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Long-term changes in fishery resources of an estuary in southwestern Atlantic according to local ecological knowledge

Vinni Santos Thykjaer | Lucas dos Santos Rodrigues | Manuel Haimovici | Luís Gustavo Cardoso

Laboratório de Recursos Pesqueiros Demersais e Cefalópodes, Universidade Federal do Rio Grande – FURG, Rio Grande, Brazil

Correspondence
Vinni Santos Thykjaer, Laboratório de Recursos Pesqueiros Demersais e Cefalópodes, Universidade Federal do Rio Grande – FURG, Av. Itália km 8, RS, Brazil.
Email: vinni.tkj@gmail.com

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Abstract

Long-term changes in the abundance of fisheries resources from the Patos Lagoon estuary and adjacent coastal waters in southern Brazil have been observed. Despite this understanding, it is well known that the perception of pristine state of the environment is susceptible to inter-generational changes, commonly known as shifting baseline syndrome (SBS). An useful approach in the reconstruction of pristine scenarios and in lack of data, as often occurs in small-scale fisheries, is the local ecological knowledge (LEK). Temporal changes in the perception of 81 fishers with 1–63 years of fishing about the resources status were analysed. More experienced fishers reported larger catches, heavier individuals and perceived a greater number of species as "scarce" nowadays and "common" at the beginning of their careers proving the existence of a SBS among them. Over time, the number of fishing sites with very high catches decreased and fishing sites shifted from the lower towards the upper estuary. The perception of the fishers corroborated the real decreasing scenario in estuarine fisheries resources shared with industrial fishing in coastal waters. The results reinforce the utility of LEK for reconstruction of biological scenarios when no empirically obtained data are available.

KEYWORDS

catches reduction, fisher perceptions, Patos Lagoon estuary, quantile regression, shifting baselines, small-scale fisheries

1 | INTRODUCTION

Increased fishing effort and the development of new technologies have resulted in population declines in fish resources and even extinctions of some marine animals (Hutchings & Reynolds, 2004). The perception that fishes were far more abundant in the past has proved to be true in several well-documented cases (Franklin, 2011; Roberts, 2010). To assess human impacts on natural ecosystems requires knowledge of their unexploited condition (Baum & Myers, 2004). This is not easy due to the loss of information among human generations on the composition, size and abundance of species in ecosystems, a phenomenon known as the "Shifting Baselines Syndrome (SBS)" (Pauly, 1995). This syndrome is related to a psychological tendency to assume that natural conditions are those observed at the beginning of the interaction with an ecosystem by contemporary users, researchers or managers. The lack of a baseline on the pristine condition of the fish resources can lead to imprecise identification of economic losses and targets for restoration (Tubino et al., 2014) or a mistaken definition of priority species and/or areas for protection (McClenachan, Ferretti, & Baum, 2012), and can negatively influence management and conservation policies.

Small-scale fisheries are economically important for subsistence, and guarantee the food security of coastal and inland communities (Hellebrandt, Allison, & Delaporte, 2014). Scarcity of data on fish

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catches and fishing effort is a common problem, and jeopardises assessment of the impact of fishing on the resources (Pomeroy & Andrew, 2011). In scenarios where there is a lack of catch data series, as is generally the case of small-scale fisheries, local ecological knowledge (LEK) has been widely used as an alternative to evidence of decreasing trends in the abundance of fish resources and shifting baselines (Drew, 2005; Eddy, Gardner, & Pérez-Matus, 2010; Hallwass, Lopes, Juras, & Silvano, 2013; Johannes, 1998; Saens-Arroyo, Roberts, Torre, Cariño-Olvera, & Enríquez-Andrade, 2005). Older fishers are often the only source of information on historical changes in local fishery resources, since written records and long-term datasets are rarely available (Hallwass et al., 2013; Johannes, Freeman, & Hamilton, 2000; Tregidgo, Barlow, Pompeu, Almeida Rocha, & Parry, 2017). This makes LEK an important tool in assessing the impacts of fishing on resources and in setting priority species and areas for protection (Bender, Floeter, & Hanazaki, 2013; Hallwass et al., 2013; Ramires, Molina, & Hanazaki, 2007; Saens-Arroyo et al., 2005). The data obtained from fishers, interpreted in the ecological context, can be used to estimate historical quantitative baselines on the abundance and sizes of exploited or extinct marine animals, and to provide a perspective on the state of resources and ecosystems in the past (McClenachan et al., 2012).

In Brazil, fisher's local ecological knowledge has been used to assess temporal changes in fishery resources. For example, Bender et al. (2013) reported that older fishers caught fish with larger body sizes and larger quantities of larger fish in the past than currently. This demonstrated that the abundance of the largest fishes declined in the Recife de Fora marine park in northeastern Brazil. Giglio, Luiz, and Gerhardinger (2015) provided evidence that artisanal fishing drastically reduced the abundance of large coastal fishes in the Abrolhos archipelago, leading to local extinction. Tubino et al. (2014) revealed that the number of gill nets increased five times in the coastal region of Itaipu, Rio de Janeiro, since the 1970s, which was identified as the probable cause for the disappearance of schools of *Mugil* spp. from the region.

The Patos Lagoon estuary (PLE) has high biological productivity and is among the richest regions, in terms of fishery resources, of Brazil (Seeliger & Odebrecht, 2010). The PLE concentrates approximately 61% of all fishers of Rio Grande do Sul state who mainly use bottom-set gillnets for fish and fyke nets for shrimps in a small-scale commercial production system (Vasconcellos & Kalikoski, 2014). The small-scale fisheries in the PLE and the industrial-scale fisheries in the adjacent coastal region have led to overexploitation of many of the main fishing resources and to the collapse of some, such as the catfish *Genidens barbus* (Lacépède) and black drum *Pogonias cromis* (L.) (Haimovici & Cardoso, 2016a). However, several other species such as whitemouth croaker *Micropogonias furnieri* (L.), mullet *Mugil liza* (Val.) and pink shrimp *Penaeus paulensis* (Pérez Farfante) are important resources for approximately 2,000 artisanal fishers in about 90 fishing communities around the PLE (Vasconcellos & Kalikoski, 2014).

Landings from this region have been recorded in a continuous series for several periods since 1945 (FURG, 2016; MPA, 2012) and

