Evaluation of the Blue Crab *Callinectes sapidus* Rathbun, 1896 Bycatch in Artisanal Fisheries in Southern Brazil

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ABSTRACT

We evaluated the incidental catch of the blue crab in artisanal fisheries through the analysis of sex ratio, catch per unit effort, net positioning, and size in which the capture probability was 50% (P_{50}). The specimens were collected from 2011 to 2013 in the estuary of Patos Lagoon, southern Brazil. The analysis showed a higher occurrence of males. Variations in the catch per unit effort showed greatest abundance values close to the mouth of the estuary. Catch per unit effort was similar when comparing fishing seasons and net positions. P_{50} indicated a low selectivity of the nets since it varied between studied areas but stayed below the size at first maturity. Catches indicated a greater effort on males, since females migrated to spawn in the ocean area adjacent to the estuary during the fishing period studied. The spatial variation of the catch per unit effort showed heterogeneity in fishing catches. Thus, optimal management of the resource should consider the particularities of each area.

Key words: Brachyura, fishery resource, Patos Lagoon, fyke net, estuary

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INTRODUCTION

The blue crab *Callinectes sapidus* Rathbun, 1896 is an important resource for artisanal fishermen in Atlantic coast estuaries, especially in the United States, the Gulf of Mexico, and Brazil. Blue crabs are caught as target species with specialized fishing gear or as bycatch in shrimp fisheries [1,2,3,4,5,6]. Though a significant activity, there is limited information on blue crab catches, which are not included in official statistics [2,4,6]. Scientific studies on the southeast coast of the state of São Paulo, Brazil reported that production reached more than 100 tons per year between the early 1990s and 2006 [7,4]. The few records available on blue crab catches in Patos Lagoon show an annual productivity of 400 tons per year, possibly exceeding 1,400 tons [6].

Fishing aims target species; non-target species are those caught incidentally and retained by the fishermen due to their economic value [8]. In the context of this study, blue crabs are captured as bycatch in pink shrimp (*Farfantepenaeus paulensis* Pérez Farfante, 1967) artisanal fisheries in Patos Lagoon estuary and are the most common bycatch species in these fisheries [9,5]. Most often used in artisanal shrimp fishing are fyke nets, which according to the latest fishing information, is practiced by 1,455 fishermen and involves 22,440 nets [6].

Pink shrimp harvests are variable and closely related to annual variations in environmental conditions. Their productivity varies from zero to more than 4,000 tons [10,6]. Thus, blue crabs are important to fishermen as an alternative income [5,6], since trade becomes more profitable when crabs are processed and all captures are used by the fishermen [5].

The scientific community has focused on the evaluation and reduction of bycatch volumes for research and management goals [8,11]. In Brazil, studies on blue crab bycatch are still limited to describing and quantifying catches without comparative analyses of abundance variation and population dynamics [9,2,12, 13,4]. Furthermore, studies do not take into account the influence of environmental variation on catches. Dumont and D'Incao (2011) [16] estimated population dynamics of blue crab bycatch in fisheries targeting the Argentinean shrimp *Artemesia longinaris* Bate, 1888. The effect of fisheries on the blue crab populations may vary spatially and temporally according to intraspecific competition, salinity, reproductive behavior, the search for food, and protection from predators are important factors that determine the abundance and segregation of species by size and gender [15,16,17,18,19,20].

Blue crab fishing is on the Forum for Patos Lagoon's agenda. The Forum is a co-management organization [21]. The lack of information on blue crab bycatch limits a real understanding of how the species is being exploited. Such knowledge could contribute to the discussion of fisheries bycatch and meliorate its management. This study evaluates possible effects of fyke net fisheries on the blue crabs population in Patos Lagoon and assesses whether there are spatial-temporal variations in the sex ratio, abundance, and size of captured individuals. It also investigates the positioning of the nets as a management alternative to reduce the impact of fishing.

