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Hook selectivity as a mitigating measure in the catches of the stingray *Pteroplatytrygon violacea* (Elasmobranchii, Dasyatidae) (Bonaparte, 1832)

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Summary

Hook selectivity, sex ratio of catches and relative abundance (Catch Per Unit Effort – CPUE) were assessed for the pelagic stingray *Pteroplatytrygon violacea* (Bonaparte, 1872), caught by longline gear in the southwestern Atlantic Ocean over the continental slope and adjacent oceanic area. The catches were carried out at depths of 200–4000 m by research cruises in 2002 and 2003, from Cabo Frio (22°52′S) to Laguna (28°28′S); and by hook selectivity experiments from 2004 to 2008, from Itajaí (26°54′S) to Tramandaí (29°59′S). Hook selectivity experiments indicated higher catches of stingrays with 'J' hooks (9/0, 10° offset) commonly used by the pelagic longline fleet than with 'circle' hooks (18/0, 10° offset). 'circle' hooks reduce the longline by-catches of this species. Most of the stingrays caught were males (6 : 1). One female aborted mid-term embryos at the time of capture. CPUE was highest between spring and autumn and lowest during winter.

Introduction

The pelagic stingray *Pteroplatytrygon violacea* (Bonaparte, 1832) is a circumglobal and preferably oceanic-epipelagic species that also inhabits areas along continental shelves and islands (Mazzoleni and Schwingel, 2002; McEachran and de Carvalho, 2002; Love et al., 2005; Ellis, 2007). Along the southeastern Brazilian coast, particularly near Niterói, studies have shown the occasional presence of this species in shallow water (depths of 30–45 m; about 18°C) (Siqueira and Sant'anna, 2007). The maximum disc width (DW) for this species was 80 cm and newborns occurred at about 7 cm DW (McEachran and de Carvalho, 2002).

The species often uses seamounts and shallow waters as places to give birth to their pups (Mollet et al., 2002; Domingo et al., 2005). In the eastern Pacific, *P. violacea* gives birth in winter, in the warmer coastal waters of Central America. It later moves to higher latitudes, including Southern California (Mollet, 2002). According to Forselledo et al. (2008), in the southwest Atlantic sexual maturation occurs in late spring, with a gestation period of 2–4 months. Parturition usually occurs from late summer to early autumn (only once a year). On the other hand, Mollet et al. (2002) suggests a shorter period of gestation, with two or more births per year.

The industrial longline fishery is an optional source of food for *P. violacea* as an opportunistic species and presents a wide range of food items, primarily squid, jellyfish, crustaceans and teleosts (Vaske, 2004; Forselledo et al., 2008). However, due its low economic value, the pelagic stingray is usually discarded. On board, during the extraction of the hook from the stingray, fishermen tend to inflict serious injuries to the mouth, ventral and caudal regions of this species (Forselledo et al., 2008). Such catches should be monitored with the aim of creating procedures to preserve the health of these animals (Dulvy et al., 2008).

The hypothesis of the study is related to hook selectivity experiments, where 'circle' hooks reduce by-catch more than the 'J' hooks commonly used by the pelagic longline fleet.

Materials and methods

Data sources

Biological samples of *P. violacea* were obtained from research cruises (2002–2008) (n = 151) in southern and south Brazil, by the Assessment Program of Living Resources from the Economic Exclusive Zone (REVIZEE) and the Sea Turtle Project (TAMAR), on board the RV 'Soloncy Moura' from the Fisheries Research and Management Center of the Southeast and South Brazil (CEPSUL) (Table 1).

The fishing gear used was a nylon monofilament surface longline, with an average of 300 hooks per set for REVIZEE cruises and 500 hooks per set for TAMAR cruises. The aim of the TAMAR project was to compare the selectivity of control hooks ('J' hook – 9/0, 10° offset and traditionally used by the longline fleet) with 'circle' hooks (18/0, 10° offset) to mitigate the by-catch of sea turtles (Giffoni et al., 2005). Conversely, the REVIZEE program used only 'J' hooks to assess the living aquatic resources in the studied area.