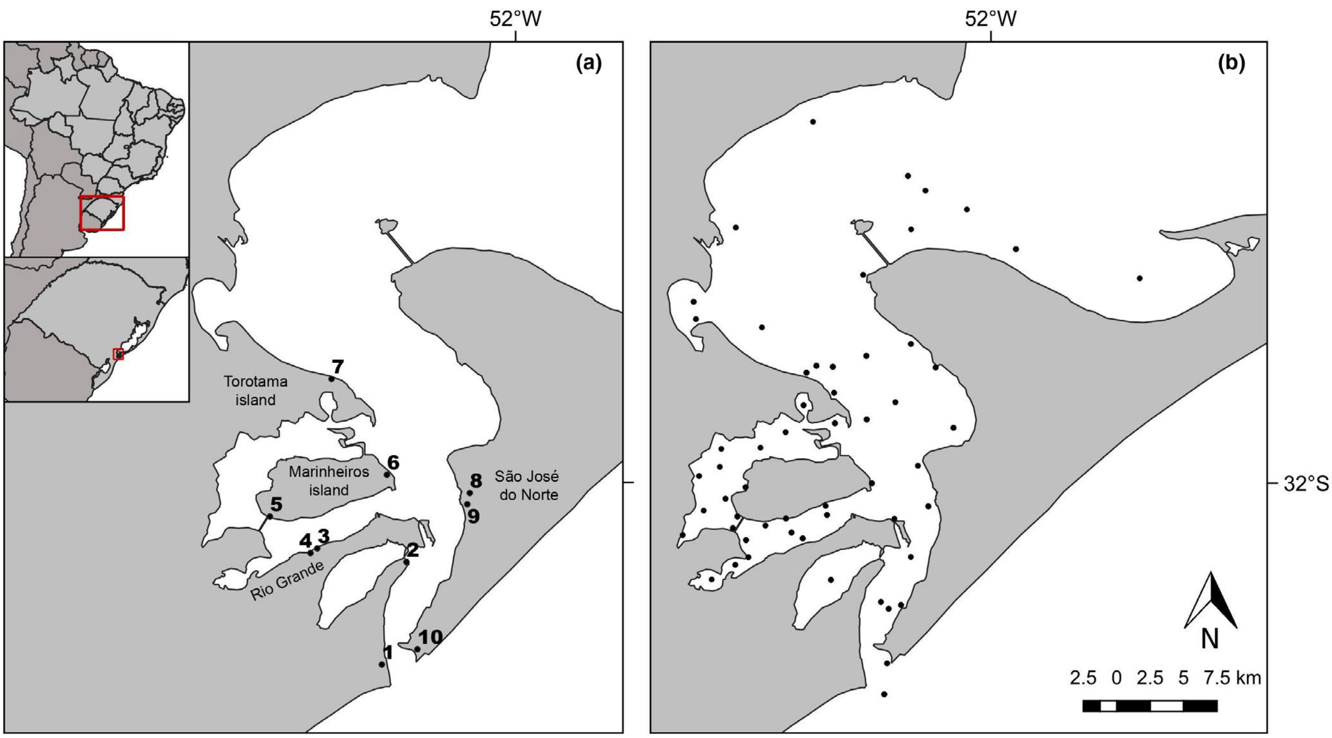


FIGURE 1 Patos Lagoon estuary. (a) The numbers show the ten main communities grouped in four major localities where the interviews were made. (I) Rio Grande: (1) 4ª Secção da Barra, (2) Mangueira, (3) São Miguel and (4) Bosque; (II) Marinheiros island: (5) Bandeirinhas and (6) Marambaia; and (III) Torotama island: (7) Torotama; (IV) São José do Norte: (8) Bolo Doce, (9) Tamandaré and (10) 5ª Secção da Barra. (b) The zones cited by fishers with the highest CPUE

showed a decreasing trend from 43,700 t in 1972 to an average of 6,300 t since 2001 (Haimovici & Cardoso, 2016a). The aim of this paper is to better understand the historical trends in the abundance of the main fishery resources of the PLE and to evaluate the use of LEK to describe such trends. Temporal changes in the current perceptions of artisanal fishers with different levels of fishery experience were collected and analysed for: (a) the highest catches of each species; (b) the largest specimens caught of each species; (c) the fishing zones with abundant catches in the estuarine ecosystem; (d) the number of species considered frequent at the beginning of their careers; and (e) the current presence/availability of the resources.

2 | METHODS

2.1 | The study area

The Patos Lagoon covers approximately 10,227 km^2 and extends in a NE-SW direction, between Lat. 30°30′S and 32°12′S, in the south of Brazil (Figure 1; Seeliger & Odebrecht, 2010). The Patos Lagoon estuary (PLE) is located at the southern end of the Lagoon, covering approximately 10% of its total area (Asmus, 1998; Figure 1), and is characterised by nursery grounds, feeding and reproduction areas of fish (Garcia & Vieira, 2001; Haimovici et al., 2006; Seeliger & Odebrecht, 2010) and crustacean stocks (Rodrigues, Ortega, & D'Incao, 2019; Ruas, Rodrigues, Dumont, & D'Incao, 2014). Artisanal fishing is mainly commercial, and uses gillnets, small bottom trawls and fyke nets for shrimps. Eight species are among the most important targets in the PLE: the whitemouth croaker *Micropogonias furnieri*, the black drum *Pogonias cromis*, the catfish *Genidens barbus*, the mullet *Mugil liza*, the pink shrimp *Penaeus paulensis*, the flatfish *Paralichthys orbignyanus* (Val.), the pejerrey fish *Odontesthes bonariensis* (Val.) and the blue crab *Callinectes sapidus* (Rathbun).

2.2 | Data collection

Ten of 14 main communities were selected for interview. These were distributed in the two cities, Rio Grande and São José do Norte, which comprised 69% of the fishing communities around the estuary and include the main fishing communities of the PLE (Figure 1; Vasconcellos & Kalikoski, 2014).

The interviews were conducted using a standardised, semi-structured questionnaire based on different studies on the same theme (Bender et al., 2013; Giglio et al., 2015; Saenz-Arroyo et al., 2005; Turvey et al., 2010), adapted to local conditions (see Supporting Information S1 for more information on the questionnaire). Before each interview, the fisher received a brief explanation of the objectives and methods of the work and was subsequently invited to collaborate. The interviews were carried out at the fisher's residence (home) whenever possible, although many of them occurred in other public places. The voluntary nature of the participation and anonymity in the elaboration of any product was emphasised. The questionnaire was randomly applied to the first fisher contacted in each community, who was then asked to indicate other fishers who lived nearby to be interviewed, using snowball sampling (Bernard, 2017). Noting the scarcity of interviewees among the less experienced (also observed by Vasconcellos, Diegues, & Sales, 2007), the sampling began to prioritise such interviewees.

Interviews began by asking their age and the age at which they started fishing (how many years of fishing experience). The fishing effort used at the beginning of their careers and at present (in total gillnet metres or fyke nets set) was also established, as well as which species that they considered common at the beginning of their careers; the largest specimen ever captured (in kg); and the largest catch (in kg) they ever remembered landing, date and zone of these catches (by zone name or indicating in map available in Supporting Information S1). In addition, they were asked what causes they consider to be responsible for the reduction in catches.

Eighty one fishers were interviewed (see Supporting Information S2 for the number of fishers per main major localities) between August 2017 and November 2018, classified in three categories of experience: Beginner/Intermediate (1–29 years of fishing experience, N = 21), Experienced (30–49, N = 38) and Veteran (50–65, N = 22). To understand fishers' perceptions of the fishery situation in the PLE, they were asked how they considered the current situation of the eight main fishery resources in the estuary between four possible responses: "Very Abundant," "Abundant," "Less Abundant" and "Scarce." Because not all the interviewees understood the classification, indirect answers were also considered. For example, "there are even too many": Very Abundant; "there are still some": Abundant; "there are almost none, they show up only once in a while": Less Abundant; and "they disappeared": Scarce. The percentages of each response were analysed by category of experience among the eight resources. They were also questioned about which species they considered common in the estuary when they started their careers, where the average number of species was compared between the categories of experience.

For the questions on the largest individual caught from each species, most responses were given in kilograms. However, in some interviews, mainly for the crustaceans pink shrimp (*Penaeus paulensis*) and blue crab (*Callinectes sapidus*), the maximum length/width was reported. For these resources, the fishers were asked to represent the size of the specimen on the nearest floor or wall, which were then measured with a millimetre ruler. Conversions to kilograms were done using total length (pink shrimp) or carapace width (crab blue) versus weight (in kg) according to Leite and Petrere (2006) and Rodrigues (2006), respectively. As none of the fishers reported the sex of the individuals, the mean weight of the resulting equations was used for males and females. For the pink shrimp, some fishers reported catches in individuals per kilogram (pieces/kg).