MATERIAL AND METHODS

Study area

This study was carried out in the shallow waters of the Patos Lagoon estuary in southern Brazil, which is an area traditionally important for artisanal fisheries [22]. The areas referred to as A, B, C and D (Fig. 1) were chosen according to differences in salinity, accessibility, and partnership with fishermen. Although points B and C are

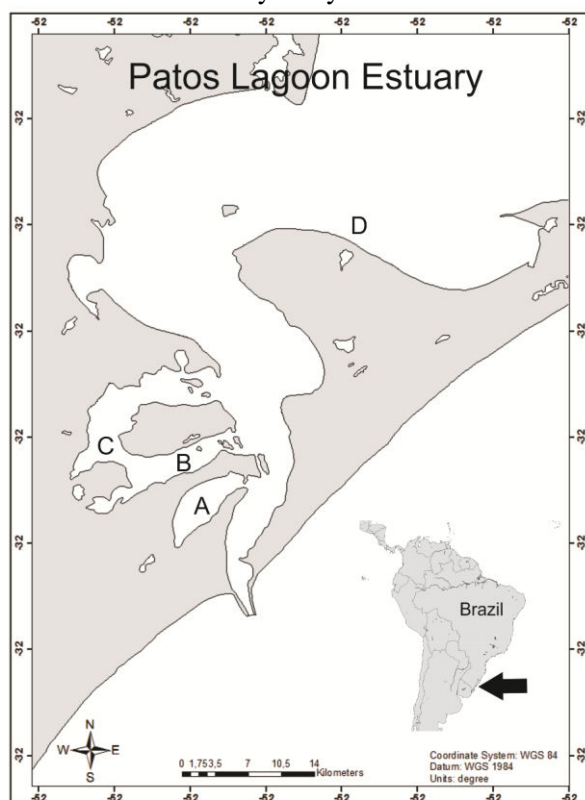close, a bridge separates the two, reducing the channel and changing local hydrodynamics [23].

Figure 1: Estuary of Patos Lagoon, southern Brazil, showing the areas where data were collected (A, B, C and D).

Field sampling and laboratory procedures

Blue crab specimens were collected from the bycatch of pink shrimp fishing, using fyke nets, from February to May for three consecutive fishing seasons (2011, 2012 and 2013) with the cooperation of local fishermen. Funnel-shaped fyke nets of the same size were mounted with rings and valves to prevent organisms from escaping. These nets were joined successively and light baiting was used to attract the organisms [24]. The mouths of the nets were positioned either parallel (mostly in shallow areas) or perpendicular to the water flow direction.

Of the two nets positioned parallel to the water flow, total catches were obtained in all areas in 2011. Of the nets positioned perpendicularly to the water flow, total catches were obtained from two nets in area B. The data obtained facilitated an analysis of the influence of different net positions on total catch. Sampling intervals in each area depended on the activity of the fishermen and varied from 15 to 25 days. We collected samples in sequential days in study areas. However, samples were not obtained in area A in 2012 and 2013 and in areas C and D in 2013 due to the low pink shrimp productivity. We separated the crabs collected from each net. Salinity was measured with a refractometer during the harvests, and the permanence time of the nets was registered to calculate the relative abundance estimated by catch per unit effort (CPUE).

The individuals were collected, stored in labeled plastic bags, transported to the laboratory, and separated by gender. We measured total wet weight with a digital scale (accuracy of 0.001 g) and carapace width (CW, millimeters) between the first anterolateral spines with a digital caliper (accuracy of 0.01 mm).

Data analysis
The sex ratio (males:females) was calculated per fishing season for each area and net position. A chi-square test analyzed differences between sex ratios with a significance level of 5% [25].

We estimated the relative abundance per net through CPUE in weight and number of specimens captured. Estimates of CPUE were calculated through the ratio between weight in grams and fishing time (grams/hour) and the ratio between number of crabs caught and fishing time (number/hour) [26]. The routines of Kolmogorov-Smirnov and Cochran tested the statistical prerequisites of CPUE analyses. Data were logarithmically transformed when necessary (Log CPUE +1) and a Kruskal-Wallis test was performed if normality and homoscedasticity were not attained [25]. All analyses had a significance level of 5% [25]. CPUE was compared (in weight and number) using a one-way analysis of variance (ANOVA) between areas A, B, C and D for the fishing season of 2011, and between fishing seasons (2011, 2012 and 2013). If significant differences were observed, a Tukey's test was performed [25].

The influence of net positioning on the CPUE in weight was compared with the Kruskal-Wallis test [25]. A type III Factorial ANOVA for unbalanced data compared the effect of net positioning on the CPUE in number, using positioning and fishing season as factors [27,28]. Statistical analyses were performed with the software R [29].

