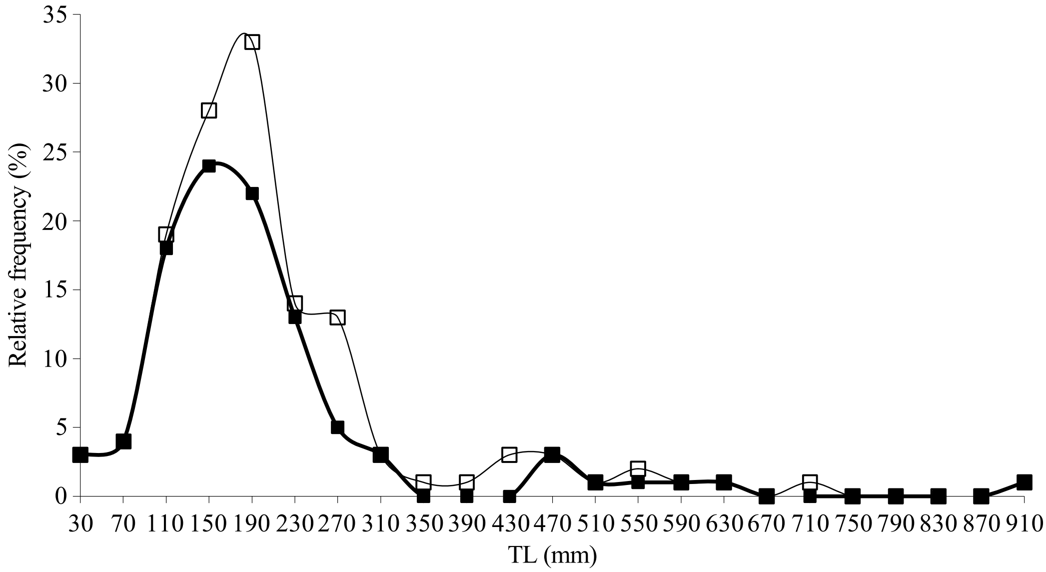

Figure 2. Relative frequencies of species (N = 112) according to individual total length (TL) registered in small-scale fisheries in Southern Brazil grouped in 40 mm size classes. Maximum TL in trawling: wide line, 100 species; minimum TL in gillnets: narrow line, 32 species.

Twenty species were common to both gears, and 70% of them had Max. TL T > Min. TL G (Figure 3). Species represented in trawling by individuals < 200 mm only contained Min. TL G > Max. TL T. Conversely, individuals > 200 mm presented TL T > Min. TL G (Figure 3).

Among the 20 species common to trawling and gillnets, 16 constitute fishing resources in the study area (Figure 4). Thirteen species, ten of which are fishing resources in the region, presented the relationship 'Max. TL T/Min. TL G' > 1.0. This reveals that trawling also acts on important sizes that are larger than the smallest individuals caught by gillnets. For five resources, *Prionotus punctatus*, *Paralonchurus brasiliensis*, *Centropomus parallelus*, *Trichiurus lepturus*, and *Larimus breviceps*, trawling catches individuals up to 1.5-2.3 times larger than the smallest ones caught by gillnets (Figure 4). The other 26 fishing resources were classified under trawling (18) or gillnets (8) (Table 1).

The minimum size of legal capture (TL C) was established for 18 fishing resources (Table 1). Trawling exploits 13 of these species. Nearly 70% (9) presented the relationship 'Max. TL T/TL C' > 1; however, it is expected that all 13 species have individuals caught with TL < TL C. Gillnets exploited 14 resources; half of them presented the relationship 'Min. TL G/TL C' > 1, and prohibited sizes were probably not caught by gillnets. The other 50% (seven resources) presented Min. TL G < TL C and were vulnerable to being captured at prohibited sizes (Figure 5).

The average size at first maturation is known for 40 species (Table 1). Trawling exploited 37 of them. Nearly 75% (29) presented the relationship 'Max. TL T/TL_{50}' > 1; however, it is expected that all 37 species caught individuals with TL < TL_{50}. Gillnets exploited 19 species. Nearly 55% of them presented the relationship 'Min TL G/TL_{50}' > 1, and probably are not caught by gillnets before the first maturation. Conversely, 45% (9 species) presented Min TL G < TL_{50} and were vulnerable to gillnets as juveniles (Figure 6).

For trawling, nearly 75% (19/25) of fishing resources analyzed for maturation size presented the relationship 'Max. TL T/TL_{50}' > 1, but it is expected that all 25 resources caught individuals

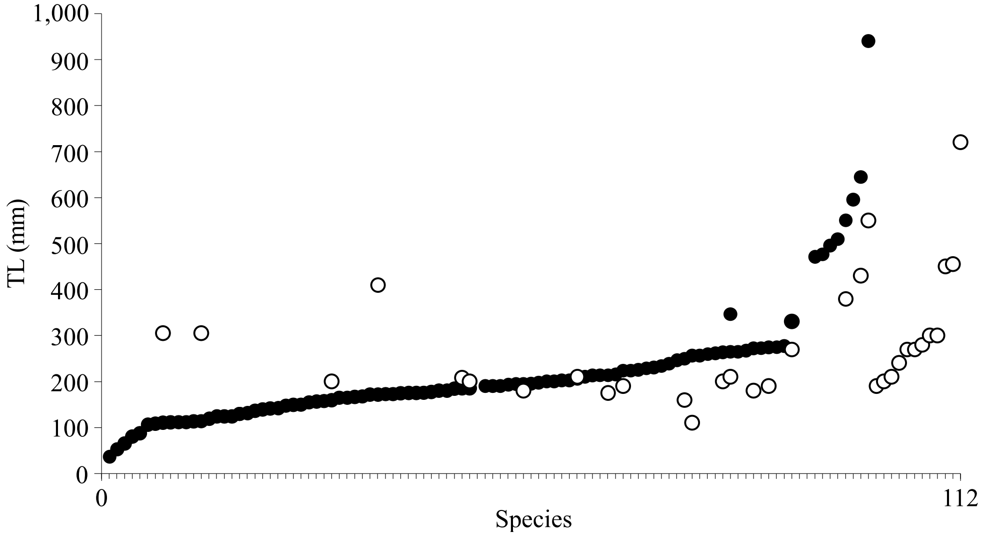

Figure 3. Distribution of values of maximum total length (TL) in trawling (dark circles) and/or of minimum total length in gillnets (white circles) of 112 species caught by small-scale fisheries in Southern Brazil.

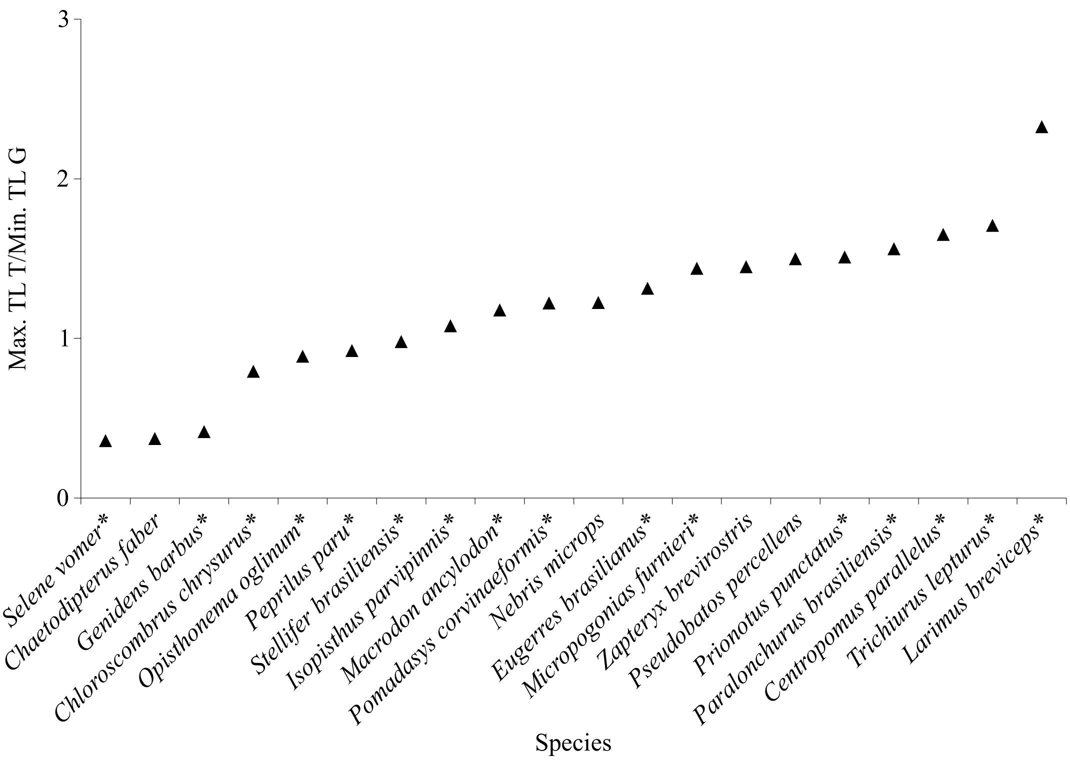

Figure 4. Species of common occurrence in both fishing gears (trawl nets and gillnets) in Southern Brazilian small-scale fisheries, and values of the relationship between the maximum total length in trawling (Max. TL T) and the minimum TL in gillnets (Min. TL G). *: species that constitute fishing resources in the study area.

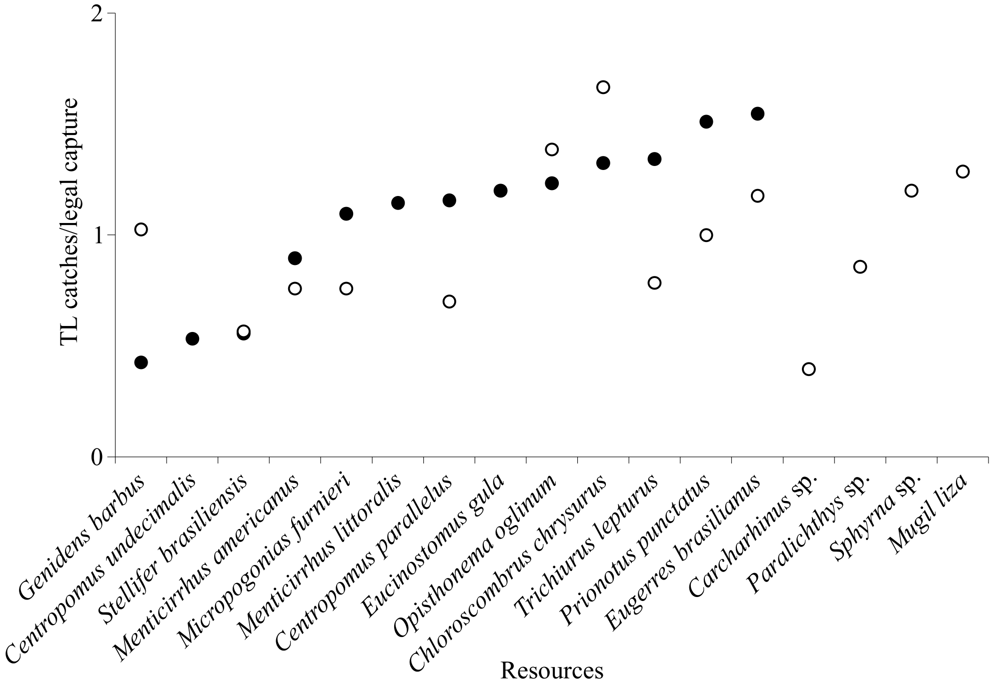

Figure 5. Relationship between total length (TL) in catches and TL of legal capture in resources exploited by small-scale fisheries in Southern Brazil. Dark circles indicate the maximum TL in trawling; white circles indicate the minimum TL in gillnets.

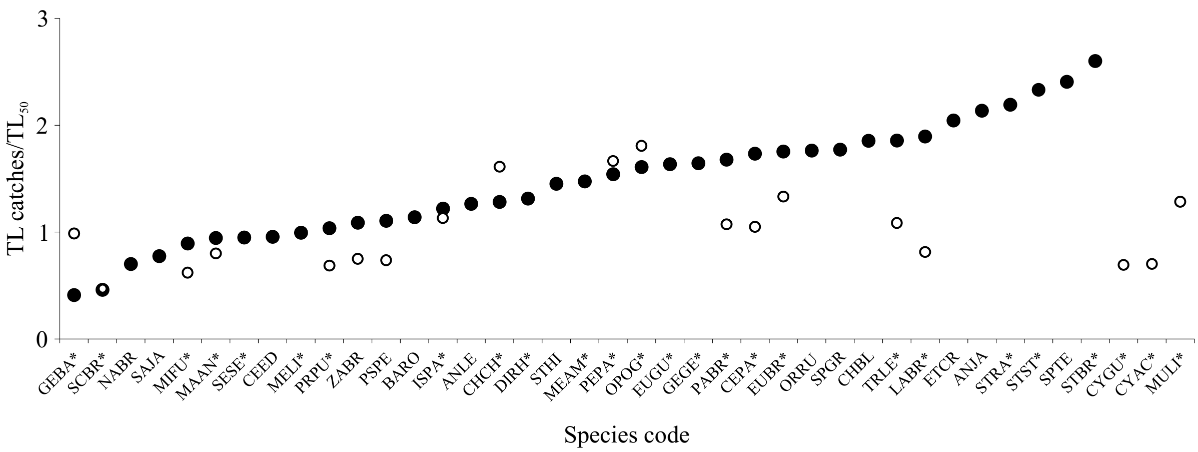

Figure 6. Relationship between total length (TL) in catches and average TL of maturation (TL_{50}) in species exploited by small-scale fisheries in Southern Brazil. Dark circles indicate the maximum TL in trawling; white circles indicate the minimum TL in gillnets. *: species that constitute fishing resources in the study area. Species code: Table 1.

with $TL < TL_{50}$. For gillnets, nearly 60% (10/17) of the resources presented 'Min TL G/TL_{50}' ≥ 1, and probably were not caught before the first maturation. However, 40% (7 resources) presented Min TL G $< TL_{50}$ and were vulnerable to gillnets in juvenile conditions (Figure 6).

Fishing resources caught of undersized for legal capture and/or before the first maturation constitute incidental capture in such gear. In trawling, size bycatch affects *Genidens barbus*, *Centropomus undecimalis*, *Scomberomorus brasiliensis*, *Menticirrhus americanus*, *M. littoralis*, *M. furnieri*, and *Selene setapinnis*; in gillnets, *S. brasiliensis M. americanus*, *M. furnieri*, *Centropomus parallelus*, *Trichirus lepturus*, *Carcharhinus* sp., *Paralichthys* sp., *Prionotus punctatus*, *Larimus breviceps*, *Cynoscion guatucupa*, and *C. acoupa* are affected (Figures 5 and 6).

DISCUSSION

Data showed that trawlers catch thrice the number of species than gillnetters, which reflects different selectivity between the two gears (Armstrong et al. 1990; Alarcón Vélez et al. 2014), as well as the mode and depth of operation. Active fishing, which is independent of fish movements and explores shallow waters, are the advantages of shrimp trawling, which result in higher yields than gillnets, which frequently work at the bottom up to 30 m depth (Chaves and Robert 2003; Afonso and Chaves 2021). Previous studies have pointed out a bathymetric heterogeneity in fish size distribution, with smaller individuals occupying mostly shallower waters, while larger ones occupy deeper waters. A similar trend was reported by Macpherson and Duarte (1991), who referred to demersal fish in the SE Atlantic (44 species) and the NW Mediterranean (31 species). This was also observed in the pelagic tuna fishery in Asia (FAO 2016). The size-depth relationship associated with gear selectivity helps to explain the size differences between captures from the gears, the smallest TL of 36 mm was found for trawling, and 100 mm for gillnets. Even so, the range of minimum TL of species caught by gillnets reached 610 mm, which is an important value in view of their high selectivity. This is due to the multiple mesh sizes found in setnets plus driftnets, from 5 to 20 cm between opposite knots, exceptionally up to 45 cm, operating simultaneously and/or alternately along the year (Chaves and Robert 2003; Afonso and Chaves 2021).

The minimum size of legal capture (TL C) is normally determined based on the reproductive condition, for example, the smallest mature fish, the average size of maturation (TL_{50}), or the size at which 100% of fish are mature (Sunil Mohamed et al. 2014). When TL C is larger than TL_{50}, it denotes caution in fisheries management. In the present work, TL_{50} was estimated for some species, and TL C was established for a lower number of resources. The values of these parameters are derived from various regions on the Brazilian coast, and in certain species both TL C and TL_{50} refer to two different stocks. Although not definitive, results indicate undersized individuals in bycatch that also occur in gillnets in the study area. The size at first maturation exceeded the maximum size caught by trawling in eight species, as well as the minimum size caught by gillnets in nine species. This means that undersized fish are caught by trawling (as expected) as well as by gillnets. Both conditions simultaneously apply to four species: *G. barbus*, *S. brasiliensis*, *M. furnieri*, and *Macrodon ancylodon*. These species play an important role in landings in Southern Brazil (MMA 2005; Chaves and Silva 2019; Chaves et al. 2021), and juveniles are being exploited by both trawling and gillnets. Because more species are caught by trawling, this gear acts on more undersized species than gillnets. However, relative to the number of species occurring in each gear, the size bycatch from gillnets is significant.

Capture of resources smaller than TL_{50} by gillnets in Brazilian waters has long been reported. Alves et al. (2012) studied mesh sizes of 7-13 cm and found undersized individuals in five of six species, including *S. brasiliensis* and *M. furnieri*. The status of the other three species recognized in the present work as occurring in gillnets is unknown because of the lack of data on TL C or

TL_{50}. Indeed, there are resources (e.g., *Centropomus undecimalis* and *Menticirrhus littoralis*) that also occur in gillnets (Afonso and Chaves 2021), but were not presented here because data on Min. TL G were not available.

The number and biomass in captures were not considered, nor were the discards accomplished on board in the case of commercial samplings. It is expected that in a single haul of trawling, a significant number of small fish were caught than with a similar effort using gillnets. On the other hand, considering the large area used to deploy gillnets (thousands of meters), and their period of exposure (up to six days fulltime), the total fishing effort of gillnets is intense, and the impact of gillnets on juveniles and undersized fish is not negligible. In the study area, SSF is only managed with respect to trawling; there are no policies on gillnet effort with respect to extension, time of exposure, or management by quotas. Only a few resources are subject to local rules disposing on the non-capture of young or of adults in the spawning period (Chaves and Silva 2019), and on the capture of threatened elasmobranchs (Chaves et al. 2019). In view of the occurrence of threatened teleost species in the study area, Afonso and Chaves (2021) recommended an effort reduction of gillnet with a mesh size of 18 cm at the end of winter and spring. Santurtún et al. (2014) stated that, for stocks that are not managed by quota, the biggest problem was discards due to minimum landing size, an alert that highlights the relevance of the present findings with respect to size bycatch in gillnets.

In the present work, gillnet captures were not individualized by mesh size, an omission that prevents an accurate analysis of the gear types most implied in non-target captures. Measures to reduce the capture of undersized fish, proposed by Alarcón Vélez et al. (2014), include the turnover of fishing areas and the extension of close seasons for fishing, taking into account the presence of juveniles. Alves et al. (2012) added that gillnet management should consider the earlier period of the reproductive cycle, since ovarian development increases the fish perimeter at the first dorsal fin in *M. furnieri* and other teleosts. The influence of the reproductive cycle on mesh size selectivity, first described by McCombie and Berst (1969), affects adult fish, but is usually ignored in fishery rules.

This work highlights the suggestion of Cardoso et al. (2021) with respect to catches, and the partial discarding of fish that could be caught in bigger sizes and provides higher yields. It applies not only to fish and shrimp trawlings, but also to gillnets. Furthermore, from a global conservation perspective, gillnets affect vertebrates such as sharks, turtles, mammals, and penguins and other birds, when migrating in waters exposed to setnets and driftnets (Cheng and Tien-Hsi 1997; FAO 2020), presenting a strong challenge for monitoring and control. Following Santurtún et al. (2014), in view of the size bycatch existing in both trawling and gillnets, it is recommended to implement landing obligations for all catches, except for species with a high survival rate after release. According to these authors, time can be provided to fishers' organizations to develop innovative solutions to trade these undersized fish, or to find processed products that use the otherwise discarded fish as raw material.

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ORIGINAL RESEARCH

Livelihoods characterization of a small-scale fishing community in the Colombian Caribbean (Colombian Caribbean SSF livelihoods)

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ABSTRACT. Coastal communities depending on small-scale fisheries (SSFs) are poorly understood. Designing policies to address their vulnerabilities requires understanding the socioeconomic context in which SSFs operate. Unfortunately, that information is usually incomplete in developing countries. This study seeks to close this gap by examining the socio-demographics, assets, livelihood strategies, food security, and poverty levels of both fishing and non-fishing households in a fishing village in the Colombian Caribbean. The analysis follows the sustainable livelihoods approach. Our results show that: (i) SSFs play a double role in fishing households: self-consumption and income generation; (ii) SSFs play an essential role in food security for both fishing and non-fishing households; (iii) livelihood diversification, including multispecies fishing and activities by household members in addition to the head, is key for diversifying risk and smoothing consumption; (iv) fishing communities face significant restrictions in access to financial markets; and (v) although fishing households earn more income than non-fishing ones, they exhibit lower education and literacy. These results show that SSF is a buffer against the vulnerability of fishing communities. Strict conservation strategies might be necessary to sustain SSF, but these must be accompanied by alternative income sources, such as compensation schemes, social protection, or policies enabling alternative livelihoods. JEL Codes: D13, I21, J22, J46, Q22, Q56.

Key words: Sustainable Livelihoods Approach (SLA), small-scale fisheries, assets, poverty, education gap, food security, Colombia.

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Caracterización de los medios de vida de una comunidad de pescadores a pequeña escala en el Caribe colombiano (medios de vida de PPE del Caribe colombiano)

RESUMEN. Las comunidades costeras que dependen de la pesca en pequeña escala (PPE) son poco conocidas. El diseño de políticas para abordar sus vulnerabilidades requiere comprender el contexto socioeconómico en el que operan los PPE. Desafortunadamente, esa información suele ser incompleta en los países en desarrollo. Este estudio busca cerrar esta brecha examinando la sociodemografía, los activos, las estrategias de sus medios de vida, la seguridad alimentaria y los niveles de pobreza de los hogares pescadores y no pescadores en una comunidad de pescadores en el Caribe colombiano. El análisis sigue el enfoque de los medios de vida sostenibles. Nuestros resultados muestran que: (i) los PPE juegan un doble papel en los hogares pesqueros: autoconsumo y generación de ingresos; (ii) los PPE juegan un papel esencial en la seguridad alimentaria tanto para los hogares pescadores como para los que no lo son; (iii) la diversificación de los medios de vida, incluida la pesca multiespecífica y las actividades de los miembros del hogar, además del cabeza de familia, es clave para diversificar el riesgo y suavizar el consumo; (iv) las comunidades pesqueras enfrentan importantes restricciones en el acceso a los mercados financieros y (v) aunque los hogares pescadores obtienen más ingresos que los que no lo son, exhiben una educación y alfabetización más bajas. Estos resultados muestran que la PPE es un amortiguador contra la vulnerabilidad de las comunidades pesqueras. Es posible que se necesiten estrategias de conservación estrictas para sostener la pesca artesanal, pero ellas deben ir acompañadas de fuentes alternativas de ingresos, como esquemas de compensación, protección social o políticas que permitan medios de vida alternativos. JEL Codes: D13, I21, J22, J46, Q22, Q56.

Palabras clave: Enfoque de medios de vida sostenibles (SLA), pesquerías de pequeña escala, activos, pobreza, brecha educativa, seguridad alimentaria, Colombia.

INTRODUCTION

Fishing is a key component in the livelihoods of millions of people (Asiedu 2011). Approximately 90% of the almost 40 million people that the Food and Agricultural Organization (FAO) register globally as fishers are classified as small-scale, and 97% of them are located in developing countries (FAO 2021).

However, there is limited information about the livelihoods of small-scale fishing (SSF) communities in developing countries (Bailey and Jentoft 1990; Cinner et al. 2010). Collecting reliable data is difficult (Pita et al. 2019) and the sector lacks quantitative studies on socioeconomic variables (FAO and World Fish Center 2008). Research on fisheries has emphasized biological issues (Béné 2003). By contrast, there is little rigorous data estimating the poverty level of fishing households (Willmann 2004). In some cases, fishers' poverty has been inferred rather than proven (Thorpe et al. 2007). A review of 202 articles concluded that fisheries' role in poverty alleviation is unclear because good conceptual models are lacking (Béné et al. 2016). Moreover, the estimation of poverty indexes and the measurement of vulnerability depend on reliable longitudinal data (Béné 2009), which has not been available. In a special issue of Marine Policy (Vol. 101, March 2019), coordinated by Pita et al. (2019), authors not only discuss the challenges of managing small-scale fisheries under scenarios of poor data, but present a variety of innovative approaches for SSF data collection, including participatory methods.

Despite this lack of detailed information, there exist multiple proposals and interventions to improve the well-being of these communities and the sustainability of fishing resources. These solutions have centered on increasing the efficiency of SSF while implementing mechanisms to conserve fish stocks, through a combination of management strategies to limit access (e.g. protected areas, community and territorial use rights, community-based management, closed seasons) and incentives to reduce fishing effort (e.g. alternative livelihoods, subsidies, conservation agreements) (Allison and Ellis 2001; Cinner 2014). As Cinner et al. (2009) argue, successful interventions to reduce fishing efforts in overexploited fisheries require understanding the socioeconomic context in which fishers operate.

Research on livelihoods in SSF communities has increased recently, and shows heterogeneous results in developing countries. For instance, in terms of income levels, findings are ambiguous: while some authors find that fishing communities are poorer than the national level, as in Malaysia (Teh and Sumaila 2007), or more vulnerable than other groups, as in Ghana (Asiedu 2011), other authors show that fishers are not always the poorest of the poor and can even be better off than non-fishing households, as shown in Malawi, Uganda and Kenya (Allison 2005), or Philippines, Bangladesh, India, Senegal and Tanzania (Tietze et al. 2000).

Besides, as Thorpe et al. (2007) assert, poverty cannot be captured only in monetary terms: literacy, access to education, health, and clean water, as well as other factors are dimensions of well-being. Landownership, debt, financial capital, and marginalization from political decision-making affect income and well-being in SSFs (Béné and Friend 2011; Nayak et al. 2014). Others have highlighted the importance of SSF interventions to strengthen tenure and community governance, cover upfront opportunity costs, reduce vulnerability to market shocks by supporting a broader livelihood portfolio, and relax credit constraints (Barr et al. 2019).

In the framework of socio-ecological systems, some researchers have proposed indexes of vulnerability (Béné 2009) or adaptive capacity (McClanahan et al. 2008, 2009; Cinner et al. 2012; Moreno-Sánchez and Maldonado 2013; Maldonado and Moreno-Sánchez 2014) for SSF communities. These indexes have included income, occupational diversification, poverty, material assets, wealth, dependence on natural resources, and social capital.

Income diversification is a livelihood strategy for fishing households (Ellis and Allison 2004; Thorpe et al. 2007; Béné 2009). Fishing is generally a part-time activity that is complemented with other sources of income. But fishing is also an essential component of food security, not only for fishing households but for their communities. SSF goes beyond being a last-resort activity for the poorest of the poor; it is relevant to other socioeconomic groups (Garaway 2005). For example, Kawarazuka (2010) analyzes the role of SSFs in the food and nutrition security of poor rural households in developing countries, particularly in Africa, Asia, and Oceania. The author shows that fish captured in common-pool resources are used for self-consumption and traded in local markets and highlights how those fisheries can compensate for the shortage of food in poor households. He also finds that SSFs provide other income-generation opportunities such as processing and trading and that –among those better-off– fishing income is used to purchase non-staple foods and to invest in agriculture. Kawarazuka (2010) also describes the importance of fish in rural poor communities for the consumption of high-quality nutrients. Confirming these findings, Kawarazuka and Béné (2010) identify two pathways between small-scale fisheries and household nutritional security: (i) the direct nutritional contribution from fish consumption; and (ii) the increased purchasing power through the sale of fish. While some members of SSF households fish as their primary source of income, and some households engage in economic activities not related to fishing at all, fishing shapes the livelihoods and food security of all households in these communities.

In general, these studies confirm the heterogeneity within and among fishing communities and the relevance of social, economic, and institutional context in understand poverty levels and vulnerability of fishing households. In the same way, the literature discussed above confirms the role of fishing in the food security of fishing households and their communities.

In Latin America, however, socioeconomic studies of SSF are limited and Colombia is not the exception. According to the Organisation for Economic Co-operation and Development (OECD 2016), there are no reliable statistics about Colombia's SSF activities and communities. For the case of Colombia, there are only some cross-sectional surveys, characterizing some aspects of fishing households (García 2010; Agudelo et al. 2011; Moreno-Sánchez and Maldonado 2013; Viloria et al. 2014). These studies have found that fishers are typically adults who belong to households exhibiting low education levels and assets ownership, whose livelihoods depend on more than one source of income. Others have collected information about fishing gear, types of boats, captured species, and levels of effort (Rueda et al. 2011; Viloria et al. 2014). However, little is known about the dynamics of the fishing household economy. Notably, there is scarce literature on the variability of income throughout the year.

Our objective then is to describe the demographics, assets, livelihood strategies, food security, poverty level, and sustainability of a fishing village in the Colombian Caribbean (Barú-Cartagena). We hypothesize that fishing and non-fishing households differ with respect to characteristics such as education, access to financial capital, income level and diversification, and food security. We collected information from fishing and non-fishing households in the village of Barú, administering monthly socioeconomic surveys from July 2018 to September 2019. The data collection started with a baseline and was followed by monthly surveys administered to each participating household. The sample included around 100 fishing households and 150 non-fishing households. To analyze the data, we organized the information following the Sustainable Livelihoods Approach (SLA).

Our contribution is a comprehensive description and analysis of a fishing community's livelihood that involves: (i) the characterization of fishing and non-fishing households in terms of capital (human, financial and social), livelihood strategies (diversification of sources of income, access, use of financial services, and the role of social capital), and livelihood outcomes (monetary poverty and food security); and (ii) a longitudinal study that collects monthly panel-data information at a household level for a year.

MATERIALS AND METHODS

Conceptual framework

We follow the conceptual framework of the sustainable livelihood approach (Chambers and Conway 1992; DFID 1999). The SLA assumes that household well-being depends on consumption and production decisions (including livelihood strategies) in light of its endowment of assets (human, social, natural, physical, and financial) in a specific institutional and geographical framework, and the interactions of these factors (Allison and Ellis 2001). Assets we consider are as follows: (1) human capital: education and employment; (2) social capital: participation in organizations and supporting networks; (3) physical capital: housing, appliances, vehicles, livestock, and fishing assets; and (4) financial capital: savings, credit. The livelihood strategies considered are labor and non-labor strategies, fishing, use of financial services, allocation of expenditures for household consumption, and food security strategies. Finally, outcomes include household income, expenditures, food security, poverty, and inequality.

Study site

Barú peninsula is part of the rural area of the Tourist and Cultural District of Cartagena de Indias in the department of Bolívar, Colombia. It covers approximately 7,117 hectares and consists of three villages: Ararca, Santa Ana, and Barú. This research project was implemented in Barú village (Figure 1). The number of residents in Barú village averages 2,700-2,800 inhabitants in the populated center, mostly ancestral Afro-descendants (Lizarazo and López 2007; Márquez 2014; Mendoza and Moreno-Sánchez 2014).

Barú is a major tourist destination with high demands of ecosystem services such as seafood and recreation. It is located in the area of influence of the National Natural Park Corales del Rosario and San Bernardo (MADS 2012), where commercial fishing is prohibited. However, subsistence fishing is allowed. In the most recent management plan, the park authorities recognized small-scale fishery activities as traditional and ancestral practices (PNN 2020). In practice, long-line and diving are the most frequent fishing arts. The management plan also identifies some species that currently are being harvested and are under some level of threat. There are two zones within the park clearly defined and managed as

Figure 1. Location of Barú Peninsula adjacent to the marine protected area Corales del Rosario and San Bernardo National Park (https://runap.parquesnacionales.gov.co/).

no-take zones, whose characteristics imply that this fishery runs under a semi-open access regime. At the time of the survey, there was no official record of fishers.

In terms of infrastructure, Barú village lacks an adequate aqueduct and sewer service, and rainwater is the primary source of water supply for most households. Drinking water comes from Cartagena by boats adapted to transport water –known as *bongoductos* (Pineda et al. 2006; Rodríguez-Sánchez et al. 2016). There is a health post in the village which offers first aid, primary care, and vaccination campaigns (MADS 2012; Villamil et al. 2015); a health center is currently under construction and is expected to provide more services and better equipment.

Target and sample population

In July of 2018, the population of Barú village accounted for 801 households: 158 fishing households (F-hh) and 643 non-fishing households (non-F-hh). We randomly selected a stratified sample of 255 households (97 F-hh, and 158 non-F-hh) to carry out the surveys. The size of the sample included oversampling of 10% to cope with attrition during the information gathering process. The sample anticipates a margin of error of 5% and a confidence level of 95%. The baseline survey was conducted between July and October 2018; follow-up surveys were administered monthly from October 2018 to October 2019.

Collection instruments

We ran a baseline survey to (i) register the participating households; (ii) gather general information assumed to remain constant throughout the study period; and (iii) initiate the collection of socioeconomic information. The baseline survey consisted of seven sections: (i) household characteristics and economic activities; (ii) household expenditures; (iii) household assets and income; (iv) finances; (v) fishing; (vi) food security; and (vii) land tenure.

Follow-up surveys were conducted once a month for each household for the following consecutive 11 months and had the same structure as the baseline except for the sections on household characteristics and land tenure. During the follow-up survey, new household members were recorded, as well as those who left.

Two members of the Barú community were trained to apply the survey and became interviewers and co-researchers for the project. This made it easier for the community to accept the researchers and thus be collaborative in offering information. The interviewers were trained in topics related to ethics, survey administration, and the objectives of the project.

Variables

In order to capture the different dimensions of the SLA, we use information to construct statistics related with several variables (Table 1).

For most of these indicators, reported statistics compare average values for fishing and non-fishing households. In some other cases, particular indicators are proposed.

For income diversification, we use the Simpson Diversity Index (SDI; Etea et al. 2019). According to this approach, if a household has only one activity the index will be zero. To the extent that the household participates in more activities and the income it receives from these activities is similar, the index tends to one. Therefore, the greater the diversification of activities and the distribution of income deriving from them, the greater the SDI.

The indicator for food security was calculated using an adaptation of the Latin American and Caribbean Food Security Scale (ELCSA) (FAO 2012). Insecurity levels were estimated using the answers to the following questions, with reference to the week previous to the survey:

- Did you want to vary the household nutrition and could not?
- Did you have to reduce the food portion of a household member?
- Did someone in this household go to bed hungry?
- Did someone in this household have to skip breakfast, lunch, or dinner due to lack of food?

If the answer to all four questions is yes, the household is considered in severe insecurity. If the answer is yes to two or three questions, the household is in moderate insecurity, and if the answer is yes to one of the questions the household is in slight insecurity. Finally, if the answer to all questions is no, the household is considered to have food security.

Table 1. Summary of variables to be evaluated in the SLA approach.

Dimension	Variable	Indicator
Endowments	Human capital	Household size, age and sex distribution, literacy and schooling
	Social capital	Organizations, fish sharing
	Physical capital	Housing, household appliances, vehicles, livestock, fishing assets
	Financial capital	Savings, credit
Strategies	Labor	Labor force participation, Labor activities, Income diversification
	Fishing	Profile of fishers, catches, fishing techniques, species
	Non-labor	Remittances, transfers
	Use of financial capital	Savings and credit, consumption, food and protein consumption
	Food security	Shortage responses
	Income and expenditures	Income, expenditures, income sources
Outcomes	Food security	Scale of food security
	Poverty	Headcount poverty index
	Inequality	Gini coefficient
	Sustainability	Fishing sustainability

To measure the inequality of income distribution and household expenditure in the Barú village, we estimated the Gini coefficient for labor income, non-labor income, total income, household per capita income, and total expenditure.

To approach the potential effects of fishing on the ecological system, we analyzed the degree to which fishing gear affects the ecosystem, and the conservation status of the main species caught.

To do this, the approach proposed by Bjordal (2005) was used, which considers seven categories of effects on coastal marine ecosystems: size selection, species selection, incidental mortality, ghost fishing, habitat effects, energy efficiency and catch quality. A score of favorability (unfavorable = 1 to favorable = 10) of the gear with respect to the ecosystem is assigned to each of these categories, which are then averaged arithmetically, resulting in an overall index of the average effect of each gear on the ecosystem. Weighted scores were calculated for the average use of each gear type, measured as the percentage of fishers who used each gear type in each month during the survey period.

RESULTS

Household's endowments

Human capital

Households in Barú were composed of four persons on average. Barú had a predominantly young community, with about 71% of the population aged under 40; the median age was 26 years. Although the gender distribution was even (52.7% men and 48.3% women), 24.8% of non-F-hh were headed by women, while among F-hh this percentage was only 4.9%.

Households showed important differences in literacy rate and schooling. The percentage of people (15 years and older) who can read and write was higher for non-F-hh than for fishing ones (Table 2). This difference was greater when heads of household were considered: 95% of household heads in non-F-hh can read and write, whereas 78% of those in F-hh can do so. Both differences were statistically significant.

Educational achievement by household members older than 24 years in non-F-hh was significantly higher than that of F-hh (7.7 versus 6.1 years). When considering only the heads of household, the difference in education level was accentuated. Non-F-hh heads were more educated (6.3 years) than those from F-hh (4.7 years).

Twenty-seven percent of the population over 18 years of age completed secondary education (34% in non-F-hh and 18% in F-hh). In both types of households, the percentage of women who have completed secondary education was higher than that of men (Table 2). Regarding school attendance rate among 5 to 18 year old household members, there were no significant differences: 75% and 80% for non-fishing and fishing households, respectively.

Finally, 53% of individuals aged between 18 and 28 were considered NEET (Not in Education, Employment or Training). For women, this rate rose up to 72%; i.e. 7 out of 10 women in this age range were neither working nor studying. We believe this was related to childbearing and childrearing by women in this age group, as well as limited job opportunities for both men and women. For men, this rate was 28%. When comparing types of households, the NEET rate was higher for non-F-hh than for F-hh, although this difference was not significant. The estimated rate for Barú was double that reported at the national level.

Social capital

The participation of Barú's households in community fisheries organizations is part of their structural social capital. The village had four formally constituted fishing organizations. The organizations' main objectives were to stabilize their members' income and to promote marketing

Table 2. Summary of human capital indicators in Barú (baseline survey). F-hh: fishing households, non-F-hh: non-fishing households.

		F-hh	Non-F-hh	Colombia
Dependency ratio[a]		0.52	0.51	0.64[b]
Literacy rate (> 14 years old)	Total	85.9%**	92.8%	95%[b]
	Household head	77.5%**	94.8%	
Schooling (years of attending, older than 24 years)	Women	6.2*	7.1	8.4
	Men	4.6**	6.7	8.6
	Total	5.4**	6.9	8.5[c]
	Household head	4.7**	6.3	
Complete high school education (> 18 years old)	Women	26%*	38%	21.9%
	Men	11%**	29%	22.2%
	Total	18%**	34%	22.1%[c]
	Household head	7.1%**	19.6%	
% NEET (18-28 years)	Women	72.3	71.43	37
	Men	28.3	36.8	14.8
	Total	49	55.9	26.1

[a]The age dependency ratio is: 'the ratio of dependents people younger than 15 or older than 64 to the working-age population (those ages 15-64)' (https://data.worldbank.org/indicator/SP.POP.DPND).
[b]World Bank (2020).
[c]Barro and Lee (2013).
*$p < 0.05$, **$p < 0.01$

and fishing control practices. According to the baseline survey, 5% of non-F-hh and 39% of F-hh were linked to one of these organizations.

Structural capital also included receiving fish as a gift and receiving support when a household needs a loan or was experiencing food shortages; these examples show the existence of support networks. In the baseline survey, 35% of non-F-hh and 27% of F-hh reported having received fish as a gift; these percentages were significantly lower during the follow-up survey, averaging 24% and 19%, respectively (Figure 2).

It should be noted that the practice of gifting fish can also be related to cognitive capital, as it expresses values of solidarity. On average, about 28% of F-hh reported giving away part of their catch to other households (Figure 2). Note that, in the month of September, both at the baseline and in the follow-up survey, the percentage of F-hh that gifted fish to others was as high as nearly 50%.

In terms of sources of support in case of food shortage, 22% and 12% of non-fishing and F-hh, respectively, turned to their families; 5.4% of non-F-hh and 2.4% of F-hh went to their friends. These differences are not statistically significant.

Physical capital

Five categories of physical assets were examined in Barú households: housing and other real estate (farms and lots), household appliances, vehicles, livestock, and fishing assets (Figure 3). Households in Barú exhibited a high level of ownership of housing and household appliances. For instance, the percentage of households that own their residence was 70% and 81% for non-fishing and fishing households, respectively.

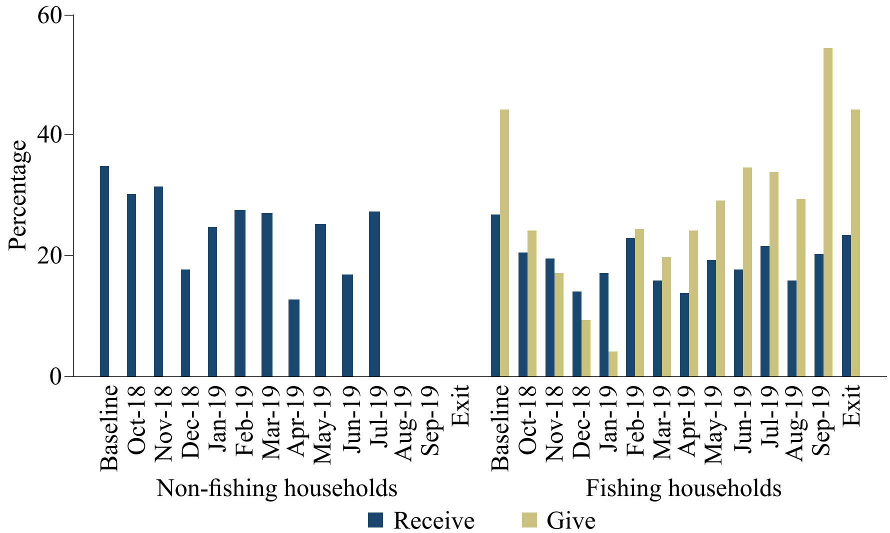

Figure 2. Proportion of households who received and gave fish as a gift.

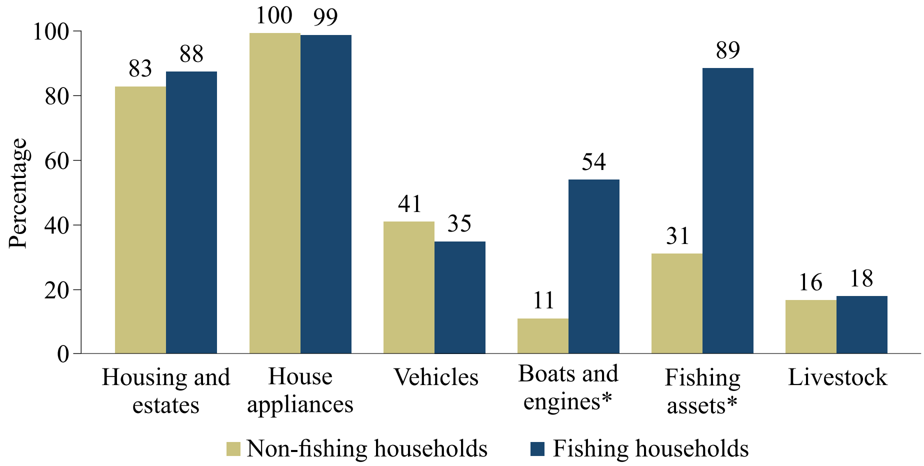

Figure 3. Percentage of non-fishing and fishing households which own physical assets (*$p < 0.01$).

However, the ownership of other properties such as lots and parcels was low; only 19% report owning lots and 1% rural parcels. No differences were found in terms of vehicle ownership (mainly motorbikes) or livestock. As expected, F-hh report greater ownership of boats, boat engines and productive assets for fishing, such as nets, handlines, fish traps, and coolers.

Among fishing assets, handlines and free-diving equipment were the most common gear among F-hh. Likewise, of these households, 43% owned boats or canoes, 35% boat engines, and 36% refrigerators or coolers. Almost a quarter of non-F-hh had freezers, and around 10% owned fishing gear such as handlines and trolling equipment. On average, the total value of assets was almost the same for both types of households (Table 3). However, when classified in categories, there were some differences mainly related to the value of fishing assets that, as expected,

Table 3. Estimated value of physical assets owned by fishing and non-fishing households (in US dollars and proportions) adjusted by the purchasing power parity of 2018 (US$-PPP).

	Non-fishing households		Fishing households		
Variable	Observed	Mean (SD)	Observed	Mean (SD)	Difference
Housing and real estate	158	49,142 (95,759)	97	48,288 (80,353)	854
Appliances and electronics	158	1,462 (3,083)	97	1,410 (1,786)	53
Vehicles	158	365 (991)	97	248 (476)	117
Boats and boat engines	158	1,162 (5,442)	97	1,607 (3,349)	-445
Fishing assets	158	150 (610)	97	756 (1,358)	-603*
Livestock	158	131 (869)	97	107 (540)	23
Total physical assets	158	52,412 (96,228)	97	52,412 (81,952)	0
Proportion of households with fishing assets	158	0.31 (0.46)	97	0.89 (0.32)	-0.58*
Proportion of households with boats or boat engines	158	0.11 (0.31)	97	0.54 (0.50)	-0.43*

*p < 0.01

was higher for F-hh. There were other differences in the value of boats and of housing, but they were not statistically significant.

The distribution of the value of assets by quintiles shows that assets are relatively evenly distributed across the population. However, in F-hh, inequality is a little more marked, as the first two quintiles of this group account for only 27% of the value of assets. Ownership of fishing-related assets is distributed evenly among the quintiles, although this is not the case for boats and engines, which are more statistically frequent among households in the 4th and 5th quintiles.

Financial capital

During the period of analysis, 93% of F-hh on average reported having informal savings, while this proportion was only 28% for non-F-hh. Non-F-hh save informally, mostly through piggy banks (29%), building materials (17%) and animals (21%). F-hh do so mainly through piggy banks (34%), animals (22%) and cash (15%).

In the baseline survey and throughout the follow-up surveys, on average, 10% of households reported having formal savings, from which 81% of the non-fishing and 60% of F-hh reported depositing these savings in banks. The main reasons for not saving formally were lack of money (69%), unwillingness (14%), high transaction costs or low returns (5%), not knowing how to access formal services (4%), not trusting financial institutions (3%), financial offices are too far away (2%), or having other types of savings (0.4%).