The fishing areas mapped by Schaefer and Reis (2008) were used to identify the zones cited by fishers in the interviews (Figure 1b). The zones with the highest catches for each species, informed with the names of inlets, channels and other reference points, were transformed into geographic coordinates using Google Earth Pro software. Kernel maps of all the answers were generated in QGIS Development Team (2018) for three periods of approximately 20 years: 1965–1980 (*n* = 69 citations), 1981–2000 (*n* = 121) and 2001–2018 (*n* = 285). In each map, the CPUEs (kg/net metre) were classified as low = 12.5–24.9; moderate: 25.0–37.4; high: 37.5–49.9; and very high: ≥50.

2.3 | Data analysis

A Dunn test (Dunn, 1961, 1964) was used to compare the mean number of species considered abundant at the beginning of careers among the three categories of experience. The highest catch, in kilogram, per unit of effort by gillnet metre was used as the abundance index (CPUE). The footage of the fisher's gillnets and fyke nets was reported in fathoms, where one fathom is equivalent to approximately 1.8 m, an estimate used in this study. For fishers who had their highest catch date up to 5 years after the start of their career, the initial effort was used to calculate CPUE. For fishers who had their largest catch in the last five years (2013–2018), the current effort was used. For fishers who had their highest catch between the initial and last periods, the average effort between the initial and current effort for each fisher was used. For those fishers who reported their greatest catch but did not provide information about their initial or current effort, the average initial effort by experience category and the overall average of the current effort across all categories were used.

Heterogeneity of variance was observed in the relationship between the dependent variables CPUE/Heaviest individual and independent variables Year of Catch/Fishing Time Experience. This limitation led to the use of a model of quantile regressions (Cade & Noom, 2003), which can estimate multiple rates of change from minimum to maximum response, providing a more complete picture of the relationships between variables not so clear by other regression methods. The following values were estimated by quantile regressions for each of the eight species: (a) Highest Estimated CPUE (HEC), or the estimate of the maximum catch in kg per linear metre of net; and (b) Heaviest Estimated Individual (HEI), or the estimate of the maximum weight of the largest specimen for each species. For each estimation (HEC and HEI), the corresponding Year of Highest Catch/Individual (YHC, YHI) and Experience of Highest Catch/Individual (EHC, EHI) were calculated.

Quantile regression splines (Koenker, 2005; Koenker & Schorfheide, 1994) were constructed for the 95th percentile (the value below which 95% of the largest catches and largest individuals are expected to fall) using the methodology proposed by Anderson (2008). The models were adjusted with the rq() function (part of *quantreg* package, 2007) combined with the bs() function (part of *splines* package) in the R programming language (R Development Core Team, 2018). The bs() function is adjustable to a given degree of polynomial. The appropriate degree for the polynomial was determined using the corrected version for small samples of the Akaike information criteria (AICc) (see Hurvich & Tsai, 1989). The model with the lowest AICc value among the set of models with degree polynomials = 1, 2, 3, 4 or 5 was chosen. If any of the other models had an AICc value above or under of up to 2 units of difference compared with the model chosen by the previous criterion and had a better visual shape adjusted to the scatter plot of the data, this was chosen by preference. The values at which the Highest Estimated CPUE and Heaviest Estimated Individual model reached the maximum values were identified as the optimal values. 95% confidence intervals were obtained for the optimal estimate re-applying 10,000 randomizations on the model (Miller, 2018). Although the interest is to show Highest Estimated CPUE and Heaviest Estimated Individual over time (years), both independent variables (not only Year of Catch, but also Fishing Time Experience) were chosen. The Fishing Time Experience variable is more accurate than the Year of Catch variable, since the first is generated by a direct result of the date of birth of fishers and the age fishing started, while the second depends exclusively on the fisher's memory. Furthermore, the optimal HEC and HEI indicated by the quantile regressions with Fishing Time Experience are a form of validation of the quantile regressions using Year of Catch.

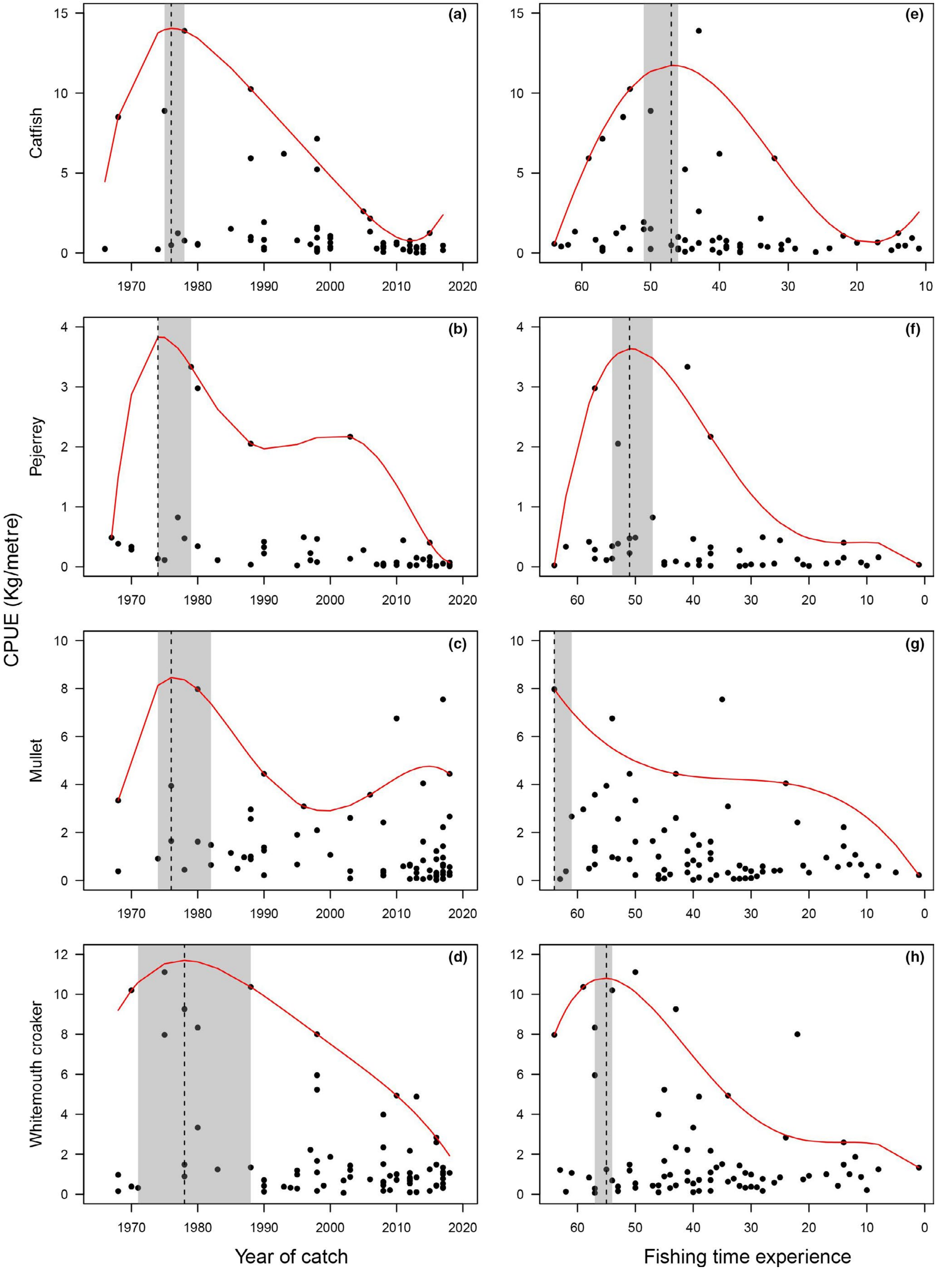
3 | RESULTS

From the 81 interviewees, an average of 514 ± 43 responses was obtained among the eight parameters for all species (see Supporting Information S2). Among the eight parameters, the number of responses per species varied from 51 to 73. These massive values provided robustness to the data analysis.