The size of the crabs captured in each area was analyzed with size class (CW) distributions grouped into 5 mm intervals. To analyze possible effects of catches on the blue crab population, the CW size with a capture probability of 50% (P_{50}) was compared to the mature size of the species estimated in the Patos Lagoon estuary by Rodrigues and D'Incao (2014) [20]. We estimated P_{50} with the following logistic model: $P=1/(1+\exp^{[-r(CW-CW_{50})]})$ [26,14], where P is the probability of capture, r is the steepness constant of the curve, CW is the carapace width and CW_{50} is the average size at first capture. The model was adjusted by the solver tool (Microsoft Excel) to minimize the amount of waste between the cumulative frequency of observed CW and the frequency calculated by the model.

RESULTS

Salinity
During 2011, the average salinity in area A was 14.4 (± 3.96), andarea B showed the highest average values in harvests with parallel (19.2 ± 5.34) and perpendicular (18.3 ± 4.01) nets. In the same year, the lowest averages were observed in areas C (11.8 ± 2.63) and D (1.7 ± 3.26). In 2012, except for area D with the lowest average (13.0 ± 2.4), salinity was similar in all areas (B parallel = 22.5 ± 5.79; B perpendicular = 25.7 ± 4.61; C = 25.0 ± 1.66). In 2013, salinity was 24.3 (± 4.76) in area B.

Sex ratio
During all fishing seasons, 90 samplings were carried out and 1,473 blue crab specimens were collected (934 males and 539 females). The chi-square test indicated significant differences ($P = 0.00$) in sex ratio during 2011 and 2012 in areas A, B and C, where more males were observed (Table 1). Sex ratio was similar in area D ($P = 0.78$; $P = 0.24$). The nets positioned perpendicularly to the water flow captured more males in all fishing seasons. However, nets parallel to the water flow showed no significant differences ($P = 0.25$) in the sex ratio in 2013.

Table 1: Number of males and females captured in all areas during the study. Chi-square test result (X^2) of the sex ratio male:female, showing the *P*-value with the significant values in bold.

AREA	FISHING SEASONS	NUNBER OF INDIVIDUALS		X^2	*P* - VALUE	SEX RATIO
		MALE	FEMALE			
A	2011	158	108	9.39	**0.00**	**1.46:1**
B Parallel	2011	119	56	22.68	**0.00**	**2.12:1**
	2012	87	55	7.21	**0.00**	**1.58:1**
	2013	61	49	1.30	0.25	1.24:1
B Perpendicular	2011	196	111	23.54	**0.00**	**1.76:1**
	2012	103	56	13.89	**0.00**	**1.83:1**
	2013	51	30	5.44	**0.00**	**1.7:1**
C	2011	62	23	17.89	**0.00**	**2.69:1**
	2012	76	22	27.75	**0.00**	**3.45:1**
D	2011	6	7	0.07	0.78	0.85:1
	2012	15	22	1.32	0.24	0.68:1
Total		934	539	118.23	**0.00**	**1.78:1**

Comparisons of relative abundance - CPUE

ANOVA showed significant differences for CPUE in weight in study areas but not in study years (Table 2). CPUE in weight was greater for area A than for Area D, but there were no other significant differences according to Tukey's test (Fig. 2 A). The mean values of CPUE in weight were 125 (± 28.65), 119.71 (± 32.7) and 92.25 (± 49.59) grams per hour in 2011, 2012 and 2013, respectively (Fig. 2 C). CPUE was significantly different in number (*P* = 0.00) between areas, but not fishing seasons (Table 3). CPUE in number was significantly higher in A than in other areas (Fig. 2 B). CPUE results (weight and number) showed that the catches in area A had smaller juveniles. There was no significant difference in CPUE in weight (H = 1.98; *P* = 0.15) or number (*P* = 0.87; Table 3) when the positions of the nets were compared.

Table 2: Comparison of the relative abundance (CPUE in weight) of blue crab between areas A, B, C and D and fishing seasons. ANOVA results contain SS (sum of squares), DF (degrees of freedom), MS (mean square), F and *P*-value.