During the period of analysis, on average, 24% of non-F-hh and 26% of F-hh received informal loans. Loan sharking –known in Colombia as *gota a gota* or *pagadiario*– was the most representative source of informal loans for both types of households (39.5 for non-F-hh and 43.8% for F-hh). Food and supplies bought on credit (21.5% and 22.9%) and loans from lenders other than usury (16.3% and 12.4%) were also noteworthy. Traditionally, access to formal credit has been scarce in this community. During the period of analysis, only 0.5% of non-F-hh and 1.9% of F-hh requested loans from the formal sector.

The level of total indebtedness averaged US$ 613 US$-PPP (US dollars and proportions) for non-F-hh and US$ 523 US$-PPP for F-hh, the difference being statistically significant. F-hh presented a lower level of indebtedness, a higher level of savings, and greater receipt of formal loans.

Livelihood strategies

Labor strategies

On average, the economically active population was 40 years old with 6.8 years of education. Labor force participation, estimated as the number of people aged 15 and older who were working out of the total population in this age range, reached 52.4% in Barú, which was lower than the national figure for the same year (68.4%) (World Bank 2020). However, employment in the village was seasonal and can therefore fluctuate over time. In non-F-hh, labor force participation was 49.5%, while in F-hh it was significantly higher at 56.3%. In other words, F-hh tended to have more people working than did non-F-hh: an average of 1.75 economically active people per household versus 1.37, respectively. F-hh had higher labor participation in the younger strata (15-19 years) and in the older population (60-79 years and above). More than half (56%) of adults over 60 in F-hh continued to provide income to the household, while only a third of this population participated in some economic activity in non-F-hh.

There were more men than women working in both types of households: of the total number of people who were working, 34.4% were women. The labor participation of women in non-F-hh was higher than in F-hh: 38.2% versus 33.6%. Labor participation of the head of households in both groups reaches 51%.

The ratio between the theoretically inactive or dependent population (under 15 years and over 65 years) and the labor force (15-65 years) in Barú was 52% in non-F-hh and 51% in F-hh. In other words, for every two persons of potential working age, there was one economically dependent person in both F-hh and non-F-hh. Between 4 and 14 % of people older than 15 reported having a second economic activity (Figure 4).

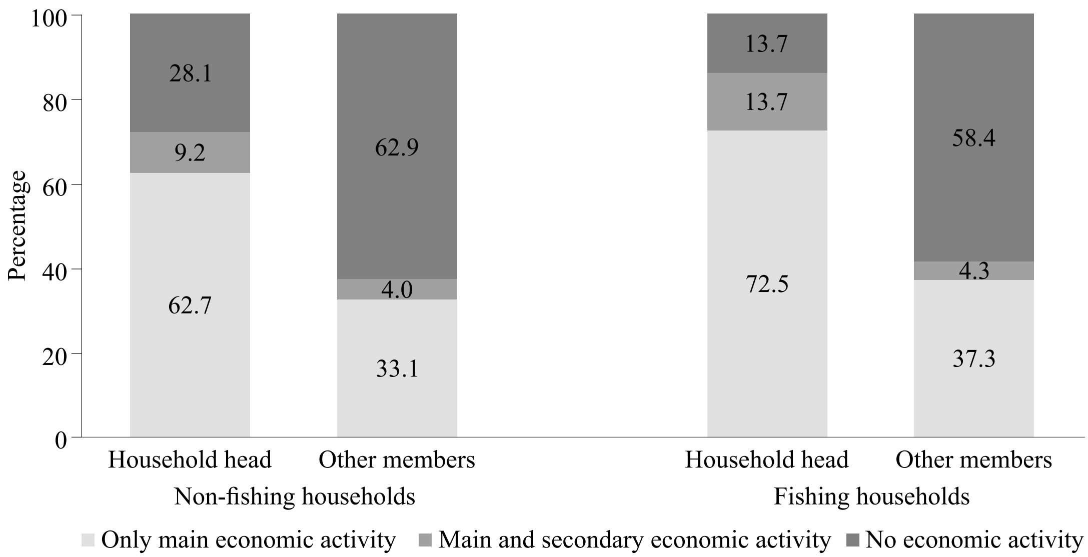

Figure 4. Percentage of household heads and other members (15 years old and older) working in zero, one, or two economic activities (for all survey months). Note: 8% of this population is studying, of whom 90% only study, while the remaining percentage works and studies at the same time.

Workers who reported carrying out only one economic activity allocate between 40 (F-hh) and 47 (non-F-hh) hours per week to that activity. When workers carry out two income-generating activities, they spent up to 52 hours per week, but reduced the average hours engaged in the primary activity. The share of F-hh which has an activity was significantly higher when compared to that in non-F-hh (Figure 5). Having a second occupation seemed to be related to the tourism seasons in the case of F-hh.

Main activities among heads of non-F-hh were tourism, the production and sale of handicrafts, construction, and sale of food. For heads of F-hh, these activities included fishing, transport, watch keeping (security) and fishing-related activities (consisting mainly of trading fish and rental of fishing equipment). Most frequent secondary economic activities for the heads of non-F-hh were food sale and handicrafts, while for F-hh were fishing, construction and food sales.

When analyzing working members other than the household head, for both types of households, most important sectors were food sales and tourism, with tourism being the most important in non-F-hh and food sales predominating in F-hh.

In addition, in F-hh, about 8% of non-head, working household members were engaged in fishing as their main activity. In terms of secondary activities, the predominant economic sector in both types of households was food sales, followed by mixed and other activities for non-F-hh and F-hh and construction for F-hh.

Participation in the formal labor market, under contract and with social benefits, included only 1.5% of workers, with no significant differences between non-fishing and F-hh. This implies that 98.5% of the workers in Barú were in the informal sector. People with formal jobs reported significantly higher incomes than those with informal jobs: US$ 862 versus US$ 631 US$-PPP per month per worker. Relative to income diversification, we found that households carry out on average 1.4 different activities from which they derive income, and F-hh diversify significantly more than non-F-hh: 1.71 versus 1.16 economic activities. About 72% of non-F-hh had one activity at most, while about 58% of F-hh had two or more activities (Figure 6).

The proportion of labor income derived from the primary economic activity for all households and for households with more than one economic

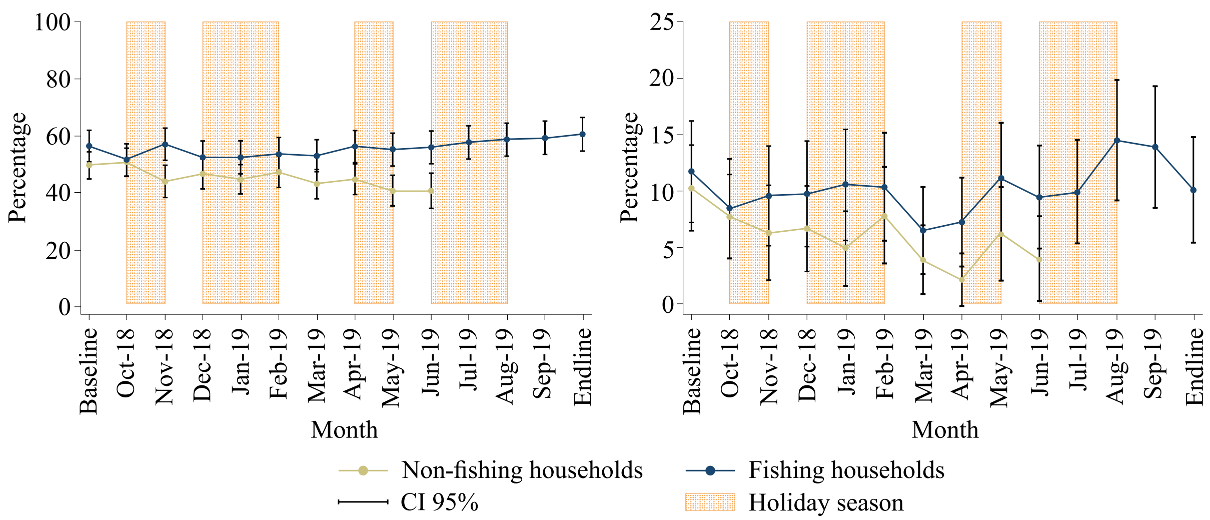

Figure 5. Percentage of the population (15 years and older) with primary economic activity (left) and secondary economic activity (right).

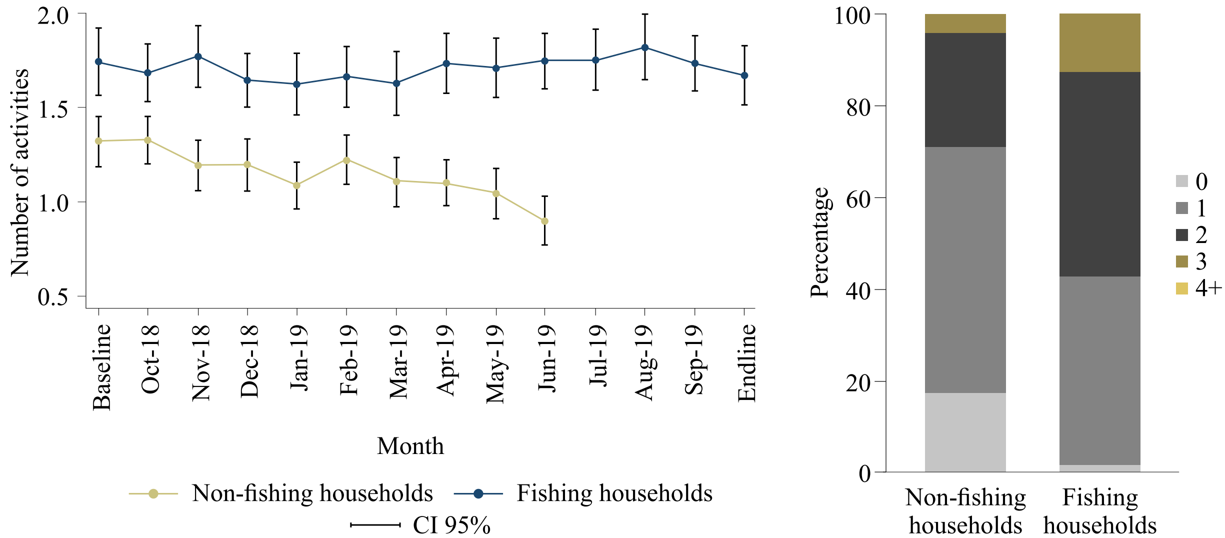

Figure 6. Number of economic activities by type of household during the study period (left), and distribution of households by number of economic activities (right).

activity was higher for non-F-hh who, on average, derived 90% of their labor income from the main activity, while F-hh derived 78% of their labor income from this activity (Table 4). According to the Simpson Diversity Index, F-hh diversified their income significantly more than non-F-hh. Households did not exhibit large diversity of income in the main economic activity; however, secondary economic activity tended to be more diverse within households.

Fishing activity

One hundred percent of the respondents who fish were men, with an average age of 45.6 years and an average of 4.28 years of education. Of the heads of F-hh, 58.3% were engaged in fishing. Fishing was the primary economic activity for 31% of the people working in F-hh, while 4% engaged in it as a secondary activity.

Fishing households allocated their catch to three uses: sale (85%), self-consumption (13%), or giving it as a gift to other households (2%). The latter two categories were part of the households' non-monetary income derived from fishing activity.

For the households surveyed, the total catch of fish resources averaged 9,000 kg of fish per month. February and July 2019 were the months with the highest catch, and January and June the lowest –the latter coinciding with important holiday seasons. This catch was around 97 kg per month per household, which was equivalent to around 23 kg per week. The monthly catch per fisherman was around 88 kg, while the catch per day averaged 4.8 kg.

When fishing was the main activity, most popular techniques were handlining (44%) and diving (38%). When fishing was considered a secondary activity, diving was the preferred fishing technique (76% versus 13% of handlining). During the period of study, we did not find variation in the use of fishing gear. On average, only 4% of F-hh diversified their gear for the whole period of the survey, combining handlining with diving, nets, pots, throw nets or longlines. Handlining was the gear with the highest catch per unit of effort (CPUE) during most of the period under study (131 kg fisherman^{-1} month^{-1}), while fish traps were the lowest (32 kg fisherman^{-1} month^{-1}) (Figure 7).

Table 4. Labor income diversity measures by type of household.

Variables	Non-fishing Mean (SD)	Fishing Mean (SD)	Means difference
Number of economic activities	1.160 (0.021)	1.709 (0.022)	-0.549*
Proportion of income from the main activity	0.899 (0.005)	0.783 (0.006)	0.115*
Proportion of income from the main activity when household has more than one activity	0.714 (0.009)	0.627 (0.005)	0.088*
Simpson Diversity Index (for the main activity of household members)	0.131 (0.007)	0.267 (0.007)	-0.136*
Simpson Diversity Index (for household members with more than one economic activity)	0.370 (0.009)	0.459 (0.005)	-0.089*

*p < 0.01

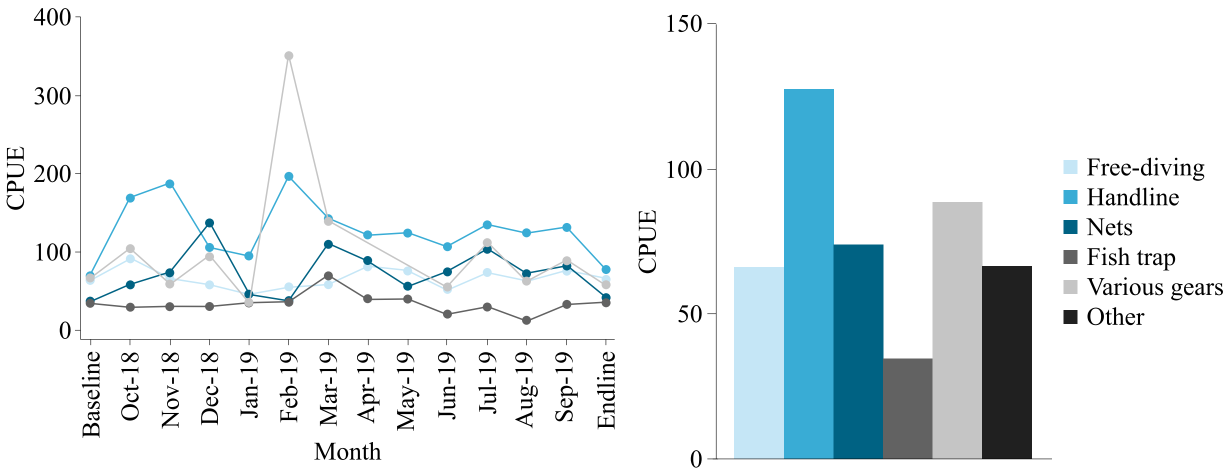

Figure 7. Catch per unit of effort (CPUE kg fisherman^{-1} month^{-1}) and total average by type of fishing gear.

Most fishers reported lobster as the most important species caught, followed by octopus and snapper. These species were associated with the coral-reef ecosystem, one of the most important ecosystems for fishing in Barú, as well as with the predominant fishing gear types among the F-hh, which were handlining and diving. There were at least other 15 species reported as captured but in lower proportions.

Three aspects to highlight: (i) fish traps and free-diving are fishing gear that target lobster; (ii) a great diversity of species is captured with handlining, notably snapper (*Lutjanus*), yellowtail snapper (*Ocyurus chrysurus*), great barracuda (*Sphyraena barracuda*), and bar jack (Carangidae); and (iii) nets are mainly used for bar jack and horse-eye jack (*Caranx hipos*, *C. latus*) (Figure 8).

Non-labor strategies

Non-labor strategies include income received from remittances and transfers from the state. On

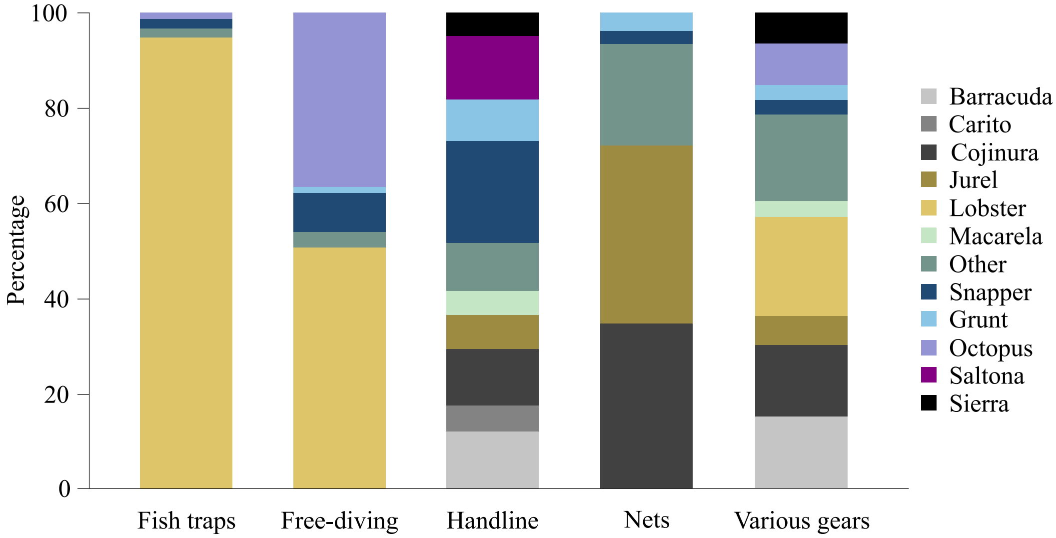

Figure 8. Main catch fish species by fishing gear.

average, 7.8% of non-F-hh and 14.8% of F-hh received subsidies. For these households, and respectively for non-F-hh and F-hh, these subsidies were associated with the conditional cash transfer program Familias en Acción (42.2% and 24.8%), third-age subsidies (45.8% and 75.9%) and compensation funds (15.7% and 3.8%). On the other hand, on average, 17.8% of F-hh and 7.8% of non-F-hh received income from remittances.

Strategies for the use of financial capital

The main use of informal and formal savings in the past, for both types of households, was to deal with unexpected or unforeseen events. Other uses were related to home improvements, education, property purchase, payments for boats or engines, and businesses, which account for 57% and 60% of the uses reported by non-F-hh and F-hh, respectively. Other reported uses included covering household expenses for food and health, general expenses, and debt repayment. Thirty six percent of households (38% non-fishing and 33% fishing) reported having no savings in the past.

In terms of use of savings during this study, on average, 18% of non-F-hh and 49% of F-hh reported using savings (formal and informal) in the month prior to the visit. The most common uses, for both types of households, were buying food and debt repayment. Moreover, about 95% of households would like to allocate their savings to future investments such as education, home improvements, house purchasing, boats and vehicles acquisition, and independent business. On the other hand, the use of savings to cover contingencies was also considered important by 32% of non-F-hh and 39% of F-hh.

Formal loans acquired in the past were mainly used for home improvements, business investment, and contingencies. Informal loans were used in the year prior to the survey by non-fishing and fishing households to cover immediate needs such as food (28% and 26%), payment of debts (25% and 15%), and contingencies (18% and 22%). Informal loans were also used to invest in businesses (12% and 6%), to purchase household items (7% and 9%) or to make home improvements (7% and 6%). During the period of the study, households continued asking for informal loans, used mainly to buy food (33% in non-F-hh and 45% in F-hh), pay other debts (30% in non-F-hh and 15% in F-hh) and cope with extraordinary events (13 and 7% for non-F-hh and F-hh).

Allocation of consumption expenditures

The monthly monetary expenditure of households in Barú was US$ 785 US$-PPP per month and was significantly higher for F-hh (US$ 836) than for non-F-hh (US$ 738). When the expenditure was calculated in per capita terms, this difference was no longer significant (US$ 236 versus US$ 222). When household size was scaled by the square root of number of members, the expenditure per capita was US$ 430 for F-hh and US$ 393 for non-F-hh.

As expected, there were some months in which expenses change. This pattern was similar for F-hh and non-F-hh (Figure 9). Particularly, in January expenditures increased significantly, probably due to the start of the school season and/or indebtedness during the holiday season and its associated expenses.

In terms of expenses composition, on average, 60% of household expenditure was allocated to food, including water, which represents 8.2% of total expenditure. Leisure and entertainment accounted for about 15-20% of expenses.

With regard to animal protein consumption, about 40% of expenses were used for white meat such as chicken and fish. However, for F-hh most of these expenses were aimed at chicken. The low figure related to the expenses on fish by F-hh did not mean that they consume less fish than non-fishing ones, as self-consumption plays an important role in terms of consumption. F-hh also consumed more milk than non-F-hh.

The frequency of consumption by type of animal protein (fish, seafood, chicken, beef, pork, or canned protein) was significantly higher in F-hh than in non-F-hh, although the proportion of monetary expenditure on protein was relatively equal for both types of households (Table 5). On average, F-hh consumed animal protein 10.3 times a week, while non-F-hh consumed it 7.6 times a week. This difference was statistically significant and was mainly defined by the higher consumption of fish and other seafood by F-hh. In a community such as Barú, households obtain fish for consumption not only from the market but also by catching it or receiving it as a gift. This consumption does not need a monetary exchange. The value of non-monetary consumption by non-F-hh –estimated at market prices– was similar to the value of fish they bought. For F-hh, the value of non-monetary consumption was up to eight to ten times the value of fish they bought.

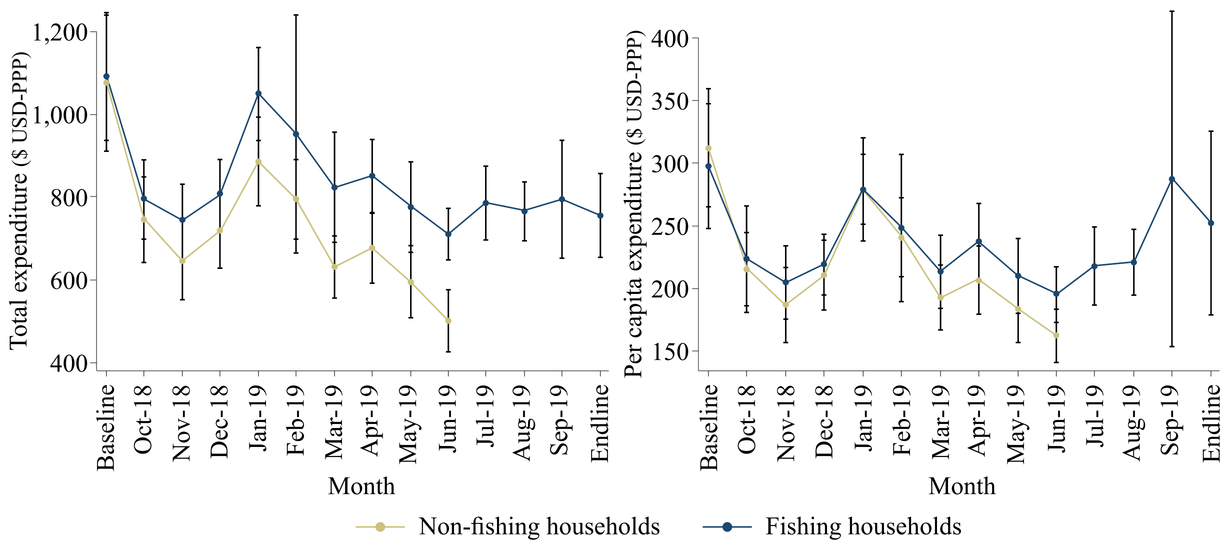

Figure 9. Household total and per capita monetary monthly expenses.

Table 5. Frequency of weekly animal protein consumption.

	Non-fishing households		Fishing households		
Type of protein	Observed	Mean (SD)	Observed	Mean (SD)	Difference (t-test)
Fish	1,454	2.47 (3.06)	1,307	4.38 (2.67)	-1.91*
Other seafood	1,454	0.09 (0.46)	1,307	0.22 (0.50)	-0.13*
Chicken	1,454	2.29 (2.12)	1,307	3.17 (1.91)	-0.88*
Beef	1,454	1.26 (1.52)	1,307	0.95 (0.95)	0.31*
Pork	1,454	1.32 (1.60)	1,307	1.31 (1.07)	0.01
Canned protein	1,454	0.18 (0.56)	1,307	0.26 (0.54)	-0.08*
Total protein	1,454	7.63 (0.10)	1,307	10.30 (0.06)	-2.67*

*p < 0.01

Food security strategies

Strategies used by F-hh included going fishing (45.5%), followed by asking family members for help, and reducing food consumption (27.3%). In the case of non-F-hh, predominant strategies were reducing food consumption (47.1%), asking relatives for help (35.3%), or informal loans in shops (35.3%) (Figure 10). However, 27% of F-hh and 47% of non-F-hh facing a food shortage reported having to reduce the food of at least one member of the household; this difference between households was significant. Note that non-F-hh were the only ones that turned to moneylenders to solve food crises.

When some members of the household must reduce their food intake, in non-F-hh, it was either mainly women who did so or all members of the household equally, and, to a lesser extent, the head of the household. It was remarkable that in F-hh the main strategy was to reduce food for all members of the household equally, followed by the heads of household. In general, in the event of shocks affecting the availability of food, the most vulnerable groups in the household, i.e. children, were protected.

Livelihood outcomes

Household income and expenditure

Monthly monetary income, including labor and non-labor sources of F-hh was higher (US$ 1,095 US$-PPP) and relatively more stable over time compared to that of non-F-hh (US$ 833 US$-PPP). Non-monetary income, estimated as the value of fish self-consumed at market prices, amounted to US$ 50.47 US$-PPP for F-hh and US$ 0.68 US$-PPP for Non-F-hh (Table 6).

On average, F-hh were better off than non-f-hh: US$ 1,145 versus US$ 834 US$-PPP. Per-capita monthly income corresponded to US$ 333 for F-hh and US$ 255 for non-f-hh. When household size was scaled by the square root of total number of members, the monthly per capita income was US$ 612 and US$ 447 for fishing and non-fishing households, respectively (Figure 11).

For F-hh, 37% of the income corresponded to income from fishing (monetary and non-monetary). Fish trade and gear rental generated an additional 6% of income for F-hh. For non-F-hh, fishing-related activities contributed with about 4% of income. The fishing sector contributed to about 20% of Barú's economy. However, this did

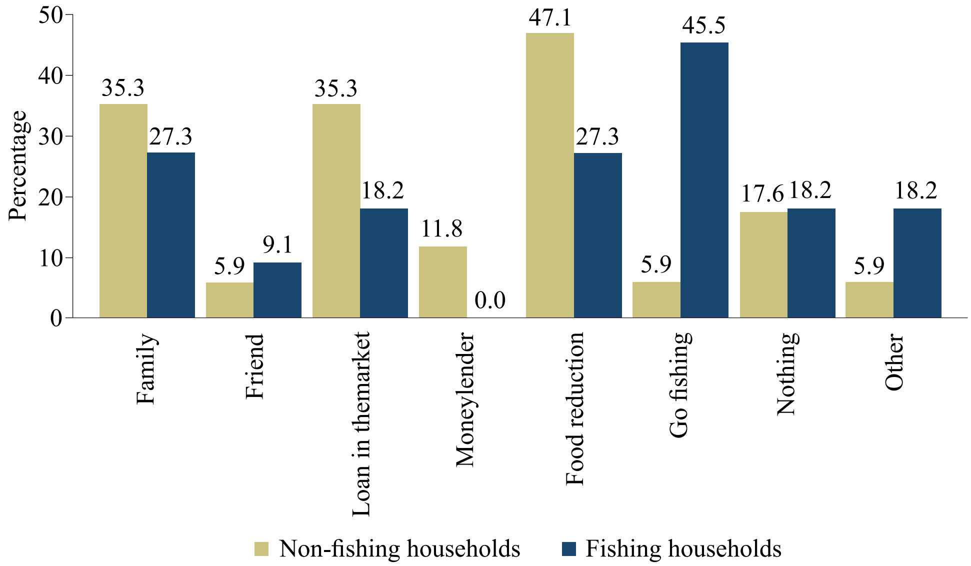

Figure 10. Household strategies to tackle food scarcity.

Table 6. Monthly income sources of households in Barú.

Household monthly income	Fishing households	Percentage	Non-fishing households	Percentage
From fishing	374.75	33	0.97	0
Labor different from fishing	679.12	59	807.82	97
Labor monetary income	1,053.87	92	808.79	97
Non-labor monetary income	40.79	4	24.04	3
Total monetary income	1,094.66	96	832.83	100
Non-monetary income from fishing	50.47	4	0.68	0
Monetary and non-monetary total income	1,145.13	100	833.51	100

not include the contribution of fishing activity to other activities such as the sale of food for tourism. The non-labor monetary income represented approximately 3.2% of the income of both households, without significant differences by type of household.

The average monthly income of a worker in Barú was US$ 678 US$-PPP, with significant statistical differences between fishing and non-fishing households. On average, heads of households earned the highest labor income of any member of the household, averaging US$ 745 US$-PPP. The dynamics of income per worker during the study highlighted the importance of holiday seasons (December-January and June-August), particularly for F-hh, whose income increases at these times

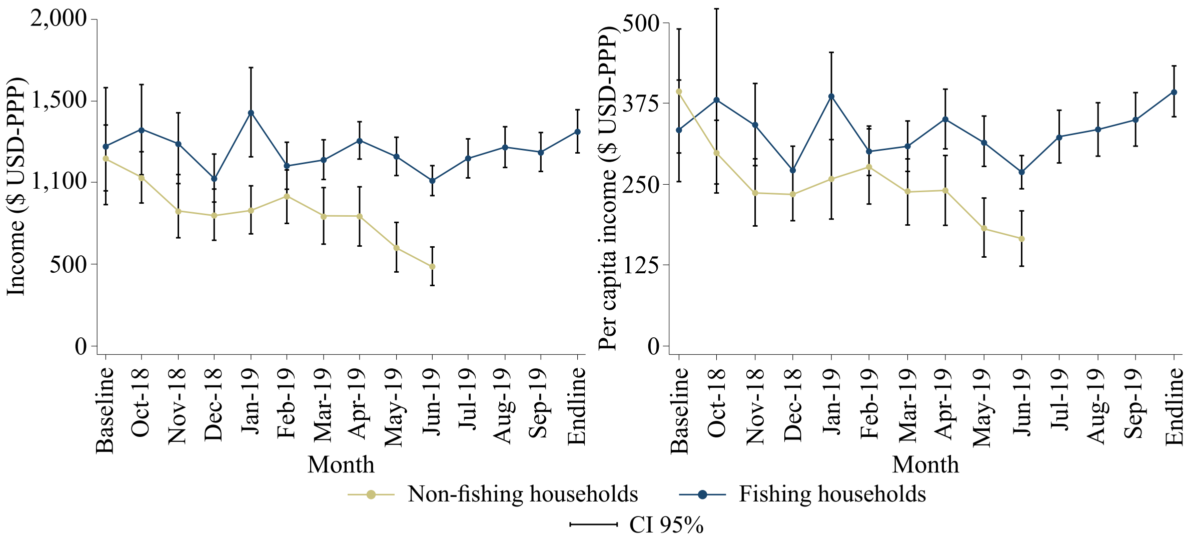

Figure 11. Total monthly household income (left) and total monthly per capita income (right).

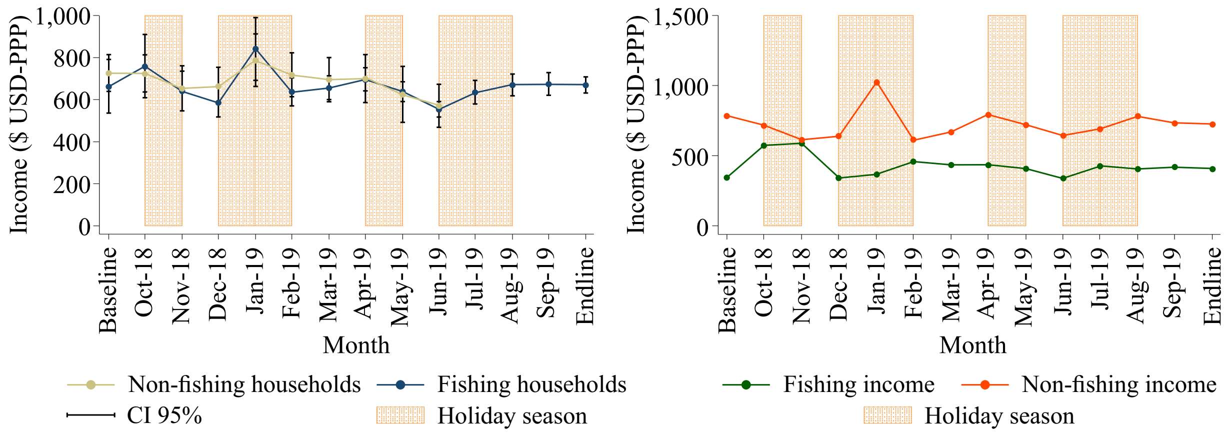

Figure 12. Labor income by worker per month (left panel) and fishing-related income for fishing households (right panel).

in terms of total labor income (Figure 12, left panel), mainly driven by fishing-related activities (Figure 12, right panel). A correlation analysis between the two series of income from fishing and income from other seasons shows a significant value of -0.2655, which suggest a substitution effect between fishing and non-fishing sources of income. Expenditure and income trends exhibited a similar tendency: when income increases (decreases), expenditure also increases (decreases) (Figure 13). This suggests that households may have had a surplus that allowed them to save. However, costs associated with productive inputs were not included in this analysis for either fishing households or non-fishing ones.

Food security

Results from our adapted indicator of food security indicated that 60% of households could be classified as food secure, and only a small fraction of households could be considered in moderate or severe food insecurity (Figure 14).

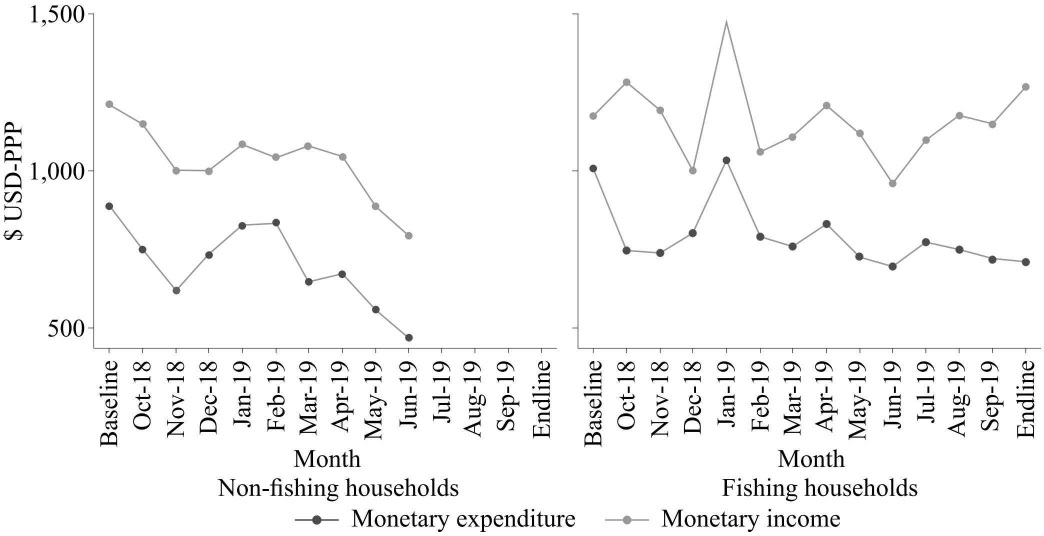

Figure 13. Total monthly income and total monthly expenditure by type of household.

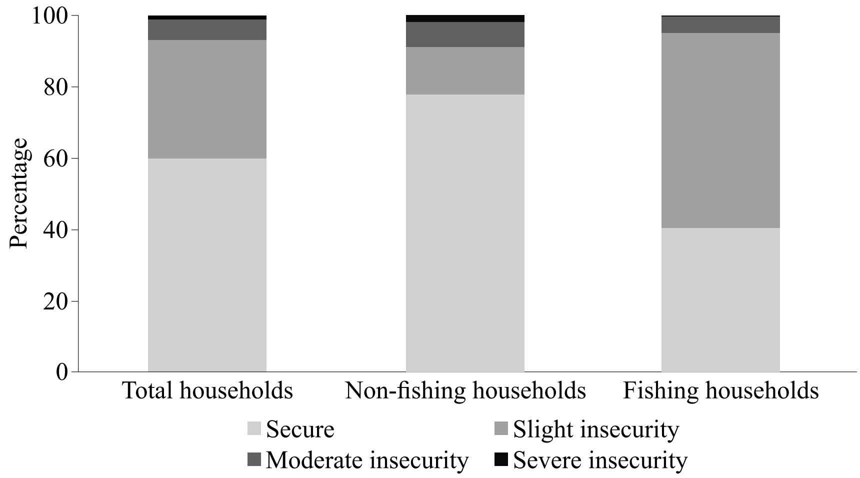

Figure 14. Annual average of types of food insecurity calculated by adapting the Latin American and Caribbean Food Security Scale (ELCSA) (FAO 2012).

None of the F-hh were in severe insecurity and there were fewer F-hh than non-F-hh in moderate insecurity. However, the slight food insecurity was much greater in F-hh. Given that they have access to fish for solving their food needs this result did not seem intuitive. The main source of slight insecurity in F-hh was related to the variation in diet, while the other sources of insecurity decreased over time (Figure 15).

To explore the relationship between fish that has been gifted and household food insecurity, a correlation analysis showed that the higher the level of food insecurity the greater the probability of receiving gifted fish (Table 7).

Poverty

According to the national poverty lines, a household is considered in poverty if its income

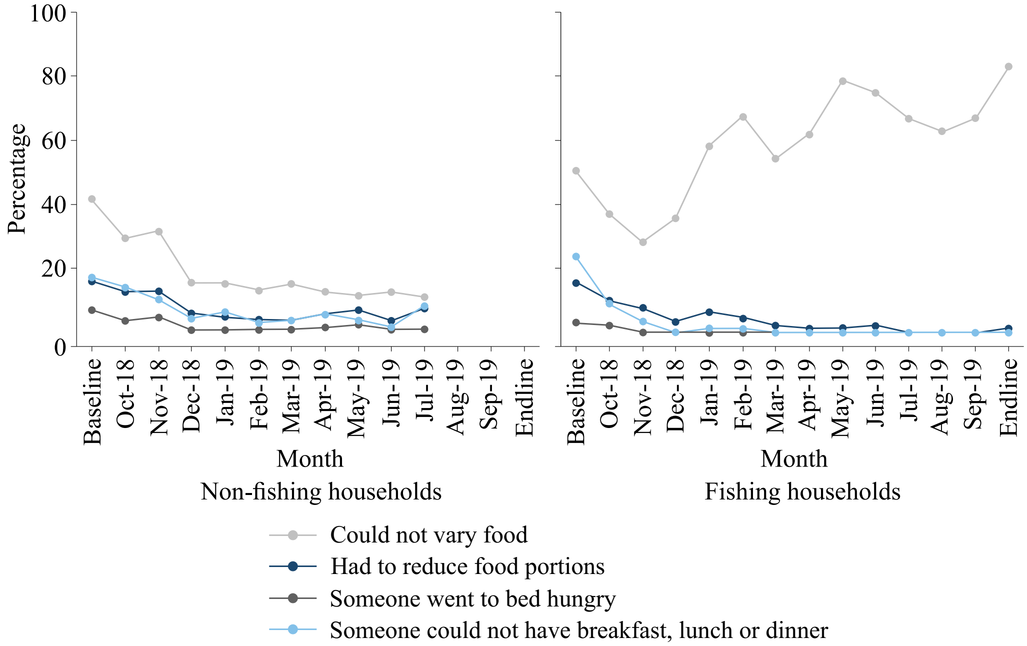

Figure 15. Types of food insecurity according to the adapted scale from the Latin American and Caribbean Food Security Scale (ELCSA) (FAO 2012).

Table 7. Correlation between food insecurity level and receiving fish as a gift.

Food insecurity	Correlation with receiving gifted fish
Secure	-0.0687*
Slight insecurity	0.0216
Moderate insecurity	0.0781*
Severe insecurity	0.0497*

*p < 0.01

is lower than US$ 180 US$-PPP and under extreme poverty if it is lower than US$ 82 US$-PPP (DANE 2018). The headcount poverty index for Barú was similar to that of the department where it was located and higher than the national level (Table 8). However, in terms of monetary poverty, F-hh were much better off than non-F-hh, and these differences were statistically significant. Extreme poverty of non-F-hh was much higher than the national level, while that for F-hh was lower than the department and the national levels.

Inequality

Non-F-hh exhibit higher measures of inequality than F-hh for all the dimensions studied (Table 9). The Gini index for Barú's total income was 0.423, which was lower than that reported for the Bolivar department (0.472) and for the country (0.517). Labor income presented the highest levels of inequality in non-F-hh, while in F-hh the source of greatest inequality was non-labor income (subsidies, remittances, and interest payments). For the total sample, the coefficients showed that non-labor income was also the source of greatest inequality.

Potential effects of fishing activity on sustainable use

According to the proportion of gear types used in Barú, the fishing gear used in Barú has a mod-

Table 8. Headcount monetary poverty index by household, total, local and national (indicators for Barú are from the average of all survey months).

	Non-fishing households	Fishing households	Total households	Bolívar department	Colombia
Poverty line	51.2	27.1	38.3	36.2	27.0
Extreme poverty line	29.4	4.5	16.1	7.0	7.2

Table 9. Gini coefficient for household income and expenditure.

Gini measures	Non-fishing households	Fishing households	Total households
Labor income	0.560	0.258	0.421
Non-labor income	0.524	0.511	0.516
Total income	0.513	0.308	0.406
Per capita income	0.532	0.322	0.423
Expenditure	0.327	0.270	0.333

erate to low effect on the ecosystem. The most harmful effects were associated with size selection, species selection, and incidental mortality (Table 10). However, the fishing gear in general has high energy efficiency, low generation of ghost fishing, high catch quality (no agglomeration or decomposition that damages the catch), and few effects on the species' habitats moderate to low effect on the ecosystem (Figure 16).

DISCUSSION

The main purpose of this study was to characterize the livelihoods of SSF communities, in particular, assets, strategies, and livelihood outcomes of fishing and non-fishing households in a community in the Colombian Caribbean. Our results show the differentiated strategies that F-hh and non-F-hh follow to develop their livelihoods given their human, social and financial capital endowments.

Households in this community differ in their illiteracy rate, which is about seven percentage points greater for fishing than non-F-hh, and even greater if only the heads of household are considered. Non-F-hh heads are more highly educated than those from F-hh, by about a year and a half. In general, those individuals whose main activity is fishing report significantly lower levels of education than the sample's average employed population. These results coincide with data from the DANE (2018) household survey, which indicates that half of the people involved in fisheries and aquaculture have reached no further than basic primary education and that about one-fifth are illiterate (OECD 2016). Moreover, these findings could confirm the point raised by Béné et al. (2016), who argue that fishing is an activity associated with low human capital. However, fishing does require higher physical and psychological efforts given the strenuous, dangerous, and uncertain related labor journeys. F-hh that are less endowed in terms of education see fishing as the only alternative for income generation.

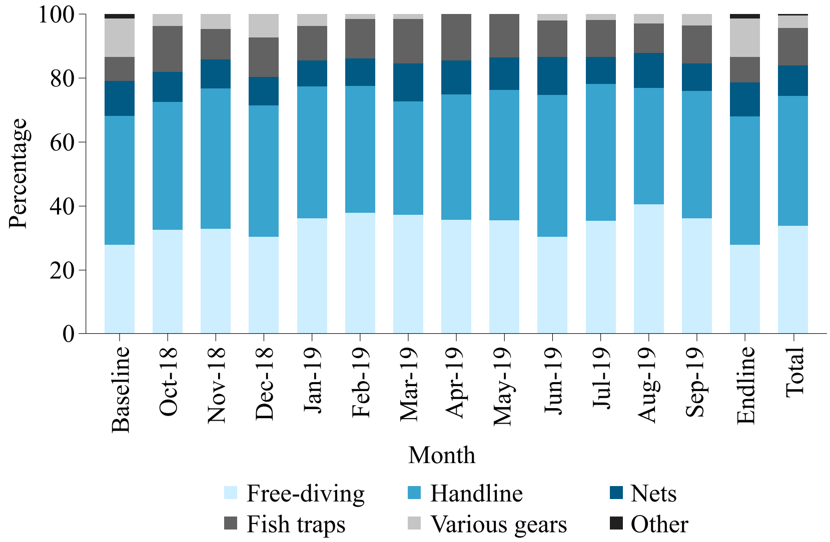

Figure 16. Percentage of fishers using each type of fishing gear.

Table 10. Estimation of the effects of the different fishing methods on the marine ecosystem of Barú (Bjordal 2005).

	Size selection	Species selection	Incidental mortality	Ghost fishing	Effects on the habitat	Energy efficiency	Catch quality	Ecosystem effect index
Hook fishing or handlining, longline, pinel, rope	5 (2.3)	4.5 (2.0)	6 (2.7)	9.5 (4.3)	8.5 (3.8)	8.5 (3.8)	8.5 (3.8)	7.2 (3.3)
Diving	8 (2.7)	9 (3.1)	5 (1.7)	10 (3.4)	10 (3.4)	8 (2.7)	9 (3.1)	8.4 (2.9)
Fishing net	2 (0.2)	3 (0.3)	5 (0.5)	3 (0.3)	7 (0.7)	8 (0.8)	5 (0.5)	4.7 (0.5)
Pot fishing (traps)	7 (0.7)	7 (0.7)	9 (1.0)	3 (0.3)	8 (0.9)	8 (0.9)	9 (1.0)	7.3 (0.8)
Total	5.5 (5.9)	5.9 (6.2)	6.3 (5.9)	6.4 (8.3)	8.4 (8.8)	8.1 (8.2)	7.9 (8.4)	6.9 (7.4)

Our results also suggest that things are changing for new generations: (i) young people might be less interested in fishing activity than their parents, and (ii) F-hh are currently investing more in human capital. In fact, some of the households initially classified as fishing ones reported not fishing during the survey implementation.

The estimated rate of people not in education, employment, or training (NEET) is twice as high in Barú as that reported nationally, showing the scarce opportunities young people have in rural and fishing communities. For women, this rate is even higher: seven out of every 10 women in this age range are neither working nor studying.

Although the average household size is similar between fishing and non-F-hh, F-hh tend to have more people working. In addition, F-hh in Barú exhibit higher occupational diversity, likely because of the uncertainty associated with fishing. F-hh diversify significantly more than non-fishing ones; not all members of F-hh fish, but this activity is their highest source of income. Our findings are consistent with Béné and Friend (2011), who argue that fishing is part of a diversified matrix of livelihood activities, where fishing-related activities remain the most important source of income.