The highest catches reported by fishers declined for all species over time, excepting for mullet *Mugil liza* (Figures 2 and 3). Except for mullet and blue crab *Callinectes sapidus*, all the highest values of gross catches cited for each species were in years prior to 1990. The cited catches of 20 t of catfish *Genidens barbus* and 10 t of black drum *Pogonias cromis* in 1988 were highlighted. The highest cited catches for these two species decreased to 2 t of catfish in 2005 and 500 kg of black drum in 2013.

The Highest Estimated CPUE of catfish (14.0 kg/net metre), black drum (9.0 kg/net metre) and the flatfish (1.9 kg/net metre) were prior

FIGURE 2 Highest catches per unit effort (kg/m; dots) of catfish (a,e), pejerrey (b,f), mullet (c,g) and whitemouth croaker (d,h) according to the Year of Catch and Fishing Time Experience reported by fishers. The highest estimated CPUE by quantile regression for each species can be observed at the point where the red line intercepts the dashed line. The dashed line represents an estimative of the optimal value of Year of Highest Catch (YHC) and Experience of Highest Catch (EHC) obtained through quantile regression models. The shaded area represents the confidence interval of 95% calculated for YHC and EHC, based on 10,000 randomizations. Colours available for the online version only


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
Catfish
Pejerrey
Mullet
Whitemouth croaker
CPUE (Kg/metre)
Year of catch
Fishing time experience
15
10
5
0
4
3
2
1
12
8
6
1970
1980
1990
2000
2010
2020
60
50
40
30
20

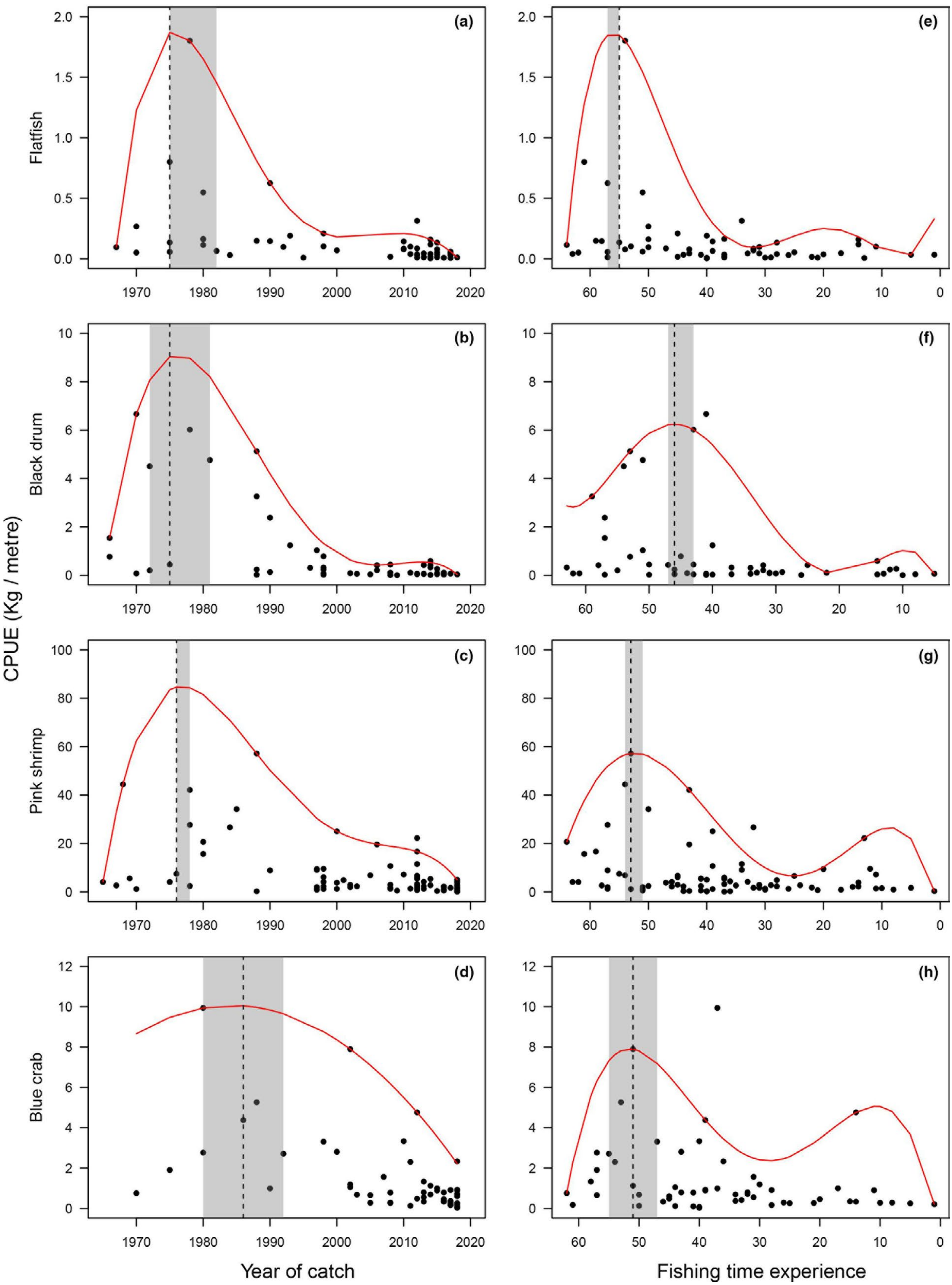


FIGURE 3 Highest catches per unit effort (kg/m; dots) of flatfish (a,e), black drum (b,f), pink shrimp (c,g) and blue crab (d,h) according to the Year of Catch and Fishing Time Experience reported by fishers. The highest estimated CPUE by quantile regression for each species can be observed at the point where the red line intercepts the dashed line. The dashed line represents an estimative of the optimal value of Year of Highest Catch (YHC) and Experience of Highest Catch (EHC) obtained through quantile regression models. The shaded area represents the confidence interval of 95% calculated for YHC and EHC, based on 10,000 randomizations. Colours available for the online version only

TABLE 1 Estimated optimal values for Highest Estimated CPUE (HEC) and Heaviest Estimated Individual (HEI). Year of Highest Catch (YHC) and Experience of Highest Catch (EHC) were calculated for the HEC. Year of Heaviest Individual (YHI) and Experience of Heaviest Individual (EHI) were calculated for the HEI. The 95% confidence intervals (CI) were calculated based on 10,000 randomizations of the highest estimate value