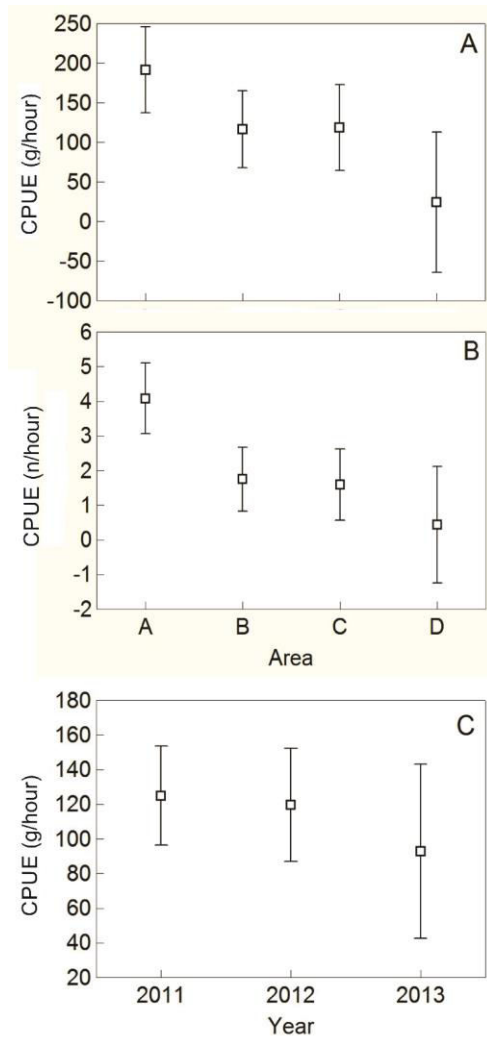| ANOVA – CPUE (in weight)					
EffectT	SS	DF	MS	F	*P*
Areas					
Areas	66,623	3	22,208	4.0038	**0.01**
Error	138,663	25	5,547		
Year					
Year	11,049	2	5,524.3	0.6185	0.54
Error	777,117	87	8,932.4		

Figure 2: Means of relative abundance (CPUE) of blue crabs captured by fyke nets during this study in the estuary of Patos Lagoon, showing the variation of CPUE in weight per area (A) CPUE in number per area per (B) and fishing season (C). Vertical bars show the 95% confidence interval.

Table 3: Comparison of the relative abundance (CPUE in number) of blue crab between areas A, B, C and D, fishing seasons 2011 to 2013 and net positions using log (CPUE +1). ANOVA results contain SS (sum of squares), DF (degrees of freedom), MS (mean square), F and *P*-value with significant differences in bold.

ANOVA – CPUE (in number)

Effect	SS	DF	MS	F	*P*
Areas					
Areas	3.43700	3	1.14567	7.4096	**0.00**
Error	3.86549	25	0.15462		
Year					
Year	0.52830	2	0.26415	0.9945	0.37
Error	23.1091	87	0.26562		
Net					
Position	0.0554	1	0.0554	0.0269	0.87
Error	110.9818	54	2.0552		

Size composition and capture probability (P$_{50}$)

Differences were observed in the number of males and females in all size classes, with a higher number of males in the largest classes. The smallest and largest specimens captured measured 7.9 mm and 157.2 mm of CW, and the catches were mainly composed of animals larger than 30 mm of CW. A multimodal trend was observed in area A, in contrast to the increase in the number of males in the largest classes (Fig. 3). Bimodal and unimodal frequency distribution were observed in areas B and C. Females occurred in all areas, with a highest number in the lowest CW classes (less than 120 mm allowed by law). P$_{50}$ values in area A for males and females were 81.7 and 62.62 mm, respectively (Fig. 3). In area B, the lowest and highest P$_{50}$ values of males were 86.89 and 105.66 mm, observed in perpendicular nets during 2011 and 2012 harvests. In the same area, the smallest and largest females were captured in parallel nets, with P$_{50}$ of 65.06 mm in 2011 and 91.27 mm in 2013 (Fig. 4 and 5). In area C (Fig. 6), the highest P$_{50}$ values for males and females were 103.94 and 73.84 mm, in 2012 and 2011. The largest males captured in area D in the 2011 harvest showed a P$_{50}$ value of 115.17 mm, whereas smaller specimens were captured in 2012 (P$_{50}$ = 70.64 mm). Females in this area followed the pattern size observed in other areas, with P$_{50}$ values of 92 mm in 2011 and 66.00 mm in 2012 (Fig. 7). Except for area D in 2011, all other observations showed that the P$_{50}$ was smaller than the size at first maturity estimated in 108 mm for males and 115 mm for females in the Patos lagoon estuary by Rodrigues and D'Incao (2014) [20]. The R^2 values were greater then 0.9, indicating a good adjustment between the observed data and the curves estimated by the model.
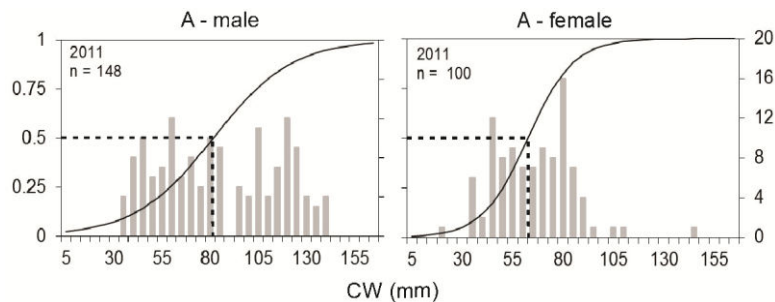