According to Ellis and Allison (2004), livelihood diversification reduces the poor's vulnerability to food insecurity, reduces dependence on natural resources, and can provide the basis for building assets that allow households to design their own exit strategies from poverty. It also improves human capital by providing skills and experience. However, the benefits of diversification are often inhibited by the local context and governance, as well as other barriers to trade and mobility (imperfect and restricted markets). For example, access to land and agriculture, as well as access to financial services, plays a significant role in livelihood diversification and household food security (Ellis and Allison 2004). In Barú, strong limitations on the potential for diversification were found. For example, even though the vast majority of households surveyed are part of native families, only six households in the sample report having land for farming. This is caused by the displacement brought about by tourism on the island at the natural park. In this sense, agricultural and livestock activities are exceptional. The main sources of income diversification are the provision of services, mainly related to tourism and construction. Our findings also show that financial services are imperfect and restricted for households in fishing communities. Although F-hh save informally much more than non-fishing ones, only 10% of F-hh save in a formal financial institution and more than 60% report shark loans from informal money lenders, which might lead them to path dependence: asking for a loan to cover the previous one.

In general, the community of Barú faces restrictions in terms of access to different forms of capital, such as land, education, or financial capital, which makes it difficult to participate in diversified labor markets. These restrictions seem to be more important for the fishers, who are older and have lower education levels.

For those in Barú who fish as a secondary activity, fishing is a coping strategy when faced with shocks. In that sense, given the semi open-access nature of the resource, fishing in Barú could provide a means of producing income both as a safety net, to deal with transitory or short-term poverty, and as last-resort activity, associated mostly with chronic or long-term poverty (Béné 2004; Béné et al. 2007).

With respect to food security, SSF have been recognized as a key to improving food security in developing countries, particularly for those whose livelihoods depend on them (Kawarazuka and Béné 2010). We found that the frequency of animal-protein consumption is significantly higher in F-hh than in non-F-hh, although the proportion of monetary expenditure on protein is relatively equal for both. However, the estimated value of fish consumption at market prices is almost twofold for F-hh than for non-F-hh, which reflects the importance of self-consumption. In other words, F-hh enjoy a diet with higher protein content for the same amount of monetary expenditure. Consistent with other studies, we found that fishing is a source of food security for the community (Gomna and Rana 2007; Chamnan et al. 2009; Mujinga et al. 2009).

The proportion of fish left by households for home consumption varies among communities and depends on the fishery in which it is being managed: from 11-20% in Papua New Guinea (Friedman et al. 2008) to 74.5% in Lao PDR (Garaway 2005). Generally, the poorest households rely more on subsistence consumption of fish, compared to better-off households with more access to markets. However, some studies by Béné (2003), in Lake Chad, show that the poorest households consume less of their own catch and sell most of it to generate income and buy cheaper food.

In Barú, 13% of fish caught is destined for self-consumption. This strategy allows the F-hh in Barú to report less cases of having to reduce food portions at home, having to send someone to sleep hungry, or having to miss a meal. Chanman et al. (2009) discuss the characteristics of fish for self-consumption: (i) smaller fish containing more nutrients; (ii) smaller fish easier to distribute among household members; (iii) species available year-round; and (iv) typically consumed whole, which improves micronutrient provision. However, F-hh in Barú face a restriction in terms of variety of food, affecting this dimension of food security.

When having to deal with income shocks affecting food security, fishing appears to be a coping strategy for F-hh to deal with food shocks. Fishing strategy is then a safety net to cover immediate food needs (Béné et al. 2007, 2016). As argued by Kawurazuka and Béné (2010), fishing is found to play a double role in Barú: (1) as an income-generating activity or cash crop; (2) as a food-generating activity or food crop. Thus, fishing is not only important in terms of improving food security per se, but also as an income-generating activity that improves livelihoods, including nutrition.

It was found that 2% of caught fish is given as a gift to other households. Further, nearly one-third of the fishers give fish as a gift and nearly one-third of households receive fish as a gift, particularly those in the worst conditions in terms of food security. This result suggests that fishers were able to focus gift efforts on the population that was most in need, playing an important role in solving extreme food insecurity. Those findings show a support network and altruistic behavior within this community.

A growing number of studies suggest that the income of F-hh is often higher than that of non-F-hh (Thorpe et al. 2007). Other literature points that artisanal fishers rank among the lowest income groups or below national income levels (Herring and Racelis 1992; Willmann 2004; Teh and Sumaila 2007). Similarly to our results, Allison (2005), Mkenda (2000) and Tietze et al. (2000) found that income of F-hh is higher than that of non-F-hh in rural communities. Despite studies showing higher incomes in F-hh compared to other rural households, Thorpe et al. (2007) highlighted that monetary income cannot be seen as the only way to measure household poverty. This assertion is even more important in the case of isolated communities where access to education, health or basic services is severely restricted, resulting in health, housing, or sanitation problems (Béné 2003). In our case, at the time of the study, the Barú community did not have access to basic services such as health, drinkable water, or sewage.

One of the most important findings of this study is that the poverty and extreme poverty levels of F-hh are lower than those of non-F-hh. Despite strong restrictions faced by F-hh in terms of access to different forms of capital (education, financial services, land), access to natural capital and higher diversification provide them with income to solve basic needs and resources to reduce food insecurity. The poverty figures for F-hh are similar to national levels, while the figures for extreme poverty are better for F-hh than they are for the national average. This shows the importance of fishing as a buffer in against the vulnerability of rural poor households.

The results also suggest that restrictions on fishing for these communities, without providing alternative income earning alternatives or social protection programs, could result in deterioration of their living conditions. In fact, our findings show that non-labor monetary income (mainly subsidies and transfers) represents only 3.2% of the income of both types of households. Prohibitions on fishing would require, for example, non-conditional or conditional- conservation cash transfers and other social protection programs allowing households to cope with the effect of not fishing on income and food security. On the other hand, as proposed by Cinner et al. (2009), ‘wealth generation and employment opportunities directed at the poorest fishers may help reduce fishing effort on overexploited fisheries'.

Although Barú is located next to a protected area, where it is only allowable to fish for subsistence, the currently used fishing gear suggests moderate to low impact activity. Although the fishing volumes are low compared to the world average in small fisheries, it is not possible to say anything about the sustainability of the catch from the survey data, because biological data on the abundance of fish are required. However, the species more frequently exploited in Barú lack of information about conservation status. Lobster, some species of snapper and horse mackerel are classified as vulnerable (Chasqui-Velasco et al. 2017; PNN 2019), while barracuda and garfish are catalogued as near-threatened (Fishbase [www.fishbase.de], Chasqui-Velasco et al. 2017). Results of the socio-demographic characterization confirm our hypotheses and coincide with findings presented in the literature on SSF around the world. As highlighted by Ellis and Allison (2004) and Beck and Nesmith (2001), the landless rural poor are among the most vulnerable groups and basically depend on wage labor and the extraction of common-pool resources. In the ancestral community of Barú, residents have been dispossessed of land due to increased tourism during the last 30 years. Livelihood systems in Barú are strongly linked to the extraction and use of natural capital, they are associated with ethnic minorities settled in areas that are strategic for the conservation of biodiversity, and they make use of common pool resources due to their lack of access to land and limited opportunities for income development. Hence, employment, productive, and capacity-building interventions allowing to diversify sources of income, as well as conservation strategies and even the assignment of property rights to use resources, would promote livelihood sustainability. Ultimately, strict conservation strategies must be developed once the external constraints, leading these communities to resource extraction and overexploitation are removed. Although there is low community participation in the management of local fisheries or the marine protected area at present, they are now more visible to the authorities, thanks to the consolidation of organizations and local councils. Future measures for conservation and fisheries management should consider the community's input and participation.

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ORIGINAL RESEARCH

Growth, longevity and mortality of pink shrimps *Farfantepenaeus brasiliensis* and *F. paulensis* in southeastern Brazil

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ABSTRACT. The study estimated the parameters of growth, longevity, fishing mortality (F), natural mortality (M) and total mortality (Z) and the exploitation rates (E) of the shrimps *Farfantepenaeus brasiliensis* and *F. paulensis* sampled in Ubatuba Bay from January to December 2000. Shrimps were identified by species, sexed and measured (carapace length –CL in mm). Overall, 1,231 individuals of *F. brasiliensis* and 687 of *F. paulensis* were analyzed. The mean size between sexes did not differ for both species. The estimated parameters of *F. brasiliensis* were: CL_∞ = 41.08 mm, k = 2.41 year^{-1} for males and CL_∞ = 47.32 mm, k = 2.23 year^{-1} for females; longevity of 1.91 years (males) and 2.05 years (females); M of 2.47 (males) and 2.28 (females); F of 7.97 (males) and 8.42 (females). For *F. paulensis,* the following values were observed: CL_∞ = 36.55 mm, k = 2.41 year^{-1} for males and CL_∞ = 49.24 mm, k = 2.51 year^{-1} for females; longevity of 1.91 years (males) and 1.81 years (females); M of 2.52 (males) and 2.52 (females); F of 7.64 (males) and 10.25 (females). The high values of k and F found for both species compared to those from the literature reflected the high E values, indicating that at the time, the closed season was still not responsible for stock recovery. We highlight the need for studies to assess the current status of stocks so they can be compared to the results found herein.

Key words: Artisanal fishery, Bertalanffy, closed season, exploitation rate, Penaeidae.

Crecimiento, longevidad y mortalidad de camarones rosados *Farfantepenaeus brasiliensis* y *F. paulensis* en el sureste de Brasil

RESUMEN. El estudio estimó los parámetros de crecimiento, longevidad, mortalidad por pesca (F), mortalidad natural (M) y mortalidad total (Z) y las tasas de explotación (E) de los camarones *Farfantepenaeus brasiliensis* y *F. paulensis* muestreados en la Bahía de Ubatuba de enero a diciembre de 2000. Los camarones fueron identificados por especie, sexados y medidos (longitud del caparazón –CL en mm). En total, se analizaron 1.231 individuos de *F. brasiliensis* y 687 de *F. paulensis*. La talla media entre sexos no difirió para ambas especies. Los parámetros estimados de *F. brasiliensis* fueron: CL_∞ = 41,08 mm, k = 2,41 año^{-1} para machos y CL_∞ = 47,32 mm, k = 2,23 año^{-1} para hembras; longevidad de 1,91 años (machos) y 2,05 años (hembras); M de 2,47 (machos) y 2,28 (hembras); F de 7,97 (machos) y 8,42 (hembras). Para *F. paulensis* se observaron los siguientes valores: CL_∞ = 36,55 mm, k = 2,41 año^{-1} para machos y CL_∞ = 49,24 mm, k = 2,51 año^{-1} para hembras; longevidad de 1,91 años (machos) y 1,81 años (hembras); M de 2,52 (machos) y 2,52 (hem-

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bras); F de 7,64 (machos) y 10,25 (hembras). Los altos valores de *k* y F encontrados para ambas especies en comparación con los de de la literatura reflejaron los altos valores de E, lo que indica que en ese momento la temporada de veda todavía no era responsable de la recuperación del *stock*. Resaltamos la necesidad de estudios que evalúen el estado actual de los *stocks* para que puedan ser comparados con los resultados aquí encontrados.

Palabras clave: Pesquería artesanal, Bertalanffy, cierre de temporada, tasa de explotación, Penaeidae.

INTRODUCTION

Farfantepenaeus brasiliensis (Latreille, 1817) and *F. paulensis* Pérez-Farfante, 1967, commonly known as pink shrimps, are highly exploited fishing resources on the southern and southeastern coast of Brazil (Costa and Fransozo 1999; Teodoro et al. 2016). Both species are exploited by two fleet types during different stages of their life cycles, i.e. industrial fleets offshore exploit adults in the open sea, while artisanal fisheries reach juveniles in estuarine environments and coastal lagoons (D'Incao 1991).

Accurate information about the age of the target organisms in fisheries is essential for calculating parameters such as longevity, growth rate and mortality, which end up reflecting the human impacts on natural populations (Kilada and Driscoll 2017). The most common method for studying age in natural populations is based on the analysis of distribution of length frequencies, in which the raw data is grouped into class intervals and, subsequently, algorithms are used to obtain the normal distribution peaks (e.g. in each month of collection) (Castilho et al. 2015; Silva et al. 2015). Finally, modal groups are detected and their combination supports the final model, adjusted with the von Bertalanffy curve (1938). According to Vogt (2019), the von Bertalanffy curve makes it possible to estimate longevity from frequency data and life history.

Some growth studies have been conducted along the Brazilian coast for Penaeidae species, namely: *Artemesia longinaris* Spence Bate, 1888 (Semensato and Di Beneditto 2008), *F. brasiliensis* (Mello 1973; Vilela et al. 1997; Leite Jr and Petrere Jr 2006; Lopes 2012), *F. paulensis* (Mello 1973; D'Incao 1984; Leite Jr and Petrere Jr 2006; Lopes 2012), *Farfantepenaeus subtilis* (Pérez-Farfante, 1967) (Silva et al. 2015; Santos et al. 2020), *Litopenaeus schmitti* (Burkenroad, 1936) (Miazaki et al. 2018; Santos et al. 2020; Carvalho et al. 2021), and *Xiphopenaeus kroyeri* (Heller, 1862) (Branco et al. 1994; Grabowski et al. 2014; Lopes et al. 2014; Castilho et al. 2015; Silva et al. 2018).

The studies concerning pink shrimps, *F. brasiliensis* and *F. paulensis*, were conducted either in Santos/Guarujá (central coast of São Paulo state) or in coastal lagoons in Rio de Janeiro State (Araruama Lagoon) and Rio Grande do Sul State (Patos Lagoon). These areas differ significantly from our study area, Ubatuba Bay (northern coast of São Paulo state). Araruama Lagoon is the largest permanently hypersaline lagoon in the world (Souza et al. 2003), while Patos Lagoon is the largest coastal lagoon in the world (Kjerfve 1986). The Santos/Garujá area is located in an estuarine complex with extensive mangrove formations (Lamparelli et al. 2001). Ubatuba Bay, however, has small estuaries that are susceptible to changes in salinity forcing *Farfantepenaeus* spp. juveniles to use shallow portions of the bay as auxiliary nursing areas (Costa et al. 2008).

In addition to calculating growth parameters, it is necessary to calculate both natural and fishing mortality, monitor stocks and elaborate adequate management plans which will guarantee the long-term maintenance of these stocks (King 2007) and consider their economic, ecological and social importance (Musiello-Fernandes et al. 2017). In the southeastern region, both species are frequently targeted due to their large sizes and high commercial value. They are also captured as bycatch of the seabob shrimp *X. kroyeri* in shallow marine areas (Mantelatto et al. 2016), whose population in Ubatuba is already overexploited (Miazaki et al. 2021). We believe these factors may be influencing and shaping populational parameters of pink shrimps in the sampling area. Thus, the present study used a length frequency analysis to estimate the (i) growth and longevity; (ii) total, natural and fishing mortality; and (iii) the exploitation rates of both sexes of *F. brasiliensis* and *F. paulensis* populations occurring in Ubatuba which are intensively exploited by trawling.

MATERIALS AND METHODS

Study area

Located on the northern coast of São Paulo state (southeastern Brazil), Ubatuba Bay (23° 26′ S, 45° 01′ W) is a traditional seabob shrimp fishing area, with more than 100 small-scale trawling boats operating (IP/APTA/SAA/SP 2021). With a total area of 8 km^2, the bay is 4.5 km wide at its entrance and decreases in width towards the beach (Mantelatto and Fransozo 1999). Three water masses influence the region: Coastal Water (Temperature > 20 °C and Salinity < 36); Tropical Water (Temperature > 20 °C and Salinity > 36); and South Atlantic Central Water (Temperature < 18 °C and Salinity < 36) (Castro-Filho et al. 1987). The seasonal influence of the water masses, coupled with the several bays formed by the presence of terminal spurs of Serra do Mar (Suguio and Martin 1978), and the transition of the tropical zone to the temperate zone, make the Ubatuba region a biodiversity hotspot for several marine organisms.

Data collection

Samples were collected monthly from January to December 2000. Shrimps were captured with a fishing boat equipped (10 m) with double rig nets, with 20 mm mesh in the wings and 18 mm mesh at the cord end, towed at an average speed of 1.7 knots. Nine transects (2 km each) were trawled: four in the internal area of the Ubatuba Bay (2, 5, 10 and 15 m isobaths) and five in the external area (20, 25, 30, 35 and 40 m isobaths) (Figure 1). Each trawl was carried out for 30 min and an ecobathymeter coupled with a GPS was used to record the depth of sampling sites.

The captured shrimps were stored in labeled plastic bags and kept frozen until analysis. In the laboratory, they were identified according to Pérez-Farfante and Kensley (1997) and Costa et al. (2003) and sexed. Afterwards, the carapace length (CL in mm) of each individual was measured with a 0.01 mm digital caliper, which was the linear distance between the postero-orbital margin and the median notch of the posterior margin of the carapace. It was decided to use CL because structures like the rostrum and telson can be damaged during the capture of organisms and the abdomen is flexible (Cole and Mistakidis 1953). Individuals with carapace length less than 25 mm were considered juveniles (Costa et al. 2008).

Data analysis

The growth and longevity of each species were analyzed separately for males and females. For each sampling month, the frequency of CL was distributed in 1 mm size classes. Modes were calculated using PeakFit software (PeakFit v4.12 for Windows Copyright 2000-2003 SYSTAT Software Inc.) which fits the observed frequencies to normal distribution curves so the mode and adjusted mean are the same. The ‘Automatic peak detection and fitting (I)’ tool considering the Gaussian distribution described by the equation:

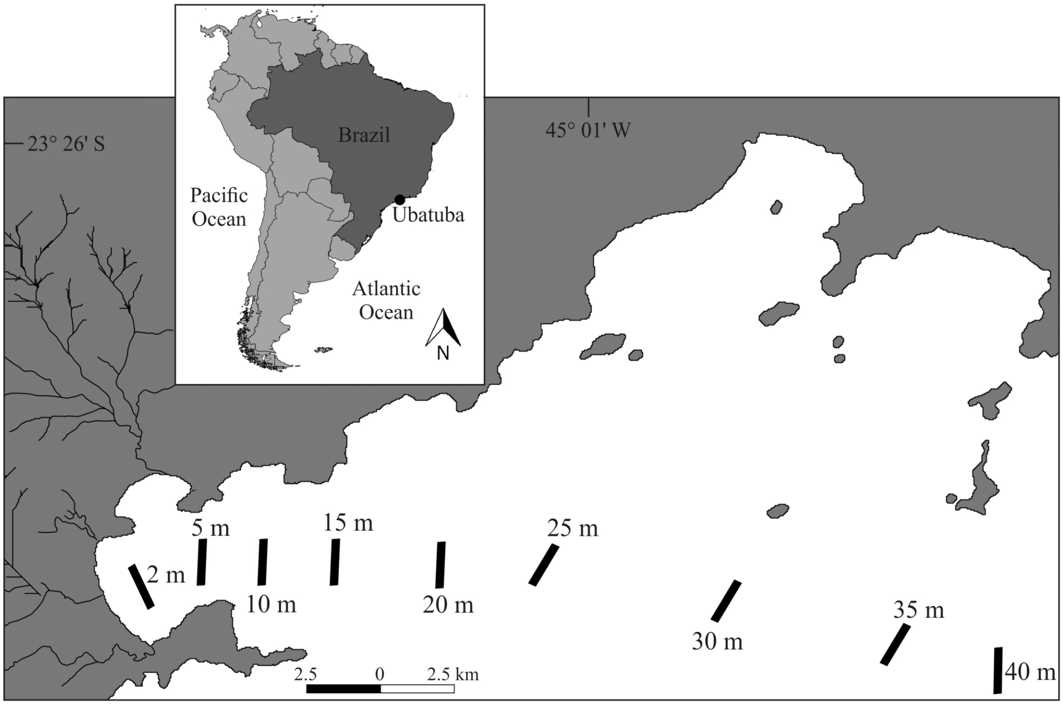

Figure 1. Map of the study area indicating the location and depth of transects.

$Y = a_0[\exp(-1/2(x-a_1)/a_2)^2]$, where a_0 is the amplitude, a_1 is the mean, and a_2 is the standard deviation was used to detect the central values of each mode. All the chosen cohorts were adjusted to the von Bertalanffy growth function (VBGF) $CL_t = CL_\infty(1-\exp^{-k(t-t_0)})$, in which CL_t is the carapace length at time (i.e. age) t; CL_∞ is the asymptotic length, k is the growth coefficient and t_0 is the theoretical age at zero length (von Bertalanffy 1938). These growth parameters were estimated for the different cohorts using Solver supplement in Microsoft Excel, varying in the equation: CL_∞, k and t_0, which minimizes the sum of residuals between the lengths observed in the field and those calculated by the von Bertalanffy model (Miazaki et al. 2021). Cohorts that presented a coherent biological rhythm in relation to longevity, k and CL_∞, were chosen. A F test ($P = 0.05$) was applied to compare growth curves between sexes, and assess if a single curve could describe these species growth (Cerrato 1990). The longevity was estimated through the von Bertalanffy inverse equation modified by D'Incao and Fonseca (1999), in which $t_0 = 0$ and $CL/CL_\infty = 0.99$ and the given longevity equation is $t = (t_0 - (1/k)\ \mathrm{Ln}\ (1 - CL_t/CL_\infty))$.

Length-converted catch curves: $-\mathrm{Ln}\ (N/\Delta t) = a + bt'$, were used to estimate the total mortality coefficient (Z), in which b is the regression slope that estimates Z, N is the number of individuals in each size class estimated by unit effort of capture h^{-1}, Δt is the time for the growth of individuals across this size class and t is the average age of the individual in this size class (Pauly 1990). Catch curves were estimated for each sex and compared by covariance analysis (ANCOVA) (Fonseca and D'Incao 2006). Mortality coefficient (Z) was defined as the sum of the fishing mortality coefficient (F) caused by fishing operations, and the natural mortality coefficient (M) including predation, competetion, disease, and adverse environmental conditions ($Z = F + M$).

Natural mortality (M) was estimated based on the mean value found from the methods of Pauly (1980) and Taylor (1959, 1960). According to Pauly: log (M) = −0.0066 − 0.279 log (CL_∞) + 0.6543 log (*k*) + 0.4634 log (T), in which CL_∞ and *k* are the growth parameters obtained by VBGF and T is the annual average temperature (°C) of the habitat. The annual average bottom temperature was 20.91 ± 2.57 °C. Taylor correlates M, *k* and t_0: M = −Ln [(1−0.95)/$A_{0.95}$], where $A_{0.95}$ is the age at which the individual reaches 95% of its asymptotic size and is defined by: $A_{0.95} = t_0 - (2.996/k)$. Fishing mortality (F) was calculated by the difference between Z and M (F = Z − M). The exploitation rate (E) was calculated by the ratio between F and Z: E = F/Z (Sparre and Venema 1997).

RESULTS

A total of 1,231 individuals of *F. brasiliensis* and 687 individuals of *F. paulensis* were analyzed (Table 1). For *F. brasiliensis* the CL ranged from 7.50 to 35.70 mm (19.14 ± 5.66 mm) in males, and from 6.60 to 44.90 mm (18.95 ± 6.63 mm) in females (Figure 2). As for *F. paulensis*, the CL ranged from 10.40 to 35.00 mm (17.46 ± 4.26 mm) in males, and from 9.10 to 46.60 mm (18.52 ± 6.12 mm) in females.

Nine modal groups were selected for each sex of *F. brasiliensis* (Figure 3). The pooled growth curves for males resulted in estimates of CL_∞ = 41.08 mm, *k* = 0.198 month^{-1} (2.41 year^{-1}), t_0 = - 0.062, and for females of CL_∞ = 47.32 mm, *k* = 0.183 month^{-1} (2.23 year^{-1}), t_0 = - 0.376 (Figure 4).

Maximum longevity (t_{max}) was estimated at 697 days (1.91 years) for males and 748 days (2.05 years) for females. Statistical comparison (*F* test) between estimated curves for both sexes showed significant differences ($F_{calc} = 56.10 > F_{tab} = 2.72$; GL = 76; $P < 0.001$).

For *F. paulensis*, modal groups for males and five for females were selected. The pooled growth curve of each sex resulted in estimates of CL_∞ = 36.55, *k* = 0.198 month^{-1} (2.41 year^{-1}), t_0 = - 0.356 for males and CL_∞ = 49.24 mm, *k* = 0.207 month^{-1} (2.51 year^{-1}), t_0 = - 0.269 for females (Figure 5). The t_{max} was estimated at 697 days (1.91 years) for males and 660 days (1.81 years)

Table 1. Abundance of *Farfantepenaeus brasiliensis* and *F. paulensis* individuals per isobath captured from January to December 2000 in Ubatuba region.

Isobath (m)	*Farfantepenaeus brasiliensis*	*Farfantepenaeus paulensis*
2	249	149
5	522	441
10	14	16
15	57	2
20	14	6
25	31	30
30	101	16
35	220	20
40	23	7
Total	1,231	687

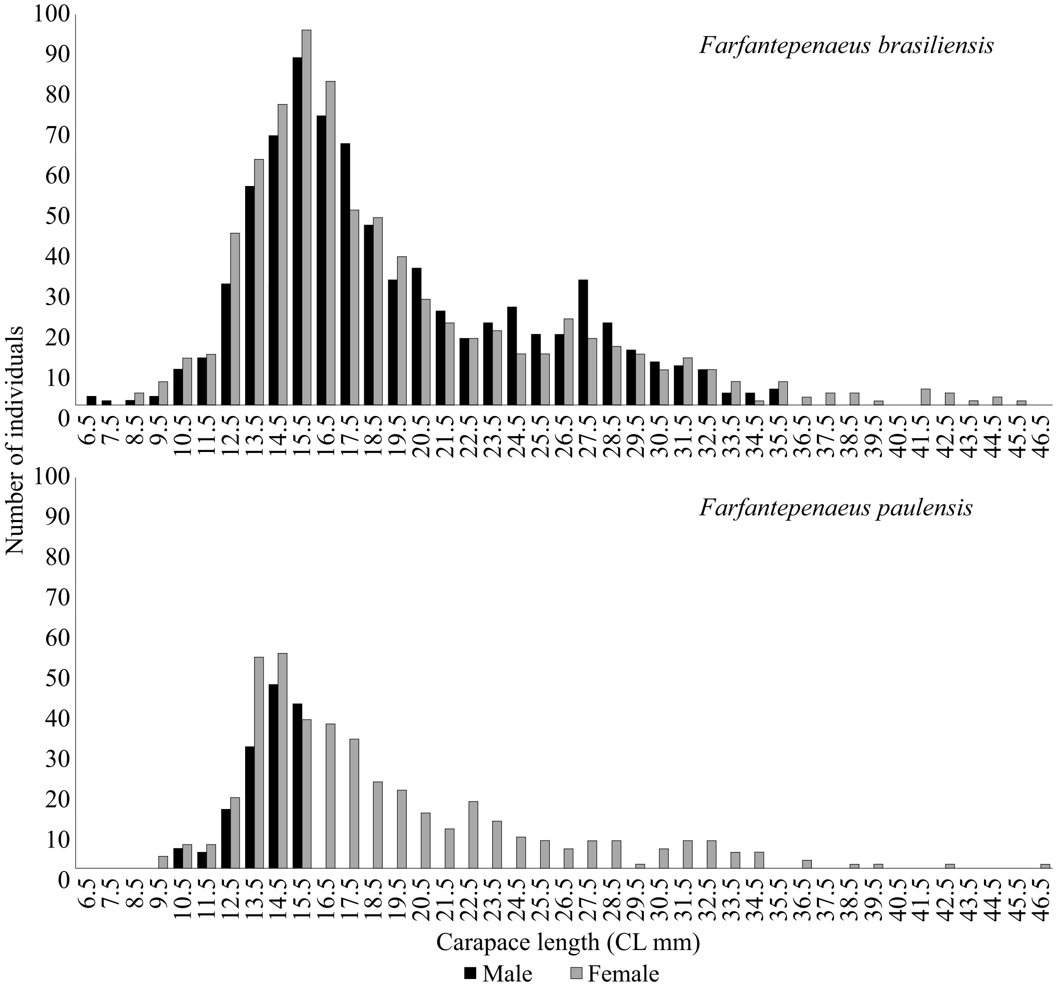

Figure 2. Size frequency distribution of males and females of *Farfantepenaeus brasiliensis* and *F. paulensis* sampled monthly, from January to December 2000, in Ubatuba region.

for females. Statistical comparison (*F* test) between estimated curves for both sexes showed significant differences ($F_{calc} = 304.62 > F_{tab} = 2.80$; GL = 48; $P < 0.001$).

Total mortality (Z) for *F. brasiliensis* was estimated as 10.44 year^{-1} and 10.71 year^{-1} for males and females, respectively, and estimated at 10.16 year^{-1} for males and 12.77 year^{-1} for females of *F. paulensis*. There were no statistical differences in Z between sexes of both species and between the species (ANCOVA, $P > 0.05$) (Table 2; Figure 6). The estimated values for the natural (M) and fishing (F) mortality coefficients and exploitation rates (E) by sex and species are in Table 2. Estimates of E for both sexes and for both species were higher than 0.5 (Table 2).

DISCUSSION

In terms of growth, mortality and stock exploitation, congeners *F. brasiliensis* and *F. paulensis* presented similar values for these

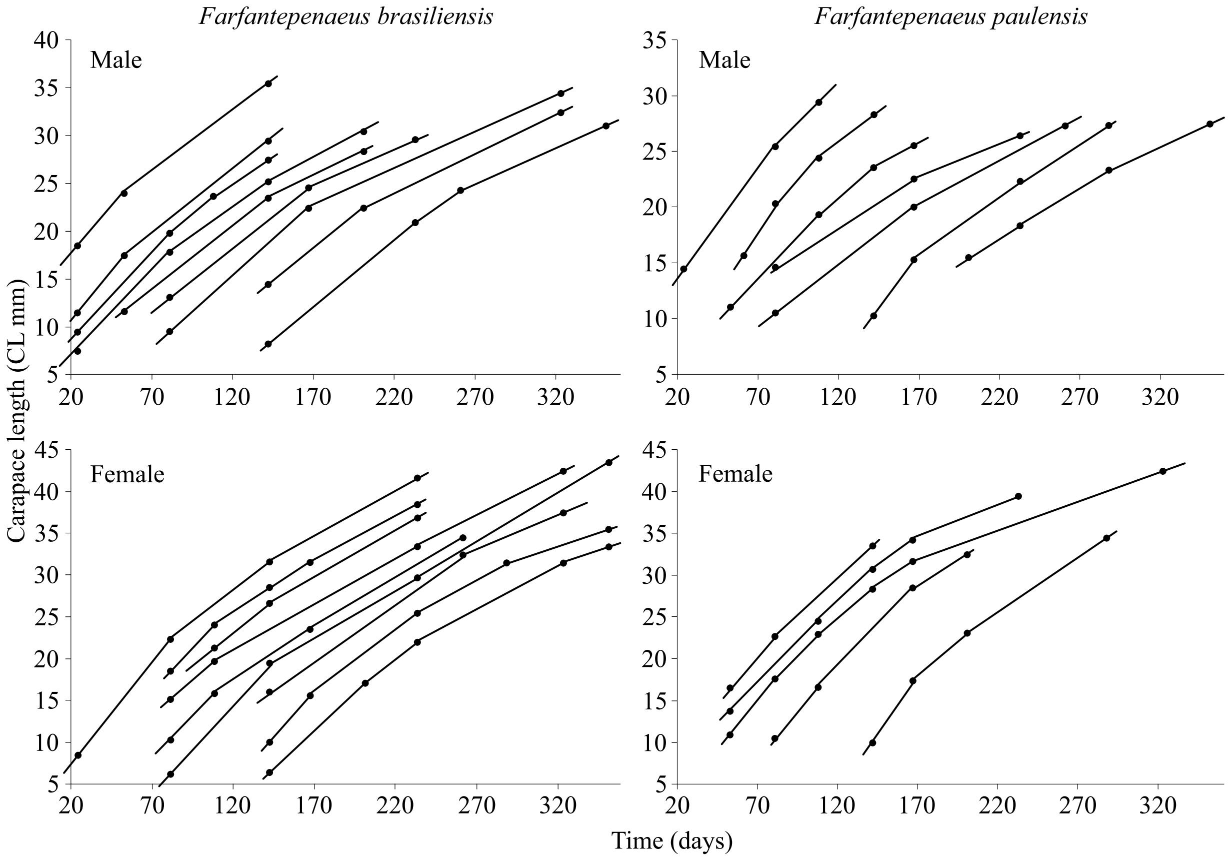

Figure 3. Modal groups selected for males and females of *Farfantepenaeus brasiliensis* and *F. paulensis* sampled monthly, from January to December 2000, in Ubatuba region. The lines represent the modal groups.

parameters in Ubatuba Bay. Overall, females of both species reached larger asymptotic sizes than males. This sexual dimorphism is common for Penaeidae (Dall et al. 1990) and has been observed in *F. subtilis* (Santos et al. 2020), *L. schmitti* (Miazaki et al. 2018) and *Penaeus merguiensis* de Man, 1888 (Saputra et al. 2018). It is related to the family reproductive strategy, pure searching. As these shrimps live aggregated in high densities, males do not guard females or territories prior to mating, so most of their energy may be allocated in developing faster in order to reproduce (Bauer 2010). As for females, they grow larger because the need to allocate their ovaries and other reproductive structures (Crisp et al. 2017).

The values in our study regarding CL_∞ were smaller compared with previous studies with the same species. We found values of CL_∞ of 41.08 mm for males and 47.32 mm for females of *F. brasiliensis*; and 36.55 mm for males and 49.24 mm for females of *F. paulensis*. Leite Jr and Petrere Jr (2006) found for *F. brasiliensis* values of CL_∞ of 50.15 mm for males and 45.91 mm for females, and for *F. paulensis* values of 71.07 mm for males and 61.74 mm for females. It is important to highlight that as we sampled in a coastal bay (up to 20 m deep) and in its adjacent marine area (up to 40 m deep) on the northern coast of the São Paulo state, Leite Jr and Petrere Jr op. cit. obtained data from the fishing fleet located on the state's southern coast, which

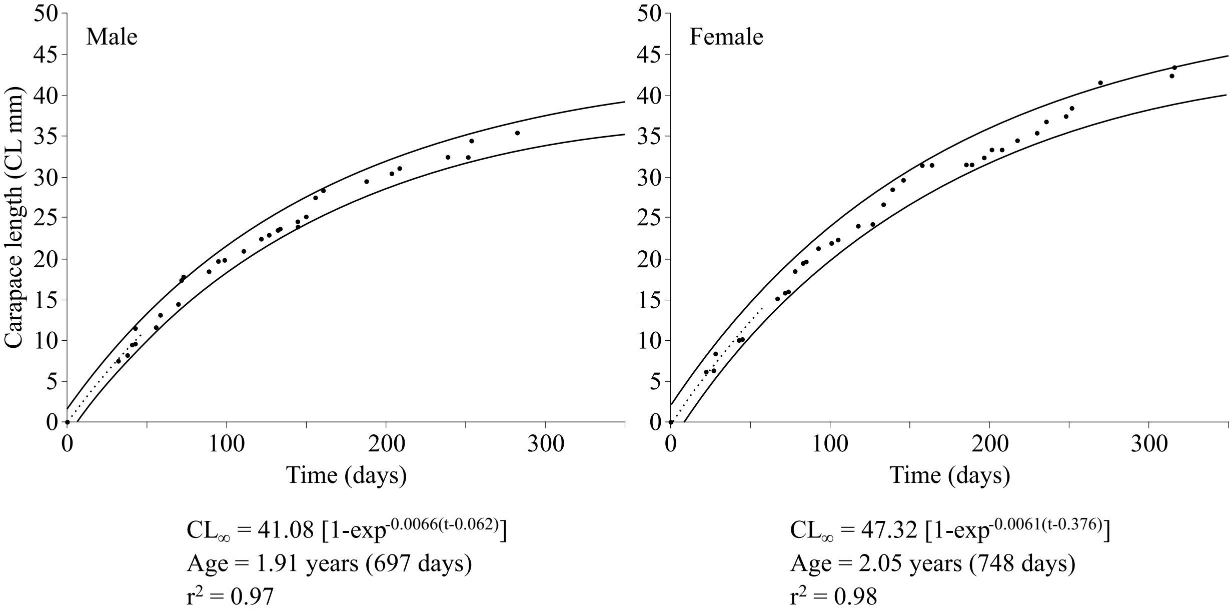

Figure 4. Growth curves and parameters of von Bertalanffy equation estimated separately for males and females *Farfantepenaeus brasiliensis* sampled monthly from January to December 2000 in Ubatuba region. The centerline is the mean and outer lines are prediction intervals (95%).

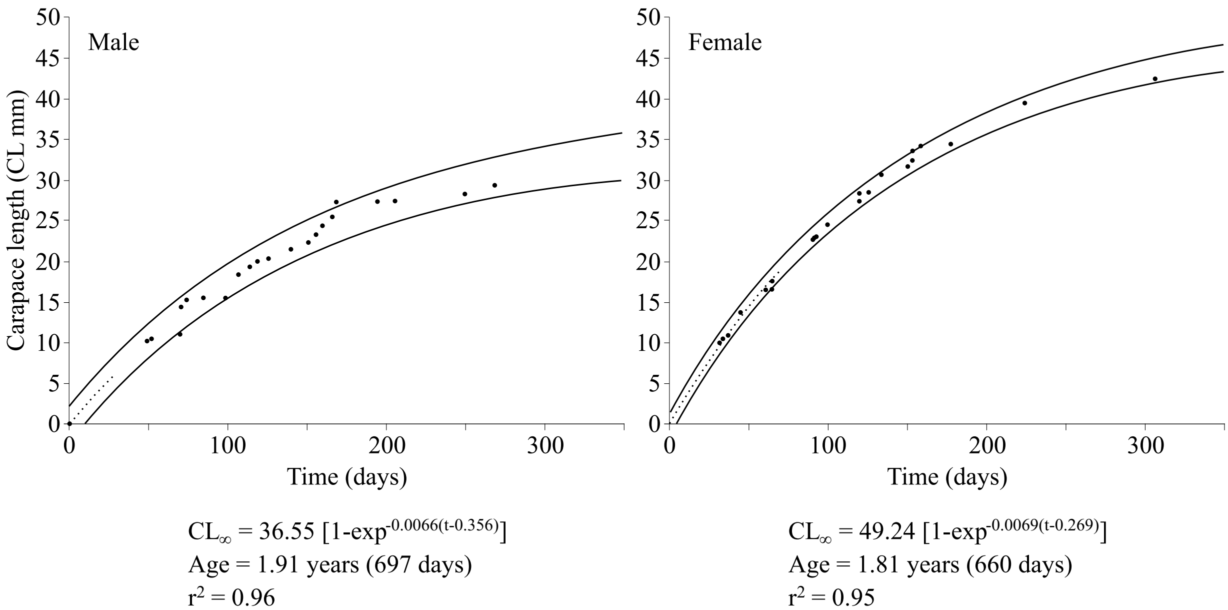

Figure 5. Growth curves and parameters of von Bertalanffy equation estimated separately for males and females *Farfantepenaeus paulensis* sampled monthly from January to December 2000 in Ubatuba region. The centerline is the mean and outer lines are prediction intervals (95%).

Table 2. Annual estimates ($year^{-1}$) of natural mortality (M), fishing mortality (F), total mortality (Z), exploitation rates (E) and Standard Deviation (SD) by sex for *Farfantepenaeus brasiliensis* and *F. paulensis*.

Species	Sex	M	F	Z	E
Farfantepenaeus brasiliensis	Male	2.47	7.97	10.44	0.76
	Female	2.28	8.42	10.71	0.79
	Mean ± SD	2.38 ± 0.13	8.20 ± 0.32	10.58 ± 0.19	0.78 ± 0.02
Farfantepenaeus paulensis	Male	2.52	7.64	10.16	0.75
	Female	2.52	10.25	12.77	0.80
	Mean ± SD	2.52 ± 0	8.95 ± 1.85	11.47 ± 1.85	0.78 ± 0.04

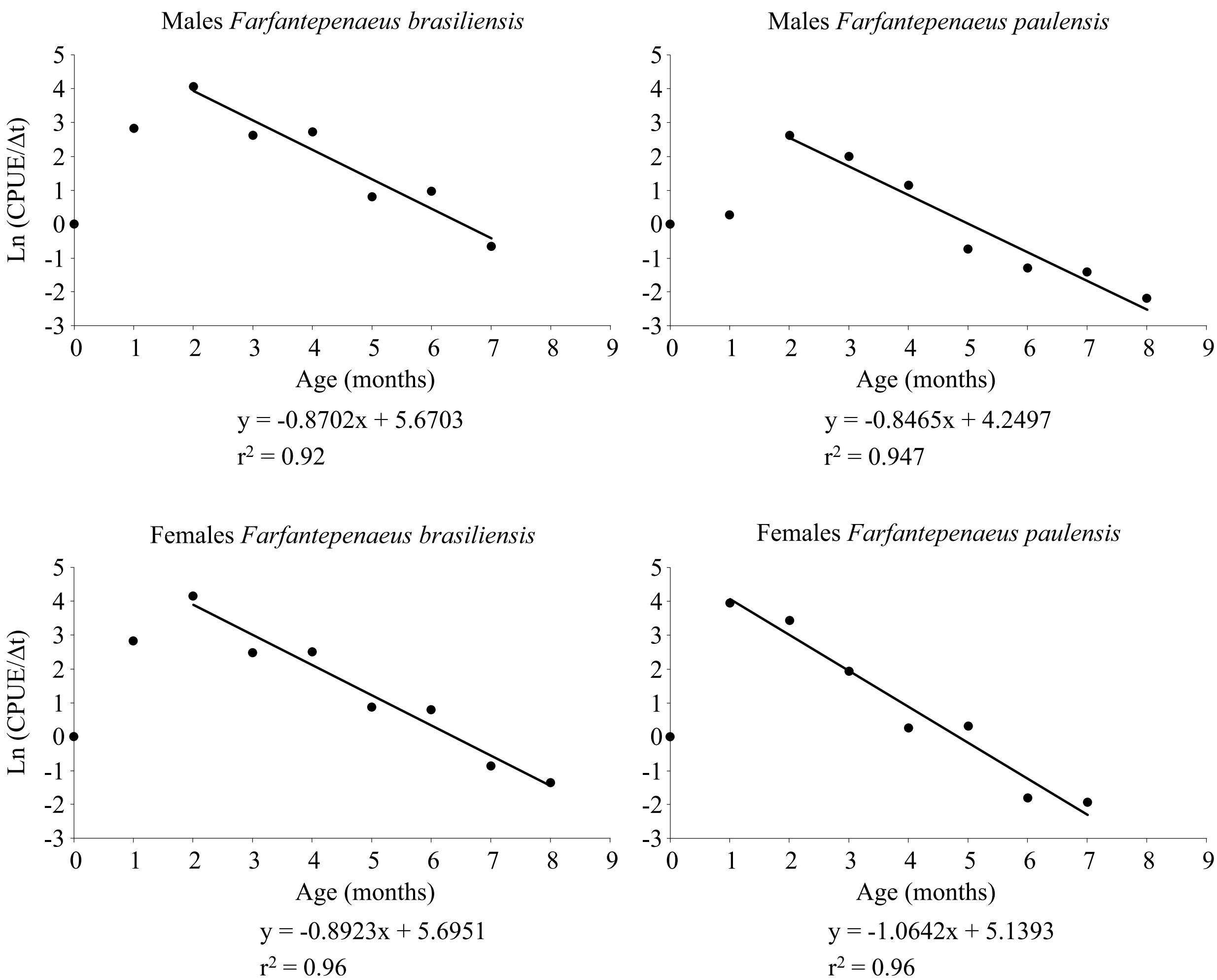

Figure 6. Length-converted catch curves estimated separately for males and females of *Farfantepenaeus brasiliensis* and *F. paulensis* sampled monthly from January to December 2000 in Ubatuba region.

usually operates in greater depths and captures larger individuals. The estimation of L_∞ is heavily influenced by the maximum length of the species in the sample and therefore by the sampling area (Froese and Binohlan 2000).

According to Vogt (2019), the average longevity of Penaeidae is 2.1 years. In our study, we found longevities of 1.91 years for males and 2.05 years for females of *F. brasiliensis*, and 1.91 years for males and 1.81 years for females of *F. paulensis*. While males of both species presented the same longevity, there was a considerable discrepancy for females. Females of *F. brasiliensis* may live up to three months longer than males in general, but females of *F. paulensis* live a month less than males. This is especially concerning for the species in the area if these females are captured in their reproductive period before spawning. Close values of longevity were obtained in northeastern Brazil by Silva et al. (2015) and Santos et al. (2020) for *F. subtilis* and by Nwosu (2009) for *Farfantepenaeus notialis* (Pérez-Farfante, 1967) in Nigeria.

Growth rates (*k*) for *F. brasiliensis* and *F. paulensis* remained above 1.8 a year as suggested by Garcia and Le Reste (1981) for peneids. The *k* of females of both species were very close to the values found by Mello (1973) in São Paulo state (23° S), from 2.52 $year^{-1}$ for *F. brasiliensis* and 2.4 $year^{-1}$ for *F. paulensis*. However, we found much higher *k* values for males than Mello op. cit., from 1.62 $year^{-1}$ for *F. brasiliensis* and 1.25 $year^{-1}$ for *F. paulensis*. Considerably higher *k* values were found herein than those found by D'Incao (1984) for both sexes of *F. paulensis* (1.03 $year^{-1}$ for females and 1.25 $year^{-1}$ for males) in Lagoa dos Patos, Rio Grande do Sul state (31° S), and by Leite Jr and Petrere Jr (2006) in Santos, São Paulo state (23° S) for both species, which were 0.9 $year^{-1}$ for females and 0.84 $year^{-1}$ for males of *F. brasiliensis* and 1.1 $year^{-1}$ for females and 0.83 $year^{-1}$ for males of *F. paulensis*. Values found in our study were probably higher than those found by Leite Jr and Petrere Jr op. cit. because they obtained data from fishery terminals, which usually discard small individuals with little economic value. We also sampled during the closed season; therefore, more juvenile individuals were included in the analysis.

An organism's growth rate can vary due to both intrinsic (genetic effects) and extrinsic reasons, e.g. variation in food availability, temperature, oceanographic phenomena (Alford and Jackson 1993), as well as from fishing pressure. According to D'Incao (1984), results revealed by Mello (1973) were probably due to the increased fishing fleet in São Paulo state coinciding with its sampling period, thus the increase in fishing may be associated with the reduced number of individuals reaching adulthood, consequently decreasing the individual length of catches. This is also probably occurring in our study area.