Common name	Scientific name	Model degree	HEC (kg/m)$_{YHC}$	YHC	95% CI	Model degree	HEC (kg/m)$_{EHC}$	EHC	95% CI
Highest Estimated Catch (HEC)									
Catfish	*Genidens barbus*	5	14.0	1976	(1975, 1978)	5	11.7	47	(46, 51)
Pejerrey	*Odontesthes bonariensis*	5	3.8	1974	(1974, 1979)	4	3.6	51	(47, 54)
Mullet	*Mugil liza*	5	8.5	1976	(1974, 1982)	3	8.0	64	(61, 64)
Whitemouth croaker	*Micropogonias furnieri*	4	11.7	1978	(1971, 1988)	4	10.8	55	(54, 57)
Flatfish	*Paralichthys orbignyanus*	5	1.9	1975	(1975, 1982)	5	1.8	55	(55, 57)
Black drum	*Pogonias cromis*	4	9.0†	1975	(1972, 1981)	5	6.2	46	(43, 47)
Pink shrimp	*Penaeus paulensis*	4	84.6†	1976	(1976, 1978)	5	57.1	53	(51, 54)
Blue crab	*Callinectes sapidus*	3	10.0	1986	(1980, 1992)	4	7.9	51	(47, 54)
Common name	**Scientific name**	**Model degree**	**HEI (kg)$_{YHI}$**	**YHI**	**95% CI**	**Model degree**	**HEI (kg)$_{EHI}$**	**EHI**	**95% CI**
Heaviest Estimated Individual (HEI)									
Catfish	*Genidens barbus*	5	30.0	1988	(1985, 1990)	5	34.4	64	(59, 64)
Pejerrey	*Odontesthes bonariensis*	-	-	-	-	3	1.0	47	(45, 50)
Mullet	*Mugil liza*	-	-	-	-	4	5.6	51	(50, 54)
Whitemouth croaker	*Micropogonias furnieri*	4	12.0	1980	(1978, 1987)	5	22.0†	64	(61, 64)
Flatfish	*Paralichthys orbignyanus*	3	16.6	1967	(1967, 2000)	5	15.0	53	(50, 54)
Black drum	*Pogonias cromis*	5	42.0	1982	(1980, 1985)	4	69.6†	64	(61, 64)
Pink shrimp	*Penaeus paulensis*	5	0.1	1983	(1978, 1988)	5	0.1	55	(53, 57)
Blue crab	*Callinectes sapidus*	1	1.5	Whole period	-	1	1.5	Whole period	-

Note: Estimated values higher than values reported from fishers (†) should be analysed carefully.

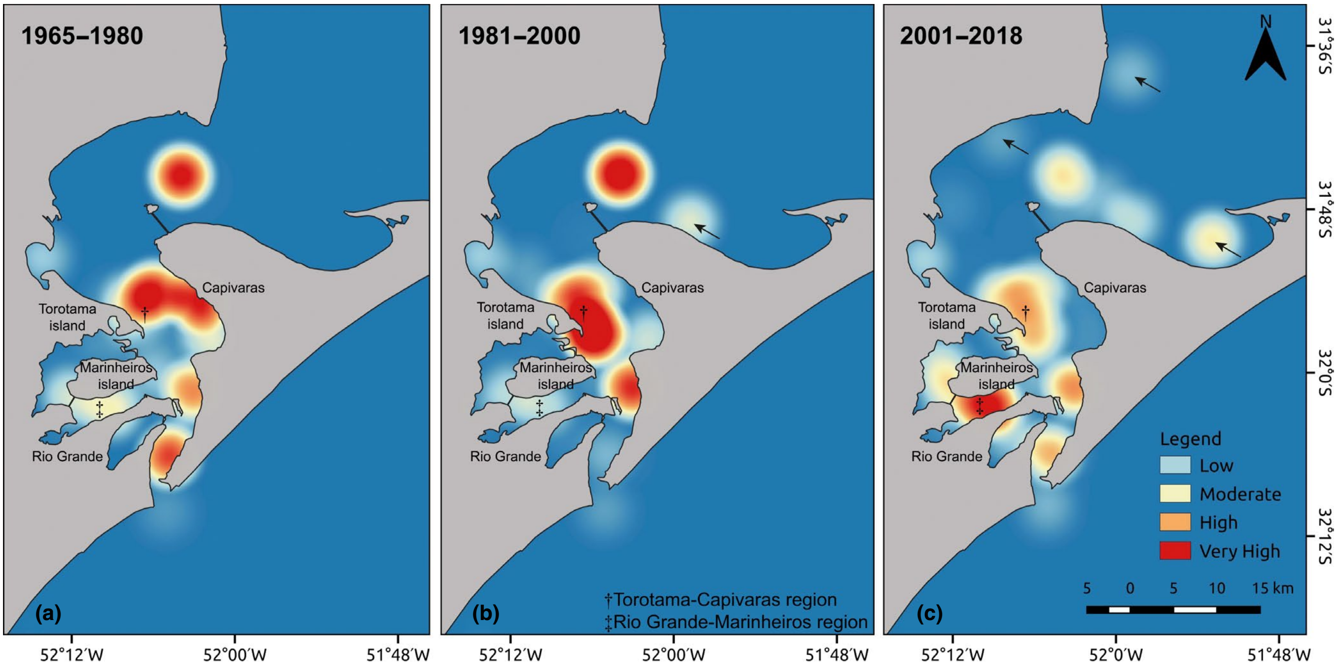


FIGURE 4 Kernel maps of the zones where the highest CPUE (Dark blue < 12.5; Low: 12.5–24.9; Moderate: 25.0–37.4; High: 37.5–49.9; Very High: ≥50) occurred generated by fisher's highest CPUE from (a) 1965–1980, (b) 1981–2000 and (c) 2001–2018. The arrows indicate the displacement of highest catch areas towards the upper estuary. The crosses and double-crosses indicate Torotama-Capivaras and Rio Grande-Marinheiros region cited in main text. Colours available for the online version only

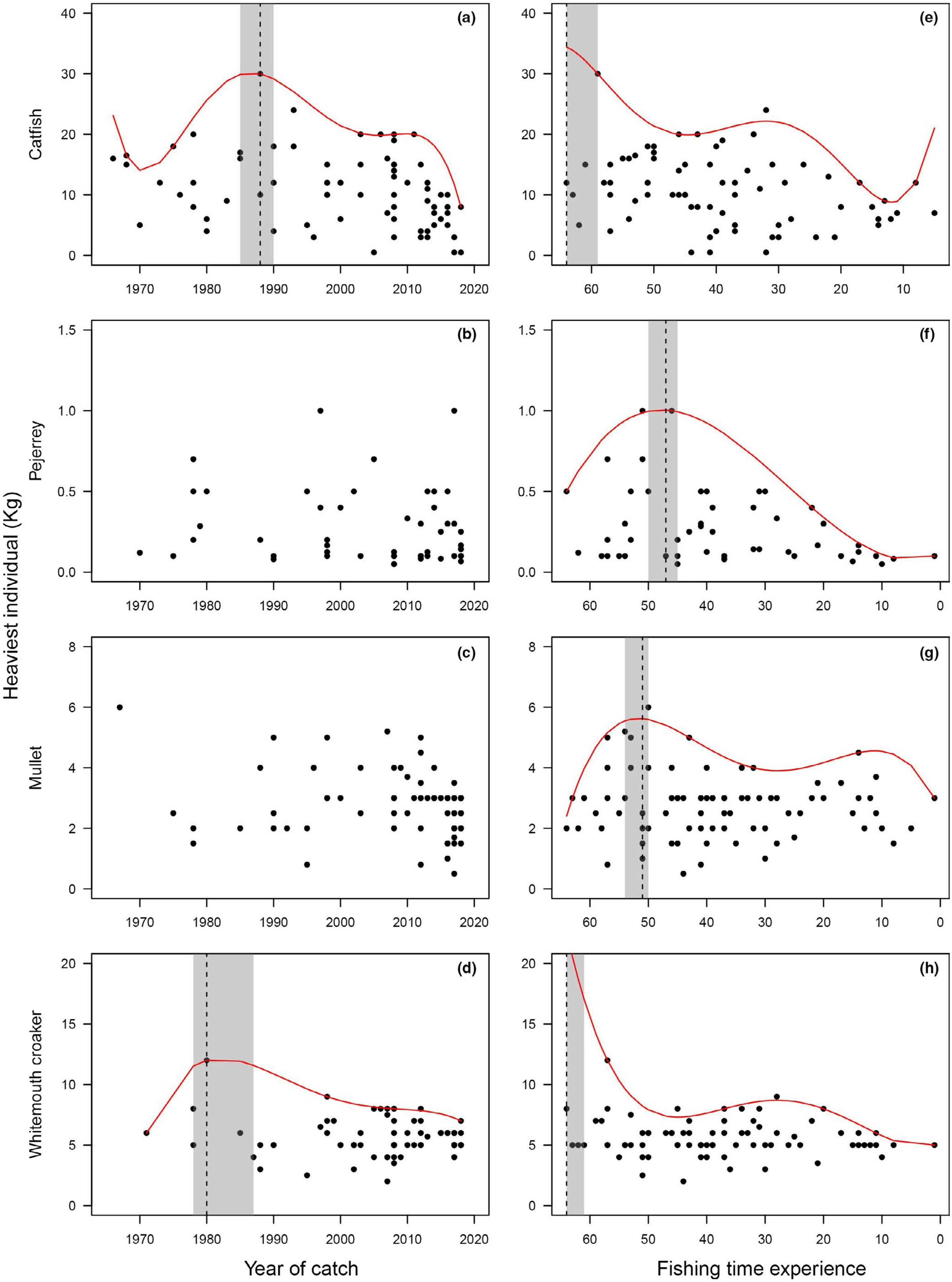
to 1975 and fell to approximately 2.0, 1.0 and 0.1 kg/net metre, respectively, in recent years. The highest CPUE of whitemouth croaker decreased from 11.7 kg/net metre in 1978 to approximately 2.0 kg/net metre in 2018. Pejerrey, mullet and pink shrimp did not show a clear decline over time.