Figure 3: Frequency distribution (bars) by carapace width (CW) grouped at intervals of 5 mm and probability of capture (logistic curve) estimated for males and females of the blue crabs captured with fyke nets in the area A of the Patos Lagoon estuary. The dashed line with origin on the ordinate indicates the size at which 50% of the individuals are captured. n = sample number.
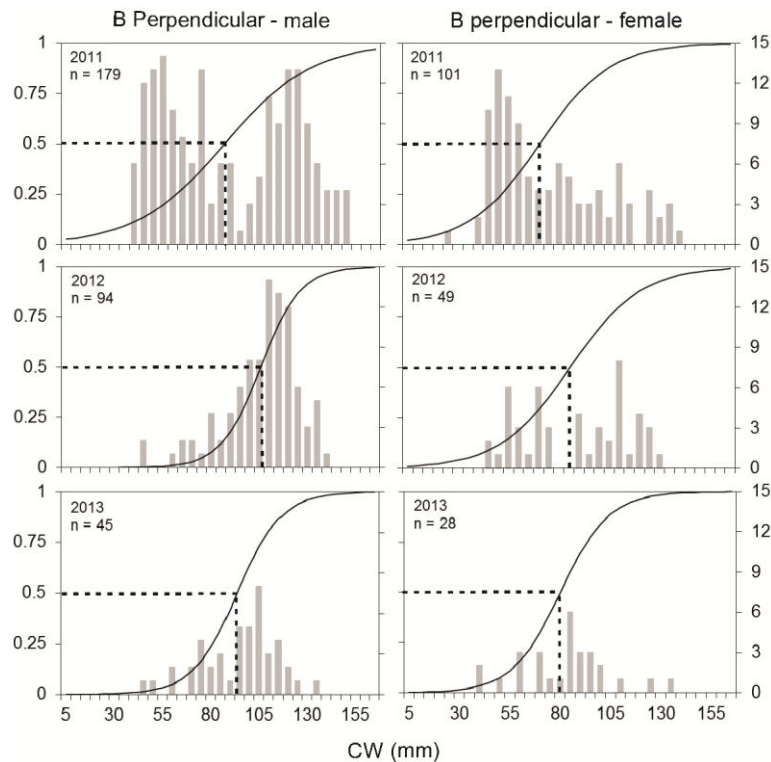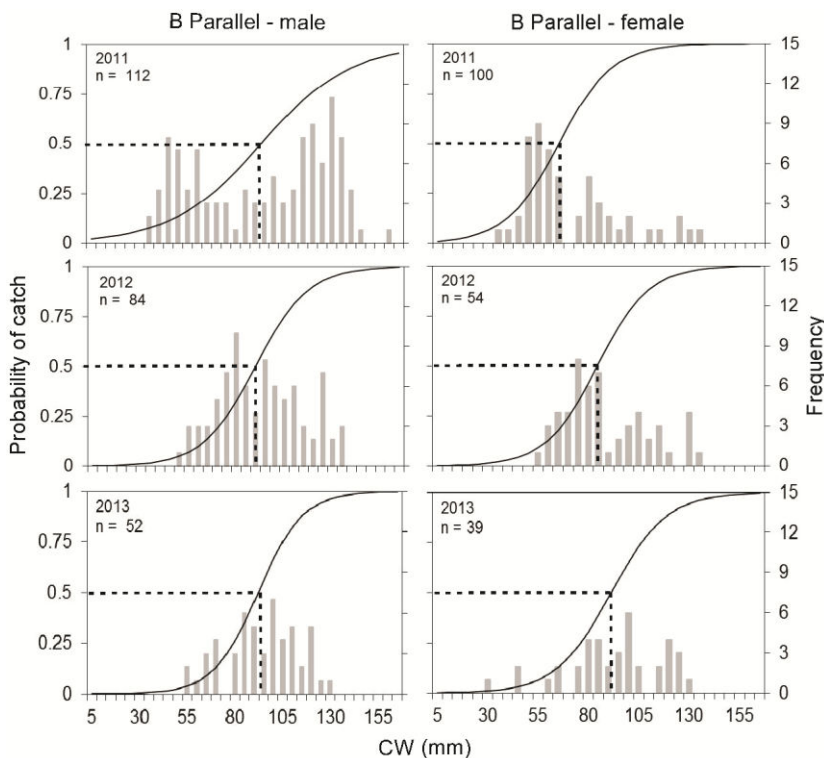
Figure 4: Frequency distribution (bars) by carapace width (CW) grouped into 5 mm intervals and probability of capture (logistic curve) estimated for males and females of the blue crabs captured with fyke nets perpendicular to the water flow in the area B of the Patos Lagoon estuary. The dashed line originated on the ordinate indicates the size at which 50% of the individuals are captured. n = sample number.