During the REVIZEE cruises, 19 longline sets were distributed between the latitudes of Cabo Frio, Rio de Janeiro (22°52′S) and Laguna, Santa Catarina (28°28′S), and longitudes of 38° to 46°W. On the other hand, for the TAMAR hook selectivity cruises, 18 longline sets were distributed between the latitudes of Itajaí, Santa Catarina (26°54′S) and Tramandaí, Rio Grande do Sul (29°59′S) and the longitudes 31° and 51°W. For each set, information such as date, latitude, longitude, depth, start and end time of set, start and end time of haul, sea surface temperature (SST), surface atmospheric pressure, sea state, and number of individuals caught per set were recorded. CPUE (Catch Per Unit Effort) was used as an index of relative abundance.

Biological sampling

Biological data recorded from *P. violacea* were disc width (DW), body weight (BW), liver weight (LW) and gutted body weight (GW). The sex ratio of *P. violacea* caught during the REVIZEE and TAMAR cruises (2002–2008)

Table 1
Details on longline fishing operations, south-western Atlantic, 2002–2008 by areas and seasons as well as by numbers of by-catch for stingray (*Pteroplatytrygon violacea*)

Cruise	Period	Season	Latitude (°S)		Longitude (°W)		Number of individuals caught
			Minimum	Maximum	Minimum	Maximum	
Revizee 01/2002	06/12–16/12/2002	Spring	25.18	28.85	43.33	47.15	12
Revizee 01/2003	16/03–24/03/2003	Summer	25.35	25.62	41.52	44.17	6
Revizee 02/2003	08/04–23/04/2003	Autumn	22.3	24.6	37.57	44.10	7
Revizee 03-04/2003	02/07–24/07/2003	Winter	24.28	28.6	42.82	47.17	2
Tamar 2004	27/11–03/12/2004	Spring	27.27	29.1	46.02	47.00	40
Tamar 01/2005	19/01–23/01/2005	Summer	27.6	30.33	46.60	47.98	8
Tamar 02/2005	23/02–04/03/2005	Summer	27.22	28.78	46.67	47.45	5
Tamar 03/2005	30/10–05/11/2005	Spring	27.55	28.87	46.67	47.35	27
Tamar 2007	13/09–17/09/2007	Winter	28.47	29.40	45.35	47.83	5
Tamar 2008	19/01–24/01/2008	Summer	27.37	29.07	46.48	47.15	26

Cruise	Number of longline sets	Number of hooks	Fishing time (h)	MSST (°C)	Depth (m)	
					Minimum	Maximum
Revizee 01/2002	7	1957	119	22.0	382	2525
Revizee 01/2003	4	1197	68	24.8	670	2614
Revizee 02/2003	9	2700	153	24.6	567	3220
Revizee 03-04/2003	12	3600	204	20.1	284	2643
Tamar 2004	6	3000	104	23.1	750	2625
Tamar 01/2005	3	1500	52	25.4	350	1456
Tamar 02/2005	8	4000	136	25.6	304	1150
Tamar 03/2005	4	2498	71	19.7	396	1163
Tamar 2007	3	1500	54	20.3	496	2700
Tamar 2008	5	2500	90	25.1	518	1538

MSST, Mean Sea Surface Temperature.

(n = 146) was analyzed through the use of the methodology suggested by Vazzoler (1996). The chi-square test was applied to check the significance of the different proportions seasonally (Zar, 1999).

For the size composition, the relationship between body weight and disc width for separated sexes, was assessed as an exponential type $BW = aDW^b$. Covariance Analysis between the total weight (g) and disc width (cm) was done using the sex as a factor.

Therefore, the coefficients for this length/weight relationship were estimated considering combined sexes. The length/weight relationship obtained was: $BW = 0.027187\ DW^{2.956}$ (total weight = $0.02717\ DW^{2.956}$; Durbin-Watson D Statistic = 1.752; First Order Autocorrelation = 0.114).

Hook selectivity

The comparison of *P. violacea* catches with ‘J’ hooks versus ‘circle’ hooks has been done through the use of the Mantel-Haenszel test (Daniel, 1995; Agresti, 2002). This procedure is based on a chi-square test and compares two groups (in this case ‘J’ and ‘circle’ hooks) in a binary response (‘presence’ and ‘absence’), adjusted by a control variable (control: ‘J’ hook; tested: ‘circle’ hook). The analysis basically indicates the odds ratio of a particular type of hook used to catch *P. violacea* versus another type.