This same trend can be observed for the highest reported catches for all species when considering fishing experience (Figure 2). Highest Estimated CPUEs were prior to 1980 for all species except the blue crab in 1986 (Figures 2 and 3; Table 1), and were reported by fishers that started fishing before 1978 and had more than 40 years of experience (Figure 2; Table 1).

The fishers interviewed reported 475 fishing sites in which the highest catches of the all eight fished species were obtained (Figure 1b). The three kernel maps generated for low, moderate and very high CPUEs (yields) showed that in the first period (1965–1980), the very high CPUEs were concentrated mainly in the region between Torotama Island and Capivaras, north of Capivaras and in the channel near the opening to the sea. In the following period (1981–2000), very high CPUEs were reported to be obtained between Torotama Island and Capivaras, north of Capivaras and in front of São Jose do Norte city. Finally, in the last period (2001–2018), very high CPUEs were obtained only in the region between Rio Grande and Marinheiros Island and sites, which were previously cited (1965-2000) with just high and moderate CPUEs. Through time, a decrease in the number of regions with very high catches was observed, from four regions in the period 1965–1980 and three regions in 1981–2000 to only one region in 2001–2018 (Figure 4). In addition, a displacement of the areas of moderate and low CPUEs towards the upper estuary was observed (Figure 4).

Inconclusive, multimodal and/or poorly adjusted models made it impossible to observe a well-defined optimal point for the heaviest individual estimated per Year of Catch for Fishing Time Experience (Table 1; Figures 5 and 6). Despite this, it is possible to note that the weight of the largest caught catfishes decreased over time both in relation to the year of catch and in relation to the fisher's experience. For pejerrey, the weight of the largest specimen declined relative to the fisher's experience (Figure 5). For mullet and whitemouth croaker, there was no obvious variation (Figure 5). Flatfish had a slighter reduction in the weight of the largest specimens in the last decade (Figure 6). There were also no reports of black drum with more than 10 kg after 2010 (Figure 6). For shrimp, a small decrease in the weight of the largest specimens caught seems to have occurred, both in relation to the year of capture and in relation to the interviewee's experience (Figure 6). Blue crab seem to maintain their body weight over time (Figure 6).

FIGURE 5 Heaviest individuals (kg; dots) of catfish (a,e), pejerrey (b,f), mullet (c,g) and whitemouth croaker (d,h) according to the Year of Catch and Fishing Time Experience reported by fishers. The highest estimated weight by quantile regression for each species can be observed at the point where the red line intercepts the dashed line. The dashed line represents an estimative of the optimal value of Year of Heaviest Individual (YHI) and Experience of Heaviest Individual (EHI) obtained through quantile regression models. The shaded area represents the confidence interval of 95% calculated for YHI and EHI, based on 10,000 randomizations. Colours available for the online version only


Heaviest individual (Kg)
Catfish
Pejerrey
Mullet
Whitemouth croaker
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
Year of catch
Fishing time experience

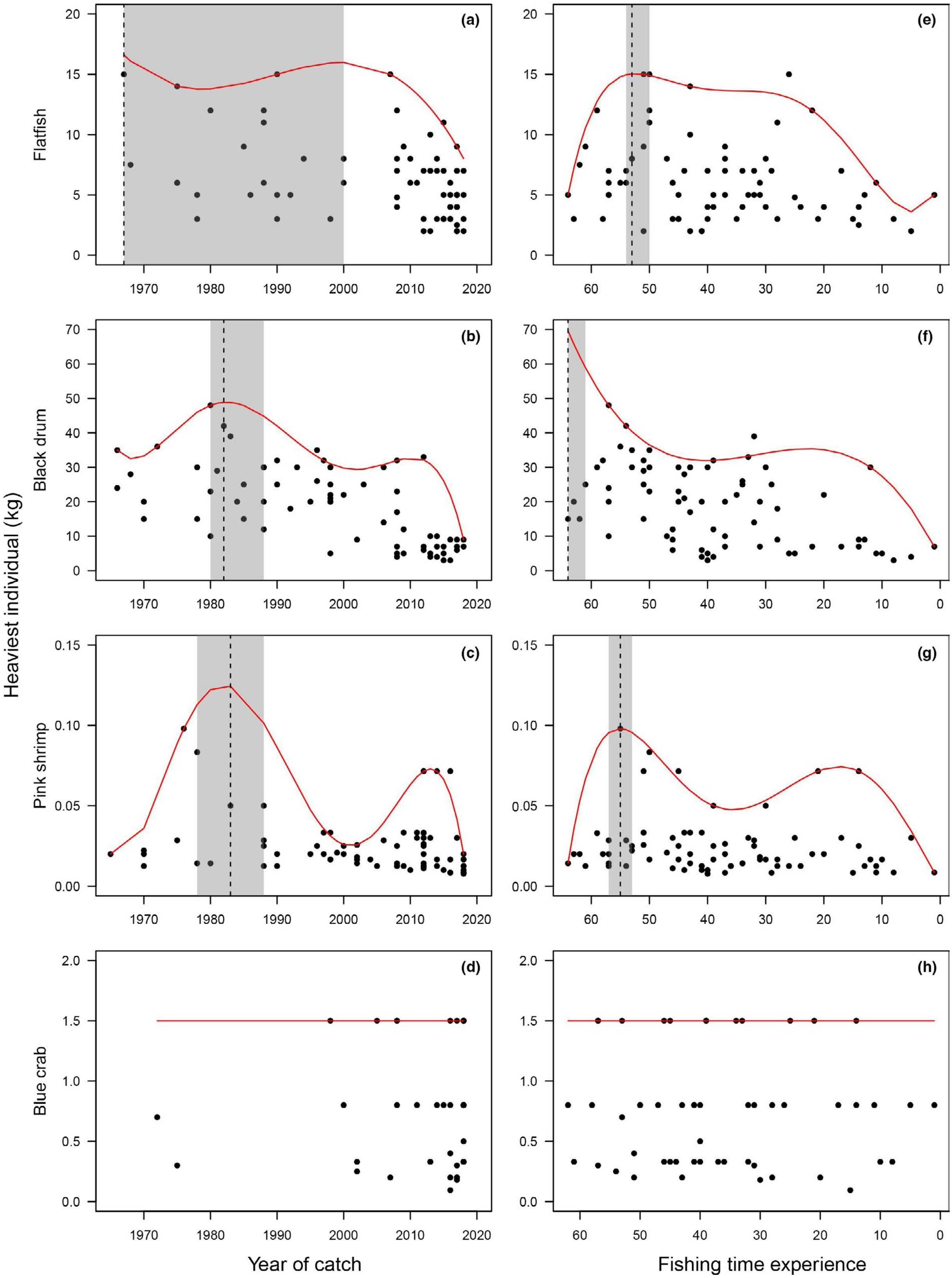


FIGURE 6 Heaviest individuals (kg; dots) of flatfish (a,e), black drum (b,f), pink shrimp (c,g) and blue crab (d,h) according to the Year of Catch and Fishing Time Experience reported by fishers. The highest estimated weight by quantile regression for each species can be observed at the point where the red line intercepts the dashed line. The dashed line represents an estimative of the optimal value of Year of Heaviest Individual (YHI) and Experience of Heaviest Individual (EHI) obtained through quantile regression models. The shaded area represents the confidence interval of 95% calculated for YHI and EHI, based on 10,000 randomizations. Colours available for the online version only