Natural mortality (M) was slightly higher for males, which is probably a reflex of their smaller sizes, since smaller individuals are more likely to be predated (Fonteles-Filho 2011). Fishery mortality (F) was higher in females. Overall, F varies with total length of individuals and is directly related to the effort and choice of fishing gear (Fonteles-Filho 2011). However, since males of both species are smaller, they present lower F values compared to females. The F values found in this study were higher than those found by Leite Jr and Petrere Jr (2006), who recorded 3.8 $year^{-1}$ for males and 2.8 $year^{-1}$ for females of *F. brasiliensis*, and 4.7 $year^{-1}$ for males and 3.4 $year^{-1}$ for females of *F. paulensis* in the Santos region, on the south-central coast of São Paulo. Nwosu (2009) studied exploited stocks of *F. notialis* and found an F of 6.44 $year^{-1}$. Considering that the majority of individuals sampled were juveniles (i.e. CL < 25 mm) (Figure 2), such a high F is extremely prejudicial to the stock's maintenance.

Globally speaking, Penaeid fisheries are responsible for high fishing mortality rates contributing to the high Z values found for populations of economic valuable species (Garcia and Le Reste 1981). Many stocks of targeted shrimps in tropical fisheries have been over-exploited. According to Gulland (1970) and Francis (1974) the optimum exploitation rate (E) for a fishery stock is around 0.5 when Fopt = M. Studies available in the literature, such as Niamaimandi et al. (2007) on *Penaeus semisulcatus* De Haan, 1844, Safaie (2015) on *P. merguiensis*, Saputra et al. (2019) on *P. indicus* H. Milne Edwards, 1837, and De Carvalho et al. (2019) on *L. schmitti*, resulted in high estimates of Z and all stocks were explored over the optimum sustainable yield.

In our study, F values were considerably higher than M values. During the sampling period, E values were higher than 0.7 for both sexes of both species. Therefore, pink-shrimp stocks were over-exploited in the Ubatuba region. It is important to consider that, due to the small estuaries, *F. paulensis* finishes its juvenile growth in the bays of Ubatuba. On the other hand, F. brasiliensis does not enter the estuaries and completely develops in shallower portions (Costa et al. 2008). Therefore, juveniles and pre-adults who have not yet migrated to the adult stock and have not reproduced are vulnerable to the seabob fisheries, which occur at up to 20 m deep, especially if the closed season is not suitable for the species. Miazaki et al. (2021) recorded a high exploitation rate for *Xiphopenaeus* spp. in the same area, reinforcing pink shrimps' vulnerability.

Seasonal closures are an important measure adopted by many tropical and subtropical shrimp fisheries to control fishing effort and prevent over-exploitation (Watson and Restrepo 1995). After 20 years of closed seasons, there still have been no recent studies about the area regarding the growth, longevity and mortality of pink shrimps. Such studies are urgently needed since several adjustments of fishing closure that occurred in the Southeast and South of Brazil (IBAMA 2008) in 2008 are still being enforced today. Data obtained from the IP/APTA/SAA/SP (2022), show that landings of pink shrimps captured in Ubatuba in the past 20 years ranged from 1.357 t in 2006 to 86 t in 2018, with annual averages of 50.308 ± 21.430 t. In 2000, 40.661 t of pink shrimp were captured in the area, while in 2021, similar values were registered, at 42.180 t. Thus, our results are of paramount importance and necessary not only to make comparisons with the current stock situation but also to reinforce the importance of regulations that control fishing activities, seeking to prevent further collapses of natural stocks, minimize the impacts caused by fishing and maintain ecologically sustainable level of stocks.

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ORIGINAL RESEARCH

Greenhouse gas emissions, consumption and fuel use intensity by an artisanal double-rig trawl fleet in southern Brazil

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ABSTRACT. In Brazil, most national marine production is captured by artisanal fisheries. The present study was conducted in a traditional trawl fishing area for the capture of the Atlantic seabob shrimp Xiphopenaeus kroyeri in southern Brazil between 1996 and 2015 to obtain initial estimates of direct fuel inputs and greenhouse gas emissions. Data include vessel characteristics, total and seabob shrimp production, and trawl duration. Approximately, four million liters of fuel were consumed for an estimated catch of around 148,000 kg of fish (26.4 l kg^{-1}), of which 19,000 kg were seabob shrimp (206 l kg^{-1}) or 13% of total production. The carbon emitted by this fleet was almost three million gigagrams (GgC), between 401 and 666 t per year. Although the number of vessels has increased over the years, catches, especially of seabob shrimp, have declined sharply, indicating over-exploitation of this resource and reinforcing the urgent need to create management programs and selective technologies for this modality.

Key words: Artisanal trawl fishery, shrimp, energy efficiency, greenhouse gases, fuel use intensity, carbon balance.

Emisiones de gases de efecto invernadero, consumo e intensidad de uso de combustibles por una flota de arrastre artesanal de doble aparejo en el sur de Brasil

RESUMEN. En Brasil, la mayor parte de la producción marina nacional es capturada por la pesca artesanal. El presente estudio se realizó en un área de pesca de arrastre tradicional para la captura del camarón siete barbas del Atlántico Xiphopenaeus kroyeri en el sur de Brasil entre 1996 y 2015 para obtener estimaciones iniciales de las entradas directas de combustible y las emisiones de gases de efecto invernadero. Los datos incluyen las características de las embarcaciones, la producción total y de camarones siete barbas y la duración de los arrastres. Se consumieron aproximadamente cuatro millones de litros de combustible para una captura estimada de alrededor de 148.000 kg de pescado (26,4 l kg^{-1} capturados), de los cuales 19.000 kg fueron camarones siete barbas (206 l kg^{-1} capturados) o el 13% de la producción total. El carbono emitido por esta flota fue de casi tres millones de gigagramos (GgC), entre 401 y 666 t anuales. Si bien el número de embarcaciones ha aumentado a lo largo de los años, las capturas, especialmente de camarón siete barbas, han disminuido drásticamente, lo que indica una sobreexplotación de este recurso y refuerza la necesidad urgente de crear programas de manejo y tecnologías selectivas para esta modalidad.

Palabras clave: Pesca artesanal de arrastre, camarón, eficiencia energética, gases de efecto invernadero, intensidad de uso de combustibles, balance de carbono.

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INTRODUCTION

According to estimates, approximately 60 million people are involved in fishing and aquaculture and around 65% depend directly on fishing for their livelihood (FAO 2020). The capture, processing, and sale of fish from artisanal fisheries play a key role in providing food to the world's population (Salas et al. 2018). In Brazil, around one million people are directly involved in fishing. Specifically, artisanal fishing historically accounts for a large part of national marine production, thus reinforcing the economic and social importance of this modality (Abdallah and Bacha 1999; Zamboni 2020). However, information related to the fishery tends to be unreliable and fishers rarely participate in its management, which causes a series of problems such as their gradual loss of political and economic representativeness (Salas et al. 2007; Medeiros et al. 2014; Dias Neto and Oliveira Dias 2015; Oliveira Leis et al. 2018).

Since this fishery involves a wide variety of environments and species, its impacts are a growing cause for concern, especially in terms of stock reduction (Garcia and Grainger 2005), changes in ecosystem structure and functioning (Pauly et al. 1998, 2005; Kelleher 2008), changes in the ocean floor (Kaiser et al. 2006; Kaiser 2019), mortality of endangered species (Sales et al. 2010; Fiedler et al. 2012, 2017, 2020), consumption of fossil fuels in navigation and fishing operations (Tyedmers 2004; Tyedmers et al. 2005; Suuronen et al. 2012), and greenhouse gas emissions (Ziegler and Hansson 2003; Fulton 2010; Port et al. 2016). In the last two decades alone, the impact of the two latter factors has served to assess the sustainability of fishing (Tyedmers 2004; Tyedmers and Parker 2012; Jha and Edwin 2019), especially large-scale fisheries in developed countries given the scarcity of data on small-scale or artisanal fisheries in developing countries (Parker et al. 2018).

For 2000, Tyedmers et al. (2005) estimated that fisheries landed approximately 80 million tons of fish, consumed 50 billion liters of oil, which is 1.2% of all oil used worldwide, and released around 130 million tons of CO_2 into the atmosphere. According to Parker et al. (2018), however, fisheries consumed an estimated 40 billion liters and emitted 179 million tons of CO_2. Because the energy for human assimilation by the consumption of this total captured is 1/12 of the energy required for the capture, the efficiency of this activity is generally low. Notably, however, different fishing modalities have different energy performances, that is, they require different levels of fuel consumption for their catch efficiency (Tyedmers 2004; Crowder et al. 2008). In this regard, passive methods (e.g. longline, trap, and gillnet) tend to require less energy than active methods (e.g. trawl, seine net) (Tyedmers et al. 2005; FAO 2007; Schau et al. 2009; Winther et al. 2009).

Demersal and benthic species for consumption are captured worldwide by trawl fisheries (Thurstan et al. 2010). Among other factors, the energy efficiency of this modality is generally deficient mainly due to variable capture patterns, large engine power, and high fuel consumption (Wileman 1984; Tyedmers 2004).

In the state of Santa Catarina, southern Brazil, approximately 20 thousand people in 36 coastal municipalities are directly involved in artisanal fishing (PCSPA-SC 2015). In these municipalities, artisanal fishing accounted for 43% of the total landing volume in the state between 2017 and 2019 (PMAP/SC 2020). Moreover, the municipality of Penha is the fifth largest artisanal producer in the state. The fleet of Penha mostly consists of open vessels with an inboard engine and without pilothouse. The most widely used fishing gear are gillnets (fixed and drift net) and double-trawl nets, mainly used to catch codling *Urophycis* spp., anchovy *Pomatomus saltatrix* (Linnaeus, 1766), catfish *Genidens* spp., croaker *Micropogonias furnieri* (Desmarest, 1823), weakfish *Cynoscion* spp., mullet *Mugil liza*

(Valenciennes, 1836), and shrimp (PMAP/SC 2020). Of the shrimp, the most frequently captured species is the Atlantic seabob *Xiphopenaeus kroyeri* (Heller, 1862) with an estimated 177.3 t year^{-1} (Branco and Verani 2006).

Although artisanal fishing in the municipality has been widely studied (Almeida and Branco 2002; Bail and Branco 2003, 2007; Branco and Fracasso 2004; Branco 2005; Branco and Verani 2006; Branco et al. 2013; Coelho et al. 2016; Acauan et al. 2018a, 2018b; Barrili et al. 2021), little is known about the energy efficiency of shrimp trawling and its real impacts on the marine environment. The present study evaluated for the first time the relationship between fuel consumption and total catches of artisanal trawl fishing, between 1996 and 2015 in a community of Armação do Itapocoroy, municipality of Penha, north-central coast of Santa Catarina, Brazil, to support ecosystem management for this activity.

MATERIALS AND METHODS

Study area

The study area is located in the municipality of Penha (26° 46′ S-48° 38′ W), north-central coast of the state of Santa Catarina, Brazil (Figure 1). Penha has an estimated population of 30,262 inhabitants and its main activities are tourism, mariculture, and fishing (Branco 2005; IBGE 2017).

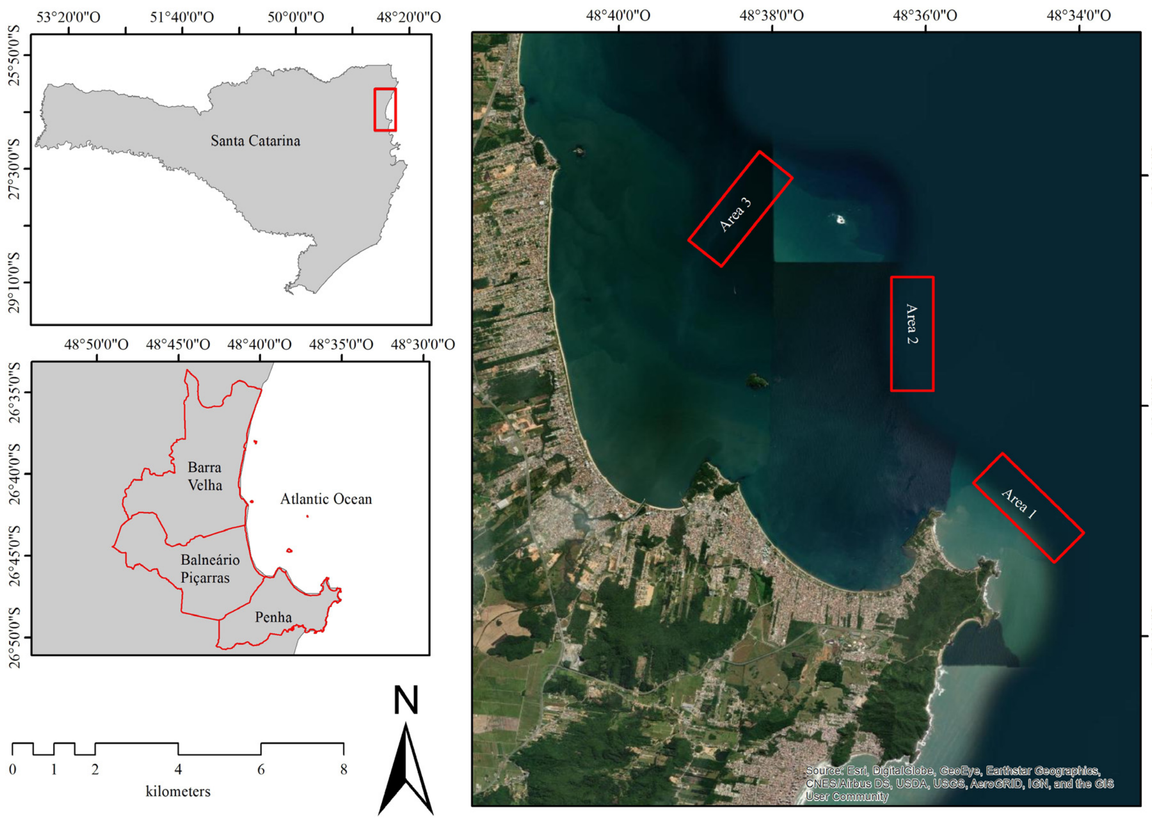

Figure 1. Location of the municipality of Penha - SC, Brazil, and the three main fishing areas of the seabob shrimp *Xiphopenaeus kroyeri* by the artisanal trawl fleet of the community of Armação do Itapocoroy.

Artisanal trawl fishing

In Armação do Itapocoroy beach, 115 artisanal vessels navigate an area of approximately 168 km^2 and mainly target the Atlantic seabob shrimp *Xiphopenaeus kroyeri* (Acauan et al. 2018a). In the present study, trawls were carried out monthly between 1996 and 2015, in the three fishing areas traditionally used by the local fishing community (Figure 1).

The same methodology was used throughout the study period. Moreover, the same double-rig trawler was used and leased from a local fisher, who also drove the vessel in all the trawls.

Two identical nets were used, with 3.0 cm mesh on the wings and 2.0 cm on the body and cod end. The speed of all the trawls was 2.0 knots. For each sampling, three trawls were performed for one hour each.

Every catch was selected by the fisher on the deck of the vessel based on their knowledge and daily practice. Species were classified into the following two initial categories: a) nominal catch, which refers to the set of species retained for sale, mainly the seabob shrimp; and b) discarded catch, which are the species returned to the sea because they are not sold or because they are sold but their size is below the minimum allowed size for sale. The nominal catch was separated into the following two categories: a) target species, that is, those that have economic importance; and b) incidental species, which are not feasible for fisheries but can be used for consumption and/or sold in the local market. The total sample catch (nominal catch + discarded catch) was separated in clearly identified refrigerated boxes. At the laboratory, these samples were selected, and the specimens were subsequently counted, weighed, subjected to biometric recognition, and identified to the lowest possible taxonomic level using specialized literature (Menezes et al. 2003; and references contained therein).

The information was entered into an excel spread-sheet after cross-validation, whereby one researcher reviews the information entered by another.

Fishery activity information

Since socio-economic data of the trawler fleet in the municipality were not systematically collected, engine power (Hp) data were initially obtained through a literature review of publications in scientific journals, unpublished data, and gray literature (theses and dissertations). Subsequently, detailed information collected by the Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina –EPAGRI (Company of Agriculture, Research, and Rural Extension of Santa Catarina) for 2011 (Everton Della Giustina and Daniela M. G. Nunes, unpublished data) revealed the low variation in engine power values over the years. Thus, an extrapolation was carried out proportionally for the other years, considering the total number of vessels operating each year (Table 1).

Data transformation

Total fuel consumption during fishing operations was estimated through the relationship between total trawling hours and total vessel engine power (Brazil 2011) using the following formula:

$$FC_{ei} = TH_{ei} \times FHP \times HP_e$$

where FC_{ei} is the amount of oil, in liters, consumed by the e^{-eth} trawl during the i^{-eth} fishing trip; TH_{ei} is the time, in hours, the e^{-eth} vessel spent trawling during the i^{-eth} trip; FHP is the amount of oil, in liters, consumed per hour and per vessel engine horsepower (standard value at 0.0963 l/Hp); and HP_e is the power of the e^{-eth} engine expressed in Hp.

The intensity of fuel use for each fishing trip FUI_i was expressed by the following formula:

Table 1. Source of engine power (Hp) data available for each year for the artisanal fleet of double-rig trawlers of Armação do Itapocoroy, municipality of Penha - SC, Brazil. Data from 2011 (EPAGRI, unpublished data) used for extrapolation and calculations of fuel consumption and intensity of use and carbon emission. -: period without information.

	Engine power (Hp)		
Year	Min	Max	Source
1996	15	45	Branco (2001), Branco and Fracasso (2004)
1997	15	45	Branco (2001), Branco and Fracasso (2004)
1998	16	40	Fracasso (2002), Branco and Fracasso (2004)
1999	16	40	Fracasso (2002), Branco and Fracasso (2004), Campos (2004)
2000	16	40	Fracasso (2002), Branco and Fracasso (2004), Campos (2004)
2001	16	40	Fracasso (2002), Branco and Fracasso (2004), Campos (2004)
2002	16	40	Branco and Fracasso (2004), Bail and Branco (2007)
2003	10	24	Bail and Branco (2007)
2004	-	-	-
2005	-	-	-
2006	-	-	-
2007	-	-	-
2008	-	-	-
2009	-	-	-
2010	10	36	Santos (2011)
2011	10	60	EPAGRI (2011), Santos (2011)
2012	-	-	-
2013	-	-	-
2014	17,44	24,25	PCSPA/UNIVALI (2015)
2015	17,44	24,25	PCSPA/UNIVALI (2015)

$$FUI_i = FC_{ei}/LC_i$$

where LC_i is the nominal catch of the i^{-eth} trip, in kg.

For the present study, the ‘carbon balance’ was considered as the ratio between the amount of carbon removed from the marine environment *vs* the carbon emitted into the atmosphere from the consumption of diesel oil during fishing operations. Therefore, total catch and seabob shrimp catch separately for each trip (kg) were transformed into carbon units (C_i) using the following equation:

$$C_i = (LC_i \times CR) / 1{,}000{,}000$$

where CR refers to the biomass/carbon conversion rate, considered 9:1 (Pauly and Christensen 1995; Ziegler 2006; Ziegler and Valentinsson 2008; Fulton 2010; Port 2015; Port et al. 2016).

The fuel consumed on each fishing trip was converted into ‘standard energy units’, defined as tEP, by which 1 toe = 45.2×10^{-3} TJ (TJ = 1,012 J) (Brasil 1999). The following equation described by Álvares Júnior and Linke (2002), Macêdo (2004) and Pinto and Santos (2004) was used:

$$EC_{ei} = FC_{ei} \times Fconv \times 45.2 \times 10^{-3} \times Fcorr$$

where EC_{ei} is the energy dissipated by the e^{-eth} vessel during the i^{-eth} fishing trip, expressed in TJ; Fconv is the factor used to convert a certain amount of fuel into tEP, considering the 'high heat value' (HHV) of the fuel, surveyed annually by the National Energy Balance of the Brazilian Ministry of Mines and Energy (EPE 2011). The value used of nautical diesel oil for 2010 was determined, namely 0.848 tEP m^{-3}. In contrast, Fcorr is the factor used to correct Fconv from HHV to "low heat value" (LHV). This conversion was required to ensure energy contents estimated by the National Energy Balance were comparable to those recommended by the Intergovernmental Panel on Climate Change (IPCC). Fcorr for solid and liquid fuels was set at 0.95 (Brazil, 2006). The amount of carbon emitted by oil consumption during the fishing trip was calculated using the following equation described by Álvares Júnior and Linke (2002), Macêdo (2004), and Pinto and Santos (2004):

$$CE_{ei} = EC_{ei} \times Femiss \times 10^{-3}$$

where CE_{ei} refers to the carbon, expressed in Gigagrams (GgC = 1,000 t carbon), emitted by the e^{-eth} vessel during an i^{-eth} fishing trip; Femiss is the carbon emission factor, expressed in ton of carbon (tC), per TJ. For diesel oil, this value corresponds to 20.2 tC/TJ (IPCC 1996; Brasil 2006). The 10^{-3} multiplication was performed to express the value in GgC. The carbon balance for each fishing trip was expressed as a ratio CE_{ei}/C_i.

Finally, GgC values were converted to tons of carbon dioxide (CO_2), using the following equation described by Macêdo (2004):

$$ECO_2 = (CE_{ei} \times 44/12) \times 1,000$$

Data analysis

Since the main purpose of this study was to obtain the aggregate estimates of fuel consumption and intensity of use, carbon emissions, and carbon energy balance for trawl fisheries in Itapocoroy, the transformed variables were grouped by year and for the entire study period.

RESULTS

During the study period (1996-2015), an annual average of 78 vessels were operating in the shrimp trawl fishery, with a minimum of 59 (2001) and a maximum of 96 (2015). The average power of vessel engines was 21 Hp (min = 10; max = 60 Hp). They operated 240 each year, with six trawls a day of one hour each. From 2004, the number of shrimp trawlers gradually increased (Figure 2).

Regarding biomass, the total catch estimate for the study period was 148,082 kg of fish (min = 2,906.5 kg in 2009; max = 12,528.2 kg in 1999). For the seabob shrimp, the total catch estimate was 19,002 kg (min = 45 kg in 2015; max = 3,418.2 kg in 2010), representing an average of 12.8% of the total catch (min = 1.0% in 2014; max = 35.5% in 2010) (Table 2). Although the number of vessels gradually increased from 2004, total and seabob shrimp catches did not increase (Figure 2).

Total catches peaked in 1999 (12,528.21 kg), followed by a gradual decline until 2009 (2,906.47 kg). Subsequently, in 2010 catches recovered with 9,626.72 kg landed, followed by another drop in catches. In contrast, seabob shrimp catches remained relatively stable from 1998, reaching a maximum in 2010 (3,418.18 kg), followed by a sharp decline, until reaching a negligible 44.97 kg in 2015 (Figure 2).

The approximate total fuel consumption was 3,909,000 l (min = 149,000 l in 2001; max = 247,000 l in 2015). As for intensity of fuel use, approximately 3,909,000 l of fuel (average = 26.4 l kg^{-1} catch) was used for the estimated total of 148,082 kg fish landed (Table 2). Considering

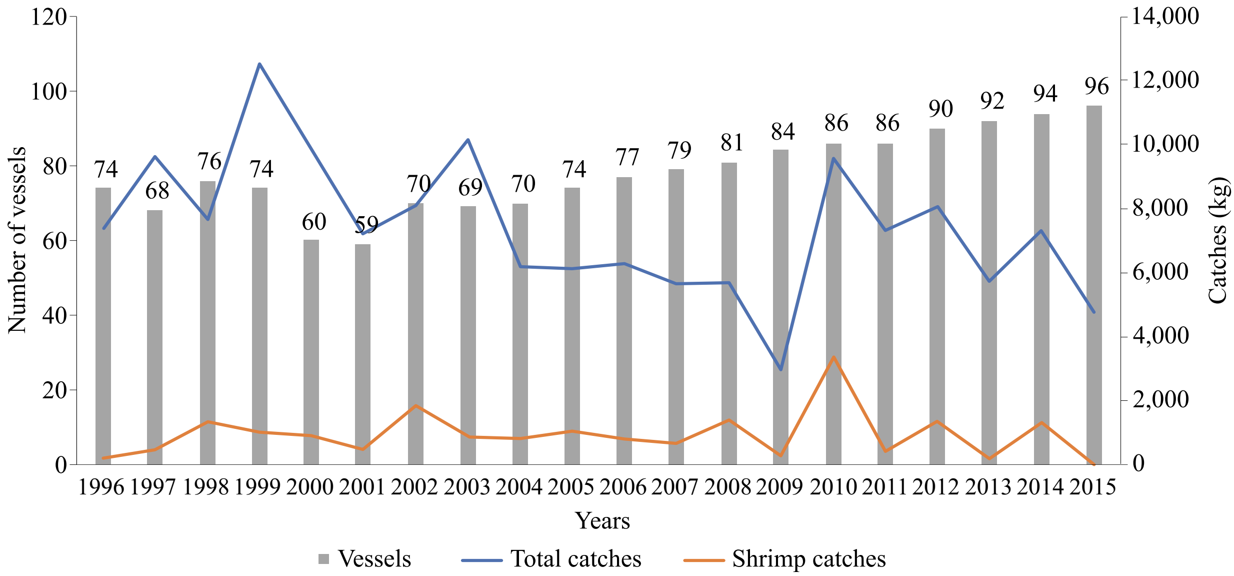

Figure 2. Number of vessels, total catch, and seabob shrimp *Xiphopenaeus kroyeri* catches by the artisanal trawl fleet of the community of Armação do Itapocoroy, municipality of Penha - SC, Brazil, from 1996 to 2015.

only the seabob shrimp, around 19,002 kg were landed with this same amount of fuel, averaging 206 l consumed for each kg of shrimp caught.

Regarding the amount of carbon emitted by this fleet over the years, the total was 2,875.22 GgC (min = 109.4 in 2001; max = 181.7 in 2015) (Table 2). For the carbon balance, the estimated total capture was 174,747.54 GgC (min = 95,883.68 in 1999; max = 476,445.3 in 2009). For the seabob shrimp alone, the total was 1,361,805.43 GgC (min = 419,763.45 in 2010; max = 36,354,339.35 in 2015) (Table 2). Finally, estimated total CO_2 emissions was 10,542.46 t, with a minimum of 401.03 t for 2001 and a maximum of 666.13 t for 2015 (Table 2).

DISCUSSION

Although fisheries play an important role in supplying animal protein to the world's population, the relationship between total expenditure and income obtained during a fishing trip is often negative in some modalities. Moreover, accurate information on these operations required assessing negative impacts on the ecosystem beyond target species and bycatch, e.g. is not readily available for all fishing activities. In this regard, Branco and Fracasso (2004) identified 28 different species of crustaceans in the seabob shrimp fishery, mostly comprising immature individuals, which causes a negative impact on the benthic ecosystem and, consequently, on the activity as a whole.

Moreover, socioeconomic data is often collected for specific periods and, in most cases, only to characterize the fishing activity in particular, even in long-term projects. The data collected with such a specific methodology fails to reflect the actual, real-life events of fisheries, which involve high dynamism due to the constant inclusion of new equipment (including engines) and/or ways of operation. Since socioeconomic data, such as number of operating vessels, were not collected annually for the present study, calculations were based on the best available data set for the other years, provided by EPAGRI.

Table 2. Information for each year (1996-2015) of number of operating vessels; estimated total nominal catch (Lci) and seabob shrimp *Xiphopenaeus kroyeri* catches, percentage (%) of seabob shrimp in relation to total catch; total fuel consumption (FCei); estimated fuel use intensity (FUIi), total and for seabob shrimp; carbon emitted by fuel consumption, estimated carbon balance (BC) for total catch and seabob shrimp catches; and CO_2 emission (ECO_2); for the artisanal double-rig trawl fleet of Armação do Itapocoroy, municipality of Penha - SC, Brazil.

		Lci (kg)				FUIi (l kg^{-1})			BC (GgC)		
Year	Vessel (n)	Total	Shrimp	Shrimp %	FCei (l)	Total	Shrimp	CEei (GgC)	Total	Shrimp	ECO_2 (t)
1996	74	7,321.40	236.6	3.23	181,460.37	24.78	766.95	133.47	164,073.88	5,077,136.43	489.40
1997	68	9,640.38	452.04	4.69	166,338.68	17.25	367.97	122.35	114,222.27	2,435,926.12	448.62
1998	76	7,675.32	1,347.74	17.56	186,500.94	24.30	138.38	137.18	160,855.60	916,067.18	502.99
1999	74	12,528.21	1,044.34	8.34	181,460.37	14.48	173.76	133.47	95,883.68	1,150,248.90	489.40
2000	60	9,842.03	898.77	9.13	153,737.26	15.62	171.05	113.08	103,406.10	1,132,350.04	414.63
2001	59	7,193.36	492.26	6.84	148,696.70	20.67	302.07	109.37	136,842.63	1,999,676.66	401.03
2002	70	8,093.64	1,834.03	22.66	176,419.81	21.80	96.19	129.76	144,296.23	636,784.86	475.80
2003	69	10,191.12	871.43	8.55	171,379.24	16.82	196.66	126.06	111,323.80	1,301,898.00	462.21
2004	70	6,144.41	818.69	13.32	176,419.81	28.71	215.49	129.76	190,072.31	1,426,528.94	475.80
2005	74	6,129.60	1,058.73	17.27	183,980.66	30.02	173.78	135.33	198,697.37	1,150,377.45	496.20
2006	77	6,270.83	820.94	13.09	189,021.22	30.14	230.25	139.03	199,543.38	1,524,229.80	509.79
2007	79	5,665.91	678.38	11.97	196,582.07	34.70	289.78	144.59	229,681.45	1,918,323.63	530.18
2008	81	5,706.77	1,411.62	24.74	201,622.64	35.33	142.83	148.30	233,884.08	945,522.32	543.78
2009	84	2,906.47	248.34	8.54	209,183.49	71.97	842.34	153.86	476,445.28	5,576,232.68	564.17
2010	86	9,626.72	3,418.18	35.51	216,744.34	22.51	63.41	159.43	149,046.28	419,763.45	584.56
2011	86	7,310.72	436.62	5.97	216,744.34	29.65	496.42	159.43	196,263.39	3,286,223.50	584.56
2012	90	8,061.67	1,367.58	16.96	229,345.75	28.45	167.70	168.69	188,329.17	1,110,168.34	618.55
2013	92	5,698.67	160.89	2.82	234,386.32	41.13	1,456.82	172.40	272,276.88	9,644,022.46	632.14
2014	94	7,348.71	1,359.78	18.50	241,947.17	32.92	177.93	177.96	217,952.22	1,177,888.99	652.53
2015	96	4,725.90	44.97	0.95	246,987.73	52.26	5,491.67	181.67	345,973.13	36,354,339.35	666.13
Total		148,081.84	19,001.93	12.83	3,908,958.90	26.40	205.71	2,875.22	-	-	10,542.46

In general, only a slight variation in the total number of vessels operating in Armação do Itapocoroy was observed between 1996 and 2004. This number increased from 2004, probably due to government incentives for fishing fleets. More vessels, however, did not lead to an increase in total catches and seabob shrimp catches annually, as the largest catch occurred in 1999 (12,528.21 t of fish) with 74 trawlers. After 2004, when the number of vessels increased gradually, total catches did not exceed 9,626.72 t (2010), with an effort of 86 vessels. Port (2015) observed a similar trend for the industrial trawl fleet that lands in Santa Catarina, Brazil, and reported an increase in seabob shrimp landings from 2003 and a peak in landings in 2010, followed by a trend of declining catches which may be related to the over-exploitation of resources.

According to Tyedmers (2004), temporal variations in some elements, such as decreasing relative abundance of stocks and increasing size and power of vessel engines, directly contribute to changes in energy performance over time. In terms of industrial fishing, evidence shows that the impact of trawling on benthic ecosystems in southeastern and southern Brazil is directly related to overfishing, that is, catches above the maximum sustainable levels (Haimovici et al. 2006; Perez et al. 2009). According to Ostrom et al. (2007), however, over-exploitation and misuse of ecological systems are rarely attributed to a single cause and the use of simplistic and generalist solutions often increases problems rather than solve them. For Grafton et al. (2008) and Squires (2009), major challenges to this issue go beyond overfishing and include environmental, ecological, and biodiversity factors. In this respect, fisheries must consider management from the ecosystem standpoint since fishing affects trophic levels that are unrelated to the commonly targeted species (Pauly et al. 1998), such as those considered vulnerable, with low reproductive success rate, slow growth, and long-life cycle (Hall et al. 2000).

Results presented here were obtained from estimated total consumption and intensity of fuel use, amount of carbon emitted, carbon balance, and CO_2 emission. However, the calculated values may have been underestimated, given the difficulty in obtaining accurate estimates of fuel consumption for each of the fishing trips. In this regard, only the burning of fuel during the fishing operation was calculated, without considering navigation time from the port to fishing areas. According to Bail and Branco (2007), the navigation time ranges from 20 min to 1 h 30 min, which would certainly increase the consumption and emission values. This difficulty is also observed when assessing industrial fleets (Port et al. 2016), since, according to Notti et al. (2012), fuel consumption in this modality can be three times higher during the trawling operation than during navigation between ports and fishing areas.

During the study period (1996-2015), the artisanal fleet of Armação do Itapocoroy consisting of around 78 vessels per year with engine power between 10 and 60 Hp landed 148,082 t of fish, of which 19,002 t were seabob shrimp. These total landed biomass values account for 0.019% of the annual average landed by industrial trawling in Santa Catarina, which operated from 2003 to 2011 with an average of 358 vessels per year with engine power between 107 and 750 Hp (Port et al. 2016). In the same period, this artisanal fleet consumed 3,908,958.90 l of fuel, representing 1.24% of the annual average of the entire industrial trawl fleet of Santa Catarina between 2003 and 2011 (Port et al. 2016). Although this percentage seems small when compared to the industrial fleet, it should be stressed that artisanal trawl fishing communities were scattered throughout the state of Santa Catarina resulting in very high fuel consumption values.

The energy efficiency of the artisanal fleet of Armação do Itapocoroy proved to be very low. In the study period, approximately 26.4 l of fuel were consumed per kilogram of fish landed. Considering only the target species *Xiphopenaeus kroyeri*, the resulting energy efficiency is 205.71 l t^{-1} of landed shrimp. In contrast, the Santa Catarina industrial trawl fleet proved much more efficient, with 413 l of fuel per ton of fish landed (Port et al. 2016). Furthermore, the low energy efficiency calculated in this study is striking when compared with the efficiency recorded in Sweden by Ziegler and Hansson (2003) and Tyedmers (2004), totaling 1,410 l t^{-1}; on a global average and in European fisheries recorded by Degnbol (2009), ranging from 640 and 4,710 l t^{-1} of fish landed; in Japan by Furuya et al. (2011), ranging from 280 to 1,500 l t^{-1}; and a worldwide average recorded by Tyedmers et al. (2005), totaling 620 l of fuel per ton of fish landed.

The energy efficiency of the trawl fleet is generally deficient, because of the behavior of the variability patterns of stock captures (aggregations and distances to fishing areas) and the significant drag force produced during fishing operations, which require a great power of engine and high fuel consumption (Wileman 1984; Tyedmers 2004). For the Armação do Itapocoroy fleet, as well as for several others throughout the country, the trawling activity has only remained economically viable due to the existence of a constant incentive from the government through a fuel subsidy policy consisting of total tax exemption for the acquisition of oil. Furthermore, the economic sustainability of this fishery is strongly related to the sale of the various species of fish caught.

Fuel consumption of the artisanal trawl fleet resulted in average annual carbon emission of 0.144 GgC and 527.123 t CO_2 into the atmosphere. These figures represent 1.25 % of the average annual values of carbon and CO_2 emissions of the industrial trawl fleet of Santa Catarina (Port et al. 2016). As mentioned earlier, the number of fishing communities scattered throughout the state should be acknowledged.

Average per year carbon emissions from the artisanal fleet were 174,750 GgC for each GgC of total biomass landed; moreover, a great imbalance was observed between the amount of carbon emitted and removed resulting from total catches, indicating that the energy efficiency of this modality is poor due to high fuel consumption, among other factors (Wileman 1984; Tyedmers 2004). According to Azevedo et al. (2014), fuel consumption can amount to between 61.1% and 74.9% of the operating costs of the seabob shrimp fishing fleet, which reinforces the importance of carrying out specific and detailed studies on the behavior of this input.

Variables included in the list of impacts caused by this fishing activity can support more assertive decision-making for fisheries management and help define public management policies that consider economic, social, and environmental impacts.

Although artisanal fishing fleets, in particular trawling, consist of small vessels, their negative environmental impacts should not be overlooked, either due to the removal of considerable volumes of biomass, which in the case of trawling is aggravated by the lack of selective gear, or due to the emission of carbon and other greenhouse gases.

Therefore, fisheries must also be characterized according to fuel consumption and their relationship with the landed biomass to understand the real negative impacts beyond the catch of target or incidental species, among other factors. This characterization would support the creation of public policies for fisheries management and species conservation, both to maintain stocks and to minimize/neutralize emissions resulting from the use of fossil fuels.

Finally, the negative balance between carbon emission and removal reinforces the urgent need to develop selective technologies for trawl fishing gear. This measure would enhance the economic feasibility of the activity through the cost-yield ratio and would effectively reduce the capture of non-target species that play a fundamental ecological role in the balance of ecosystems.

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ORIGINAL RESEARCH

Camarones, camaroneros y escasez hídrica: desafíos para la sostenibilidad pesquera de *Cryphiops caementarius* en la cuenca del Río Choapa, Chile (2019-2021)

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RESUMEN. *Cryphiops caementarius* es un camarón anfídromo nativo de relevancia ecológica y pesquera en cuencas hidrográficas del norte de Chile. Esta especie representa un componente importante de la identidad cultural de las comunidades de camaroneros que subsisten de ella, otorgando servicios ecosistémicos para el bienestar social. Actualmente, las poblaciones se encuentran altamente amenazadas, principalmente por la escasez hídrica y modificación de hábitat producto de la peor sequía de los últimos 10 años en la zona centro-norte de Chile y la consecuente sobreexplotación de los recursos hídricos para usos humanos. Si bien existen medidas de administración vigentes para la actividad extractiva de camarones, como talla mínima de extracción y veda biológica, esta actividad no es reconocida formalmente por la institucionalidad pesquera nacional, existiendo desconocimiento de aspectos básicos de su funcionamiento, como la cantidad de camaroneros asociados, estado actual de sus poblaciones y sectores históricos de pesca. En este contexto, el objetivo principal del presente estudio fue caracterizar en conjunto con las organizaciones de camaroneros de la cuenca del Río Choapa, el sistema socio-ecológico en cual subyace la pesquería de *C. caementarius*, durante el período 2019-2021, a través de: i) la recopilación del conocimiento tradicional de las organizaciones de camaroneros; ii) un seguimiento de la pesquería a través de registros recopilados por los camaroneros durante sus faenas de pesca y iii) la construcción de un modelo conceptual basado en la percepción de los actores del sistema relacionados con la actividad camaronera local. A partir de estos resultados, se presentan recomendaciones para la implementación de plan(es) de conservación y manejo que apoye(n) la sostenibilidad de la pesquería de *C. caementarius* en la cuenca del Río Choapa. Se discute una probable extinción local de sus poblaciones en la zona altitudinal alta de la cuenca y en ríos tributarios, y una posible conducta migratoria facultativa por la severa fragmentación y degradación del hábitat fluvial. Se concluye, que es necesario diseñar y desarrollar en conjunto con los actores sociales, acciones de conservación y manejo orientadas a apoyar la toma de decisiones locales y otorgar mayor resiliencia a la especie y a la pesquería en un contexto de gran vulnerabilidad ambiental dado el actual escenario de escasez hídrica que afecta a esta cuenca y a otras del norte de Chile.

Palabras clave: Anfidromía, crustáceos dulceacuícolas, fragmentación de hábitat, pesquería de camarones, sequía.

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Prawns, prawn fishers and water scarcity: challenges for fishery sustainability of *Cryphiops caementarius* in the Choapa river basin, Chile (2019-2021)

ABSTRACT. *Cryphiops caementarius* is a native amphidromous prawn of ecological and fishing relevance in hydrographic basins of northern Chile. This species represents an important component of the cultural identity for prawn fishers' communities that subsist from it, providing ecosystem services for social wellbeing. Currently, these populations are highly threatened, mainly due to water scarcity and habitat modification as a result of the worst drought seen in the last 10 years in the north-central zone of Chile and the consequent overexploitation of water resources for human uses. Although there are management measures in force for the extractive activity of prawn, such as minimum extraction size and biological closure, this activity is not formally recognized by the national fishing institutions, being a lack of knowledge of basic aspects of its operation, such as the number of associated prawns, the current status of their populations and their historical fishing sectors. In this context, the main objective of the present study was to characterize, together with the fishers' organizations of the Choapa river basin, the socio-ecological system in which the *C. caementarius* fishery underlies, during the 2019-2021 period throughout: i) the compilation of the traditional knowledge of prawn fishers' organizations; ii) the tracking of the fishery through the records compiled by the fishers during fishing activities; and iii) the construction of a conceptual model based on the perception of the stakeholders related to the local prawn activity. From the results obtained, recommendations are presented for the implementation of conservation and management plan(s) that support the sustainability of the *C. caementarius* fishery in the Choapa river basin. A probable local extinction of its populations in the high-altitude zone of the basin and in tributary rivers is discussed, as well as a possible facultative migratory behavior due to the severe fragmentation and degradation of the fluvial habitat. It is then remarked the need to design and develop, together with stakeholders, further conservation and management actions aiming at supporting local decision-making and granting greater resilience to the species and fishery in a context of great environmental vulnerability, given the current scenario of water scarcity that affects this and other basins in northern Chile.

Key words: Amphidromy, freshwater crustacean, habitat fragmentation, prawn fisheries, drought.

INTRODUCCIÓN

El camarón de río del norte *Cryphiops caementarius* es una palaemónido endémico de las cuencas hidrográficas de la región Andina de Perú y norte de Chile. En Chile, su rango de distribución geográfica abarca desde la cuenca del Río Lluta (~ 18° S) hasta la cuenca del Río Aconcagua (~ 33° S) (Velásquez et al. 2020) (Figura 1 A). En estas cuencas, el rango de distribución altitudinal de sus poblaciones está determinada por las condiciones biofísicas del ambiente fluvial (régimen hidrológico, diversidad de hábitats bentónicos, presencia de meandros y canales), el grado de intervención antrópica del cauce (alteración de la dinámica hidrológica, presencia de barreras físicas), y la segregación espacial de los estadios ontogénicos (larvas, juveniles y adultos) en las diferentes zonas limnéticas del sistema (hábitat estuarino: desembocadura; hábitat fluvial: potamon y ritron) (Velásquez et al. 2022a). Esta segregación espacial refleja la conducta migratoria anfídroma de la especie, donde las hembras ovígeras migran río abajo durante la época de primavera y verano, desde los hábitats fluviales hacia el hábitat estuarino, para que ocurra la eclosión de los huevos, desarrollo larval y el posterior retorno de los juveniles río arriba para completar su ciclo de vida e incorporarse a la fracción adulta (Bauer 2013).

En gran parte de su rango de distribución en el norte de Chile, *C. caementarius* se encuentra sometido a una fuerte presión extractiva con fines comerciales, especialmente en las cuencas de los ríos Lluta, Quebrada Camarones, Huasco, Limarí y Choapa (Bahamonde y Vila 1971; Morales y Meruane 2013a; Velásquez et al. 2022a) (Figura 1 B), donde a la fecha no existe un manejo y regulación efectiva para esta actividad. La extracción se desarrolla en hábitats altamente fragmentados con permanentes períodos de sequía, producto de la alteración del régimen de las precipitaciones derivadas del cambio climático (Garreaud et al. 2020), sobre-explotación de los recursos hídricos (Nicolas-Artero 2021) y permanentes conflictos socio-ambientales con la industria minera y agrícola (Carranza et al. 2020), constituyendo una severa amenaza para la viabilidad de las poblaciones de *C. caementarius*, ocasionando en algunos casos mortandades masivas como las reportadas en las cuencas de los ríos Copiapó, Huasco y Choapa durante 2014, 2018, 2020 y 2021 (Figura

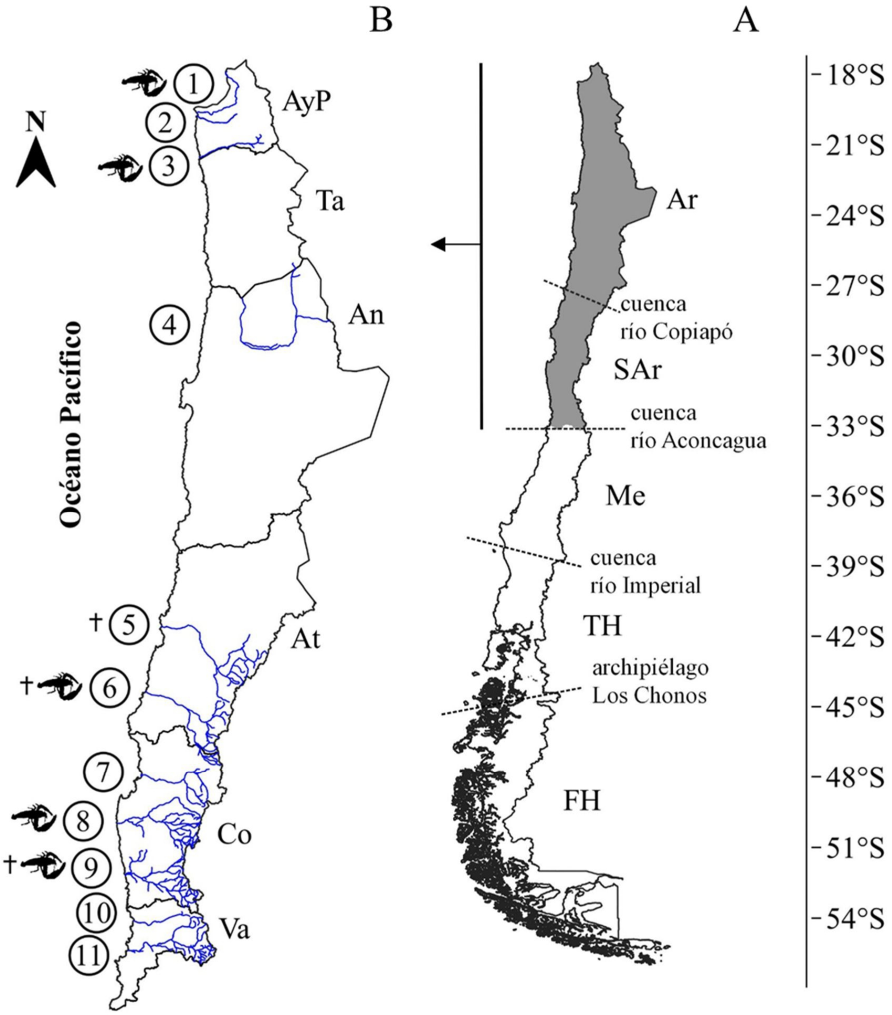

Figura 1. Sinopsis biogeográfica de *Cryphiops caementarius* en Chile Continental (*sensu* Bahamonde y López 1963; Bahamonde y Vila 1971; Bahamonde et al. 1998; Jara et al. 2006; Dennenmoser et al. 2010; Morales y Meruane 2013a; Velásquez et al. 2020). A) Rango de distribución geográfica en el norte de Chile (área gris). Regiones climáticas e hidrográficas de Chile (Niemeyer y Cereceda 1985; Romero 1985). Ar: árido, SAr: semiárido, Me: Mediterráneo, TH: templado húmedo, FH: frío húmedo. B) Cuencas que albergan las principales poblaciones. 1: Río Lluta, 2: Quebrada Azapa, 3: Quebrada Camarones, 4: Río Loa, 5: Río Copiapó, 6: Río Huasco, 7: Río Elqui y estero El Culebrón, 8: Río Limarí, 9: Río Choapa, 10: Río La Ligua, 11: Río Aconcagua. Regiones administrativas. AyP: Arica y Parinacota, Ta: Tarapacá, An: Antofagasta, At: Atacama, Co: Coquimbo, Va: Valparaíso. Siluetas de camarón: pesquería. Cruces: registros de mortandades por escasez hídrica (*sensu* Velásquez et al. 2022b).