During the commercial fleet cruises, it was called the ‘test group’. The initial portion of the longline was composed of 500 hooks (250 ‘circle’ and 250 ‘J’). These hooks were arranged in the sequence: J, Circle, J, Circle, J…. The longline section between two float lines was called ‘samburá’ and contained 5 equidistant gangions, allowing both hook types to be placed at all possible positions within the longlines (Giffoni et al., 2005). The same procedure was used while operating the longlines from the research vessel cruises, with the difference that in the commercial longline the fleet used more than 500 ‘J’ hooks. Bait was the mackerel *Scomber japonicus*.

Table 2
Results of Mantel-Haenszel procedure applied to *Pteroplatytrygon violacea* caught by two hook types (‘circle’ and ‘j’), on selectivity experiments, TAMAR Project, 2002–2008. The ‘J’ hook had 1.4 more chances to catch rays than the ‘circle’ hook

	Positive	Negative	Total
C	68	1001	1069
J	93	977	1070
Total	161	1978	2139

Mantel-Haenszel statistic = 0.714; Mantel-Haenszel Chi-square = 3.84; P = 0.05; Odds ratio (cross-product ratio) for the first table is: (93/977)/(68/1001) = 1.4.

Results

Hook selectivity

The Mantel-Haenszel procedure applied to the hook selectivity data showed that the ‘J’ hook had 1.4 more chances to catch *P. violacea* than the ‘circle’ hook. This difference was considered significant (P = 0.05) (Table 2). The selectivity experiments also showed higher quantities of *P. violacea* being caught by ‘J’ hooks than by ‘circle’ hooks, considering both sexes (males: n = 85; females: n = 11) (Fig. 1).

The hook selectivity experiments showed that the ‘J’ hook caught larger individuals (36–58 cm DW; mean 44.5 cm DW; SD = 4.3 cm; n = 64) than the ‘circle’ hook (34–50 cm DW; mean 42.8 cm DW; SD = 3.1 cm; n = 35) (Fig. 2). The

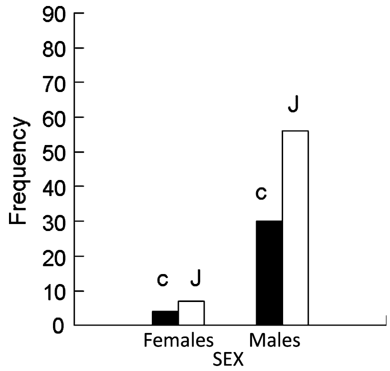

Fig. 1. Number of *Pteroplatytrygon violacea* individuals caught by hook type ('circle' and 'J') and sex, from selectivity experiments during TAMAR cruises, 2002–2008 (males: n = 85, females: n = 11).

t-test was used to compare the mean sizes (P < 0.05) (Table 3).

Sex ratio of the catches

The male sex ratio was significantly higher than females throughout most seasons (P < 0.01). However, during autumn the sample size was very low and the sex ratio was not considered. For the period 2002–2008, the sex ratio was 7.4 : 1 in summer, 3.6 : 1 in winter and 6.4 : 1 in spring. The total was 6 : 1 (male: female) ($\chi^2 = 74.08$; P < 0.01) (Table 4).

The catches of *P. violacea* occurred between 17.4 and 27.7°C SST. The mean temperature was 23.1°C (n = 87; SD = 2.35°C). However, there was no relationship between CPUE and SST for either hook type (Fig. 3).

On 24 January 2008, a pregnant female *P. violacea* (57.5 cm DW; 4.5 kg) was caught over the continental slope at 1021 m depth (27°01′S/46°15′W) with four mid-term embryos (one male: 5 cm DW; three females: 5.2, 5.4 and 5 cm DW) in its uterus, which aborted on board.

CPUE – The index of relative abundance

During the REVIZEE and TAMAR cruises, *Pteroplatytrygon violacea* catches were distributed throughout the year on the Brazilian southern continental slope and adjacent oceanic areas, between the isobaths at depths of 200 and 4000 m.