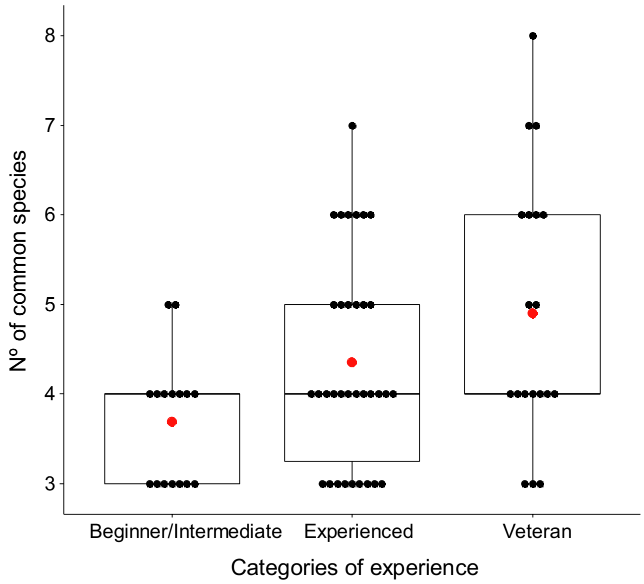


FIGURE 7 Boxplot and number of species cited as common at the beginning of fishing career for each of the three categories of experience of fishers in the Patos Lagoon estuary. Red dots indicate the average for each category, bold horizontal lines the medians and regular horizontal lines the 25th and 75th quantiles. Colours available for the online version only

Moreover, among the heaviest specimens reported in the interviews it is noteworthy that a 30 kg catfish caught in 1988 contrasts with the average weight of 10.1 kg in the last two decades (Figure 5), and a black drum of 39 kg, captured in 1983, with the average weight of 9.2 kg in the last two decades (Figure 6).

The number of different species considered as common at the beginning of fisher's careers reduced when comparing Veteran and Beginner/Intermediate fisher's perceptions (Figure 7; Dunn test, $\chi^2 = -2.66$, $p = 0.004$). Beginner/Intermediate fishers cited at most five species as common, while Veteran fishers cited eight species. Catfish, pejerrey, flatfish and black drum were considered more common early in the career by a larger proportion of Veteran fishers than Experienced and Beginner/Intermediate fishers (Table 2). Mullet was considered a common species among 93.8% Beginner/Intermediate fishers, while Experienced and Veteran fishers consider this species less common early in their careers.

In terms of the perception of the current state of the estuary's resources, five species—catfish, pejerrey, whitemouth croaker, flatfish and blue crab—were considered scarce by a higher proportion of Veteran fishers compared with the Experienced and Beginner/Intermediate fishers. Catfish was considered abundant and even very abundant by Beginners/Intermediates; by contrast, it was considered scarce frequently by Veterans who never considered it as very abundant. It was noted that Veterans have a greater perception of scarcity for pejerrey, whitemouth croaker and flatfish, than the less experienced fishers who tend to perceive them as less abundant or abundant. Black drum was considered scarce by more than 80% in all categories of experience (Figure 8). Fishers of the different experience categories did not notice clear changes in the abundance of pink shrimp, blue crab and mullet (Figure 8).

Fishers cited increasing fishing effort as the main reason (69.4%) for the decrease in catches in the PLE, which mainly includes an increase in the number of fishers and the use of more nets per fisher. The industrial fishery that catches some of the same resources in coastal waters was the second most cited reason with 23.6%.

4 | DISCUSSION

Differences in the perceptions among fishers with different levels of experience of changes in the fishery resources of Patos Lagoon estuary in southern Brazil were found. In general, more experienced fishers reported higher catches, heavier individual catches and a greater number of species as common at the beginning of their activities. A greater proportion of more experienced fishers perceived resources as scarce nowadays. Thus, it is evident that the baseline has changed in a few decades, even among people who are in daily contact with nature, evidencing the existence of

TABLE 2 Frequency of citations (%) of species that fishers considered common at the beginning of their careers

		Fishing Time Experience		
Common name	**Scientific name**	**Beginner/Intermediate (*n* = 16)**	**Experienced (*n* = 34)**	**Veteran (*n* = 19)**
Catfish	*Genidens barbus*	62.5†	70.6†	78.9†
Pejerrey	*Odontesthes bonariensis*	6.3†	20.6†	47.4†
Mullet	*Mugil liza*	93.8	58.8	63.2
Whitemouth croaker	*Micropogonias furnieri*	68.8	100	84.2
Flatfish	*Paralichthys orbignyanus*	6.3†	38.2†	68.4†
Black drum	*Pogonias cromis*	18.8†	29.4†	47.4†
Pink shrimp	*Penaeus paulensis*	81.3	76.5	84.2
Blue crab	*Callinectes sapidus*	6.3	17.6	5.3

†Decline between categories.