Figure 5: Frequency distribution (bars) by carapace width (CW) grouped into 5 mm intervals and probability of capture (logistic curve) estimated for males and females of the blue crabs captured with fyke nets parallel to the water flow in the area B of the Patos Lagoon estuary. The line originated on the ordinate indicates the size at which 50% of the individuals are captured. n = sample number.
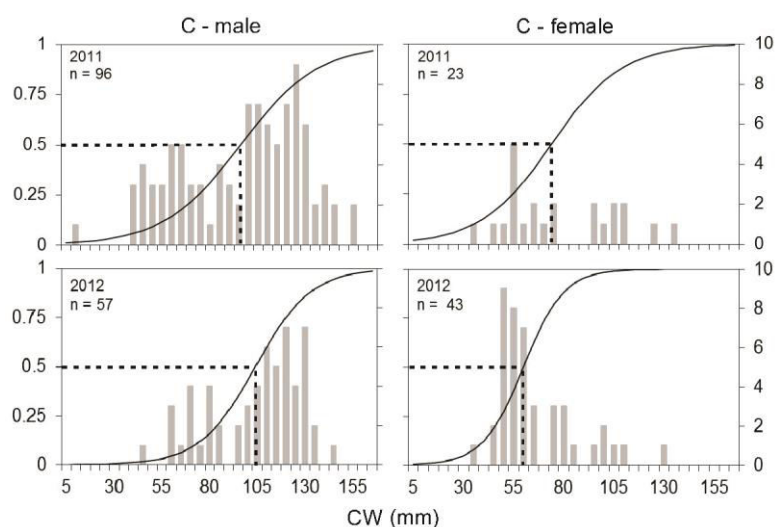
Figure 6: Frequency distribution (bars) by carapace width (CW) grouped at intervals of 5 mm and probability of capture (logistic curve) estimated for males and females of the blue crabs captured with fyke nets in the area C of the Patos Lagoon estuary. The dashed line with origin on the ordinate indicates the size at which 50% of the individuals are captured. n = sample number.
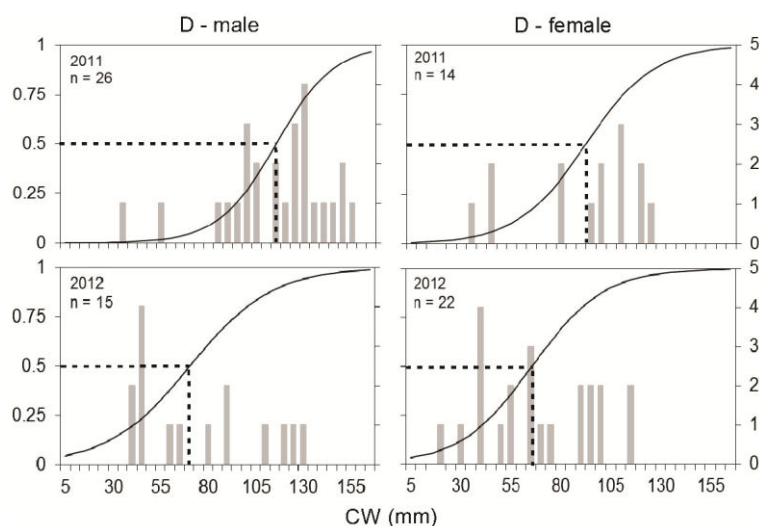

Figure 7: Frequency distribution (bars) by carapace width (CW) grouped at intervals of 5 mm and probability of capture (logistic curve) estimated for males and females of the blue crabs captured with fyke nets in the area D of the Patos Lagoon estuary. The dashed line with origin on the ordinate indicates the size at which 50% of the individuals are captured. n = sample number.