Table 3
Results of '*t*' test, applied to mean DW of *Pteroplatytrygon violacea* by hook type ('circle' and 'J'), obtained from selectivity experiments, TAMAR Project, 2002–2008. Mean DW caught by 'J' hook was significantly larger than the 'circular' hook (P < 0.05)

Group	N	Mean	SD
C	35	42.8	3.1
J	64	44.5	4.3

Separate Variance $t = -2.288$; d.f. = 88.7; P = 0.025; Difference in Means = −1.723; 95.00% CI = −3.22–−0.226; Pooled Variance $t = -2.094$ d.f. = 97; P = 0.039; Difference in Means = −1.723; 95.00% CI = −3.357–−0.090.

Some sets were recorded by TAMAR observers aboard the commercial fleet in international waters, e.g. the Rio Grande rise, the Hunter Channel, and distant locations within the Brazilian Exclusive Economic Zone (EEZ) such as the Vitória and Trindade sea mountains (Fig. 4). The highest CPUE values occurred during autumn and spring (2.01–5.20 ind./100 hooks) for TAMAR cruises and during spring and summer (0.68–1.33 individuals/100 hooks) for REVIZEE cruises.

In order to group both cruises, only the CPUE of 'J' hooks was considered when making the seasonal maps of catches.

Discussion

The industrial pelagic longline fleet based in Santa Catarina state (Brazil), targets sharks, tunas and swordfish, with spatial and seasonal variations in their species distribution and availability. On the other hand, by-catches of cartilaginous fishes that are not target species use to occur in this fishery, e.g. the ecologically important pelagic stingray *P. violacea* (Bonaparte, 1832) in the epipelagic environment. In several cases, the longevousness (low resilience to fishing intensity) of the species threatens them with extinction (Camhi et al., 2004).

Strategies attempting to reduce by-catches of protected marine species have been tested on a global basis. For sea turtles, technological alternatives have been tested, comparing the selectivity of different hook types, e.g. the 'circle' versus the traditional 'J' type hook (Sales et al., 2010). In the present study, the 'circle' hooks caught pelagic stingrays with a significantly smaller mean DW (P < 0.05) than the 'J'

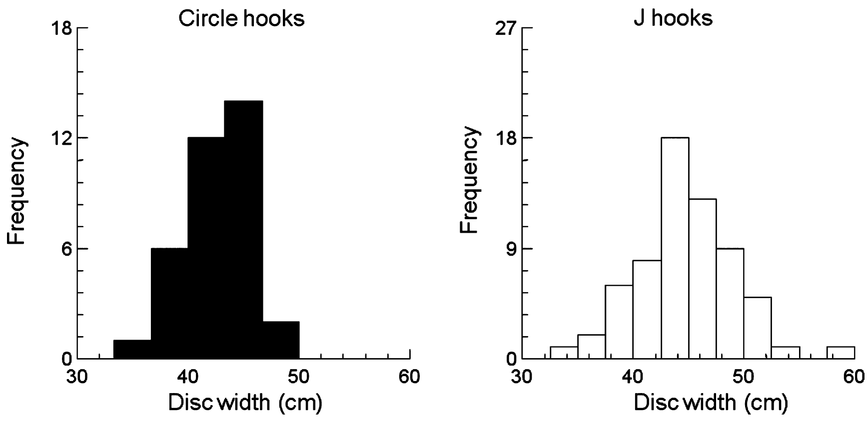

Fig. 2. Size compositions of *Pteroplatytrygon violacea* caught by 'circle' and 'J' hooks tested during selectivity experiments on TAMAR cruises, 2002–2008. 'Circle' hook (mean = 42.8 cm, SD = 3.1 cm, n = 35); 'J' hook (mean = 44.5 cm, SD = 4.3 cm, n = 64). DW, disc width (cm)

Table 4
Chi-square test results applied to seasonal sex ratios, *P. violacea* catches, 2002–2008

	n males	n females	n Total	% males	% females	Number of males expected	Number of females expected	χ^2	χ^2 critic	P
Summer	37	5	42	88.1	11.9	21.0	21.0	24.38	3.841	0.000*
Autumn	6	1	7	85.7	14.3	3.5	3.5	3.57	3.841	0.059
Winter	18	5	23	78.3	21.7	11.5	11.5	7.35	3.841	0.007*
Spring	64	10	74	86.5	13.5	37.0	37.0	39.41	3.841	0.000*
Total	125	21	146	85.6	14.4	73.0	73.0	74.08	3.841	0.000*

*P < 0.01; n = 146.