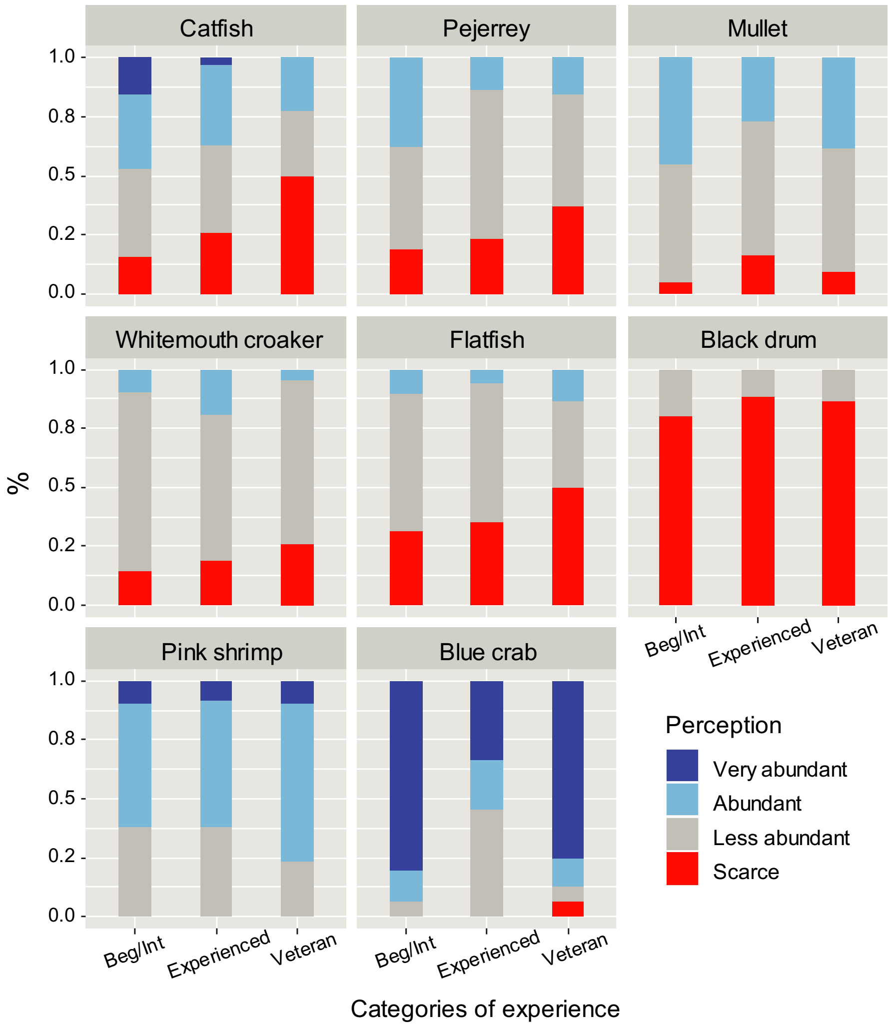


FIGURE 8 Fisher's perceptions about current situation of the main fishery resources in the estuary between the categories of experience. Beg/Int = Beginner/Intermediate. Number of interviews for category of experience available in Table 2. Colours available for the online version only

a shifting baseline syndrome (Papworth, 2009; Pauly, 1995). Such rapid shifts in perceptions help to explain why human societies are so tolerant of the increasing loss of biodiversity (Saénz-Arroyo et. al, 2005). However, reconstruction of baselines by this exercise goes back to fishers who started their careers at most in the 1950s and it is known that commercial fishing for export purposes goes back at least to the second half of the 19th century (Odebrecht, 2003). Therefore, the perception of the older fishers interviewed in this study probably still did not reflect the pristine conditions of the fishery resources in the Patos Lagoon estuary, and it is plausible to consider that the declines in the abundance can be greater than presented here.

These results corroborate the use of local ecological knowledge for the reconstruction of biological scenarios when no empirically obtained data are available. For the period covered by this study (1967–2018), the fisher's reports indicate that there was a reduction in the values of the highest CPUEs over the years for most species, excluding mullet. For all species, except for blue crab, the highest catches were reported for years prior to 1980 (Figures 2 and 3). This perception agrees with the reduction of artisanal landings registered in Rio Grande, which reached a maximum of 43,700 t in 1972 and decreased to an average of 6,300 t since 2001 (Haimovici & Cardoso, 2016a). This shows a concordance between the fisher's perception and the falls in the abundance of most of the species exploited by artisanal fishing in the Patos Lagoon estuary. The same decline was observed when considering the years of experience in the fishery of the interviewees and indicates that the process of abundance reduction continues. Fishers with more than 40 years of experience reported the highest CPUEs, which indicates some degree of accuracy in the memory of fishers. Several studies have been demonstrating the effectiveness of local ecological knowledge to assess the history of fishing resources. Johaness et al. (2000) showed that fishers can provide critical information on historical changes in local marine stocks. In Brazil, Bender et al. (2013) showed that local fisher's knowledge can recognise long-term declines of reef fish species in eastern Brazil while Lima, Begossi, Hallwass, and Silvano (2016) reported short-term temporal changes in the amount and composition of fishing resources exploited by small-scale coastal fisheries on the southeastern Brazilian coast. Thus, this study is further evidence of the efficacy of local ecological knowledge in recognising temporal changes in local fishing resources.

When dealing with the distribution of fishing, the perception of a decrease in the number of sites with very high CPUE (yields) and the dispersion towards the inner estuary of the sites with high CPUEs over time (Figure 4) indicate the active search for rentable fishing grounds despite the overall decrease in the abundance of fishing resources in the PLE. However, sites previously with very high CPUEs, such as the Torotama-Capivaras, continued to be cited and are still an important concentration zone for fishes and consequently fisheries.

The increase in the number of fishers in recent decades (Reis & D'Incao, 2000) could be considered as one of the main factors for the reduction in catch and possibly has forced displacements to more distant and formerly less attractive fishing grounds of the higher estuary. It can also be assumed that the decline in catches has resulted in the search for other fishing sites (also observed by Pérez, 2014; Silvano, Nora, Andreoli, Lopes, & Begossi, 2017) and a greater displacement towards the upper estuary region.

During the exploratory analysis of the data, linear regressions were performed using their conditional means to describe the relationship between the dependent and independent variables. Besides it, the heteroscedasticity found in the data quantile regressions were chosen to estimate the CPUE and heaviest individual. These kinds of models are known to be more robust to non-normal errors and outliers while ordinary least squares can be inefficient if the errors are highly non-normal (Baum, 2013). Quantile regression also provides a richer characterisation of the data, allowing the impact of a covariate on the entire distribution of y, not merely its conditional mean to be considered (Baum, 2013). Furthermore, these regressions allowed the highest CPUE and heaviest individual to be estimated, which were calculated from the higher values but also taking account of the lower ones, which avoided the risk of observing only the highest values cited by fishers (Anderson, 2008). The use of quantile regressions in LEK involves some precautions: (a) quantile regressions (mainly near the 95th quantile) are very sensitive to outliers, so the users must be sure the values reported by fishers are possible in the study area; and (b) the sampling should cover uniformly all reported years and fishing experience, ensuring representability. The choice to model the 95th percentile was taken with some care after exploring potential alternatives. Modelling the 95th percentile places special emphasis on the Year of Catch/Fishing Time Experience having large CPUE/Heaviest individuals (Anderson, 2008). The use of other percentiles (i.e. 75th) could ignore fishers having very large CPUE/Heaviest individuals, if there are relatively few of these available (Anderson, 2008).

Most fishers (69.4%) cited an increase in fishing effort both in the PLE and in the coastal marine waters as the main reason for catch reduction within the PLE. This could be because there was an increase in aid for credit and benefit policies for artisanal fisheries in the late 1990s (Abdallah & Sumaila, 2007; Haimovici et al., 2006), favouring the acquisition of equipment, fishing boats and infrastructure for processing and storage of products. According to those interviewed, there was a considerable increase in the number of fishers and gillnets within the estuary after these government incentive programmes. The current situation of overfishing for several artisanal fishing resources in the PLE, as demonstrated by this study, and for industrial resources in the coastal region as demonstrated by Haimovici and Cardoso (2016a), requires the attention of fishery managers. However, there is a clear lack of proper management measures or enforcement in southern Brazil, as several threatened marine megafauna species are killed annually in high numbers and most of the fish resources are overexploited (Fogliarini, Bugoni, Haimovici, Secchi, & Cardoso, 2019; Haimovici & Cardoso, 2016b; Prado, Mattos, Silva, & Secchi, 2016, this study). From a governance context of lack of enforcement or ineffective management or conservation strategies, Dowling et al. (2016) suggested that the most effective measures would be spatial and temporal approaches, as for example, the establishment of no-fishing zones or seasonal closures. A recent rule prohibiting industrial bottom trawling all along the coast of the state of Rio Grande do Sul from the beach up to 12 nautical miles to the west can be considered as hopeful. However, given the situation of the resources reported in this and other studies, greater efforts will be required from public authorities and users to recover populations and ensure their sustainable exploitation.

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ORCID

Vinni Santos Thykjaer https://orcid.org/0000-0003-3095-6807
Lucas dos Santos Rodrigues https://orcid.org/0000-0003-2310-2619
Luís Gustavo Cardoso https://orcid.org/0000-0003-1026-0853

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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