Figure 1. Biogeographic synopsis of Cryphiops caementarius *in Continental Chile (sensu Bahamonde and López 1963; Bahamonde and Vila 1971; Bahamonde et al. 1998; Jara et al. 2006; Dennenmoser et al. 2010; Morales and Meruane 2013a; Velásquez et al. 2020). A) Geographic distribution range in northern Chile (gray outline). Climatic and hydrographic regions of Chile (Niemeyer and Cereceda 1985; Romero 1985). Ar: Arid, SAr: semiarid, Me: Mediterranean, TH: temperate wet, FH: cold wet. B) Basins that host the main populations. 1: Lluta river, 2: Quebrada Azapa, 3: Quebrada Camarones, 4: Loa river, 5: Copiapó river, 6: Huasco river, 7: Elqui river and El Culebrón stream, 8: Limarí river, 9: Choapa river, 10: La Ligua river, 11: Aconcagua river. Administrative regions. AyP: Arica and Parinacota, Ta: Tarapacá, An: Antofagasta, At: Atacama, Co: Coquimbo, Va: Valparaíso. Prawn's outline: fishery. Crosses: records of mortality due to water scarcity (sensu Velásquez et al. 2022b).*

1 B) (Velásquez et al. 2022b). Desde 2013, el Ministerio de Medio Ambiente de Chile (MMA) clasifica a *C. caementarius* en la categoría de Vulnerable (VU), lo que significa que es una especie amenazada con una alta probabilidad de extinción en estado silvestre dentro de los próximos 100 años.

Actualmente, la pesquería de *C. caementarius* es de libre acceso, pero no está incluida en la nómina de pesquerías artesanales de acuerdo a los términos legales de la Ley General de Pesca y Acuicultura de Chile (LGPA). Por otra parte, su extracción es regulada mediante el D.S. Nº 145 de 1986, el cual ajustó el período de veda desde el 1 de diciembre hasta el 30 de abril, período en el cual se prohíbe su extracción, tenencia, posesión, industrialización, comercialización y transporte. Respecto a la talla mínima de extracción (TME), ésta corresponde a 30 mm de longitud cefalotorácica (LC) tomada desde la órbita ocular derecha hasta el extremo posterior del cefalotórax. También quedan vedadas indefinidamente las hembras ovígeras, las cuales deben ser devueltas al agua, aunque tengan la TME. Respecto a las artes de pesca, se permite la caña, atarraya y la captura manual. Para los efectos de control de la TME, esta especie debe transportarse y comercializarse entera, lo cual se debe acreditar mediante una guía de libre tránsito otorgada por el Servicio Nacional de Pesca y Acuicultura de Chile (SERNAPESCA). De esta forma, si bien esta especie cuenta con medidas de administración vigente, la Subsecretaría de Pesca y Acuicultura de Chile (SUBPESCA) no reconoce formalmente la actividad extractiva como pesquería (Res. Ex. 3115) ni a sus usuarios como actores del sistema pesquero de Chile.

El problema principal que enfrenta *C. caementarius* en las cuencas chilenas es que presenta una explotación pesquera escasamente regulada y un alto riesgo de conservación, cuyo conjunto de problemas incluye: (1) no reconocimiento legal de esta pesquería; (2) condición de pesquería de libre acceso; (3) bajo conocimiento del estado poblacional y de explotación del recurso con un estado de conservación vulnerable; (4) escasa fiscalización para controlar el cumplimiento de la normativa vigente; (5) falta de coordinación inter-institucional entre los actores del sistema que intervienen en las cuencas; (6) desconocimiento e incumplimiento de la normativa vigente; (7) falta de registro y estadísticas oficiales de extracción de esta pesquería; (8) fragmentación y degradación del hábitat fluvial y (9) presencia de especies exóticas invasoras (Velásquez et al. 2022a). En parte, estos aspectos son considerados en las recomendaciones emitidas por la Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO) al Estado Chileno en relación con la elaboración de una legislación específica para regular pesquerías continentales (al cual pertenece *C. caementarius*) en el marco de la LGPA, tomando en cuenta la Declaración de Roma sobre Pesca Continental responsable (FAO 2016).

En Chile, son escasas las organizaciones formalizadas de camaroneros, y las que cumplen esta condición están concentradas principalmente en la región semiárida del país (Figura 1 A y B) (Morales y Meruane 2013a), siendo la cuenca del Río Choapa una de las más representativas por su dimensión de usuarios y trayectoria en experiencias de manejo de camarones (Cárcamo et al. 2021; Velásquez et al. 2022a). En este contexto, el objetivo principal del presente estudio fue caracterizar, en conjunto con las organizaciones de camaroneros de la cuenca del Río Choapa, el sistema socio-ecológico en cual subyace la pesquería de *C. caementarius* durante el período 2019-2021 a través de: i) la recopilación del conocimiento tradicional de las organizaciones de camaroneros, sobre aspectos poblacionales y pesqueros de *C. caementarius*; ii) un seguimiento de la pesquería de *C. caementarius* a través de registros recopilados por los camaroneros durante sus faenas de pesca y iii) la construcción de un modelo conceptual basado en la percepción de los actores del sistema relacionados con la actividad camaronera local.

A partir de estos resultados se presentan recomendaciones para la implementación de plan(es) de conservación y manejo que apoye(n) la sostenibilidad de la pesquería de *C. caementarius* en la cuenca del Río Choapa, considerando que esta especie otorga servicios ecosistémicos de provisión económica y gastronómica a través de su pesquería, soporte ecológico por sus patrones migratorios y posición intermedia en la trama trófica fluvial, y valoración biocultural como componente de la identidad patrimonial de las comunidades del norte de Chile (IFOP 2022).

MATERIALES Y MÉTODOS

Condición hídrica y actividad camaronera en el área de estudio

La cuenca del Río Choapa se localiza en la región de Coquimbo, norte semiárido de Chile (Figura 1 A y B) y está fuertemente influenciada por sequías prolongadas durante verano y otoño, y un período de precipitaciones concentrada en invierno (Niemeyer y Cereceda 1985; Romero 1985). El contraste de estos hidroperíodos genera una alta variabilidad de los caudales medios mensuales, como los registrados durante 2019 en donde se registró una mínima de 0,10 $m^3 s^{-1}$ en enero (verano), y una máxima de 1,55 $m^3 s^{-1}$ en junio (invierno); mientras que en 2020 los caudales fluctuaron con una mínima de 0,01 $m^3 s^{-1}$ en diciembre (verano) y una máxima de 1,18 $m^3 s^{-1}$ en julio (invierno) (DGA 2022).

La cuenca del Río Choapa enfrenta una megasequía que se ha prolongado desde el año 2010 en gran parte de la zona centro-norte de Chile (Garreaud et al. 2020), y que ha generado continuos problemas para asegurar el suministro hídrico para consumo humano y actividades agrícolas. Por este motivo, el Ministerio de Obras Públicas de Chile (MOP) decretó a esta cuenca como zona de escasez hídrica (DGA 2022). Este decreto permite al MOP entregar soluciones para mitigar en el corto plazo los daños derivados de la megasequía a través de intervenciones físicas de cuerpos naturales de agua, como canalizaciones y extracción de aguas. No obstante, la ejecución de estas obras representa un riesgo permanente para la biota acuática nativa de la cuenca, ya que ha generado mortandades de especímenes de *C. caementarius* y pejerreyes (*Basilichthys microlepidotus*) durante 2014, 2020 y 2021 (Figura 1 B) (Velásquez et al. 2022b).

En esta cuenca, los camaroneros están agrupados en dos organizaciones centralizadas, la Asociación Gremial de Productores y Extractores de Recursos Dulceacuícolas del Choapa A.G (25 socios; 5 mujeres y 20 hombres), y el Sindicato de Trabajadores Independientes Camaroneros del Choapa (37 socios; 6 mujeres y 31 hombres). Ambas están conformadas por socios provenientes de la comuna de Illapel y las localidades de Tunga, Doña Juana, Choapa Viejo y Limahuida (Figura 2), y cuyo rango etario varía entre 29 y 81 años de edad.

Distribución altitudinal de *Cryphiops caementarius*

Durante las épocas de verano e invierno de 2019, se realizaron muestreos en conjunto con las organizaciones de camaroneros para conocer el rango de distribución altitudinal (metros sobre el nivel medio del mar; m s. n. m.) de *C. caementarius* en la cuenca del Río Choapa. Se realizaron prospecciones exploratorias en los principales cursos fluviales de la cuenca cercanas a la naciente en la precordillera de Los Andes (~ 1.000 m s. n. m.) hasta el afluente en el Océano Pacífico (Sitio Ramsar Salinas de Huentelauquén), recorriendo específicamente desde los ríos Illapel y Choapa, pasando por los esteros Camisas y Canela, hasta la desembocadura del Río Choapa (Figura 2). Simultáneamente, se recorrieron áreas aledañas a las principales presiones antropogénicas locales de la cuenca, como zonas urbanas (comu-

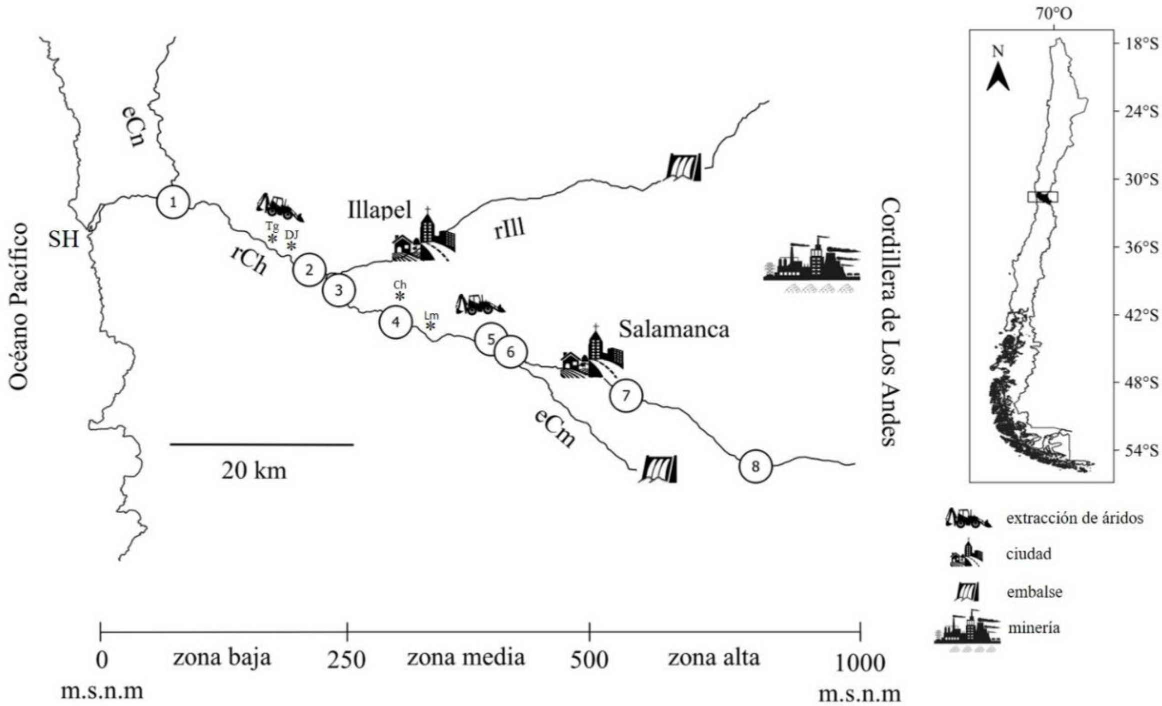

Figura 2. Estratificación altitudinal de los cursos fluviales prospectados y sitios de estudio para la distribución espacial de *Cryphiops caementarius* en la cuenca del Río Choapa. Cursos fluviales. rIll: Río Illapel, rCh: Río Choapa, eCm: estero Camisas, eCn: estero Canela, SH: Sitio Ramsar Salinas de Huentelauquén. Los sitios (1 al 8) corresponden a los lugares de muestreos de presencia/ausencia. Los asteriscos indican las localidades de procedencia de los camaroneros. Tg: Tunga, DJ: Doña Juana, Ch: Choapa Viejo, Lm: Limahuida.

Figure 2. Altitudinal stratification of surveyed fluvial courses and study sites for the spatial distribution of the Cryphiops caementarius *in the Choapa river basin. Fluvial courses. rIll: Illapel river, rCh: Choapa river, eCm: Camisas stream, eCn: Canela stream, SH: Ramsar Site Salinas de Huentelauquén. The sites (1 to 8) correspond to the presence/absence sampling places. Asterisks indicate origin localities of the prawn fishers. Tg: Tunga, DJ : Doña Juana, Ch: Choapa Viejo, Lm: Limahuida.*

nas de Illapel y Salamanca), sitios de extracción permanente de áridos, embalses de aguas (El Bato en el Río Illapel; Corrales en el estero Camisas) y actividad minera a gran escala (Figura 2). Esta prospección permitió definir los sitios de muestreo para determinar la ocurrencia espacial y temporal de *C. caementarius* en la cuenca del Río Choapa. Para esto, se realizaron muestreos estacionales (verano y otoño 2019) de presencia/ausencia en 8 sitios estratificados altitudinalmente en tres zonas de la cuenca: baja (~ 0-250 m s. n. m.; sitios 1, 2, 3), media (~ 250-500 m s. n. m.; sitios 4, 5, 6) y alta (~ 500-1.000 m s. n. m.; sitios 7, 8) (Figura 2).

Conocimiento tradicional de las organizaciones de camaroneros

El conocimiento tradicional de los camaroneros de la cuenca del Río Choapa se recopiló a través de la aplicación de entrevistas semiestructuradas a cuatro grupos de informantes calificados (N total = 17) durante marzo de 2019 (Figura 3 A y B). Se consideraron informantes calificados a los camaroneros que tenían una experiencia de al menos diez años en la actividad. El grupo etario de los entrevistados varió entre 29 y 65 años e incluyó a 6 mujeres (35,3%) y 11 hombres (64,7%), quienes respondieron las siguientes pre-

Figura 3. Conocimiento tradicional de las organizaciones de camaroneros. A y B) Aplicación de entrevistas semi-estructuradas. Extracción de camarones por parte de camaroneros. C) Captura nocturna a través de buceo o “garceo”. D) Captura diurna a través de recolección dirigida. E) Ejemplares capturados de talla comercial. F) Ejemplares congelados para comercialización.

Figure 3. Traditional knowledge prawn fishers' organizations. A and B) semistructured interviews. Prawn extractions by the prawn fishers. C) Nocturnal capture through diving or 'garceo'. D) Diurnal capture through directed recollection. E) Specimens captured of commercial size. F) Frozen specimens for commercialization.

guntas relacionadas a los aspectos poblacionales y pesqueros de *C. caementarius* en la cuenca del Río Choapa: i) ¿Cuáles son las zonas y épocas del año donde se ha registrado la mayor presencia de camarones juveniles y adultos? ii) ¿Qué factores naturales y/o antrópicos cree usted han afectado, positiva o negativamente la supervivencia y/o accesibilidad que tiene los camarones ante la pesquería? y iii) ¿Qué sabe usted sobre la migración de los camarones en el río? Las respuestas de los informantes fueron indicadas según la representatividad y consenso grupal del discurso.

Registro pesquero

Durante el período 2019-2021, se realizó un seguimiento de la pesquería de *C. caementarius* en la cuenca del Río Choapa, en conjunto con las organizaciones de camaroneros. Estos registros se realizaron a través de información recopilada por los camaroneros durante sus faenas habituales de pesca (buceo “garceo” nocturno y/o recolección diurna dirigida) en el río (Figura 3 C y D), donde se registraron: i) fecha de faena; ii) inicio y final del tramo fluvial recorrido (asignado con nombres de referencia, conocido por los camaroneros); iii) hora(s) de faena y iv) la cantidad total de individuos (ind.) y kilogramos (kg) de camarones capturados. A partir de esta información, se determinó: i) la cantidad de usuarios camaroneros que extraen el recurso; ii) las temporadas de pesca (estaciones del año); iii) los sectores de pesca a lo largo de la cuenca y iv) la captura por unidad de esfuerzo (CPUE; ind. h^{-1} y kg h^{-1} de camarones capturados por camaronero) como indicador directo del esfuerzo pesquero e indirecto de la abundancia de camarones.

La clasificación de los sectores de pesca se realizó acorde a la concurrencia de los camaroneros a los tramos fluviales recorridos durante sus faenas. Una vez identificados, se calcularon los promedios de CPUE (ind. h^{-1}; kg h^{-1}) para cada sector y se georreferenciaron para su representación espacial en mapas cartográficos temáticos. Esta representación se realizó a través de un modelo de elevación digital mediante la extensión hidrografía del programa QGIS.

Modelo conceptual basado en la percepción de actores sociales

Para representar la red de actividades humanas y presiones, y cómo éstas impactan a *C. caementarius* en la cuenca del Río Choapa, desde la percepción de actores claves se desarrolló un modelo conceptual basado en el marco “Driver-Pressure-State-Impact-Response” (DPSIR; Causa o Fuerza Motriz-Presión-Estado-Impacto-Respuesta) (EEA 1999). Este marco de evaluación ambiental describe un enfoque para evaluar las causas, consecuencias y respuestas al cambio de manera holística y sistémica, y ha sido utilizado en estudios de problemáticas ambientales, incluyendo manejo costero y pesquero (Atkins et al. 2011; Martins et al. 2012). Para la identificación de características claves (componentes y relaciones) en cada uno de los cinco componentes/módulos del modelo DPSIR, se utilizaron dos fuentes de información: i) revisión de literatura disponible y ii) entrevista a informantes claves y expertos regionales.

Se emplearon preguntas del tipo abiertas que sirvieron de guion de la entrevista para identificar los componentes (Tabla 1). Diez entrevistas se aplicaron durante los meses de mayo a agosto de 2019, incluyendo a informantes que representaron a tres usuarios directos de la cuenca (camaroneros), dos investigadores que han trabajando en la zona, y cinco servicios públicos con injerencia en el manejo y fiscalización de la cuenca. Una vez identificados y caracterizados los componentes, un modelo conceptual basado en DPSIR fue construido usando el software IHMC Cmap Tools (Cañas et al. 2004).

RESULTADOS

Distribución altitudinal de *Cryphiops caementarius*

El rango de distribución altitudinal de *C. caementarius* se extiende desde Las Salinas de Huentelauquén en la desembocadura del Río Choapa, hasta el sector de Tahuinco (~ 402 m s. n. m.) en la zona media de la cuenca, a través de ~ 40 km de eje fluvial. En cuanto a los muestreos de presencia/ausencia, éstos indicaron que los especímenes fueron registrados durante verano y otoño 2019 en las zonas bajas (sitios 1, 2, 3) y media del Río Choapa (sitios 4, 5, 6) (Figura 2).

Tabla 1. Preguntas guías para identificar y caracterizar los diversos componentes del Marco DPSIR aplicado a *Cryphiops caementarius* en la cuenca del Río Choapa.
Table 1. Guiding questions to identify and characterize the various components of the DPSIR Framework applied to Cryphiops caementarius *in the Choapa river basin.*

Componente	Preguntas guía
Impactos (I)	¿Qué cambios (impactos) usted conoce o ha percibido en la calidad de la pesca del camarón y en la calidad ambiental del lugar del río donde se ejecuta la actividad? ¿Qué impactos identifica en la situación socio-económica del sector camaronero del Río Choapa? ¿Los impactos identificados los califica como negativos o positivos?
Estados (S)	¿Cómo es el estado del lugar donde se ejecuta la pesca del camarón o el lugar donde viven los camarones?
Presiones (P)	¿Cuáles son las causas inmediatas (presiones) que usted identifica como explicativas para esta situación o estado? ¿En qué lugar (geográfico) usted las identifica u ocurren?
Fuerzas motrices (D)	¿Cuáles son las actividades humanas o eventos (condiciones) naturales que causan esas presiones? ¿En qué lugar (geográfico) usted las identifica u ocurren?
Respuestas (R)	¿Sabe si se han implementado acciones o medidas de manejo, mitigación, compensación u otra para disminuir, corregir los impactos? ¿Han tenido efectos? ¿Qué acciones o medidas adicionales implementaría usted? ¿Quién debería implementar estas acciones o medidas?

Conocimiento tradicional de las organizaciones de camaroneros

Las entrevistas grupales arrojaron los siguientes resultados: i) los camarones de menor tamaño (juveniles) ocurren principalmente en la época de otoño e invierno en la zona baja de la cuenca, mientras que los camarones de mayor tamaño (machos adultos) ocurren en la época de verano principalmente en la zona media de la cuenca; ii) la abundancia de *C. caementarius* y su pesquería se ha visto afectada por la permanente sequía que enfrenta la cuenca, la extracción permanente de áridos, las intervenciones físicas del cauce fluvial, la contaminación química de las aguas por actividades mineras y agrícolas, la presencia de embalses de agua, y el cierre perimetral de propiedades privadas de uso agrícola colindantes con el cauce del río, lo que dificulta o imposibilita el acceso a sectores históricos de extracción del recurso que hace ~ 30 años atrás se extendía hasta la zona alta de la cuenca. Ellos indican que estas perturbaciones son las causantes de la desaparición de sus poblaciones en la zona alta de la cuenca y iii) los camaroneros indican que esta especie no necesariamente debe llegar a la desembocadura del Río Choapa (Salinas de Huentelauquén) para completar su ciclo de vida, ya que afirman que desovan en diferentes áreas y/o sectores a lo largo de la cuenca, según las condiciones hídricas y ambientales locales.

Registro pesquero

Se registró un total de 578 faenas de pesca realizadas por 33 camaroneros en 8 sectores de pesca distribuidos altitudinalmente en la zona baja (5 sectores) y media (3 sectores) de la cuenca del Río Choapa, específicamente desde ~ 36 hasta 402 m s. n. m. (Figura 4). Las faenas se realizaron en las épocas de otoño (12 faenas; 01 de mayo-19 de junio 2019), invierno (128 faenas; 22 de junio-

Figura 4. Sectores de pesca de *Cryphiops caementarius* en la cuenca del Río Choapa. Zona baja: 1: Mincha, 2: Tunga, 3: Doña Juana, 4: Coyuntagua, 5: Puente Negro. Zona media: 6: Choapa, 7: Limahuida, 8: Los Loros.
Figure 4. Fishing sectors of Cryphiops caementarius *in the Choapa river basin. Lower zone: 1: Mincha, 2: Tunga, 3: Doña Juana, 4: Coyuntagua, 5: Puente Negro. Middle zone: 6: Choapa, 7: Limahuida, 8: Los Loros.*

20 de septiembre 2019), primavera (421 faenas; 22 de septiembre-29 de noviembre 2019/contingencia sanitaria COVID-19/1-21 de diciembre de 2020), y verano (17 faenas; 22 de diciembre de 2020-28 de enero de 2021).

Los sectores con mayor cantidad de faenas de pesca fueron Tunga (sector 2; 105 faenas) y Puente Negro (sector 5; 151 faenas) en la zona baja de la cuenca, mientras que los sectores con menor faenas fueron Los Loros (sector 8; 26 faenas) y

Limahuida (sector 7; 15 faenas) en la zona media de la cuenca (Tabla 2). El promedio total de horas efectivas de faena fue de 3,01 ± 0,52 h, con un valor máximo de 3,92 ± 1,48 h en Los Loros (sector 8) y un valor mínimo de 2,44 ± 0,79 h en Limahuida (sector 7) (Tabla 2). La cantidad promedio de camarones capturados fluctuó entre 71,69 ± 21,39 ind en Mincha (sector 1) y 22,06 ± 28,92 ind. en Coyuntagua (sector 4) (Tabla 2), con un promedio total de 44,63 ± 17,11 ind. El peso promedio de la captura fluctuó entre 2,44 ± 1,28 kg en Los Loros (sector 8) y 0,97 ± 1,28 kg en Coyuntagua (sector 4), con un promedio total de 1,81 ± 0,57 kg (Tabla 2).

La CPUE (ind. h^{-1}) fluctuó entre 22,24 ind. h^{-1} en Mincha (sector 1) y 8,37 ind. h^{-1} en Coyuntagua (sector 4), con un promedio total de 16,67 ind. h^{-1} (Tabla 2; Figura 5). Por otra parte, la CPUE (kg h^{-1}) fluctuó entre 0,73 kg h^{-1} en Choapa (sector 6) y Limahuida (sector 7) 0,37 kg h^{-1} en Coyuntagua (sector 4), con un promedio total de 0,59 kg h^{-1} (Tabla 2; Figura 5).

Modelo conceptual basado en la percepción de actores sociales

El modelo conceptual construido en base a entrevistas a actores claves relaciona los flujos de los distintos componentes del modelo DPSIR para *C. caementarius* en la cuenca del Río Choapa (Figura 6). Respecto a los Impactos (I), existió coincidencia en cuanto a una percepción negativa en la evolución temporal del recurso y su pesquería. Dentro de los principales impactos identificados por los actores se encuentran: la sobreexplotación, disminución de la calidad del producto y tamaños, baja abundancia de juveniles, y mortalidad por eventos de contaminación. Si bien, la ocurrencia de estos impactos se identifica desde hace más de 20 años, se percibe una mayor intensidad en los últimos 10 años. A su vez estos impactos sobre el recurso generan impactos socioeconómicos, como por ejemplo, conflictos entre usuarios y entre camaroneros organizados y no organizados, malas prácticas extractivas

Tabla 2. Registro pesquero de *Cryphiops caementarius* en la cuenca del Río Choapa. Para cada sector se indica: cantidad de viajes realizados por camaroneros (v), promedio de horas de viajes (h), promedio de cantidad de camarones capturados (ind.), promedio de kilogramos camarones capturados (kg), captura por unidad de esfuerzo (CPUE; ind. h^{-1} y kg h^{-1}).

Table 2. Fishing record of Cryphiops caementarius *in the Choapa river basin. For each sector, the following is indicated: number of travels made by fishers (v), mean of travel time (h), mean number of captured prawns (ind.), mean kilograms of captured prawns (kg), catch per unit of effort (CPUE; ind. h^{-1} and kg h^{-1}).*

Sector de pesca	v	h	Ind.	kg	Ind. h^{-1}	kg h^{-1}
Zona baja						
Mincha (1)	29	3,22 ± 0,83	71,69 ± 21,39	2,18 ± 0,69	22,24	0,68
Tunga (2)	105	2,79 ± 0,78	46,92 ± 36,67	1,53 ± 1,20	16,84	0,55
Doña Juana (3)	89	2,47 ± 0,89	34,06 ± 37,25	1,09 ± 1,17	13,76	0,44
Coyuntagua (4)	90	2,63 ± 1,18	22,06 ± 28,92	0,97 ± 1,28	8,37	0,37
Puente Negro (5)	151	3,34 ± 0,89	59,93 ± 31,06	2,15 ± 0,96	17,93	0,64
Zona media						
Choapa (6)	73	3,30 ± 1,07	52,5 ± 47,61	2,39 ± 1,28	32,54	0,73
Limahuida (7)	15	2,44 ± 0,79	24,80 ± 22,04	1,77 ± 1,39	10,17	0,73
Los Loros (8)	26	3,92 ± 1,48	45,08 ± 30,31	2,44 ± 1,28	11,51	0,62

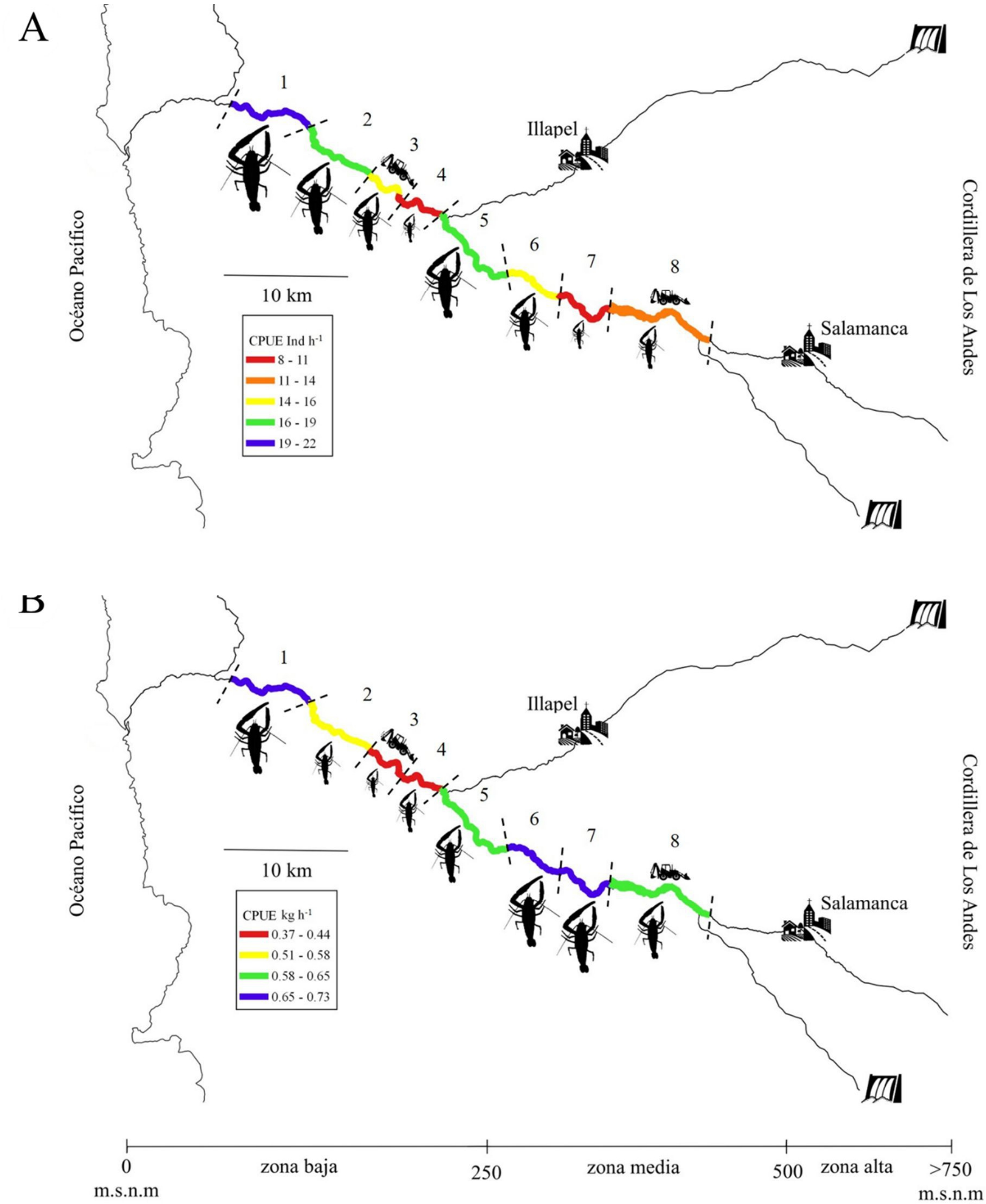

Figura 5. Zonificación espacial de los sectores de pesca de *Cryphiops caementarius* en la cuenca del Río Choapa. A) Captura por unidad de esfuerzo (CPUE) ind. h^{-1}. B) CPUE kg h^{-1}. Tamaño de las siluetas de camarones son proporcionales a la magnitud de capturas. Ver sectores en Figura 4.

Figure 5. Spatial zoning of the Cryphiops caementarius *fishing sectors in the Choapa river basin. A) Catch per unit effort (CPUE) ind. h^{-1}. B) CPUE kg h^{-1}. Size of the prawn outline are proportional to the captured magnitude. See sectors in Figure 4.*

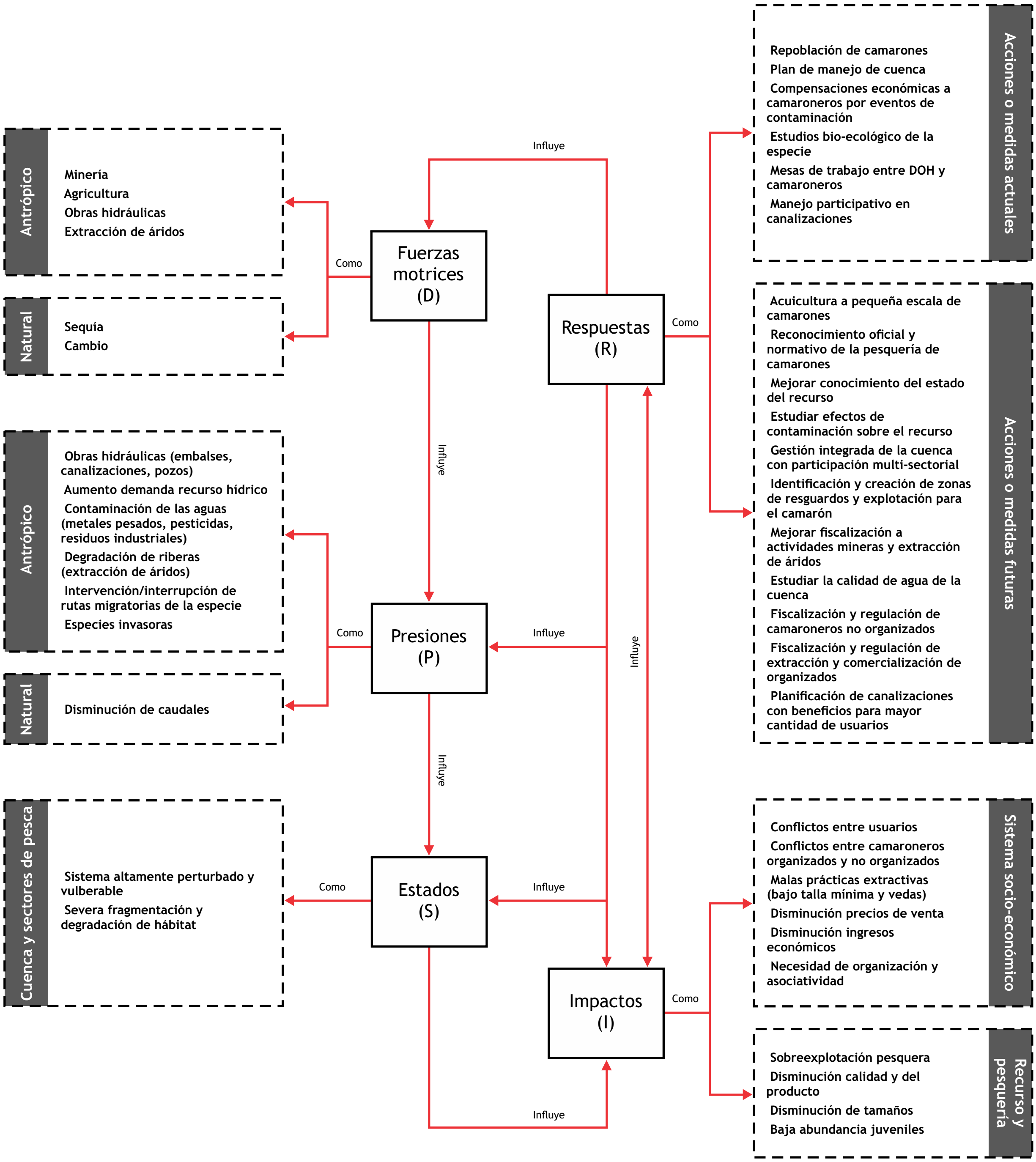

Figura 6. Modelo y flujo de los componentes DPSIR (Causa o Fuerza Motriz-Presión-Estado-Impacto-Respuesta) para *Cryphiops caementarius* en la cuenca del Río Choapa.

Figure 6. Model and flow of DPSIR (Driver-Pressure-State-Impact-Response) components for Cryphiops caementarius *in the Choapa river basin.*

(incumplimiento de TME y veda), y disminución de precios de venta e ingresos económicos de camaroneros organizados.

Respecto a la percepción del Estado Ambiental (S) de la cuenca y sectores de extracción, se reconoce como un sistema altamente perturbado y vulnerable, además de presentar una severa fragmentación y degradación del hábitat fluvial de *C. caementarius*, producto principalmente de alteraciones en el caudal hídrico por la disminución en el régimen de precipitaciones y perturbaciones antropogénicas sobre el cauce fluvial. Los camaroneros señalan la existencia de eventos de vertimiento y presencia de elementos contaminantes como metales pesados y pesticidas.

Dentro de las Presiones (P) de origen antrópico, indicadas como causas del estado ambiental del río, se identificaron de manera coincidente por los diversos actores: obras hidráulicas (embalses, canalizaciones, y pozos), aumento de la demanda del recurso hídrico, vertimiento de contaminantes (residuos industriales líquidos, metales pesados, pesticidas), degradación de riberas por movimiento de áridos, intervención/interrupción de rutas migratorias de *C. caementarius* y presencia de especies invasoras. Estas presiones son identificadas principalmente en las zonas media y alta de la cuenca. Dentro de las presiones de origen natural, se identificaron para toda la cuenca la disminución y alteración drástica en la dinámica hidrológica (caudales y nivel de agua). Las actividades humanas identificadas como las principales Fuerzas Motrices (D), causantes de estas presiones sobre las zonas media y alta de la cuenca fueron: minería, agricultura, desarrollo de obras hidráulicas, extracción de áridos, y la sobreexplotación o extracción no regulada de *C. caementarius*. Las fuerzas motrices identificadas como naturales de origen regional y global fueron la sequía y el cambio climático, respectivamente.

Entre las acciones o medidas de manejo, mitigación, y compensación para disminuir o corregir los impactos identificados (Respuestas, R) reconocidas como ya implementadas, se encuentran: repoblación de *C. caementarius* a escala experimental, planes de gestión hídrica, compensaciones económicas a camaroneros por eventos de contaminación, estudios biológicos, mesas de trabajo, obras de canalizaciones y multas por uso indebido del agua.

En cuanto a las acciones o medidas de manejo identificadas como adicionales o a implementar en el futuro, se encuentran: manejo de *C. caementarius* mediante acuicultura de pequeña escala, reconocimiento oficial y normativo de la pesquería, mejoramiento del conocimiento bio-ecológico y efectos de la contaminación sobre *C. caementarius*, gestión integrada de la cuenca, identificación y creación de zonas de resguardo y explotación, mejoramiento de la fiscalización a mineras y zonas de extracción de áridos, implementación de monitoreo de calidad del agua, fiscalización y regulación de camaroneros no organizados y de la extracción y comercialización, y planificación de canalizaciones con beneficios para mayor cantidad de usuarios de la cuenca.

DISCUSIÓN

Históricamente, el fomento y marco regulatorio de las pesquerías chilenas ha estado orientado hacia el territorio marítimo y costero (Castilla 2010), relegando las pesquerías de especies nativas de aguas continentales a un nivel secundario, muy poco estudiado y regulado (FAO 2016). Esta carencia de estudios pesqueros y ecológicos básicos dificultan la toma de decisión respecto a la conservación y pesquerías de pequeña escala como la de *C. caementarius*. Este tipo de pesquerías son claves para la alimentación local y mundial, proporcionando, además, numerosos medios de vida en países en vía de desarrollo (Short et al. 2021). En el caso de *C. caementarius*, su pesquería posee una fuerte componente socio-cultural que requieren ser incorporada en la planificación de su manejo en cuencas, por lo que el reconocimiento del saber tradicional y la percepción de los actores locales, sobre todo de comunidades rurales como los camaroneros, corresponde a un insumo de relevancia en el desarrollo participativo de enfoques de manejo y co-manejo de cuencas y pesquerías de pequeña escala, así como también, para avanzar en el reconocimiento formal y normativo de la pesquería de *C. caementarius* en Chile. Existen ejemplos de la incorporación de dichos conocimiento y percepciones para mejorar el conocimiento y el manejo efectivo de pesquerías de pequeña escala de aguas continentales de peces y crustáceos (Gebremedhin et al. 2018; Nunes et al. 2019; Silvano y Hallwass 2020). Sin embargo, procesos de transición desde actividades pesqueras tradicionales y no formales al desarrollo de un sector profesional y regulado puede encontrar obstáculos, como la pesca ilegal, sobreexplotación y conflictos sociales (Villasante et al. 2022), impactos que fueron identificados por los actores sociales asociados a la actividad camaronera del Choapa.

Los camaroneros de la cuenca del Río Choapa demostraron poseer un alto nivel de conocimiento respecto a la distribución, migración y sectores históricos de pesca de *C. caementarius*, particularmente de las características ambientales que favorecen y desfavorecen su presencia en distintas zonas y/o sectores a lo largo de la cuenca. Ellos indican que la sequía, junto con el mal manejo de las canalizaciones, son las causantes de la disminución de los caudales, lo que ha afectado fuertemente la abundancia del recurso y los rendimientos de los sectores históricos de extracción. Por otra parte, el modelo DPSIR mostró ser una herramienta útil como primera aproximación sistémica de la cuenca y la pesquería desde la percepción de los actores sociales asociados a la actividad camaronera. El análisis DPSIR permitió visualizar parte de las relaciones que se establecen entre los sistemas sociales y ecológicos asociados a *C. caementarius*, sin embargo, es probable que otras relaciones y vínculos más complejos no sean evidentes y/o requieran de profundizar en el desarrollo de investigación e indicadores semi o cuantitativos (Santos-Martín et al. 2013). A este respecto, como ejemplo se puede señalar la necesidad de establecer las causas de la ausencia de *C. caementarius* en la zona alta de la cuenca del Río Choapa y el potencial impacto de las canalizaciones y otro tipo de intervenciones sobre los patrones migratorios de la especie. Esta ausencia de *C. caementarius* en la zona alta del Río Choapa y los cursos fluviales del Río Illapel, esteros Canela y Camisas, indican una aparente extinción local de las poblaciones, que encontraría sustento en lo indicado por los camaroneros, quienes afirman que hasta la década de los 90's las poblaciones se distribuían en todos los cursos fluviales de la cuenca hasta ~ 1.000 m s. n. m. La restricción altitudinal de sus poblaciones hacia las zonas baja y media del Río Choapa sugiere probablemente poblaciones relictas, producto de la severa fragmentación de hábitat que afecta el área, derivada de la sequía, continuas perturbaciones físicas de los cauces fluviales y la presencia de los embalses El Bato en el Río Illapel y Corrales en el estero Camisas (Velásquez et al. 2022a, 2022b). Este tipo de amenazas incrementa la vulnerabilidad de las poblaciones locales debido a la interrupción de las rutas migratorias de hembras ovígeras (Velásquez et al. 2022b), situación que según los camaroneros, condiciona a las hembras a desovar en diferentes zonas y/o sectores a lo largo del sistema fluvial de la cuenca y no necesariamente requiere llegar a las condiciones estuarinas de la desembocadura (Salinas de Huentelauquén) para completar su ciclo de vida, como se describe tradicionalmente para esta especie (Bahamonde y Vila 1971; Rivera y Meruane 1994). Si bien esta conducta facultativa eventualmente le otorgaría resiliencia a la conservación de *C. caementarius*, se requiere conocer cuáles son los efectos en los procesos de crecimiento, mortalidad y reclutamiento de individuos que completan su ciclo de vida en hábitats fluviales.

Independiente de lo anterior, y acorde a lo indicado por los actores, para la conservación de *C.*

caementarius y su pesquería es necesario la implementación de medidas orientadas a mantener la calidad del hábitat fluvial y las rutas de migración que han sido alteradas por la escasez y demanda hídrica. Países como Nueva Zelanda, han promovido la inclusión de medidas y soluciones tecnológicas para mejorar la conectividad fluvial, facilitando las rutas migratorias de peces anfídromos (Franklin y Gee 2019). Por otra parte, Kikkert et al. (2009) y Verástegui et al. (2017) proponen diseños de corredores biológicos para mitigar los efectos del funcionamiento de las represas en Puerto Rico y Perú sobre las rutas migratorias de camarones anfídromos, entre los cuales se encuentra *C. caementarius*.

La pesquería de *C. caementarius* en el Río Choapa está concentrada en las zonas bajas y media de la cuenca hasta ~ 402 m s. n. m., y se realiza principalmente durante la época de primavera (72,83% de las faenas totales de pesca). En esta época, los caudales del Río Choapa empiezan a disminuir, las temperaturas de las aguas son más cálidas (Velásquez et al. 2022a) y las hembras de camarón empiezan su proceso migratorio río arriba para reproducirse con los machos (Bahamonde y Vila 1971; Rivera y Meruane 1994), propiciando las condiciones idóneas para la actividad camaronera local. El área de pesca coincide con el rango de distribución altitudinal de la especie, y está restringida río abajo de los embalses de la cuenca, similar a lo descrito para las cuencas de los ríos Huasco y Limarí, cuya pesquería se ejerce río abajo de los embalses Santa Juana y La Paloma, respectivamente (GESAM 1997).

Respecto a la cantidad total de camarones capturados, existe un patrón en relación al escalamiento altitudinal de la cuenca, ya que las mayores capturas se encuentran en la zona baja del Río Choapa, y a medida que ascienden hacia la zona media, éstas disminuyen. Por el contrario, se observó un patrón inverso en el peso total de los camarones capturados, el cual disminuye gradualmente desde la zona media hacia la zona baja de la cuenca, similar a lo descrito por Rivera y Meruane (1994) y UCN (2014) para la misma cuenca. Estos patrones altitudinales también fueron descritos para camarones capturados en las cuencas de los Ríos Huasco (Acuña et al. 2003) y Limarí (Rivera y Meruane 1994). Si bien no existen mayores registros previos para la cuenca del Río Choapa, los resultados obtenidos en este estudio pueden ser referidos a estudios poblaciones y pesqueros en las cuencas costeras del sur del Perú para la misma especie, cuya pesquería se ejerce hasta ~ 800 m s. n. m. y las CPUE (kg h^{-1}) mostraron valores promedio anuales de 2,36 kg h^{-1} en el Río Majes-Camaná y 4,31 kg h^{-1} en el Río Ocoña (Campos et al. 2017), magnitudes entre 4 y 7 veces más grandes que la registrada en el Río Choapa.