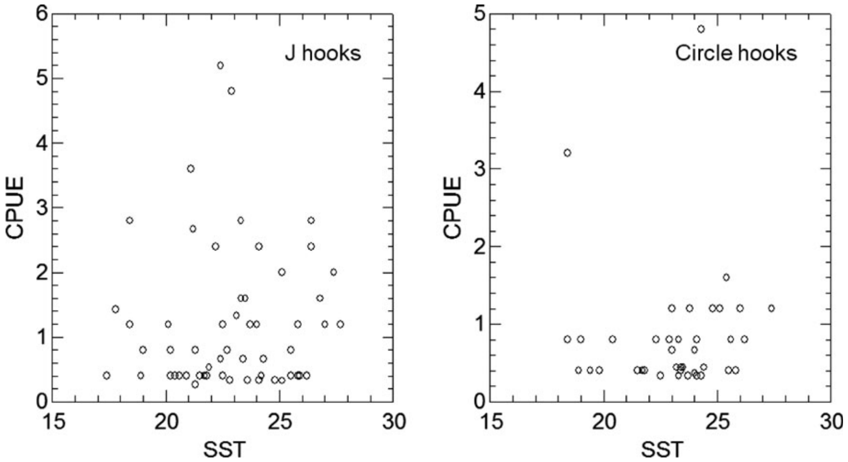

Fig. 3. Relationship between *Pteroplatytrygon violacea* CPUE (rays/100 hooks) and SST (°C), during TAMAR cruises, using 'J' hooks (left) and 'circular' hooks (right). CPUEANZJOTA – 'J' hook CPUE; CPUEANZCIRC – 'circular' hook CPUE. TEMP – SST (°C)

hooks. However, the *P. violacea* size range caught by the 'circle' hook of 40–50 cm DW overlaps its first sexual maturation size of 48 cm DW for males and 40–50 cm DW for females (McEachran and de Carvalho, 2002). This can be problematic for stingray conservation, but additional data is needed to reach more conclusive results, and assure that this type of hook is harmful to the reproductive cycle of the species. Ward et al. (2009) observed that several elasmobranch species tended to be smaller on circle hooks, although non-significantly.

The Mantel-Haenszel procedure indicated a reduction in the catches of *P. violacea* with the 'circle' hook, compared to the traditional 'J' hook. Pacheco et al. (2010) also observed higher *P. violacea* catch rates with the 'J' than the 'circle' hook. The 'J' hook CPUE (9.28 ind./1000 hooks) was almost 10 times higher than the 'circle' hook CPUE (0.99 ind./1000 hooks). 'Circle' hooks (18/0, 0° offset) and 'J' hooks (9/0, 0° offset) were used with squid *Illex* sp. and *light lumi* placed on each hook as bait. In the selectivity experiment data used in this study, the mackerel *Scomber japonicus* was used as bait ('J' hook: 9/0, 10° offset; 'circle' hook: 18/0, 10° offset). Although between the experiments there were technical differences with hook types, baits, and areas, the 'circle' hooks proved to be more effective in reducing the *P. violacea* by-catches. Circle hook perforations usually occur externally, increasing the survival rates of the catches. Fish are usually hooked at the jaw (Malchoff et al., 2002; Skomal et al., 2002; Cooke and Suski, 2004; Horodysky and Graves, 2005). However, Pacheco et al. (2010) observed that the 'circle' hook mortality rate was not significantly lower than the 'J' hook rate in stingrays caught in their experiments (P = 0.78).

McEachran and de Carvalho (2002) found *P. violacea* males that reached the mean size of first sexual maturity at 48 cm, while females matured between 40 and 50 cm DW. Therefore, it seems that the longline used by the R.V. 'Soloncy Moura' in Brazil, with characteristics similar to the commercial longline operated by the fleet based in Itajaí (Santa Catarina state), mainly caught pelagic stingrays in the reproductive phase. However, more data, mainly from observers aboard commercial longliners, are necessary to confirm this hypothesis.