DISCUSSION

The large number of blue crab males registered in 2011 and 2012 could be the result of female migration behavior associated with the reproductive biology of the species in Patos Lagoon, where a higher number of males was observed during summer and early autumn [20].

It should be noted that the effect of nets on males has an impact on the population of blue crabs. Studies in Chesapeake Bay, US reported that the capture of males affects reproduction, as it changes mating availability, decreasing the size of mature males and reducing their reproductive potential and reducing the quality of sperm and seminal fluid [30,31].

Area D presented the lowest mean of CPUE in weight with lower average salinity when compared to area A. The largest catches occurred in the areas closest to the mouth of the estuary that connects it to the ocean, mainly in area A. According to Seeliger (1998) [32], areas closest to the ocean are greatly influenced by salt water, which confirms the salinity variations observed in this study. Area A was an important habitat for juvenile blue crabs, especially the smallest crabs. Study results reflect the influence of salinity and blue crab behavior on catches. Blue crab preference for areas with higher salinity is related to lower energy expenditure [3]. Salinity variation influences the distribution and abundance of the species with segregation by sex and size [3,33,19,34,35]. Variations in the abundance of individuals due to the search for food, growth, survival, and protection against intraspecies competition must also be considered [15,16,19].

The productivity of the blue crab in the Patos Lagoon estuary is poorly monitored, and annual production tendencies are difficult to diagnose [6]. However, the values of mean annual CPUE in weight for crabs in the estuary calculated in this study provide important production estimates associated with the pink shrimp fishery. The annual CPUE did not differ throughout the study. However, the effective effort in the estuary might mask an accurate assessment of abundance from CPUE data. Little fluctuation in mean CPUE values reflects the variations in the number of fishermen and nets acting in each fishing season. Changes in effective effort can maintain high and stable levels of CPUE while the abundance of stock decreases [26].

Blue crab catches with fyke nets represent an important income for fishermen, and larger specimens ensure better sales and meat production [5,6]. Thus, in an attempt not to change the structure of the nets, an alternative solution could be the modification of fishing positions to reduce the effect of blue crab catches on the population, without reducing the capture of larger individuals. However, this study was not able to identify net positions that reduce the impact of blue crab catches in the studied area based on the CPUE and size structure of individuals.

Analysis of the size structure and size where capture probability is 50% highlight the need for more selective management favoring smaller and immature blue crabs. Except for area D in 2011, males and females captured were smaller than 120 mm, the size permitted by the law. Crabs were also captured before reaching size at first maturity estimated by Rodrigues and D'Incao (2014) [20] as 108 mm for males and 115 mm for females. Management techniques to reduce catches of immature individuals should be tested in the estuary without compromising the capture of the target species. Fishing with fyke nets facilitates selective management by fishermen, since crabs can be discarded still alive into the estuary [9]. However, it is still difficult to quantify and evaluate such discards.

Multispecies assessment of fishing has become more common as single species management has failed [8]. Current fishing regulations neglect blue crab bycatch in artisanal fisheries with fyke nets. The Normative Instruction 03/04, which regulates fishing activities in the estuary of Patos Lagoon, is single-species based and does not include blue crab fishing. This activity is only regulated by SUDEPE's ordinance [36], which establishes a minimum capture size, allows the exclusive use of long lines for crabs and prohibits fishing near the breakwaters. For comparison, blue crab fisheries in the United States are regulated by laws and fishing quotas that vary between states, though fishing is traditionally performed using crab pots that guarantee the selection of smaller individuals [37].

CONCLUSIONS

The paper indicate that fishing with fyke nets increases capture of blue crab males and may be harmful to the reproduction of the species. The positioning of the nets in

the water was an ineffective management alternative, and we recommend comparing other areas of the estuary for a better evaluation. It would be appropriate to rethink the exploitation of blue crab. The optimal management of this resource should consider the particularities of each area, requiring methods or devices that enable a greater selectivity of immature individuals.

ACKNOWLEDGEMENTS

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Erratum

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