Durante los períodos de sequía, la demanda de aguas disponibles de la cuenca del Río Choapa se incrementa por los regantes del sector agrícola local, especialmente en las zonas altitudinales baja y media, que albergan los sectores de pesca utilizados por los camaroneros. Esta situación conduce a una evidente alteración de tramos fluviales, repercutiendo negativamente sobre la extracción del recurso (Velásquez et al. 2022a, 2022b). Si la megasequía se prolonga más tiempo, las áreas de habitabilidad y colonización de camarones podrían verse críticamente afectadas, más de lo que está actualmente. En este contexto, medidas que estén orientadas a la acuicultura de *C. caementarius* se identifica como una medida para complementar los medios de vida de los camaroneros, disminuir la presión de pesca y el aporte de juveniles para iniciativas de repoblación. En Chile, por más de 20 años se han realizado investigaciones para controlar el ciclo de vida en ambiente controlado de esta especie (Morales y Meruane 2013b), lo que ha permitido que en la actualidad la acuicultura de pequeña escala sea una alternativa productiva que ayude a potenciar economías locales y mitigar la sobreexplotación pesquera en zonas con escasez hídrica en el norte de Chile.

CONCLUSIONES

A partir del conocimiento científico y tradicional existente para *C. caementarius* y su sistema socio-ecológico en la cuenca del Río Choapa, se proponen las siguientes medidas generales orientadas a su conservación biológica y dar sostenibilidad a su pesquería:

1) Implementar una propuesta de ordenamiento de la pesquería de *C. caementarius* que incluya una modificación legal para incorporar la figura de "pesca de pequeña escala de aguas terrestres" en la LGPA. La implementación implicará una instancia inédita en cuanto a su aplicación en aguas continentales en Chile.
2) Crear una gobernanza asociada a la actividad camaronera, a través de la formalización de un comité o mesa multisectorial, integrada por las organizaciones de camaroneros y actores provenientes de la institucionalidad territorial, pesquera-acuícola, hídrica, ambiental, y académica con injerencia en la provincia del Choapa y región de Coquimbo, que permita informar, otorgar facilidades y articular instancias para el desarrollo de actividades orientadas a la conservación y manejo de la especie.
3) Integrar el conocimiento tradicional de las organizaciones de camaroneros con el conocimiento científico, para direccionar apropiadamente estrategias de conservación y manejo acorde al ciclo de vida y pesquería de *C. caementarius*, como la implementación de medidas de mitigación frente a amenazas naturales (megasequía) y antropogénicas (canalizaciones y sobrexplotación de recursos hídricos), y la evaluación de los patrones migratorios (paradigma de la migración anfídroma) de las poblaciones locales.
4) Determinar la(s) causa(s) de ausencia de *C. caementarius* en la zona alta del Río Choapa y en los cursos fluviales del Río Illapel, y esteros Canela y Camisas. Dilucidar las forzantes que gatillaron la aparente extinción local de las poblaciones en estos cursos, permitirá comprender, prevenir y mitigar las presiones ambientales que enfrenta *C. caementarius* en las zonas baja y media de la cuenca.
5) Identificar y zonificar las áreas de reproducción de adultos, desove de hembras, y reclutamiento de juveniles de *C. caementarius* en las zonas baja y media de la cuenca, para promover la conectividad entre áreas y potenciar la persistencia local de la especie.
6) Implementar conjuntamente con las organizaciones de camaroneros, un programa de seguimiento anual de la pesquería de *C. caementarius*, para contar con información consistente en el tiempo de los volúmenes de captura y esfuerzo de pesca por parte de los camaroneros.
7) Implementar medidas de mitigación frente a las continuas perturbaciones físicas del cauce del Río Choapa derivadas de la megasequía, que integre a los actores del sistema y las organizaciones de camaroneros, para el resguardo de áreas claves para el ciclo de vida de *C. caementarius*, sectores históricos y temporadas de pesca.
8) Otorgar mayor resiliencia a las condiciones de habitabilidad fluvial frente a la escasez hídrica, a través de la protección de tramos fluviales claves para la habitabilidad de biota acuática nativa y la identificación de los tramos fluviales más susceptibles a la megasequía.

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ORIGINAL RESEARCH

Desafiando la tradición de país harinero: una mirada económica de la actividad pesquera de Piura, Perú

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RESUMEN. Piura es una región del norte de Perú que destaca por su pesca artesanal, su industria procesadora y exportadora de productos para consumo humano directo (CHD) y su gastronomía marina. Usando información primaria y secundaria, se caracterizó la cadena de valor de la actividad pesquera regional durante el 2014 y se estimaron indicadores de producción, valor agregado (VA) y empleo. El desembarque de Piura fue de 732.000 t y generó USD 1.771 millones en ingresos, USD 700 millones de valor agregado y 49.000 empleos. Las capturas fueron destinadas principalmente a: (1) la elaboración industrial y exportación de productos de CHD, preferentemente suministrados por la pesca artesanal (82% del desembarque, 59% del VA y 46% del empleo) y (2) el suministro de recursos frescos para el consumo doméstico (13% del desembarque, 37% del VA y 52% del empleo). Esta región no sigue el patrón nacional, caracterizado por una gran extracción industrial de anchoveta para la producción y exportación de harina y aceite de pescado (CHI). Finalmente, dado que está extensamente documentado que la pesca artesanal aún tiene una amplia agenda de pendientes para lograr la sostenibilidad y que hay que prever escenarios climáticos futuros que puedan impactar la productividad pesquera, se recomienda desarrollar una gobernanza más sólida y participativa que ayude a prevenir posibles colapsos y fomente la competitividad de las actividades económicas aquí descritas.

Palabras clave: Cadena de valor, análisis económico, gobernanza pesquera, pesca artesanal.

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Challenging the tradition of a fishmeal producing country: an economic overview of the fishing activity in Piura, Peru

ABSTRACT. Piura is a region in Northern Peru that stands out for its artisanal fisheries, export-oriented processing industry focusing on products for direct human consumption (DHC), and marine gastronomy. Primary and secondary information was used to characterize the Piura region's fisheries sector value chain during 2014. This resulted in the estimation of indicators for production, value added (VA) and employment. Piura reported landings of 732,000 t of fish and invertebrates generating USD 1,771 million of income, USD 700 million of VA and 49,000 jobs. The main supply chains of Piura's landings were: (1) industrial production and export of DHC products mainly sourced from artisanal fisheries (82% landings, 59% of VA, and 46% of employment); and (2) supply of fresh seafood for domestic consumption (13% landings, 36% of VA, and 52% of employment). The national pattern for Peru is not followed by this region whose main characteristics are: the massive industrial extraction of anchoveta for fishmeal and fish oil production (IHC). Finally, given that Peruvian artisanal fisheries have a long way to go before achieving sustainability, our findings were discussed within a broader governance framework seeking to strengthen participatory governance to prevent potential future collapses and increase the competitiveness of the economic activities characterized throughout this research.

Key words: Value chain, economic assessment, fisheries governance, small-scale fisheries.

INTRODUCCIÓN

El Perú es una de las principales potencias pesqueras a nivel global (FAO 2020a). Históricamente, ha sido reconocido como un país dedicado fundamentalmente a la producción de harina y aceite de pescado y, consecuentemente, ha mantenido una escasa presencia en los mercados internacionales de productos orientados al consumo humano directo (CHD) (Hidalgo 2002). No obstante, cuenta con un importante sector pesquero artesanal (Castillo et al. 2018; De la Puente et al. 2020) y una industria acuícola en expansión (Mendo et al. 2016) que han contribuido a impulsar el desarrollo del sector pesquero nacional y la presencia de sus productos de CHD en el mercado internacional en años recientes (Christensen et al. 2014; PROMPERÚ 2021).

Piura, una región al norte de Perú (Figura 1), tiene la actividad pesquera con la mayor importancia relativa de todo el país. Entre el 2008 y 2012, la pesca aportó el 5,0% de su producto bruto interno (PBI); mientras que, el promedio nacional fue tan solo de 1,2% (Galarza y Kamiche 2015). Esta región destaca por su actividad pesquera artesanal, llegando a registrar en 2012 el 20% de los 116 puntos de desembarque censados en todo el país, el 30% de los más de 44.000 pescadores artesanales, el 33% de los más de 12.000 armadores artesanales y el 35% de las 16.000 embarcaciones artesanales del país (PRODUCE 2013). En 2013, tuvo el 33% de las plantas pesqueras de productos de CHD del país (Galarza y Kamiche 2015) y elaboró el 50% de la producción nacional (PRODUCE 2016a). En 2015, se estimó que el 33% de los pescadores artesanales se ubicaban en Piura, llegando a ser una población de casi 22.000 pescadores artesanales (Castillo et al. 2018). Esta región también cuenta con una importante actividad de maricultura de conchas de abanico que ha llegado a representar el 80% de la producción nacional (Mendo et al. 2016).

En la historia reciente de la pesquería peruana (2011-2020), el 2014 destaca por ser uno de los mejores años en términos de capturas destinadas al CHD y el peor año para la pesca industrial de anchoveta, pesquería responsable de los insumos de la industria de harina y aceite de pescado (PRODUCE 2021). Esto guarda relación con la ocurrencia de un evento El Niño de magnitud moderada (Bouchon Corrales et al. 2015) que, además de generar un efecto adverso para la anchoveta, favoreció la ocurrencia de una mayor disponibilidad de especies que pudieron ser aprovechadas por la pesca artesanal en algunas localidades de la costa peruana (Medina et al. 2015). En ese sentido, comprender las dinámicas económico-pesqueras de 2014 podría servir para ilustrar el devenir de la industria pesquera peruana en un escenario climático futuro menos favorable para la anchoveta (Salvattecci et al. 2022), pero también con alternativas para mantener la pesca artesanal.

El 2014 fue un buen año para el sector pesquero piurano. Sus desembarques ascendieron a 732.000 t (PRODUCE 2016b). Si fuese un país, Piura se hubiese situado entre los primeros 25 países pesqueros del mundo, entre Ecuador (663.000 t) y Dinamarca (745.000 t) (FAO 2016). A pesar de la importancia específica de Piura para la pesca y procesamiento de alimentos de origen marino en el Perú, no se han caracterizado sus cadenas productivas previamente. Por ello, se desconoce el detalle de la importancia de la contribución de la pesca en términos de producción,

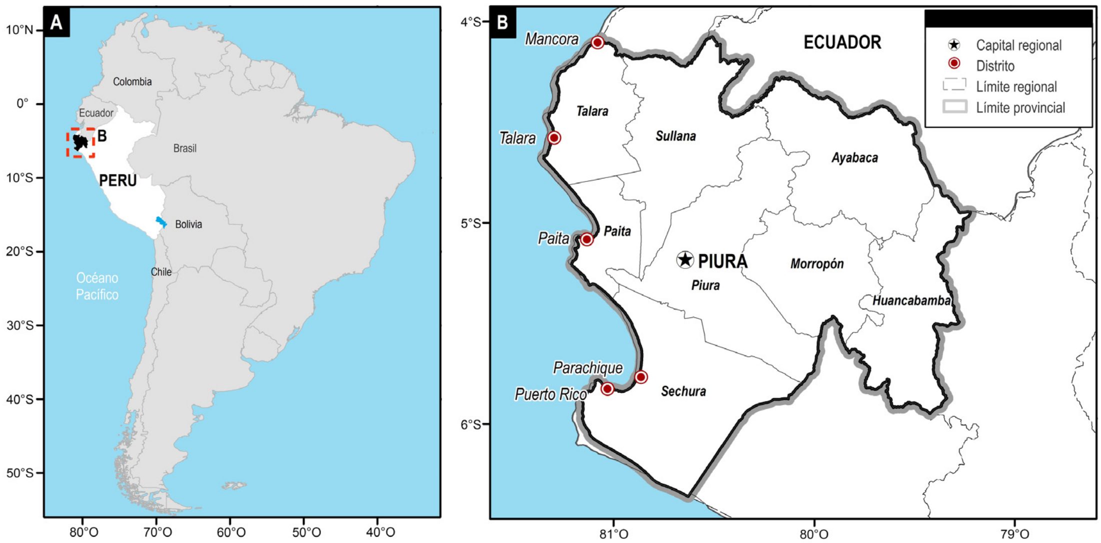

Figura 1. A) Ubicación de Piura en Sudamérica. B) Provincias y principales puntos de desembarque de Piura.
Figure 1. A) Location of Piura in South America. B) Provinces and main landing sites of Piura.

generación de valor agregado y empleo, mientras recorre los distintos eslabones de la cadena productiva desde el mar a la mesa. Más aún, se desconoce cómo varían dichas contribuciones según recurso pesquero, método de captura y giro productivo (por ejemplo, fresco, congelado, enlatado, harina y aceite). Este enfoque de cadena de valor permite examinar de manera holística la actividad pesquera con la finalidad de diseñar estrategias de mejora de la sostenibilidad de la cadena (FAO 2020b).

Es así que la presente investigación caracteriza la cadena de valor de los productos pesqueros de la región de Piura durante 2014, y discute la contribución a la economía y sociedad del sector pesquero piurano con la finalidad de avanzar hacia un desarrollo justo y sostenible de esta actividad.

MATERIALES Y MÉTODOS

La cadena de valor de la región de Piura fue elaborada utilizando el *plug-in* de cadenas de valor del *software* Ecopath con Ecosim (Christensen et al. 2011), que permite rastrear el flujo de los recursos desembarcados mientras recorren las cadenas productivas del mar a la mesa. Los diferentes eslabones de la cadena incluyen a los productores (por ejemplo, las flotas pesqueras, la maricultura de organismos filtradores), los distribuidores (por ejemplo, intermediarios), los procesadores (por ejemplo, las enlatadoras, congeladoras, etc.), los comerciantes mayoristas (por ejemplo, mercados regionales de pescado), los comerciantes minoristas (por ejemplo, mercados municipales, supermercados, restaurantes) y los consumidores (por ejemplo, la población local, el mercado internacional). A lo largo de estos eslabones, los recursos marinos se transforman en productos pesqueros, perdiendo biomasa (por ejemplo, la fracción comestible de una concha de abanico, *Argopecten purpuratus*, oscila entre el 10-25%; IMARPE e ITP 1996) y ganando valor (Figura 2).

La cadena de valor del sector pesquero piurano fue elaborada para el año 2014, tomando como referencia a la cadena de valor del sector pesquero peruano del año 2010 (Christensen et al. 2014). Se estimó el volumen de producción, ingresos, costos, ganancias, empleo y generación de valor

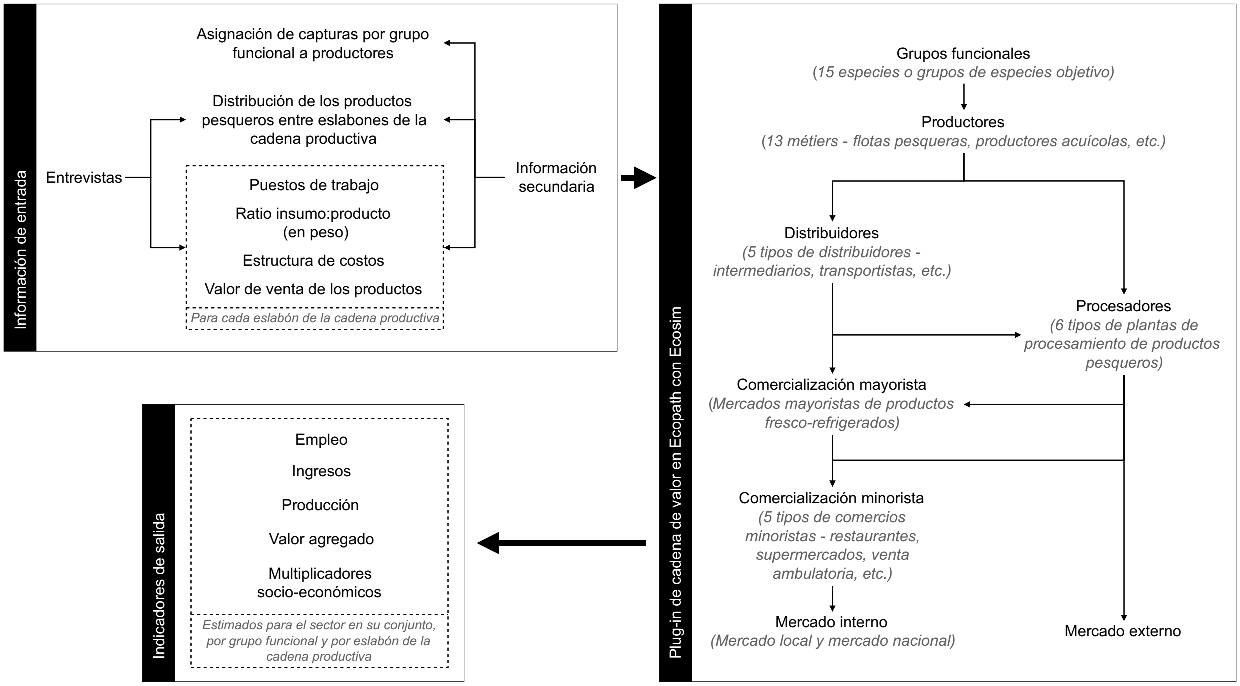

Figura 2. Flujo metodológico para la estimación de indicadores productivos y económicos de la cadena de valor de Piura de 2014.
Figure 2. Methodological flow for the estimation of productive and economic indicators of the 2014 Piura's value chain.

agregado (limitado solamente a la ganancia operativa y al costo del empleo) de cada componente de la cadena productiva de Piura. Para ello, se utilizó información secundaria y entrevistas abiertas a actores clave del sector. Estas tuvieron el objetivo de facilitar la elaboración de estructuras de costos operativos y de validar la información secundaria. Se realizaron 35 entrevistas, incluyendo a pescadores artesanales (n = 9), procesadores y exportadores (n = 8), especialistas pesqueros (n = 14) y funcionarios públicos (n = 4).

Fuentes de información y procedimiento de estimación

Producción

La fase extractiva se organizó utilizando 13 métiers. Cada métier representa a un grupo de embarcaciones que utilizan métodos de pesca similares, cuentan con características similares (como capacidad de bodega, longitud de eslora) y por lo tanto comparten estructuras de costos e ingresos. Las capturas de estos métiers se organizaron agrupando los desembarques en 15 grupos funcionales (Tabla 1). Estos pueden incluir a una especie en el caso de que sea de gran importancia (por ejemplo, calamar gigante o pota *Dosidicus gigas*), o a grupos de especies que comparten características ecológicas similares y se aprovechen de manera similar (por ejemplo, peces demersales grandes). La fracción del desembarque de cada grupo funcional que corresponde a cada métier fue asignada utilizando información secundaria (Estrella Arellano y Guevara Carrasco 1998a, 1998b; Estrella Arellano et al. 1998; 1999; 2000a; 2000b).

Los ingresos brutos de la flota se obtuvieron al multiplicar los desembarques según grupo funcional por sus precios playa (por ejemplo, el valor de la primera transacción). Los precios fueron

Tabla 1. Desembarques de la Región Piura durante 2014, según grupo funcional y métier.
Table 1. Landings of the Piura Region during 2014, by functional group and métier.

Grupos de especies	Métiers	Desembarque (miles de toneladas)
Pota (*Dosidiscus gigas*)	Embarcaciones poteras	475,97
Concha de abanico (*Argopecten purpuratus*)	Maricultura	53,79
Merluza (*Merluccius gayi peruanus*)	Flota de arrastre industrial de merluza	43,05
	Flota palangrera artesanal	7,78
Anchoveta (*Engraulis ringens*)	Flota de cerco artesanal	11,28
	Embarcaciones industriales de cerco	39,24
Perico (*Coryphaena hippurus*)	Flota espinelera pelágica	23,34
Pelágicos medianos: Barrilete (*Katsuwonus pelanis*), Bonito (*Sarda chiliensi chiliensis*), Caballa (*Scomber japonicus*), etc.	Flota de cerco artesanal	18,28
	Flota pintera (líneas y anzuelos)	2,32
Grupo mixto: lisa (*Mugil cephalus*) y otros (Chiri –*Peprilus medius*, espejo –*Selene peruviana*, etc.)	Flota de cerco artesanal	13,95
Atunes: aleta amarilla (*Thunnus albacores*) y otros	Flota atunera artesanal	3,32
	Embarcaciones industriales de cerco	8,49
Calamar (*Loligo* sp.)	Flota pintera (líneas y anzuelos)	8,49
Anguila (*Ophichthus pacifici*)	Flota anguilera de menor escala	8,09
Otros invertebrados: langostinos de la Familia Penaeidae, pico de pato (*Tagellus dombeii*), diversos bivalvos y gasterópodos	Buceo a pulmón	0,74
	Buceo con compresora	1,42
	Embarcaciones artesanales arrastreras	2,39
Otros demersales medianos: cachema (*Cynoscion analis*), cabrilla (*Paralabrax humeralis*), coco (*Paralonchurus peruanus*), etc.	Flota de cerco artesanal	1,80
	Flota cortinera artesanal	0,68
	Flota pintera (líneas y anzuelos)	1,63
Condrictios: tollos (*Mustelus* spp.), pez gallo (*Callorhinchus callorynchus*), tiburón martillo (*Sphyrna* spp.), etc.	Flota cortinera artesanal	3,18
Camotillo: diversas especies de pequeños demersales de la Familia Serranidae	Embarcaciones artesanales arrastreras	1,61
	Flota pintera (líneas y anzuelos)	0,69
Demersales grandes: corvina (*Cilus gilberti*), congrios (*Genypterus maculatus* y *Brotula clarkae*), charela, chita (*Anisotremus* spp.), cojinova (*Schedophilus sp.* y *Seriolella* sp.), mero (*Epinephelus* spp.), etc.	Flota cortinera artesanal	0,11
	Buceo a pulmón	0,12
	Flota pintera (líneas y anzuelos)	0,54
Total		732,28

tomados de la base de datos del Instituto del Mar del Perú (IMARPE 2020). Las estructuras de costos por faena de pesca de cada tipo de métier se obtuvieron mediante entrevistas, salvo en la maricultura de concha de abanico (Sánchez 2017), la flota artesanal de palangre y atunera (Grillo 2016) y la flota artesanal de espinel de altura (De la Puente et al. 2015), que se obtuvieron de publicaciones. El número de viajes de pesca por año, las estructuras de costo por faena, el número de tripulantes y otras variables obtenidas durante las entrevistas fueron utilizadas para estimar el tamaño de la flota, el empleo total y los demás indicadores económicos de cada métier siguiendo lo descrito por Christensen et al. (2014).

Distribución

La distribución de los desembarques se hace, por lo general, a través de intermediarios que compran, transportan y venden la pesca. Se estimó la distribución del volumen de cada métier hacia tres tipos de destinos: (i) plantas de procesamiento; (ii) distribución local dentro de Piura y (iii) distribución nacional fuera de Piura. El volumen distribuido desde los puntos de desembarque a las plantas de procesamiento se obtuvo de información oficial del Ministerio de la Producción (PRODUCE 2016b). El volumen distribuido hacia el consumo fresco dentro Piura se obtuvo de la Encuesta Nacional de Hogares (ENAHO 2014). El volumen distribuido fuera de Piura se obtuvo a partir de la diferencia entre el desembarque total y la suma del volumen distribuido dentro de Piura y hacia las plantas de procesamiento.

Se identificaron cinco tipos de vehículos frigoríficos ("cámaras") asociados con el transporte de pesca en Piura. Se recogieron las estructuras de costos de cada tipo de cámara por kilómetro recorrido y se estimó un destino promedio medido en kilómetros de distancia recorrida para cada ruta de transporte. Los principales costos involucrados estuvieron relacionados con el combustible, lubricantes, hielo, peajes, honorarios y pago por servicios del personal necesario para la descarga y estiba. Los ingresos fueron estimados a partir de la adición del porcentaje de ganancia sobre el precio de primera venta de cada recurso que reciben los intermediarios por su labor, obtenidos a partir de consultas a actores clave.

El empleo equivalente a tiempo completo se calculó como la suma del número de personas involucradas en el transporte, desembarque y estiba de la pesca en cámaras. Las personas involucradas en el transporte fueron calculadas multiplicando el número de cámaras por dos, dado que, por lo general, en cada cámara trabaja un chofer y un ayudante. Las personas involucradas en el desembarque y estiba se agruparon en cuadrillas. Por eso, se calculó el número de personas en una cuadrilla para cada tipo de flota y, en consecuencia, el total de personas se calculó usando el volumen por descarga y el número de días trabajados al año.

Procesamiento

Las plantas de procesamiento de Piura por lo general procesan y comercializan directamente sus productos finales, tanto en los mercados internacionales como en el nacional. Por esta razón, este eslabón inicia con la recepción de materia prima en planta, sigue con su transformación y empaque y termina cuando el producto ha sido exportado o dispuesto para su venta dentro del país. Según el Ministerio de la Producción, 105 plantas procesadoras estuvieron activas en Piura durante el 2014 (PRODUCE 2017). Estas fueron agrupadas en seis categorías: 1) congeladoras (n = 53); 2) procesadoras de harina residual o de subproductos (n = 25); 3) enlatadoras (n = 11); 4) desvalvadoras de conchas de abanico (n = 8); 5) plantas de curado (n = 6) y 6) harineras industriales (por ejemplo, procesadoras de harina y aceite de anchoveta capturada por embarcaciones industriales; n = 2). Adicionalmente, se consideró el procesamiento ilegal de harina de pescado capturada por embarcaciones de menor escala y artesanales, dado que dicha actividad se reporta sistemáticamente en Piura (Grillo et al. 2018).

Los volúmenes de producción por cada tipo de producto se calcularon a partir de la multiplicación de la materia prima recepcionada en planta por cada grupo de especies por el rendimiento teórico de producción de cada producto (IMARPE e ITP 1996). El volumen total producido se distribuyó hacia la exportación y el consumo interno. El volumen y valor de las exportaciones fue tomado de estadísticas oficiales (sistematizadas por ADEX 2017). Se asumió que el volumen consumido internamente en Perú fue la diferencia entre el volumen total producido y el exportado. Su valor monetario fue estimado tomando como referencia el precio promedio de exportación para cada tipo de producto. Los costos operativos de producción fueron proporcionados por tres empresas consultadas. El empleo equivalente a tiempo completo se estimó a partir del número de personas empleadas por turno de trabajo de producción, incluyendo personal operativo y administrativo, y el número teórico de turnos necesarios para alcanzar el volumen de producción por cada tipo de producto.

Comercialización

Para estimar el volumen y valor de la pesca consumida internamente en 2014, se calculó el consumo de pescados y mariscos utilizando la metodología del Programa Nacional "A Comer Pescado" (UGEE 2015), información demográfica del Instituto Nacional de Estadísticas e Informática de Perú (INEI) y la base de datos de consumo de recursos pesqueros por parte de las familias, recogida en la ENAHO. Al consumo *per cápita* de recursos hidrobiológicos de Piura 2014 de 24,1 kg por persona (A Comer Pescado 2015) se le restó el consumo de productos enlatados, cuyos insumos no provienen de pesca desembarcada en la región, obteniendo un nivel de consumo de pescados e invertebrados marinos de 20 kg por persona. La población de Piura en 2014 fue de 1,83 millones de habitantes, por lo que, el consumo total fue de 37.000 t. Se consideró que la distribución del consumo por provincias fue proporcional a la población (las provincias marino costeras cuentan con el 18% de la población, las del centro con el 67% y las del Alto Piura con el 15%).

La ENAHO del 2014 señala que el 52% de las familias piuranas compran pescado en mercados minoristas, el 21% en bodegas, el 18% de venta ambulatoria, el 8% directo de mercados mayoristas y el 1% de supermercados. Estas proporciones se utilizaron para definir las magnitudes de los flujos de distribución dentro de Piura. Adicionalmente, se estimó el consumo en restaurantes y ramadas (por ejemplo, restaurantes informales e improvisados en las vías públicas en los que el pescado suele ser la principal o única oferta alimenticia). Se accedió al registro de restaurantes marinos de algunos de los distritos con mayor actividad gastronómica de Piura (por ejemplo, Máncora, Piura, Sullana y Sechura) y se estimó el empleo que generan, así como su demanda promedio de pescado, ponderando para esto una medida de la valoración de su importancia turística y el volumen poblacional. Las ramadas, al ser de naturaleza informal, no cuentan con registros disponibles que permitan caracterizar su actividad. Por ello, se hicieron consultas para definir los lugares en donde hay más probabilidad de encontrar estos establecimientos, determinándose que la probabilidad de encontrar ramadas es alta en las zonas rurales del centro y la costa de la región, pero baja en la sierra y en las zonas urbanas. Utilizando el criterio seguido para restaurantes, se definió la demanda de pescado de estos establecimientos y el empleo.

Además, se visitaron los dos mercados pesqueros mayoristas y siete de los 71 mercados minoristas para contabilizar de manera directa el empleo. Para ello, se identificó el número de puestos de venta de recursos hidrobiológicos y el número de personas trabajando en cada uno. En el caso de la venta ambulante, la cantidad promedio de venta diaria se estimó a partir de consultas y, a partir de este dato, se estimó el número de vendedores ambulantes. No se contabilizó el empleo en bodegas y supermercados porque se consideró que la fracción de dedicación para esta labor, por parte de los trabajadores de dichos establecimientos, fue mínima.

El valor del pescado consumido internamente fue calculado multiplicando los volúmenes para cada tipo de destino (por ejemplo, mercados minoristas, bodegas, ambulantes, mercados mayoristas, supermercados, restaurantes y ramadas) por sus precios de playa y un margen de ganancia para cada tipo, estimados a partir de entrevistas a encargados de los puntos de venta.

Contextualización de los indicadores económicos

Para comprender cómo calzan los indicadores económicos (volumen y valor de la producción, ingresos, costos, ganancias, empleo y generación de valor agregado) estimados para Piura durante 2014 en la historia económica regional, se procedió a analizar su actividad pesquera en el tiempo. Para ello, se recopilaron series de tiempo de desembarques de las principales especies durante el período 1950-2015 (1950-1999 de Caillaux 2011; 2000-2015 de PRODUCE 2010, 2016b). Se construyó también una serie de tiempo de la capacidad de procesamiento de los productos pesqueros para el período 1996-2017 usando información del INEI (1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010a, 2011; 2012; 2013, 2014, 2015, 2016) y del Ministerio de la Producción (PRODUCE 2017). También se construyeron series de tiempo para el 2000-2017 del valor monetario de las exportaciones de productos pesqueros para el CHD y de harina y aceite de pesado (CHI) de todo el Perú y de las empresas domiciliadas en Piura, utilizando datos de la Asociación de Exportadores del Perú (ADEX 2017). Para identificar la importancia relativa del valor de las exportaciones de CHI sobre los de CHD a lo largo del tiempo, se calculó la razón anual CHI/CHD 2000-2017, tanto para Piura como para todo el Perú. Finalmente, los resultados de esta investigación fueron comparados con aquellos producidos para la cadena de valor del sector pesquero peruano durante el 2010 (Christensen et al. 2014).

RESULTADOS

La contribución del sector pesquero a la economía de la región Piura

El desembarque 2014 de Piura fue de 732.000 t y generó ingresos por USD 1.771 millones, una estimación conservadora de generación de valor agregado (VA) por USD 700 millones y 48.800 empleos (Tabla 2). Haciendo una comparación con estimados nacionales de Christensen et al. (2014), Piura representaría el 20 y 21% del valor agregado y el empleo a nivel del sector pesquero peruano, respectivamente.

Se estimó el multiplicador económico del valor agregado en 2,98 (Tabla 3). Este fue considerado un estimado conservador porque no logró recoger todas las dimensiones que generan valor agregado, como por ejemplo, impuestos directos e indirectos, margen de ganancia de los proveedores de servicios, etc. Sin embargo, con él podemos afirmar que, como mínimo, por cada dólar generado en la fase de extractiva se generan casi dos más en tierra a lo largo de los eslabones restantes de la cadena de valor. Por su parte, el multiplicador de empleo fue 2,28, significando que, por cada empleo en el mar se generan 1,28 más en tierra.

Al dividir la cadena de valor según la clasificación de la actividad extractiva, se muestra que la pesca artesanal representó el 87% del desembarque de Piura en 2014, lo que permitió generar el 88% del VA (multiplicador de 2,98; Tabla 3) y el 95% del empleo (multiplicador 2,28). Ello deja a la pesca industrial con un rol marginal de 13% del desembarque, 12% del VA (multiplicador de 2,96) y 5% del empleo (multiplicador 2,18).

Tabla 2. Resumen de los indicadores económicos estimados para los distintos eslabones de la cadena de valor del sector pesquero de Piura durante 2014.
Table 2. Summary of the economic indicators estimated by echelon of the Piura region's fisheries sector value chain during 2014.

Ítem	Producción	Distribución	Procesamiento	Comercialización mayorista	Comercialización minorista	Total
Producción (miles de toneladas)	732,28	620,36	340,91	24,13	29,11	-
Ingresos (millones de dólares)	384,56	437,41	772,07	50,90	126,12	1.771,07
Costos (millones de dólares)	284,29	375,40	534,61	47,73	102,49	1.344,52
Valor agregado (millones de dólares)	234,65	91,95	306,11	7,70	59,36	699,77
Empleos (miles de personas)	21,47	4,49	12,30	0,98	9,65	48,89

Al analizar la cadena de valor según el destino final de los recursos pesqueros, encontramos que la fracción de la pesca que se usó en la elaboración productos de CHD tuvo principalmente como fin la exportación (por ejemplo, congelados, enlatados y curados), utilizando el 82% del volumen total desembarcado y generando el 59% del VA total (multiplicador 2,63) y el 46% del empleo (multiplicador de 1,62). Cabe mencionar que, para el procesamiento de estos productos se utilizaron principalmente recursos ligados a la extracción artesanal, esto es, pota, y que estos representaron casi el 90% de la materia prima para estos fines. Por otro lado, el 13% del desembarque correspondiente a la fracción destinada al consumo local de Piura y doméstico de Perú en estado fresco generó el 37% del VA (multiplicador de 4,34) y 52% del empleo (multiplicador de 3,62). Por último, la anchoveta industrial para CHI representó solo el 5% del desembarque, 4% del VA (multiplicador de 1,50) y 2% del empleo (multiplicador de 1,69).

El resumen gráfico de la cadena de valor en términos de volumen, ingresos y empleo, permite distinguir con claridad las dos dinámicas económico-pesqueras principales de la cadena de valor de Piura en 2014 (Figura 3). La primera, enfocada en la extracción artesanal e industrial destinada al procesamiento y exportación principalmente de siete de las 97 especies desembarcadas, las cuales están relacionadas a los métiers de embarcaciones poteras, maricultura, embarcaciones industriales de cerco, flota espinelera pelágica, flota anguilera de menor escala y flota de arrastre industrial. La segunda, enfocada en la extracción exclusivamente artesanal para el consumo local y nacional en estado fresco. Ésta agrupa a las especies artesanales de la primera dinámica y a otras 90 especies desembarcadas en Piura. En este grupo se encuentra, principalmente, la actividad de los métiers de buceo, flota de palangre artesanal, flota cortinera artesanal, flota de cerco artesanal, flota pintera (líneas y anzuelos), embarcaciones artesanales arrastreras y la flota atunera artesanal. Dentro de esta dinámica destaca notablemente la comercialización minorista que genera grandes cantidades de empleo, principalmente, en restaurantes, mercados minoristas y ramadas (Figura 3 C).

El recurso más importante para el consumo local fue la caballa *Scomber japonicus*. En las

Tabla 3. Valor agregado y empleo generados en la producción y en toda la cadena de valor, según métier, tipo de actividad extractiva, destino de la producción y grupos funcionales.
Table 3. Value added and employment generated during production and the entire the value chain, highlighting the contribution by métier, type of extractive activity, final destination of production and functional groups.

	Valor agregado (millones de dólares)			Empleo (miles de personas)		
Flota	Extracción	Total	Multiplicador	Extracción	Total	Multiplicador
Métier						
Embarcaciones industriales de cerco	17,61	26,45	1,50	0,55	0,92	1,69
Flota de arrastre industrial de merluza	4,02	25,07	6,23	0,34	1,07	3,11
Flota anguilera de menor escala	6,93	33,10	4,77	0,25	0,49	1,98
Embarcaciones poteras	91,36	315,03	3,45	8,21	19,60	2,39
Flota espinelera pelágica	20,90	45,96	2,20	2,59	3,21	1,24
Flota atunera artesanal	7,55	11,53	1,53	0,28	0,40	1,43
Embarcaciones artesanales arrastreras	4,76	14,61	3,07	0,53	1,29	2,41
Flota pintera (líneas y anzuelos)	18,87	55,65	2,95	2,28	4,86	2,14
Flota de cerco artesanal	25,79	70,23	2,72	3,74	9,64	2,58
Flota cortinera artesanal	7,07	18,02	2,55	0,59	1,24	2,08
Flota palangrera artesanal	1,81	4,77	2,64	0,58	1,47	2,52
Buceo	3,91	10,39	2,66	0,36	0,72	2,03
Maricultura	24,07	68,95	2,86	1,18	3,97	3,37
Actividad extractiva						
Artesanal	206,09	615,14	2,98	20,34	46,40	2,28
Industrial	28,56	84,62	2,96	1,14	2,48	2,18
Destino						
CHD (mercado nacional e internacional)	156,79	411,21	2,63	13,90	22,56	1,62
Fresco (mercado nacional)	60,26	261,43	4,34	7,03	25,40	3,62
CHI (mercado nacional e internacional)	17,61	27,13	1,50	0,55	0,92	1,69
Especies o grupos de especies						
Pota	91,36	315,03	3,45	8,21	19,60	2,39
Concha de abanico	24,07	68,95	2,86	1,18	3,97	3,37
Merluza	5,84	29,83	5,11	0,93	2,54	2,74
Anchoveta	9,01	13,53	1,50	0,84	1,18	1,39

Tabla 3. Continuación.
Table 3. Continued.

	Valor agregado (millones de dólares)			Empleo (miles de personas)		
Flota	Extracción	Total	Multiplicador	Extracción	Total	Multiplicador
Perico	20,90	45,96	2,20	2,59	3,21	1,24
Pelágicos medianos	17,11	46,35	2,71	2,99	6,28	2,10
Grupo mixto	7,04	17,31	2,46	0,49	3,07	6,26
Atunes	17,50	27,51	1,57	0,37	0,75	2,00
Calamar	9,63	25,33	2,63	1,41	2,14	1,51
Anguila	6,93	33,10	4,77	0,25	0,49	1,98
Otros invertebrados	7,18	19,90	2,77	0,65	1,15	1,76
Otros demersales medianos	7,77	28,35	3,65	0,63	2,11	3,35
Condrictios	5,26	11,70	2,23	0,48	0,84	1,76
Camotillo	1,30	4,55	3,50	0,33	1,16	3,52
Demersales grandes	3,75	12,37	3,30	0,13	0,41	3,11
Total	234,65	699,77	2,98	21,47	48,89	2,28

provincias costeras de Piura (Paita, Sechura y Talara) éste recurso representó el 25% del total consumido, seguido por el jurel *Trachurus murphyi* (16%), la cachema *Cynoscion analis* (15%) y la cabrilla *Paralabrax humeralis* y *Paralabrax callaensis* (10%). En las provincias del centro de la región (Morropón, Piura y Sullana) la caballa representó el 24% del volumen, seguido por la cachema (22%), el jurel (20%) y la caballa salada (7%). Finalmente, en los distritos más andinos de la región (Ayabaca y Huancabamba), la caballa salada representó el 75% del volumen total. Las especies más importantes en términos de volúmenes de desembarque artesanales (pota, perico y concha de abanico) no figuraron entre los recursos consumidos por los habitantes de la Región Piura.

Por último, al evaluar la cadena de valor de Piura según los métiers más representativos para la generación de VA, tenemos que la pota, responsable del 65% del volumen desembarcado, generó el 45% del VA total regional durante 2014 (multiplicador de 3,45) y el 40% del empleo total (multiplicador de 2,39). Le siguió el cerco artesanal que, con 6,2% del desembarque, generó el 10% del VA (multiplicador de 2,72) y el 20% del empleo (multiplicador de 2,58). En tercer lugar, se encuentra la maricultura, responsable del 7,4% del desembarque, generó 10% del VA (multiplicador de 2,86) y el 8% del empleo (multiplicador de 3,37). En cuarto lugar, se encuentra la flota pintera (líneas y anzuelos), que con solo 1,9% del desembarque generó el 8% del VA (multiplicador de 2,95) y el 10% del empleo (multiplicador de 2,14) (Figura 4; Tabla 3).

Contextualización de la actividad pesquera de Piura

La dinámica pesquera actual de Piura, fuertemente dependiente de unas pocas actividades artesanales que aportan grandes volúmenes, es relativamente reciente y guarda relación con el aumento de la capacidad de procesamiento de

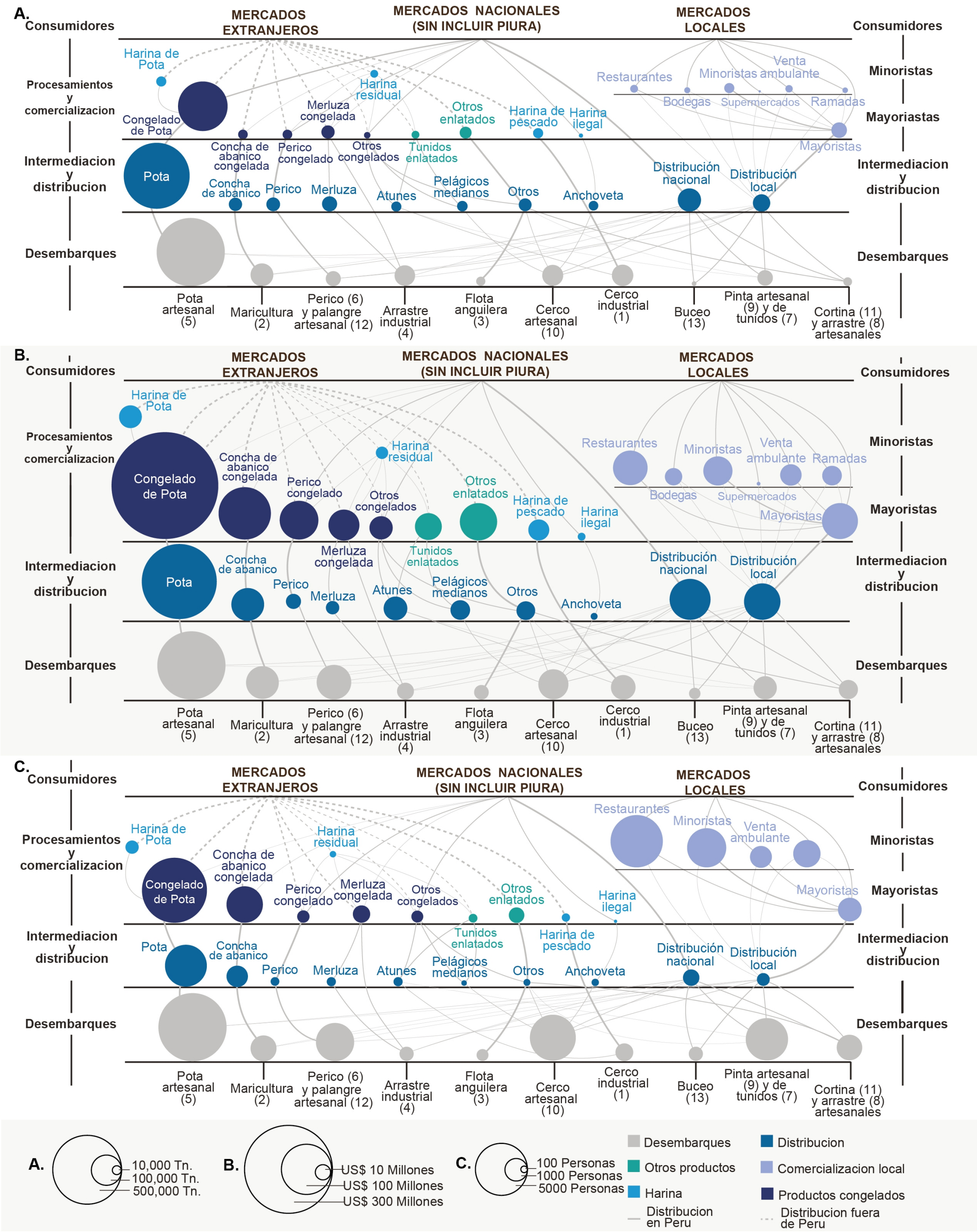

Figura 3. Estructura de la cadena de valor del sector pesquero de Piura en 2014 según volumen (A), ingresos (B) y empleo (C).

Figure 3. Piura region's fisheries sector value chain in 2014 structured according to volume (A), income (B) and employment (C).

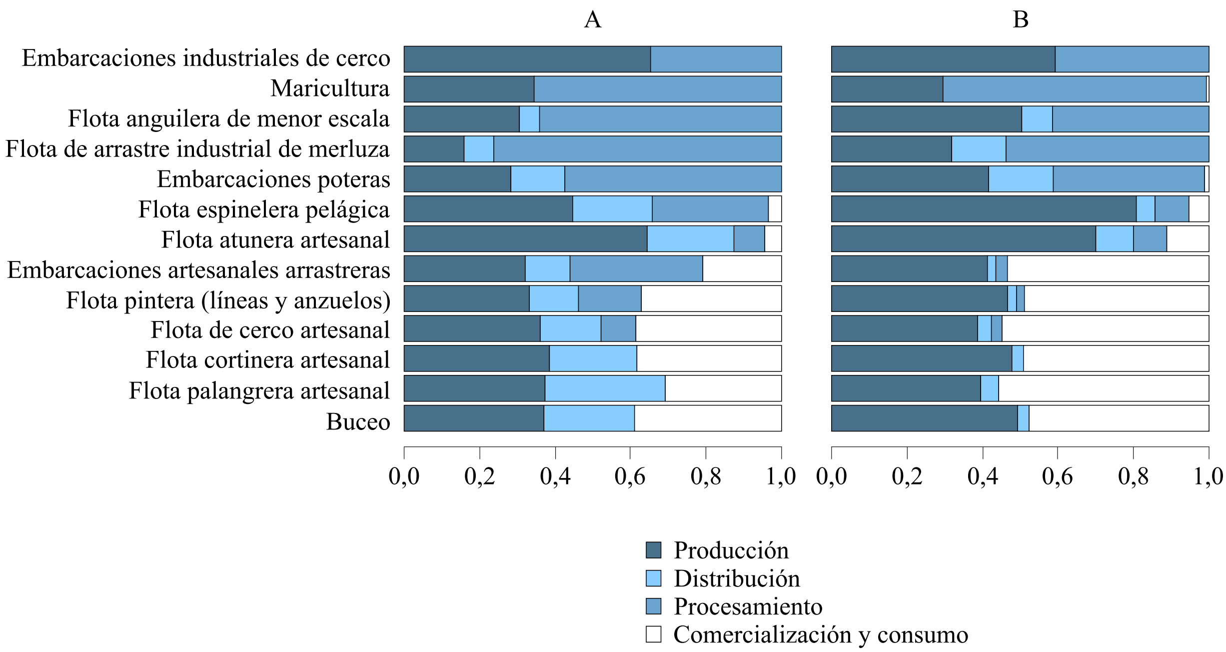

Figura 4. Proporción del valor agregado (A) y empleo (B), según métier y eslabón de la cadena productiva.
Figure 4. Proportion of added value (A) andemployment (B) by métier, according to the different value chain echelons.

productos congelados y la disminución de la producción de harina y aceite de pescados provenientes de la flota industrial de anchoveta (ver material suplementario). Desde 2000 en adelante, ha aumentado el valor de las exportaciones de CHI (Figura 5 A) y CHD (Figura 5 B); sin embargo, la dominancia de la primera sobre la segunda ha disminuido considerablemente (Figura 5 C). A nivel nacional, la razón CHI/CHD pasó de 5,0 en el promedio anual 2000-2004, a 1,6 en 2013-2017. En Piura, la razón fue menor a 0,3 en los años 2013-2017 y, desde el 2005 en adelante, el CHI es menor al CHD.

DISCUSIÓN

Los resultados de este estudio revelan la importancia de Piura para la diversificación del sector pesquero peruano dado que esta región, a diferencia de la dinámica nacional (ver Christensen et al. 2014), no muestra una dependencia por la anchoveta para CHI a lo largo del tiempo. Además de esto, Piura tiene una dinámica productiva dominante bastante interesante en términos socioeconómicos. Ésta se basa en la producción industrial de productos de CHD para la exportación, elaborados a partir del suministro mayoritario de pesca del sector artesanal.

Esta naturaleza artesanal permite que la fase extractiva de la producción de CHD de Piura capture más valor agregado y empleo, aumentando así su aporte socioeconómico para las comunidades pesqueras artesanales, en comparación a si fuera una actividad que estuviera integrada de manera vertical al procesamiento industrial y a la exportación. Esto último representa una tendencia que se impone mundialmente para garantizar el suministro de pesca desde países en vías de desarrollo hacia países desarrollados, pero que trae consigo la reducción del poder de negociación de los agentes de la pesca artesanal (FAO 2014). Por el momento, no parece ser posible una

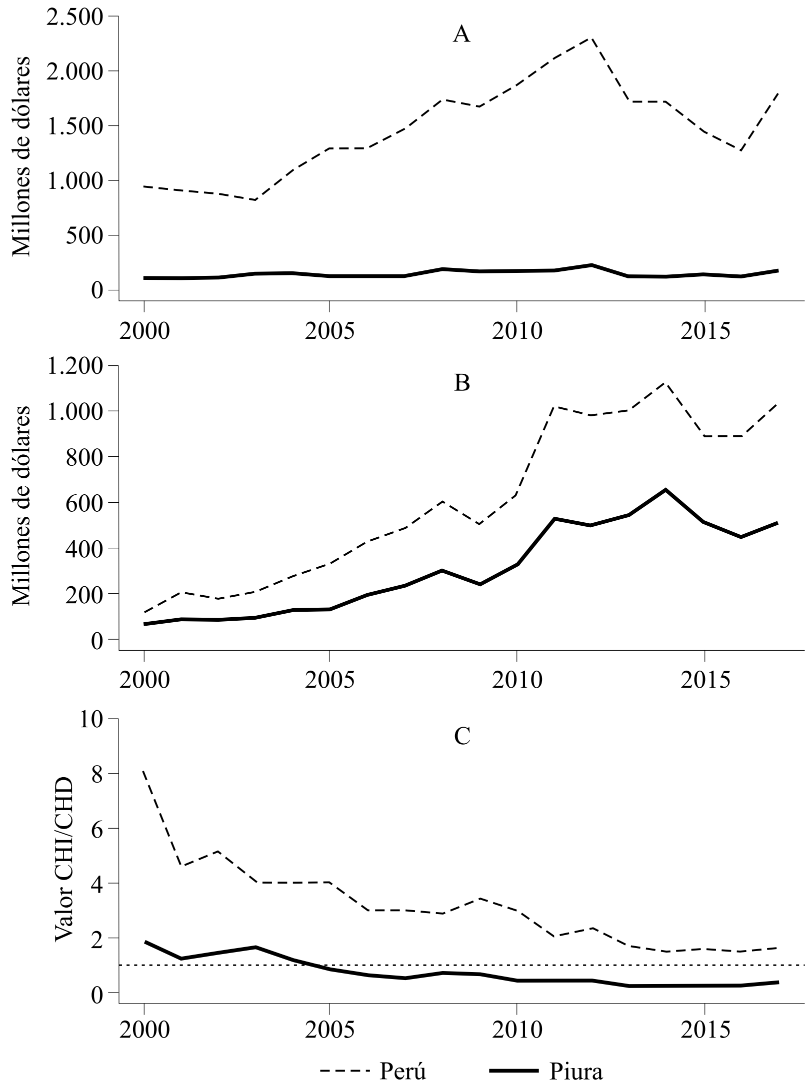

Figura 5. Valor de las exportaciones 2000-2017 en Piura y en todo el Perú correspondiente al consumo humano indirecto (CHI) (harina y aceite de pescado) (A), a los productos de consumo humano directo (CHD) (congelados, enlatados, curados, etc.) (B) y razón entre A y B (C).

Figure 5. Value of exports 2000-2017 from Piura and Peru corresponding to indirect human consumption (CHI) (fishmeal and fish oil) (A), products for direct human consumption (CHD) (frozen, canned, cured, etc.) (B), and the ratio between A and B (C).

integración vertical de la producción de CHD de Piura, dado que, por un lado, se tiene una gran cantidad de personas dependientes de la extracción artesanal (Castillo et al. 2018) y por el otro, una dinámica de procesamiento que obedece a una lógica industrial de mayor eficiencia. No obstante, el procesamiento emplea a más de 12.000 personas, cifra que se asemeja a la estimada por PRODUCE (Mendo et al. 2020a) y que merece todo menos ser subestimada.

A pesar de que la dinámica de CHD de Piura es notablemente diferente a la de la pesquería industrial de anchoveta para CHI, ésta también descansa sobre un modelo primario exportador. Este contexto particular permite plantear que gran parte de la pesca artesanal de Piura depende de la existencia de mercados de exportación. No obstante, para darle una mayor resiliencia a su cadena de valor, sería recomendable implementar políticas que fomenten la diversificación productiva y el desarrollo de mercados nacionales y locales para la pota, perico y conchas de abanico. Paradójicamente, los habitantes de la región de Piura no consumen estas tres especies clave para los desembarques de su región, según muestran los resultados de esta investigación.

Los multiplicadores de valor agregado y empleo del sector pesquero peruano difieren de los obtenidos para Piura, lo que permite inferir que esta región no está debidamente representada por los indicadores de las cadenas de valor a nivel nacional. Mientras que en Perú el CHI genera 1,6 puestos de trabajo y USD 1,8 en tierra por cada uno generado en el mar (Christensen et al. 2014), estos valores ascienden a solo 0,69 puestos de trabajo y USD 0,5 para Piura. Adicionalmente, los multiplicadores para el CHD en Piura también son más bajos que aquellos registrados a nivel nacional, esto es, equivalentes al 86% del multiplicador de valor agregado y 50% del de empleo para Perú (Christensen et al. 2014). Estas diferencias podrían explicarse principalmente por tres motivos: 1) durante 2014 se registraron los menores desembarques de anchoveta para CHI a nivel nacional de la última década, siendo su importancia relativa en el sector pesquero menor a otros años; 2) el CHI tiene una menor importancia para la cadena de valor de Piura en relación al resto del país y 3) la mayoría de la pesca que se captura y procesa en Piura se exporta o sale de la región, minimizando la contribución al valor agregado y sobre todo al empleo de la región en las fases de distribución, comercialización mayorista y comercialización minorista. En ese sentido, parte importante de la contribución de la pesca de Piura a la economía y sociedad ya no es percibida por esta región y, por ello, no ha sido considerada en el marco de la presente investigación. Esto significa que, si consideráramos la extensión de la cadena de valor de Piura a todos los procesos que ocurren dentro de territorio peruano, obtendríamos que su contribución total a la sociedad peruana es mayor a la estimada.

También es interesante notar que la dinámica de CHD de Piura se ha desarrollado en años recientes en los que, coincidentemente, la flota industrial nacional activa de anchoveta para CHI se ha reducido hasta en un 40% luego de la implementación del régimen de cuotas individuales (Kroetz et al. 2019). A pesar de esto, dicha flota no ha logrado reorientarse hacia pesquerías como la pota. Tampoco las más importantes empresas de CHI, afiliadas a la Sociedad Nacional de Pesquería (SNP), han logrado participar activamente de su procesamiento y exportación. Tal es así que, contando con el 35% de la capacidad de producción de congelados del país, solo han exportado el 4% del volumen de pota en el 2016-2019 (Mendo et al. 2020a). Esto posiciona a la actividad de CHD de Piura, fuertemente arraigada a la extracción artesanal, como una actividad alejada del poder empresarial tradicional y dominante del sector pesquero peruano a nivel nacional.

En cuanto al consumo local fresco, se observan coincidencias entre Piura y el Perú. En ambos casos, este rubro contiene una fracción pequeña de los desembarques, pero involucra a una gran cantidad de agentes económicos. Por eso, el multiplicador económico de valor agregado fue de 4,34 y el de empleo de 3,62. Ambas cifras son mayores a las reportadas por Christensen et al. (2014) para Perú. Si bien se podrían entender estos multiplicadores como típicos de una cadena de valor larga, que nace en el mar y termina en consumo en el país de origen, también puede ser una señal de que el pescador artesanal que suministra el consumo doméstico no estaría capturando todo el valor que podría, ya que éste se estaría disipando en una gran cantidad de actores dedicados a la intermediación y comercialización mayorista y minorista de los recursos. Esto puede verse, por ejemplo, en los métiers de buceo, palangre y cortina artesanal. Entonces, si bien la dinámica del fresco para el consumo local tiene multiplicadores económicos mucho más altos que el procesamiento CHD, esto podría no ser necesariamente más beneficioso para el pescador artesanal. En general, aspectos como la inclusión, eficiencia y justicia son conceptos que suenan bastante ajenos a las prioridades de gestión del sector pesquero peruano.

El análisis de cadena de valor del sector pesquero peruano del año 2010 reveló que, a pesar de que la pesca industrial de anchoveta para reducción en harina y aceite representó casi el 87% del volumen total desembarcado en el país, su aporte al producto bruto interno (PBI) y al empleo es solo del 31 y el 23%, respectivamente (Christensen et al. 2014). Es decir, el aporte socioeconómico de esta pesquería no es conmensurado a sus volúmenes de captura, sino mucho menor.

Los resultados presentados por Christensen et al. (2014) evidencian la necesidad de utilizar indicadores diferentes al volumen de desembarque para definir las prioridades de gestión pesquera y, consecuentemente, darle así más atención a las pesquerías y giros productivos de mayor importancia para la economía y sociedad. Por ello, sugieren que los esfuerzos de gestión pesquera deberían reorientarse hacia recursos desatendidos como, por ejemplo, los de la pesca artesanal. Esta recomendación es válida también para el caso de Piura, dado que sus dos dinámicas principales se inician con actividades artesanales y, más allá de las notorias diferencias operativas de cada una, ambas tienen un déficit de atención política por parte del aparato del Estado, cuya administración no logra definir una visión de largo plazo ni aplicar, de manera sostenida, políticas públicas que no sean interrumpidas por los vaivenes de la inestabilidad política del país (Gozzer-Wuest et al. 2021). Asimismo, ante escenarios climáticos futuros que podrían cambiar la productividad pesquera, resultaría necesario mejorar continuamente las políticas públicas de la pesca artesanal para que la adaptación a estos posibles cambios no acarree grandes consecuencias socioeconómicas negativas.

Las pesquerías artesanales muestran debilidades institucionales que ponen en duda si podrán mantener su importancia socioeconómica a lo largo del tiempo. Por ejemplo, la pesquería de pota opera bajo una informalidad generalizada (Gozzer-Wuest et al. 2022). Esto es extensible al perico, en tanto que una proporción importante de la actividad es realizada por la misma flota (Castillo et al. 2018). Por su parte, la pesca de la concha de abanico de la Bahía de Sechura se desarrolló de manera espontánea, no contando con un planeamiento espacial que precediera su inicio y, asimismo, su marco regulatorio ha tenido un desarrollo lento (Kluger et al. 2019a).

Por su parte, las pesquerías artesanales para el consumo doméstico también tienen una agenda de mejoras pendientes. Por ejemplo, dos de las especies más importantes para el consumo en Piura, la cabrilla y la cachema, muestran sistemáticamente grandes proporciones de individuos por debajo de la talla mínima legal (IMARPE 2015, 2021) y están clasificadas como plenamente explotadas, pero con algunos indicios de sobreexplotación (Argumedo Guillén et al. 2021; Pérez Huaripata 2021). También se reporta sistemáticamente pesca ilegal costera (Ganoza Chozo et al. 2014, 2021a; Mendo et al. 2022); la necesidad de mejorar la operatividad de los artes de pesca de cerco artesanal (Ganoza Chozo et al. 2021b), de pinta (ver Argumedo Guillén et al. 2021), para la captura del pulpo *Octopus mimus* (De la Cruz et al. 2020) e inclusive de arrastre artesanal ilegal (Mendo et al. 2020b); la necesidad de establecer vedas reproductivas y limitar el esfuerzo pesquero artesanal (De la Puente et al. 2020; Argumedo Guillén et al. 2021) y la evaluación de la posibilidad de establecer áreas de manejo (Mendo 2002).

La falla sistemática en tomar oportunamente acciones de manejo es un indicio de una débil gobernanza. Por eso, resulta incierto que el importante aporte económico y social de la cadena de valor pesquera de Piura pueda mantenerse a lo largo del tiempo si es que no se prioriza el desarrollo de una gobernanza ajustada a la misma

(Epstein et al. 2015; Villasante et al. 2022). En este punto es clave entender la naturaleza dominante artesanal de esta región, así como sus particularidades que deberían llevar a la toma de decisiones descentralizadas de gestión. Resulta poco verosímil mejorar la gestión a través de fortalecer el manejo actual centralizado mediante el solo aumento de su dotación presupuestaria. Por ello, la transición hacia un modelo *bottom-up* de gobernanza resultaría más efectivo para mejorar los niveles de sostenibilidad de las pesquerías artesanales (Aguión et al. 2021). En ese contexto, el comanejo, definido como la compartición de tareas y responsabilidades de manejo entre los gobiernos y los usuarios locales (Defeo et al. 2016), es identificado como la única solución realista para muchas pesquerías artesanales (Gutiérrez et al. 2011) y, además, también puede llegar a generar mejoras en indicadores bioeconómicos (Defeo et al. 2016).

Se han identificado comunidades pesqueras en Perú que, a pesar de la falta de instrumentos legales que les brinden respaldo, han logrado encontrar incentivos internos suficientes para asumir reglas de control autoimpuestas, como Ilo, La Islilla, El Ñuro, Los Órganos o San Juan de Marcona (Miranda y Gutiérrez 2015; Nakandakari et al. 2017; Grillo-Núñez et al. 2021). No obstante, a pesar de la posibilidad de encontrar atributos intrínsecos para funcionar en un esquema de comanejo, la falta de respaldo institucional (Miranda y Gutiérrez 2015) y la falta de definición de derechos exclusivos (Gutiérrez et al. 2017) resultan una de las principales trabas para su implementación. Cabe mencionar que definir claramente los derechos de acceso incentiva el aumento de la participación de los pescadores artesanales en el monitoreo y en los procesos de toma de decisiones (Aguión et al. 2021). Considerando que las pesquerías artesanales de Perú funcionan bajo un régimen de acceso abierto *de facto* (Nakandakari et al. 2017; De la Puente et al. 2020), avanzar en esta dirección en el corto plazo podría representar una notable mejora para la calidad de vida de las personas y la de los recursos sobre los cuales se sostienen sus ingresos. Por otro lado, el desarrollo de liderazgo y capital social por parte de las comunidades de pescadores artesanales han demostrado ser dos atributos clave para una gestión pesquera exitosa (Gutiérrez et al. 2011). En ese sentido, decidir invertir prioritariamente mayores esfuerzos en generar estas capacidades en los actores de la pesca artesanal permitiría avanzar hacia su sostenibilidad.

El comanejo implicaría darle una mayor relevancia al componente humano de la actividad, lo que, a su vez, generaría condiciones para avanzar en el manejo pesquero basado en el ecosistema (Hilborn 2011). En lo inmediato, se podría empezar a operativizar el uso de información socioeconómica en la toma de decisiones de gestión pesquera, tal como reconoce actualmente el ordenamiento jurídico pesquero nacional (Artículo Nº 9 de la Ley General de Pesca, Decreto Ley Nº 25.977). Al respecto, en los últimos años se han hecho importantes esfuerzos por entender la pesca artesanal de Piura en esta dimensión (ver Ocampo-Raeder 2011; Espinosa Anaya 2015; Nakandakari et al. 2017; Velarde 2018; Kluger et al. 2019b; Palacios 2019; Grillo-Núñez et al. 2021; Mendo et al. 2022); sin embargo, no hay evidencia de haber integrado este tipo de conocimiento en la gestión.

CONCLUSIONES

El desarrollo reciente del sector pesquero de Piura no sigue el patrón dominante del sector pesquero peruano, esto es, la pesca industrial de anchoveta para la producción de harina y aceite de pescado. Como principal motor del desarrollo económico pesquero, esta región ha adoptado una dinámica exportadora de producción industrial de alimentos para el consumo humano directo elaborados en base a recursos extraídos, principalmente, de manera artesanal. Esta dinámica, sumada a la dinámica destinada al consumo local y nacional en estado fresco, logran que la pesca artesanal en Piura represente el 87% del desembarque, el 88% del valor agregado y el 95% del empleo del sector pesquero en Piura. Por ello, la consolidación y fortalecimiento de esta cadena de valor pasa por mejorar la gobernanza y gestión de la pesca artesanal, como base para el aseguramiento a largo plazo de los beneficios económicos y sociales para sus actores. En ese contexto, el presente estudio aporta un instrumento de priorización para definir áreas de la cadena de valor que se deben cuidar más para evitar pérdidas socioeconómicas y ganar resiliencia, en un contexto de escenarios futuros climáticos y de productividad pesquera variables. Por ejemplo, el presente estudio ha permitido identificar algunas áreas urgentes de intervención como la promoción del consumo local de especies como la pota, el perico y la concha de abanico; el desarrollo de programas para el fortalecimiento de las capacidades de los pescadores artesanales que distribuyen recursos frescos localmente y que retienen una fracción minoritaria de los beneficios económicos de los recursos que extraen; la aceleración de los procesos de regularización de la flota para disminuir la informalidad en pesquerías artesanales que sustentan una proporción mayoritaria de las exportaciones pesqueras de Piura, como la pota y el perico, entre otras.

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ORIGINAL RESEARCH

A data-limited approach to determine the status of the artisanal fishery of sea silverside in southern Chile

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ABSTRACT. Artisanal fisheries are essential, but for most the status of the stock supporting the fishing activity remains unknown due to lack of data and difficult access to sampling. For example, the artisanal fishery of sea silverside *Odontesthes* (*Austromenidia*) *regia*, in Los Lagos administrative region in Chile, requires a data-limited approach to determine its status because the fishery administration has not invested in its monitoring. The approach consisted of estimating the spawning potential ratio (SPR) from length-frequency data collected in 2019 using length-based spawning potential ratio (LBSPR) and biological reference points using the only-catch optimized method (OCOM) to catch data covering the period from 1960 to 2020. In addition, five age-structured sea silverside populations were simulated considering uncertainty in recruitment and utilizing life-history parameters estimated by FishLife. According to LBSPR, the SPR was 0.58 (95% confidence intervals: 0.5-0.7), suggesting a fully exploited fishery status. The OCOM result was inconsistent with the life-history parameters and was discarded as a valid sea silverside stock assessment. The age-structured population simulations indicated evidence of a reduction in the spawning stock biomass close to 75% of the unexploited condition in 1960. Thus, the underexploited status reached a probability close to 49.4%, and the fully exploited status was 41.2%. The framework for a data-limited stock-assessment approach and results obtained here for the sea silverside are starting essential steps that may be emulated in other artisanal data-limited fisheries.

Key words: Data-poor, assessment, small-scale fishery, simulations, life-history.

Un enfoque de datos-limitados para determinar el estatus de la pesquería artesanal de pejerrey de mar en el sur de Chile

RESUMEN. Las pesquerías artesanales son esenciales, pero para la mayoría de ellas se desconoce el estado de las poblaciones que sustentan la actividad pesquera debido a la falta de datos y al difícil acceso a los muestreos. Por ejemplo, la pesquería artesanal del pejerrey de mar *Odontesthes* (*Austromenidia*) *regia*, ubicada en la región administrativa de Los Lagos de Chile, requiere un enfoque con datos limitados para determinar su estado debido a que la administración pesquera no ha invertido en su monitoreo. El enfoque consistió en estimar la razón de potencial de desove (SPR) a partir de datos de frecuencia de talla recolectados en 2019, utilizando la relación de potencial de desove basada en la talla (LBSPR) y puntos biológicos de referencia utilizando el método optimizado de solo-captura (OCOM) sobre los datos de captura entre 1960 y 2020. Además, se simularon cinco

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poblaciones de pejerrey de mar estructuradas por edad bajo incertidumbre en el reclutamiento y utilizando parámetros de historia de vida estimados por FishLife. Según el LBSPR, el SPR fue de 0,58 (intervalos de confianza del 95%: 0,5-0,7), lo que sugiere un estado de explotación plena. El resultado del OCOM fue inconsistente con los parámetros de historia de vida y se descartó como una evaluación válida del *stock* de pejerrey de mar. Las simulaciones de la poblacionales estructurada por edades mostraron una reducción en la biomasa desovante cercana a 75% de una condición no explotada en 1960. Así, el estado subexplotado alcanzó una probabilidad cercana a 49,4%, y el estado de explotación plena de 41,2%. El marco para un enfoque de la evaluación de *stock* con datos limitados, y los resultados obtenidos aquí para el pejerrey de mar, están iniciando pasos esenciales que podrían emularse en otras pesquerías artesanales limitadas en datos.

Palabras clave: Datos limitados, evaluación, pesquería artesanal, simulaciones, historia de vida.

INTRODUCTION

Global total marine catches were 84.4 million metrics tons in 2018, from which 78.7% came out from biologically sustainable stocks. In 2017, this fraction reached 65.8%, and stocks fished biologically unsustainably were 34.2% (FAO, 2018). Unfortunately, there are problems with artisanal fisheries, either because they are difficult to sample or because information on them is generally incomplete, or both, increasing the uncertainty of global fishery statistics. Nevertheless, artisanal fisheries are essential mainly because they are not only an indispensable source of food for human consumption, but also generate employment for fishers, providing economic well-being for all agents involved in the socio-ecological system resulting from these fisheries (Salas et al. 2007; Pomeroy and Neil 2011).

In Chile, artisanal fisheries contributed almost 38% to the national landings in 2020, industrial fisheries 21% (mainly pelagic fish) and aquaculture 41% (mainly salmon and mussel aquaculture) (SERNAPESCA 2020). Almost 61% of the artisanal fisheries landings are fish, 29% seaweed, 6% mollusks, and the rest are crustaceans, sea urchin, and tunicates (SERNAPESCA 2020). The silverside *Odontesthes* (*Austromenidia*) *regia* Humboldt, 1821, is a small pelagic fish that supports an artisanal fishery, inhabiting marine coastal waters in the Humboldt Current System, from northern Peru to southern Chile (Brian and Dyer 2006; Arellano and Swartzman 2010; Deville et al. 2021). Silversides are small, slender and elongated fish which live between 1 and 4 years, and their spawning season lasts between two and five months (Pajuelo and Lorenzo 2000; Moresco and Bemvenuti 2006; Arrieta et al. 2010). Thirteen species of silversides have been described in Chile, with representatives of the subgenus *Austromenidia* (including *Odontesthes regia*) being the most abundant in the marine ecosystem (Dyer and Gosztonyi 1999). Sea silverside has high genetic diversity and at least two co-distributed genetic groups (Deville et al. 2021). The species can inhabit diverse marine environments, such as estuaries, beaches, sandy bottoms, and moves in small schools near the coast, between 0 and 50 m depth (Cifuentes et al. 2012).

In Los Lagos administrative region, southern Chile, the sea silverside is a species of great commercial interest for artisanal fishers, where landings represent 90% of the total landings of the species (SERNAPESCA 2020). Overall, the main fishing gear used for the silverside fishery corresponds to gillnets (2-3 m deep, 3-4 cm mesh size), which are positioned in the coastal zone (SUBPESCA 2003). The official records of sea silverside artisanal landings in Chile increased from 58 t in 1960 to 661 t in 2020. In Los Lagos, landings started in 1965 attaining peaks of 4,420 t and 3,271 t in 1990 and 1999, respectively. However, after the last peak, sea silverside landings declined to only 4 t in 2011 and started to recover until 2020 (Figure 1).

There are concerns about the status of the artisanal sea silverside fishery. Therefore, a data-limited approach was used to determine the status of

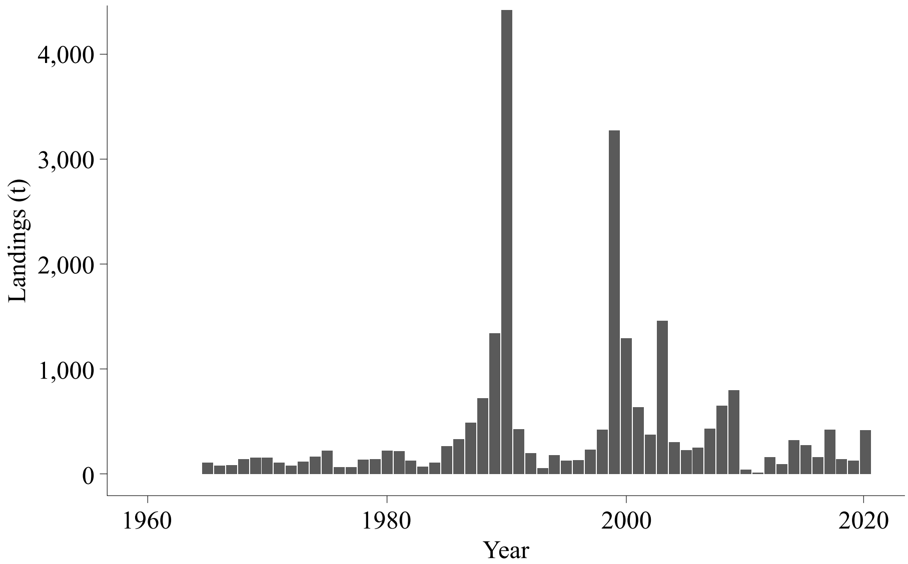

Figure 1. Landings of sea silverside in Los Lagos administrative region in Chile during the period 1960-2020.

the fishery in the Los Lagos Region. The sea silverside reproductive aspects, age, and growth were studied in Peruvian waters by Villavicencio and Muck (1984), Gómez Alfaro et al. (2006), Arrieta et al. (2010), and Campos León et al. (2020). Plaza et al. (2011) described sea silverside as an asynchronous multiple-spawner with an extensive spawning season in Chile. Pavez et al. (2008) studied biological and fishery aspects of sea silverside in Los Lagos administrative region. These authors concluded that catches were supported by the spawning stock, particularly reproductive aggregations near shore, and the fishery could be affecting the reproductive potential since sea silverside is a low-fecundity species.

Most data-limited stock assessment methods consider commercial catch (Free et al. 2020; Ovando et al. 2022), body length data (Hordyk et al. 2014a, 2014b; Prince et al. 2015; Hordyk et al. 2016), or both. The performance of data-limited methods is usually evaluated by simulation considering uncertainty in the population dynamics (Zhou et al. 2017a; Carruther and Hordyk 2018; Free et al. 2020; Sharma et al. 2021). This paper evaluates the sea silverside status in Los Lagos administrative region, uses length-frequency data to compute the spawning potential ratio, and evaluates the models' performance by simulating the population dynamics.

MATERIALS AND METHODS

Study area and data sources

The study area is referred to as Los Lagos administrative region in Chile. Total landings were obtained from official records of the Servicio Nacional de Pesca y Acuicultura (SERNAPESCA, https://sernapesca.cl). Biological data were obtained by sampling the artisanal activity in four fishing zones during 2019. Punta Quillahua and Amortajado have zones exposed to the sea along the continental coast. The other two, Bahía Ancud and Golfo de Quetalmahue, are semi-enclosed fishing zones in northern Chiloé island (Figure 2). The fishing zones are associated with Ancud as the main port for landings. A total number of 552 sea silversides were sampled. For

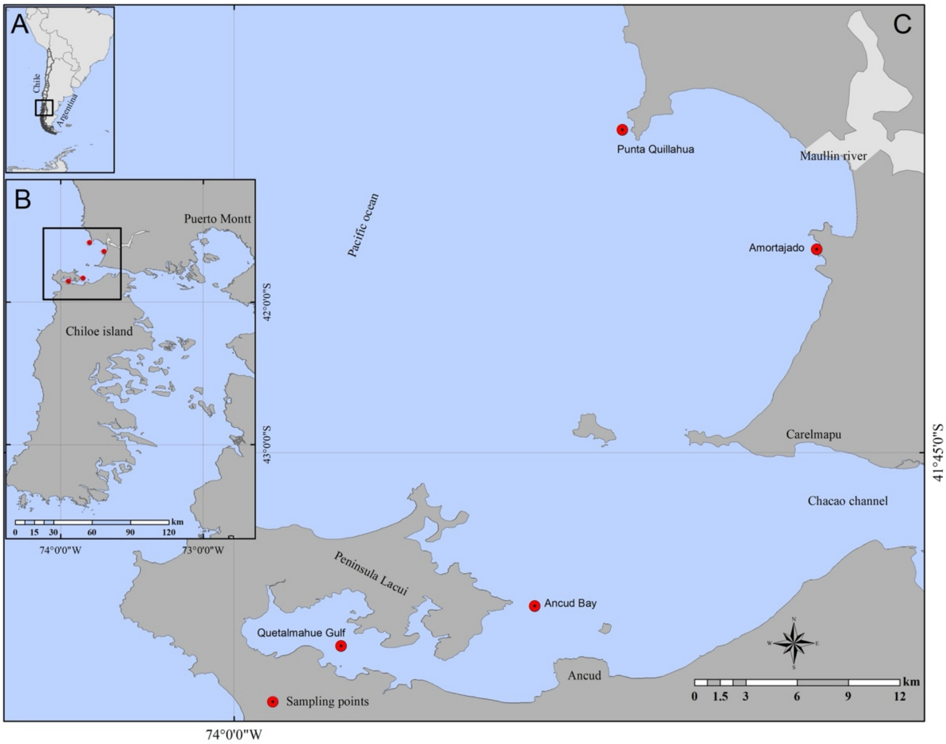

Figure 2. Study area in Chile (A) showing sampling locations in northern Chiloé island, and (B) zoom of sampled locations during 2019 (C).

each individual, total mass (W) was measured using a scale Pesamatic Model WTB 2000 (± 0.01 g) and total length (TL) with a board meter (± 0.1 cm). Sex of individuals (males, n = 338; and females, n = 214) was determined through macroscopic observation of gonads, after dissection.

Biological data analysis

Biological data were grouped according to the following austral seasons: summer (January-March), autumn (April-June), winter (July-September), and spring (October-December). Then, the average, standard deviation, and range of total length (cm) and body weight (gr) were computed by season and sexes. Besides, parameters of the length-weight relationship (LWR) were determined, in which the body is a potential function of total length (Froese 2006):

$$W = aL^b$$

where W is the total body weight, L is the total length (cm), and a and b are unknown parameters to be estimated. Although the LWR is a non-linear model and the parameters could be estimated through a non-linear least-square approach, the body weight violates the linearity and homoscedasticity. Froese (2006) and Ogle (2016) stated that bodyweight follows a log-normal distribution, and therefore a multiplicative error term could be a better choice. Hence, linearizing the equation by applying logarithms makes the error additive, stabilizes the variance, and the unknown parameters can be estimated using a linear model. The log-normal and gamma distributions were fitted to observed body weight data using maximum likelihood estimation implemented in the function fitdistr of the R-package MASS (Venables and Ripley 2002). According to the log-likelihood and Akaike information criterion (AIC) (Akaike 1974), body weight of sea silverside follows a gamma distribution (log-likelihood = -2206.2, AIC = 4416.4) rather than a log-normal distribution (log-likelihood = -2209.7, AIC = 4423.4). Therefore, unknown parameters (*a* and *b*) of the LWR were estimated using a generalized linear model (GLM) with gamma family and natural logarithm as link function. The following linear predictor was used:

$$W = \alpha + \beta \cdot \text{SEX} \cdot \text{SEASON} \cdot \log L + \text{SEX} + \text{SEASON}$$

where α is the intercept, β the slope, SEX is a factor for males and females, SEASON is a factor for summer, autumn, winter, and spring. The R-package (DHARMa) (Harting 2022) for residual diagnostics was utilized, which uses a simulation-based approach to create standardized residuals for a fitted GLM. After testing residuals, normal residuals followed. An ANCOVA was used with a *Chi*-squared test to evaluate significant effects of fixed groups, i.e. SEX and SEASON (Lai and Helser 2004). A submodel consisted of removing one of the fixed factors resulting non-significant and represented by a model with different intercepts and fixed slope (model 1), a model with changes in the slope and fixed intercept (model 2), and a model with changes in both the intercept and slopes simultaneously (model 3) (e.g. Nahdi et al. 2016). The best submodel was selected with AIC (Akaike 1974), and the Nagelkerke pseudo-r^2 (Nagelkerke 1991) was computed. The R-package MASS was utilized to fit GLMs (Venables and Ripley 2002) and the R-package rcompanion (Mangiafico 2015) for computing the Nagelkerke pseudo-r^2.

Once LWR was analyzed, the condition factor among seasons and sexes was studied. The relative condition factor (Le Cren 1951) was computed as $K_n = W/L^b$, where K_n is the allometric condition factor, W is the body weight, L is the total length, and b is the allometric exponent of the LWR (Nahdi et al. 2016).

Status of the fishery

Length-based spawning potential ratio

Annual length-frequency data were utilized to apply the length-based spawning potential ratio (LBSPR) model of Hordyk et al. (2014a, 2014b). The LBSPR is a steady-state stock assessment model that estimates the spawning potential ratio as an index of status. In addition, the method also estimates the parameters of a logistic selectivity curve (Hordyk et al. 2016). The input is one or more length-frequency data, the von Bertalanffy (VB) asymptotic length (l_∞), the ratio between the natural mortality (M) and the VB growth coefficient (M/k) (Prince et al. 2015), and the length at first maturity (l_m) obtained from Pavez et al. (2008) (Table 1).

Catch data analysis

The only-catch stock assessment model called OCOM (Optimized Catch-Only Method) of Zhou et al. (2017a) as implemented in the package ‘datalimited2’ (Free 2018) for the software R (https://www.r-project.org) was applied to determine the status of the sea silverside artisanal fishery in Los Lagos administrative regions. As mentioned, landing data covered the period from 1960 to 2020 (Figure 1) assuming they are a proxy of the catch since landings could be less or equal to the catches.

The OCOM uses Schaefer’s logistic surplus production:

$$B_{i+1} = B_i + rB_i\left(1 - \frac{B_i}{K}\right) - C_i$$

where B_i is the biomass at the beginning of the year i, r is the intrinsic growth rate, K is the carrying capacity, and C_i is the observed catch during year i. The unknown parameters to be estimated are r and K, and the estimation procedure utilizes a prior for r to solve K through the ratio B_i/K or stock saturation, i.e. $s = B_i/K$. The prior for r is based on natural mortality (M), and prior for the stock saturation is based on a boosted

Table 1. Life-history parameters estimated for sea silverside according to Pavez et al. (2008), and life-history parameters estimated by FishLife. Additional derived parameters needed for simulation of a population dynamics highlighted by an asterisk (see text).

Process	Parameter	Symbol	Units	Pavez et al. (2008)	FishLife
Growth	Asymptotic length	l_∞	cm	24.0	29.0
	Asymptotic weight	w_∞	g	95.0	241.0
	Growth coefficient	k	year^{-1}	1.047	0.597
		t_0	year	0.632	-0.274*
	Coefficient of variation of length at age	CV_L	-	n.a.	0.05*
Mortality	Natural mortality rate	M	year^{-1}	1.2	1.1
	Maximum age	t_{max}	year	3 +	5
Maturity	Age at maturity	t_m	year	n.a.	1.3
	Length at maturity	l_m	cm	15.8	16.9
	Shape maturity at length	δ	cm	2.0	0.5*
	Spawning time	τ	-		0.583*
Stock-recruitment	Steepness	h	-	-	0.815
	Standard deviation of recruitment deviations	σ_R	-	-	0.567
	Autocorrelation of recruitment deviations	ρ_R	-	-	0.352
Length-weight relationship (LWR)	Intercept LWR	a	g cm^{-b}	0.0050	0.0098*
	Allometry coefficient LWR	b		3.1	3*
Average temperature	Temperature	T	°C	12.6	18.1

regression trees (BRTs) model developed by Zhou et al. (2017b). The estimation considered n = 10,000 values for r and s, and the optimization function solved viable r-K pairs to set upper and lower K values, which are not part of a prior range. Derived quantities are MSY = $rK/4$ and $F_{MSY} = r/2$ based on optimized r-K pairs.

Simulation of sea silverside age-structured populations

In addition to the known life-history parameters of Pavez et al. (2008) for the sea silverside, other life-history parameters were obtained by applying the FishLife package developed by Thorson et al. (2017) and Thorson (2020) for the software R. FishLife is an efficient method to estimate life-history parameters for little-studied species. It is based on a multivariate model that utilizes a comprehensive evolutionary model of life-history parameters fitted to longevity, growth, natural mortality, maturity, and temperature data from FishBase (Froese and Binohlan 2000; Froese and Binohlan 2003; Froese and Pauly 2022). FishLife utilizes stock-recruitment parameters and population parameters from the RAM Legacy Database (https://www.ramlegacy.org) (Ricard et al. 2012). According to a multivariate normal distribution, the model predicts a vector of life-history parameters along phylogenetic lineages, with lower taxonomic levels having more precise parameters than higher levels.

Based on FishLife, additional derived parameters were obtained for sea silverside such as the von Bertalanffy age at length zero (Pauly 1983), the assumed coefficient of variation of length at age, shape of maturity (based on 95% maturity, Pavez et al. 2008), the spawning time as year fraction (i.e. the month starting the reproductive period according to Plaza et al. 2011), and the length-weight parameters based on cube law (Froese 2006) (Table 1). Once all the parameters were obtained, five age-structured sea silverside population models were simulated for the period 1965-2020 (Table 2). The simulations considered uncertainty in unexploited recruitment level and interannual variability. The unexploited recruitment (R_0) scales the population level, specifically the unexploited spawning stock biomass (SSB_0) at the beginning of 1965. The interannual variability is a process error impacting the trajectory of the population from 1965 to 2020, given the observed catch history. The steepness (h), standard deviation of deviations of log recruitment (σ_R), and autocorrelated annual deviations (ρ_R) allowed us to estimate the stock-recruitment model of Beverton and Holt parameterized by Punt and Cope (2019), as:

$$R_i = \frac{R_0 SSB_{i-1}}{SSB_0} \frac{4h}{(1-h)+(5h-1)SSB_{i-1}/SSB_0} \exp(\varepsilon_i - 0.5\sigma_R^2)$$

where ε_i are the annual deviations of recruitment, which are autocorrelated, as:

$$\varepsilon_i = \rho_R \varepsilon_{i-1} + \sqrt{1-\rho_R^2}\,\eta_i$$

where ρ_R is the serial correlation coefficient and $\eta_i \sim N(0, \sigma_R^2)$ (Thorson et al. 2014; Hawkshaw and Walters 2015). The simulation approach consisted of selecting the lower limit for R_0, on a log scale ($\log R_0$), and projecting forward from 1965 to 2020, while solving the fishing mortality rate (F_i) given the observed catch, selectivity (v_j), and the projected vulnerable biomass (V_i) of the population (Table 2). The Baranov catch equation was utilized to compute the fishing mortality rate through the Newton-Raphson algorithm (Gulland 1965; Quinn and Deriso 1999). The basic idea that underlies each simulation is to reconstruct possible trajectories of stock change from the start of the fishery to the most recent year, given population dynamics (i.e. the stock-recruitment model, recruitment variability, and survival) (Table 2), selectivity (v_j), and observed catches.

Once R_0's lower limit was determined, R_0's upper range was defined using two times σ_R^2. Five sea silverside populations were simulated, each with 1,000 alternative and equally probable trajectories of recruitment, and hence for the state variables of the population. Invalid trajectories, e.g. those resulting in extinction before 2020, were discarded. With valid trajectories, the ratio between the spawning biomass in 2020 and the unexploited spawning biomass, i.e. SSB_i/SSB_0, allowed to estimate the following status condition: depletion ($SSB_i/SSB_0 < 0.25$), overexploitation ($0.25 \leq SSB_i/SSB_0 < 0.4$), fully exploitation ($0.4 \leq SSB_i/SSB_0 < 0.75$), and under exploitation ($SSB_i/SSB_0 > 0.75$). The status categories are in agreement with the Chilean Law (Payá et al. 2014) and consider a target reference point to be 50% of the unexploited spawning biomass, i.e. $SSB_{\text{target}} = 0.5SSB_0$, with a range between 0.4 and 0.75 of SSB_0. The limit reference point was the half of the target, i.e. $SSB_{\text{lim}} = 0.25SSB_0$.

RESULTS

Biological data

The total length of sea silverside ranged between 14.8 and 24.0 cm for females and 15.4 and 23.4 cm for males, showing similar total length and weight averages and standard deviations (Table 3). Nevertheless, the length-frequen-

Table 2. Equations of the age-structured simulation model for sea silverside in Los Lagos region, Chile.

Process or state	Equation	Number
Length at age	$L_j = l_\infty(1 - \exp(-k(j - t_0))$	1
Maturity at size l	$m_l = 1/(1 + \exp((l_m - l) / \delta)$	2
Maturity at age j	$m_j = \sum_{l=1}^{L} m_l \left(\frac{1}{L_j CV_L \sqrt{2\pi}}\right) \exp\left(-\frac{(l - L_j)^2}{2(L_j CV_L)^2}\right)$	3
Selectivity at size l	$v_l = \left(1 + \exp(-\frac{\log(19)\,(l - l_{50})}{d}\right)^{-1}$, where $d = l_{95} - l_{50}$	4
Selectivity at age j	$v_j = \sum_{l=1}^{L} v_l \left(\frac{1}{L_j CV_L \sqrt{2\pi}}\right) \exp\left(-\frac{(l - L_j)^2}{2(L_j CV_L)^2}\right)$	
Weight at age	$w_j = aL_j^b$	5
Abundance	$N_{i,j} = \begin{cases} R_i,\ j = 1 \\ N_{i,j-1} \exp(-M),\ 1 < j < t_{max};\ i = 1 \\ N_{i-1,j-1} \exp(-M - v_{j-1} F_{i-1}),\ 1 < j < t_{max};\ i > 1 \end{cases}$	6
Total biomass at i beginning of year	$B_i = \sum_{j=1}^{t_{max}} N_{i,j} w_j$	7
Spawning biomass	$SSB_i = \sum_{j=1}^{t_{max}} m_j w_j N_{i,j} \exp(-\tau Z_{i,j})$	8
Vulnerable biomass	$V_i = \sum_{j=1}^{t_{max}} v_j w_j N_{i,j} \exp(-0.5 Z_{i,j})$	9
Unexploited spawning biomass	$SSB_0 = \varphi_0 \,.\, R_0$	10
Reproductive potential without fishing	$\varphi_0 = \sum_{j=1}^{t_{max}} m_j w_j s_j \exp(-\tau M)$; where $s_j = \begin{cases} 1 & j = 1 \\ s_{j-1} \exp(-M) & j = 2, ..., t_{max} \end{cases}$	11
Reproductive potential F at fishing mortality	$\varphi_F = \sum_{j=1}^{t_{max}} m_j w_j s_j \exp(-\tau (M + v_j F)$; where: $s_j = \begin{cases} 1 & j = 1 \\ s_{j-1} \exp(-(M + v_j F) & j = 2, ..., t_{max} \end{cases}$	12

Table 3. Summary of total length, body weight, and minimum (min) and maximum (max) values of sea silverside. Standard deviation shown in parenthesis.

			Total length (cm)			Body weight (g)		
Sex	Season	n	Mean (cm)	Min	Max	Mean (g)	Min	Max
Female	Summer	61	20.2 (2.4)	14.8	23.8	59.1 (20.1)	23	94
	Autumn	46	20.3 (1.1)	18.6	23.4	52.7 (9.3)	39	78
	Winter	45	20.9 (1.3)	17.4	23.9	61.8 (12.3)	36	95
	Spring	62	20.1 (1.4)	17.6	24.0	54.6 (12.5)	37	89
	Annual	214	20.3 (1.7)	14.8	24	57.0 (14.9)	23	95
Male	Summer	76	19.6 (2.0)	15.4	23.4	54.0 (15.1)	23	82
	Autumn	43	20.2 (1.1)	17.5	22.3	52.5 (8.7)	38	70
	Winter	68	20.4 (1.0)	18.5	22.8	57.9 (10.1)	41	85
	Spring	151	19.6 (1.1)	17.2	23.2	49.9 (8.9)	34	84
	Annual	344	19.8 (1.4)	15.4	23.4	52.8 (11.2)	23	85
Both	Annual	558	20.0 (1.5)	14.8	24	54.4 (12.9)	23	95

cy evidenced the most extensive range of sea silverside specimens in summer, from 15 to 24 cm (Figure 3).

The general model for the length-weight relationship (LWR) showed no significant differences between males and females. Indeed, the factor sex showed no effects in the intercept (SEX, P = 0.083), nor in the slopes (SEX · log*L*, P = 0.334), neither in the intercept among sex by season (SEX · SEASON · log*L*, P = 0.547) or in the slope by season (SEX · SEASON . log*L*, P = 0.070). Discarding SEX from the general model and considering only seasonal effects, the AIC values for models 1, 2, and 3 were 3008.2, 3007.4, and 3008.7, respectively. Although the AIC was close among competing models, the best model for the LWR was model 2 (Table 4), with a fixed intercept and different slopes among seasons (Nagelkerke pseudo-$r^2 = 0.921$). The highest expected weight at a given length occurred in summer and the lowest in autumn for fish larger than 20 cm (Figure 4 A). This result was a consequence of different seasonal slopes for the LWR, with a slope higher in summer and lower in autumn (Table 4). According to the standard error, the slope was not different from 3, and the lowest 95% confidence interval was 2.901 while the highest equaled 3.058. Accordingly, the allometric condition factor (K_n) did not show significant differences among seasons for males and females, but females showed a lower range in autumn and larger in spring (Figure 4 B).

Status of the fishery

Length-based spawning potential ratio

The fit of the steady-state LBSPR model to the annual length-frequency of sea silverside performed well (Figure 5 A). The resultant spawning potential ratio (SPR) was 0.58, with 95% confidence intervals (CI) between 0.5 and 0.7. The ratio fishing to natural mortality (F/M) was 3.1 (CI: 1.9-4.3), and the logistic selectivity parameters were L_{50} = 19.7 cm (CI: 19.1-20.2 cm), and L_{95} = 22.6 cm (IC: 21.8-23.4 cm). The resultant selectivity curve was to the right of the maturity ogive (Figure 5 B), suggesting that on average a significant proportion of fish were spawning before being caught.

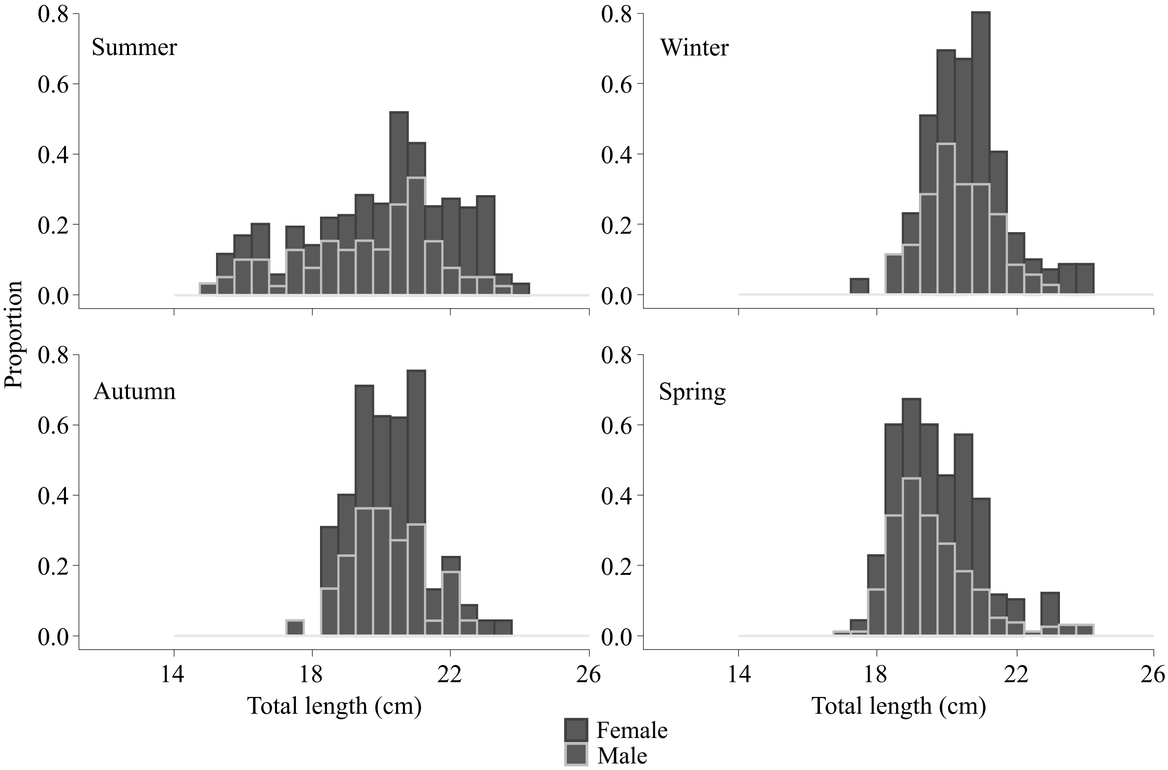

Figure 3. Length-frequency data of sea silverside by sex and seasons during 2019.

Table 4. Coefficients for the best model describing the length-weight relationship of sea silverside. Model 2 estimated by generalized linear model, family gamma and natural logarithm as link function. Nagelkerke pseudo-r^2 = 0.921, likelihood ratio test: -708.5 ($p < 0.01$).

Coefficients	Estimate	Standard error	t-value	P-value
Intercept	-4.926	0.114	-43.39	< 0.01
Length*Summer	2.983	0.038	78.43	< 0.01
Length*Autumn	2.953	0.038	78.06	< 0.01
Length*Winter	2.976	0.038	79.15	< 0.01
Length*Spring	2.971	0.038	77.90	< 0.01

The only-catch stock assessment model

Population parameters and biological reference points obtained using the optimized only-catch model (OCOM) indicated a median carrying capacity (K) of 8,197 t and a median intrinsic growth rate (r) of 0.342 (Table 5). The maximum sustainable yield (MSY) was 700 t, and the fishing mortality rate at MSY (F_{MSY}) was 0.171 (IC: 0.083-0.542). Finally, the saturation (B_{2020}/K) showed a reduction of 0.313 in biomass in 2020, slightly above the limit biomass and equivalent to B_{2020}/B_{MSY} = 0.575 (IC: 0.192-1.175) (Figure 6 C).

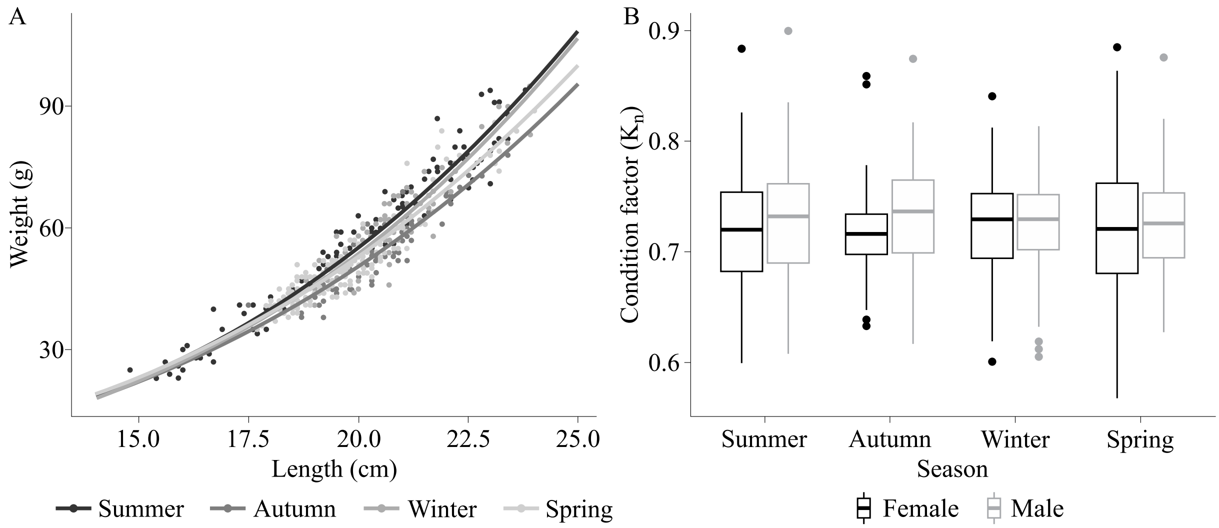

Figure 4. A) Length-weight relationships by seasons. B) Condition factor by sex and seasons of sea silverside (2019).

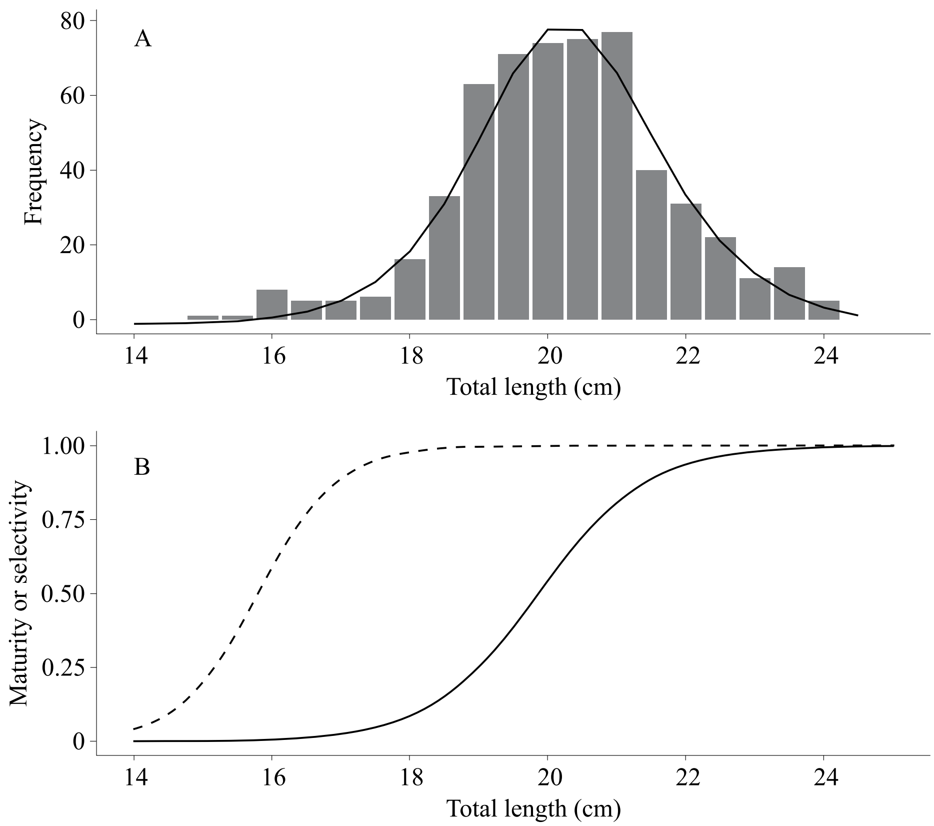

Figure 5. A) LBSPR fitted (continuous line) to the annual length-frequency data (bar). B) The logistic selectivity curve (continuous line) obtained and compared with the maturity ogive (segmented line) of Pavez et al. (2008).

Table 5. Estimates of the logistic surplus production model (r, K) and biological reference points for sea silverside based on the OCOM model applied to the catch history in Los Lagos region, Chile (1960-2020).

Parameter	Median	Lower limit	Upper limit
r	0.342	0.014	0.463
K	8,197	7,007	13,625
MSY	700	466	812
B_{MSY}	4,098	3,504	6,813
F_{MSY}	0.171	0.133	0.232
B_{2020}/K	0.313	0.222	0.583

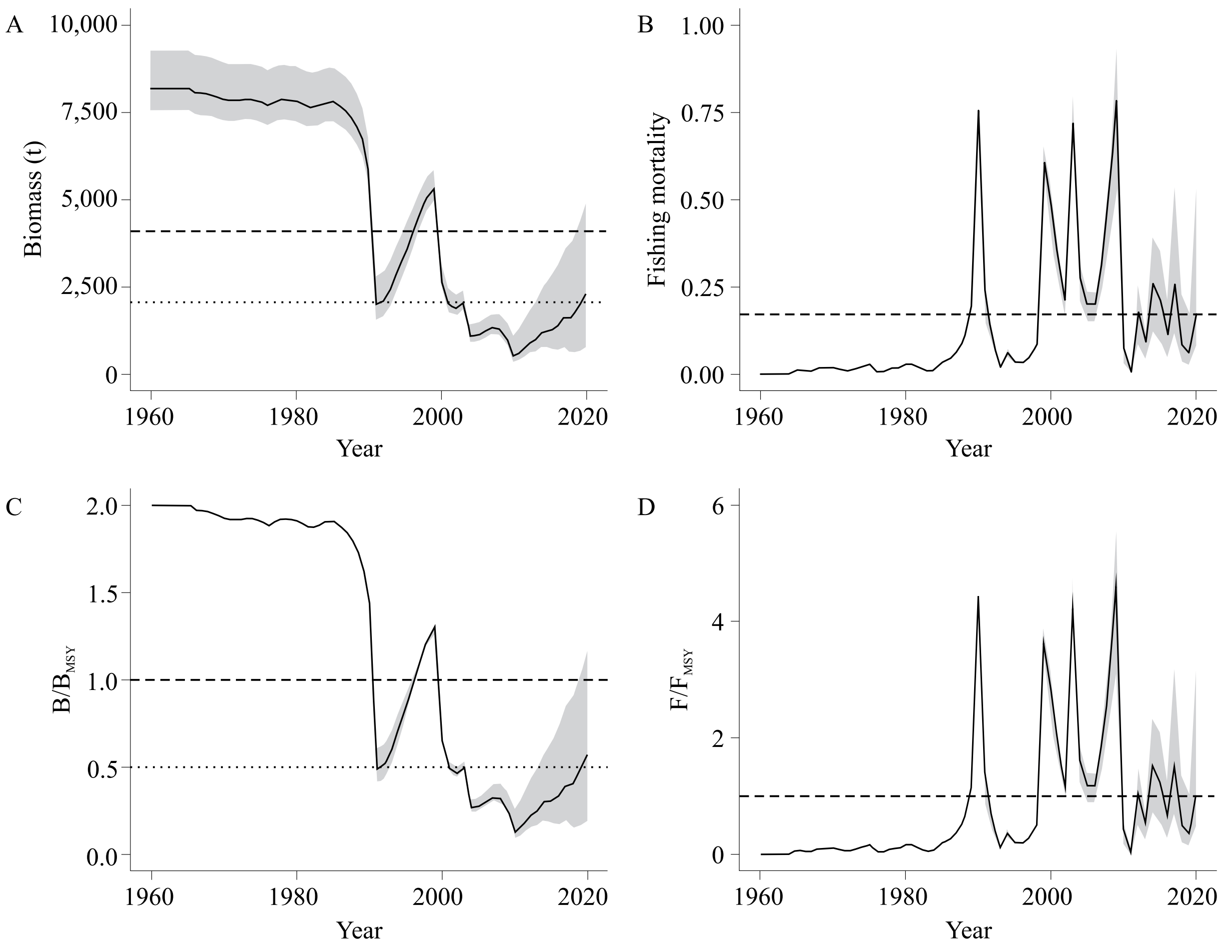

Figure 6. A) Results of the only-catch optimized method: changes in sea silverside biomass. B) Fishing mortality. C) Relative changes in biomass. D) Relative changes in fishing mortality regarding the target biological reference points (segmented line) associated with the logistic surplus production maximum sustainable yield. The dotted line in panel A and C is the limit biological reference point.

According to the selected r-K pairs, biomass trajectories revealed no effect of fishing between 1960 and 1990. However, overfishing occurring in 1989-1990 impacted the sea silverside population negatively (Figure 6). After that, a slight recovery occurred until 1999, but the overfishing between 1999 and 2005 determined a depletion. Eventually, the sea silverside exhibited a recovery from 2005 to 2020 with increased uncertainty.

Simulations of age-structured sea silverside populations

The minimum value for the unexploited recruitment ($\log R_0$) was 4.8, and according to σ_R = 0.567, the upper limit for $\log R_0$ was 5.6 (Figure 7). From this range, the level of unexploited recruitment was selected at random. Simulations of the state variables were summarized by utilizing the percentile at 10, 50, and 90%. The five populations share identical life-history parameters (Table 2), and they differed only in R_0 and interannual recruitment variability (Figure 7 A). Higher catches in 1990, 1999-2000, and 2003, negatively affected the total biomass (Figure 7 B), particularly the spawning stock biomass (Figure 7 C).

The spawning potential ratio, SSB_i/SSB_0, showed similar performance in the five simulated populations (Figure 8). The status in 2020 was similar and fluctuated between 72.7 and 76.9% among the five simulated sea silverside populations. Considering the underlying uncertainty in the spawning stock biomass, the probabilities for under-exploited and fully exploited status were higher (Table 6).

DISCUSSION

This study aims to develop a data-limited approach to determine the status of the sea silverside stock in Los Lagos administrative region. Primary data required for such an approach rely on monitoring fishery and biological data regularly, depending on how the fishers operate within territorial, social, economic, and cultural aspects. As in most artisanal fisheries, monitoring the Los Lagos sea silverside fishery is complex due to dispersion and access to multiple fishing coves and fishing grounds in species widely distributed in a complex territory.

Biological data collected here were limited in sample size and spatially but covered all the seasons during 2019. Nevertheless, samples revealed a length structure for males and females supported by adults, matching results of Pavez et al. (2008) in 2007. These authors found sea silverside specimens ranging between 10 and 32 cm, with an average total length of 23.6 cm and average weight of 98.8 g. Although, not rigorously compared, our results suggest a reduction in the average length and average weight of sea silverside compared with Pavez et al. (2008). Fishers operated mainly with standardized gillnets (SUBPESCA 2003), and the average length comparison with data of Pavez et al. (2008) could be correct. In addition, larger specimens collected in autumn and winter could be associated with the pre-reproductive and beginning of the reproductive cycle (Plaza et al. 2011). Besides, length-weight relationships were similar between males and females, but the expected body weight was lowest in autumn and the highest in summer, coinciding with better conditions for feeding (Iriarte et al. 2007, 2011) and with results reported by Gómez-Alfaro et al. (2006) in Pisco, Peru. Regarding to the condition factor (CF) of sea silverside, it did not change among seasons, but the wider CF occurred in females during spring, which coincided with the reproductive cycle and the transition to higher concentrations of phytoplankton biomass in the coastal waters (Iriarte et al. 2007).

As mentioned, length-frequency data are one of the primary data to determine the fish population status (Hordyk et al. 2014a, 2014b). Thus, the annual length frequency of sea silverside

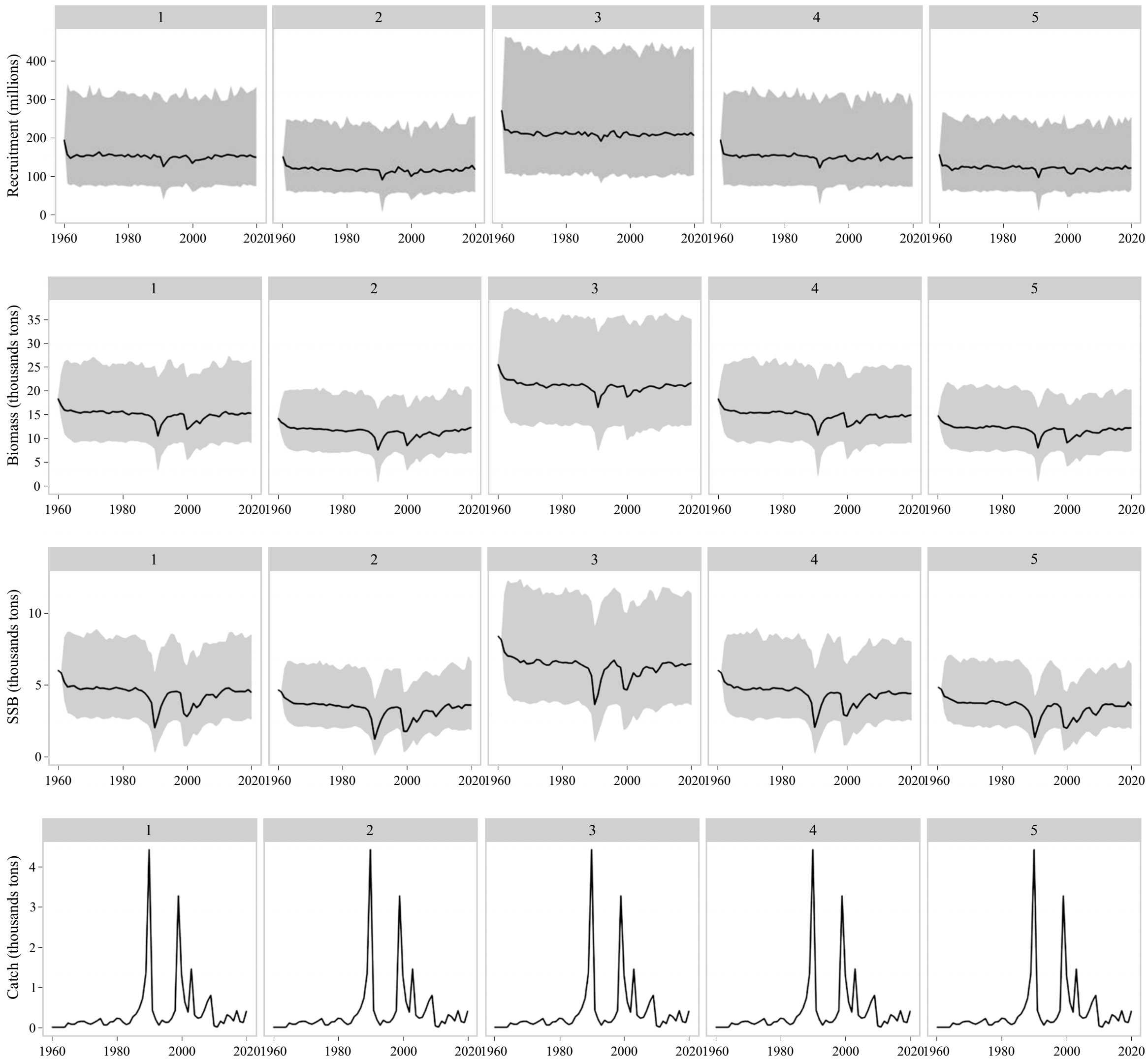

Figure 7. Simulations of age-structured of sea silverside populations (columns) based on the uncertainty in recruitment (A), resulting total biomass (B), spawning stock biomass (SSB) (C), conditioned to the observed catch history (1960-2020) (D). The grey area represents percentile intervals at 90%, and the continuous line indicates the median of simulations per recruitment scenarios (columns).

obtained here is fundamental to estimate the spawning potential ratio (SPR), resulting in 58% with confident intervals between 50 and 70%. These results mean that the sea silverside would be fully exploited in Los Lagos administrative region. The fishing gear utilized by fishers varies, but in Los Lagos, the gillnet is the main fishing gear used by fishers (SUBPESCA 2003), followed by beach seine pulled by hand to the beach (personal observations). The length at first capture estimated here was 19.7 cm, i.e. the length at 50% selectivity. Thus, the length at first capture was higher than maturity length (l_m = 15.8 cm, Pavez et al. 2008). Furthermore, the selectivity curve obtained with LBSPR allows a significant fraction of sea silverside to spawn prior to be cap-

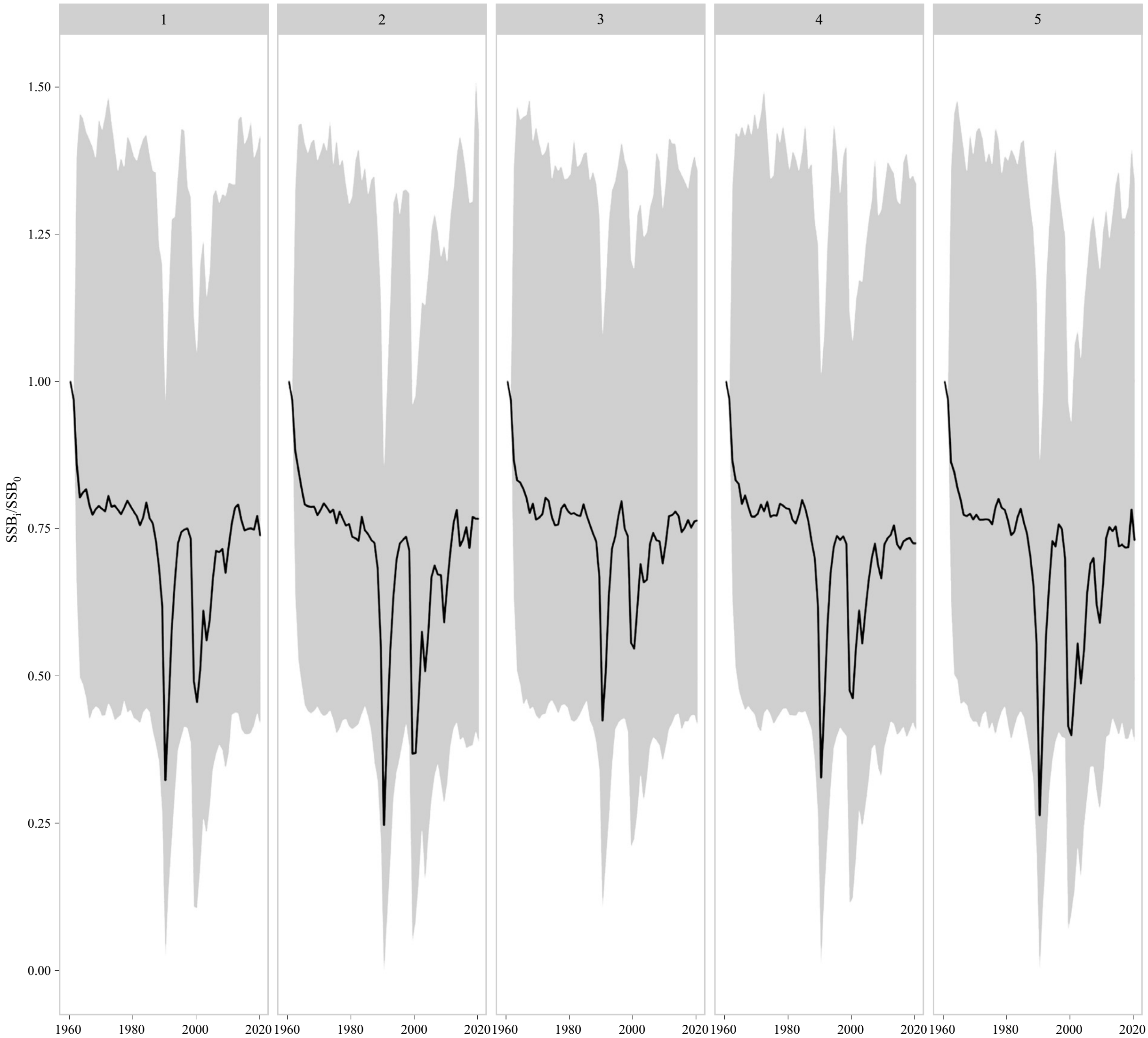

Figure 8. Reproductive potential indicator for sea silverside status, consistent in the ratio between the spawning stock biomass in a given year (SSB_i) and its unexploited level (SSB_0). The grey area represents percentiles at 90%, and the continuous line is the median of alternative and equally probable spawning biomass trajectories.

tured. Therefore, although sea silverside aggregates close to the coast to spawning, raising its vulnerability to fish activity, there is no evidence that the fishery affects the reproductive potential, as suggested by Pavez et al. (2008).

Nevertheless, the reduction in average total length from 23.6 in 2007 to ca. 20 cm in 2019 would indicate a sensible reduction in fecundity due to the repetitive removal of larger female individuals in the past. Partial fecundity as a function of total length was demonstrated for sea silverside in the study area by Plaza et al. (2011), and for the sea silverside in Peru (Gómez Alfaro et al. 2006). However, the reduction in the SPR to 58% (IC: 50-70%) obtained by applying the LBSPR method should consider the caveat of this

Table 6. Performance of the simulated age-structured population model under uncertainty during the recruitment process of sea silverside given by the observed catch history (1960-2020). The effective number of viable population trajectories shown in parenthesis.

Indicator		Populations simulated 1 (723)	2 (419)	3 (924)	4 (695)	5 (462)	Weighted average
Status	SSB_{2020}/SSB_0	73.9	76.9	76.6	72.7	73.2	74.7
Collapse	$Pr[SSB_{2020}/SSB_0 < 0.25]$	0.6	1.7	0.9	1.3	2.6	1.3
Overexploitation	$Pr[0.25 \leq SSB_{2020}/SSB_0 < 0.4]$	8.2	9.3	7.9	7.6	7.6	8.0
Fully exploitation	$Pr[0.4 \leq SSB_{2020}/SSB_0 < 0.75]$	42.3	37.7	39.5	43.9	42.2	41.2
Under exploitation	$Pr[SSB_{2020}/SSB_0 > 0.75]$	49.9	51.3	51.6	47.2	47.6	49.4

data-limited stock assessment model. Indeed, the LBSPR is a steady-state or equilibrium model, and therefore the length-frequency data must be representative of average conditions. Furthermore, although sea silverside is a small pelagic fish with a short life cycle, the recruitment variability should be influencing the abundance and length structure like in the summertime. However, the fishery is supported by larger adults, and hence, the length structure is not influenced by fluctuations in recruitment. In addition, the fishing effects in the length structure are represented in the descending arm of the length-frequency histogram. That is the reason why the LBSPR estimated a ratio F/M = 3.1 (IC: 1.9 to 4.3).

In terms of the catch history, the Only-Catch Optimized Method (OCOM) (Zhou et al. 2017a; Free 2018) revealed a different status for the sea silverside artisanal fishery in Los Lagos region. Indeed, the OCOM showed that the sea silverside population was recovering from the lowest depleted biomass (B/B_{MSY} = 12.9%) from 2010 to 2020 (B/B_{MSY} = 57.5%). In 2020, however, the uncertainty represented by the confidence interval was vast from a depleted to a fully exploited status. In addition, the median value for r was 0.342, which according to the natural mortality estimates the r value seemed to be lower than expected. Indeed, the estimates of natural mortality (M) ranged between 1.1 and 1.2, and hence F_{MSY} = 0.87M = 0.96-1.0 (Zhou et al. 2012), and $r = 2F_{MSY} \approx 2$. Therefore, the OCOM results seemed to be inconsistent with the sea silverside biology and considered invalids. In order to proceed to a more formal stock assessment with surplus production models, it will be necessary to collect fishery data and obtain catch per unit effort as a relative abundance index.

Age-structured simulations showed that the spawning stock biomass would be reduced to approximately 75% from the unexploited condition in 1960. The underexploited status reached a probability close to 49.4%, and the fully exploited status was 41.2%. The underexploited status could be a consequence of sampling recruitment from a log-normal distribution. The short life cycle of sea silverside could benefit from the low frequency of higher recruitments. Nevertheless, higher catches observed in 1990, 1999-2000 and 2003 affected the response of the stock negatively and transitorily because these higher catches were sporadic and acted as outliers. Therefore, simulations conditioned to the observed catch seemed more consistent with the LBSPR method, i.e. the sea silverside is in a fully exploited status in Los Lagos region. The approach was based on the estimated life-history parameters with FishLife rather than those known for sea silverside (Pavez et al. 2008). Parameters obtained by FishLife have the advantage that they are consistent and estimated simultaneously within a given model. Thus, the statistical uncertainty contained in the covariance can be utilized to improve the estimates when new and better data become available. Besides, the life-history parameters (mean and variance-covariance) could be sampled at random to construct operating models and evaluate the data-limited stock assessment models here utilized (e.g. Carruthers and Agnew 2016).

In the meantime, it is necessary to start with monitoring the sea silverside fishery in terms of fishing effort and catch per unit effort, and biological data. New data will facilitate estimating the fishery's status and the implementation of fishery management regulations. Therefore, the framework for a data-limited stock-assessment approach and the results obtained here for the artisanal sea silverside fishery is a starting and essential step.

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NOTE

DNA barcoding reveals overlooked shark and bony fish species in landing reports of small-scale fisheries from northern Peru

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ABSTRACT. Species-level identification of commercially landed fish provides pivotal information for stock assessment and fishery management. However, there is a common lack of species determination in landing records from small-scale fisheries (SSFs) worldwide. Using DNA barcoding analyses, we detected four overlooked bony fish (yellow snapper, union snook, blackspot wrasse, and steeplined drum) and one shark species (the sicklefin smooth-hound) in official landing records of SSFs from northern Peru. Of particular concern is the sicklefin smooth-hound shark *Mustelus lunulatus* that was found to be overlooked and could mistakenly be landed as the humpback smooth-hound *M. whitneyi*. Increased efforts should be made to improve species identification capacities in Peruvian fishing landings. There is an urgent need to quantify the catch levels of members of the genus *Mustelus* to species level. This would contribute to a better understanding of the levels of exploitation in each particular species and to improved management decisions.

Key words: Smooth-hound, mitochondrial DNA, marine diversity, shark conservation, *Mustelus*.

Código de barras de ADN revela tiburón y peces óseos no identificados en las estadísticas de desembarque de las pesquerías artesanales del norte del Perú

RESUMEN. La identificación a nivel de especie de los peces desembarcados comercialmente proporciona información fundamental para la evaluación poblacional y la ordenación pesquera. Sin embargo, es común tener dificultades para determinar la identidad de algunas de las especies de las pesquerías artesanales (SSF) en todo el mundo. Utilizando el análisis de códigos de barras de ADN, se detectaron cuatro especies de peces óseos (pargo amarillo, robalito, doncella y bereche) y una especie de tiburón (tollo) pasados por alto en los registros oficiales de desembarque de SSF del norte de Perú. Particularmente preocupante es la ocurrencia del tollo *Mustelus lunulatus*, que podría estar desembarcándose por error como tollo común *M. whitneyi*. Deben realizarse mayores esfuerzos para mejorar las capacidades de identificación de algunas de las especies de los desembarques pesqueros de Perú. Existe una urgente necesidad de cuantificar los niveles de captura de miembros del género *Mustelus* a nivel de especie. Esto contribuiría a una mejor comprensión de los niveles de explotación de cada especie en particular y a la mejora de las decisiones de gestión.

Palabras clave: Tollo, ADN mitocondrial, diversidad marina, conservación de tiburones, *Mustelus*.

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Accurate species identification at landing points is pivotal to assessing exploited stocks' diversity to improve conservation planning and management. Information about catch estimates and species composition allows managers to determine a fishery's status. Small-scale fisheries (SSFs) play a crucial role in producing fishing landing data through fishing logbooks or landing declarations. However, management in various SSFs remains underserved and is characterized by a common lack of species determination in landing records, affecting the accuracy of official fish catch and stock estimates (Morgan and Burgess 2005).

In Peru, estimated total landings of SSF during 2018 were around 1.1 million tons (De la Puente et al. 2020). However, despite its social and economic importance, most Peruvian SSFs have weak management systems (De la Puente et al. 2020; Gozzer-Wuest et al. 2021), limited records and low taxonomic resolution on fisheries landings (Velez-Zuazo et al. 2015; Amorós et al. 2017). Landing data from Peruvian SSFs is gathered by the Instituto del Mar del Perú (IMARPE) through a network of field observers (Guevara-Carrasco and Bertrand 2017). They are tasked with the complex assignment of identifying several aquatic species, including highly similar congeneric species or individuals that have lost their distinctive morphological characteristics due to cellular and biochemical changes associated with postmortem (Ocaño-Higuera et al. 2009). Species identification of shark landings can be even more challenging because they are often landed headless and finless; albeit shark finning has been banned since 2016 (Supreme Decree Nº 021-2016 PRODUCE, El Peruano 2016).

The Peruvian sea is home to at least 67 shark species (Cornejo et al. 2015; Kelez et al. 2020), half of which interact with Peruvian SSFs (Gonzalez-Pestana et al. 2016). Currently, six *Mustelus* species occur in Peruvian waters: *M. californicus*, *M. dorsalis*, *M. henlei*, *M. lunulatus*, *M. mento*, and *M. whitneyi* (Cornejo et al. 2015). In Peru, the humpback smooth-hound *M. whitneyi* is listed among the top six most landed shark species (Gonzalez-Pestana et al. 2016), representing the only member of *Mustelus* genus reported to species-level in recent landing records from northern Peru (i.e. the regions of Piura and Tumbes). Landing records from the same regions reported two other *Mustelus* species (*M. mento* and *M. dorsalis*) to species level only during the mid-1990s. On the other hand, the sicklefin smooth-hound *M. lunulatus* has never been reported to species-level in Peruvian landing records, despite being listed as a commercial species by IMARPE in the '90s decade (Elliot-Rodriguez et al. 1996). Furthermore, two independent molecular studies found *M. lunulatus* in retail markets and supermarkets from Lima and Tumbes (Marín et al. 2018; Biffi et al. 2020). *Mustelus* species are traded in domestic markets simply as *tollos* (López de la Lama et al. 2018). They often look similar and display partially overlapping characters within species, making their identification difficult even for experts (Morgan and Burgess 2005; Pérez-Jiménez et al. 2005). Aiming to reveal economically important species that could be overlooked in official landing reports, a DNA barcoding approach for the authentication of fish landings of SSFs from northern Peru was used. The results of genetic identification were contrasted against official landing records from Tumbes and Piura obtained over the past three decades.

A total of 95 fish samples were collected in twelve landing sites from northern Peru, including the regions of Piura (n = 8) and Tumbes (n = 4) (Figure 1; supplementary material, Table S1) from May to August 2019. Fin clip samples were preserved in ethanol 96% at the moment of landing and stored at -15 °C until DNA extraction. Genomic DNA was isolated using the phenol-chloroform method (Sambrook and Rusell 2001). We used two mitochondrial markers: cytochrome c oxidase subunit I (COI) and the control region (D-Loop); the latter was used only to discriminate

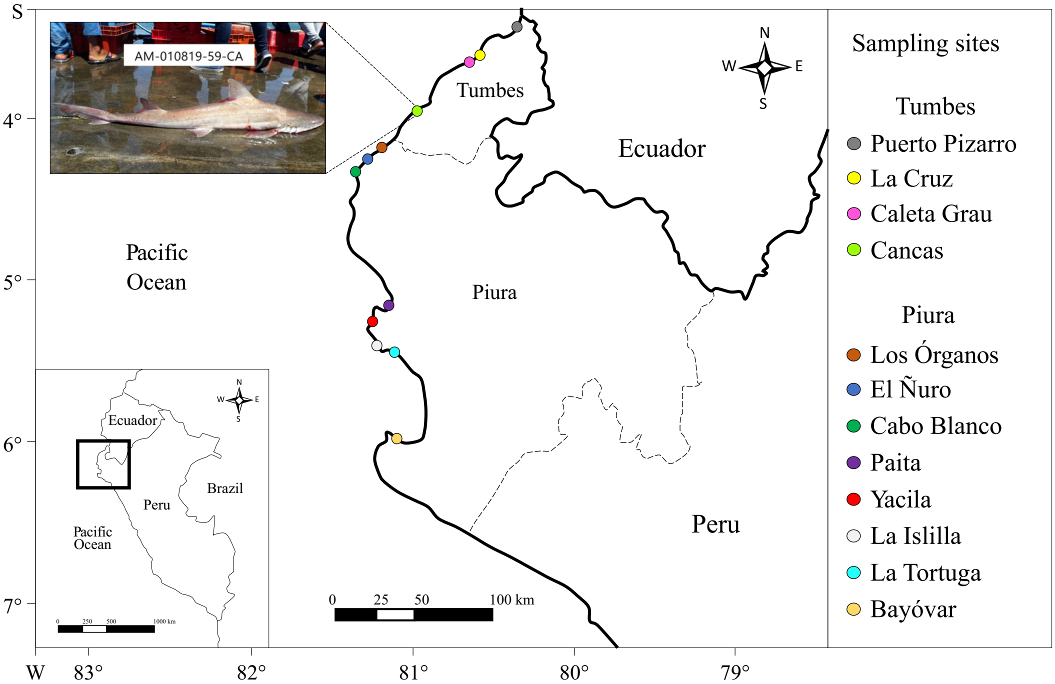

Figure 1. Sampling locations from this study. Fish landing sites from Tumbes region: Puerto Pizarro, La Cruz, Caleta Grau, and Cancas. Fish landing sites from Piura region: Los Órganos, El Ñuro, Cabo Blanco, Paita, Yacila, La Islilla, La Tortuga, and Bayóvar. The inset picture depicts the landing of *Mustelus lunulatus* collected at Cancas fish landing site (Tumbes).

tuna species (Pedrosa-Gerasmio et al. 2012) (primer sequences are shown in supplementary material, Table S2). PCR products were amplified in a local private laboratory using the same conditions described in Marín et al. (2018). PCR products were purified and sequenced at the Macrogen Inc. sequencing facilities in Korea. Sequences were manually edited using MEGA 7 (Kumar et al. 2016). For species identification, both the Identification Engine at the Barcode of Life Data System and the Basic Local Alignment Search Tool (BLAST) at the National Center for Biotechnology Information were used. Species identification obtained by DNA barcoding analyses was compared with the corresponding scientific and common/market names included in the IMARPE reports from Tumbes and Piura landing sites. These reports were issued from 1986 to 1988 (Wosnitza-Mendo et al. 1988), from 1996 to 2000 (Estrella et al. 1998a, 1998b, 1999 and 2000), and from 2010 to 2020 (Sistema de Captación de Información de la Pesca Artesanal del IMARPE) and were kindly provided by IMARPE (IMARPE 2019, 2020, 2021). DNA sequences obtained in this work were submitted to the GenBank database under the accession numbers MN880503 to MN880608.

DNA barcoding results revealed the presence of 40 fish species belonging to 15 families (supplementary material, Table S3). Among these species, five were found to be overlooked in the IMARPE landing reports by location or at least were not explicitly mentioned in the data provided by IMARPE (i.e. some species could be implicitly included in the statistics as aggregated records such as ‘others’ or registered to the genus level only). These five species were *M. lunulatus*, *Centropomus unionensis*, *Decodon melasma*, *Larimus acclivis*, and *Lutjanus argentiventris* (Table 1; supplementary material, Figure S1).

Table 1. List of overlooked species from the SSF in northern Peru as identified through DNA barcoding.

Species match (BOLD/NCBI)	Common name	Family	Label	Sampling site	Sampling date	n	GenBank ID accession
Mustelus lunulatus	Sicklefin smooth-hound	Triakidae	*Tollo mama*	Cancas, Tumbes	June 25, 2019	2	MN880526
					August 1, 2019		MN880605
Centropomus unionensis	Union snook	Centropomidae	*Robalo plateado*	Cancas, Tumbes	June 27, 2019	1	MN880528
Decodon melasma	Blackspot wrasse	Labridae	*San pedrano*	La Islilla, Piura	May 23, 2019	1	MN880543
Lutjanus argentiventris	Yellow snapper	Lutjanidae	*Paramo rojo*	Cancas, Tumbes	June 25, 2019	2	MN880525
			Paramo muelon		July 30, 2019		MN880602
Larimus acclivis	Steeplined drum	Sciaenidae	*Bereche*	La Tortuga, Piura	June 11, 2019	1	MN880556

Among the total number of smooth-hound shark samples collected in this study (n = 8), six samples (75%) were identified as *M. whitneyi* (100% sequence identity in BOLD). In comparison, two samples (25%) were identified as *M. lunulatus*. (99.7-99.8% sequence identity in BOLD, GenBank access MN880526 and MN880605). The two *M. lunulatus* samples were collected at Cancas landing site (Tumbes, collection date June and August 2019, supplementary material, Figure S1) and mislabeled as *tollo mama* (common name for *M. whitneyi*). Since this species is not reported in statistics, its landings could often be misidentified as *M. whitneyi* at landing points, or just listed in the IMARPE annual statistics landing reports under the category *tollo*. The latter may include different species such as *M. whitneyi*, *M. lunulatus*, *Triakis maculata* and *Schroederichthys chilensis* (Flores-Palomino et al. 1994; Flores 1996; Fernández et al. 2000). Additionally, the Peruvian Ministry of Production, which compiles official statistics, considers *tollo* as one single species despite being a common name for several species, as previously mentioned (PRODUCE, 2020).

A previous study by Marín et al. (2018) reported this species' incidence in a fillet sample bought in a supermarket in Lima (collection date June 2017). Similarly, using the DNA barcode approach, Biffi et al. (2020) identified four *M. lunulatus* samples (two came from retail markets in Tumbes and two from supermarkets in Lima) collected between May and June 2017. Before our study, there were no records of *M. lunulatus* collected from Peruvian landings and authenticated by DNA analysis. Together, these identifications support the hypothesis of regular catches of this species in northern Peru.

Globally, there is a general lack of data reporting on sharks' catch particularly species-specific data, which makes fisheries conservation and management challenging (NOAA 2020). Furthermore, most life history patterns of shark species (including *Mustelus* species) display slow growth, long gestation times, low fecundity, and late sexual maturity (Medina-Morales et al. 2020), which makes them especially vulnerable to exploitation. Therefore, there is an urgent need to quantify catch levels of members of the genus

Mustelus to species level. This would contribute to a better understanding of the exploitation level in each particular species, so as to improve management decisions (Pérez-Jiménez et al. 2016). Misidentifications of other *Mustelus* species, such as *M. whitneyi*, also raise concerns over its catch landing estimates, which may be biased by the landings of *M. dorsalis* and *M. mento* (reported to species level only during the years 1996, 1997, and 1999).

Further studies are needed to determine to what extent Peruvian landings of *M. lunulatus* (or other *Mustelus* species) are misidentified as *M. whitneyi*. Additionally, the IUCN Red List of Threatened Species listed *M. whitneyi* and *M. lunulatus* as critically endangered and least concern, respectively. Inaccurate species identifications may also have an impact on global IUCN listings. In this regard, a molecular survey of *Mustelus* landings could be a good starting point to obtain accurate baseline data. However, more substantial efforts must also be made to find more practical and cheaper species identification solutions. For instance, the possibility of developing field identification techniques based on diagnostic morphometric measurements is required, which should be developed alongside DNA barcoding to obtain more voucher specimens of *Mustelus* species. Additionally, multivariate and machine learning methods successfully applied in Carcharhinidae shark species should also be evaluated, as this approach could be applied to other Chondrichthyan species (Johnson et al. 2017). It is also highly recommended that field observers receive more intense training by recognized experts on identification of the *Mustelus* species. There are two identification guides for commercially important Peruvian shark species (IMARPE 2015; Romero et al. 2015), but none of these include *M. lunulatus*.

Our results also detected four landed Osteichthyes species that were not included in landing reports. Two yellow snappers *Lutjanus argentiventris* (supplementary material, Figure S2) were sampled at Cancas landing site (Tumbes, collection date June and July 2019), and one was misidentified as spotted rose snapper *L. guttatus* by fishermen. Official landing records only include two species of genus *Lutjanus*: *L. guttatus* and *L. jordani*. In another case, a sample taken in Cancas (Tumbes, collection date June 2019) landed as white snook *Centropomus viridis* was actually the union snook *Centropomus unionensis* (supplementary material, Figure S3). Official landing records include only *C. nigrescens* and aggregated records to genus level of *Centropomus* spp. One individual identified as the blackspot wrasse *Decodon melasma* (supplementary material, Figure S4) and one sample of the steeplined drum *Larimus acclivis* (supplementary material, Figure S5) collected in La Islilla and La Tortuga landing sites (Piura), respectively, were found to be overlooked in the official landing reports. Three other overlooked species detected in this study (*C. unionensis*, *L. acclivis*, and *L. argentiventris*) have been described as part of the marine diversity of Tumbes (Luque 2007), whereas the blackspot wrasse *D. melasma* has been reported in a survey cruise by IMARPE (Pastor et al. 2018). Nevertheless, there is still a lack of knowledge about the population status and landing estimates of these species. Further studies are needed to determine whether catches are significant or negligible from the point of view of the impacts of fishing on the health of the stocks.

Finally, this note emphasizes the usefulness and importance of DNA barcoding analyses in detecting species that may have been overlooked in official statistics. Accordingly, we recommend that proper attention should be paid to these events. More specialized training on how to identify morphologically similar species should be given to field observers and fishermen, which would significantly improve landing data and, consequently, could trigger future management actions to preserve Peruvian marine diversity.

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