In the studied area of 2002–2008, the male sex ratio was significantly higher than the female ratio throughout most of the seasons (P < 0.01). Studies carried out with *P. violacea*, caught by the Uruguayan longline fleet operating in the Southwestern Atlantic, Pacific and Indian oceans, detected a total sex ratio of 2 : 1 (male: female). Seasonally, it was 6 : 1 in summer; 1.5 : 1 in autumn; 1.3 : 1 in winter and 1 : 1 in spring. It seems that the higher ratio of males was related to warmer seasons and the increase in the mean seawater temperature (Forselledo et al., 2008). The southwestern Atlantic is probably a mating area for *P. violacea* males, due to the higher catch ratios of males to females mainly during summer as well as the high percentage throughout the year of adult males with rigid claspers (DW > 40 cm) combined with their gregarious mating patterns.

During the January 2008 cruise, a pregnant *P. violacea* female was recorded as aborting mid-term embryos on-deck, shortly after her capture. At Itaipu beach in Niterói, Rio de Janeiro state in January and February, Siqueira and Sant'anna (2007) examined five females measuring between 48 and 65.5 cm DW and weighing from 3 to 8.5 kg. The uterus was empty in three of these females, and two females aborted

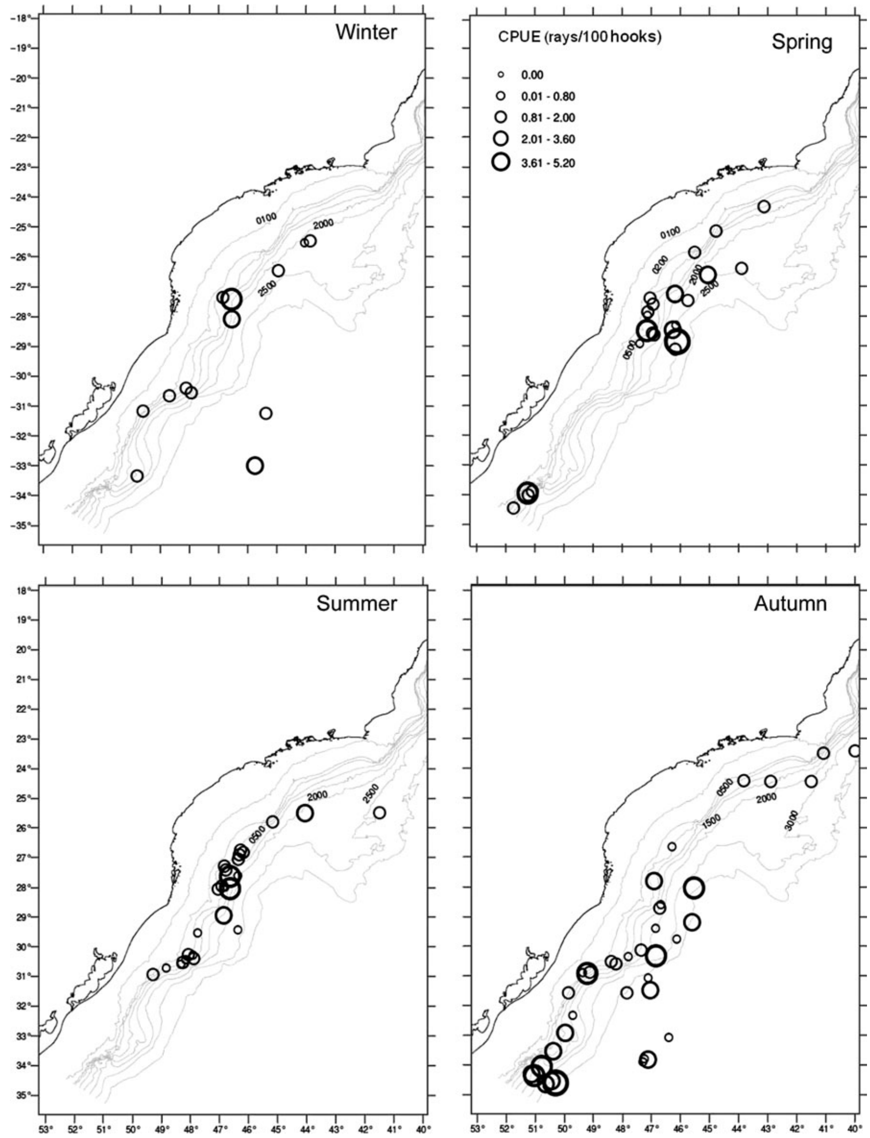

Fig. 4. Seasonal distribution of *Pteroplatytrygon violacea* CPUE (rays/100 hooks), over the slope and adjacent oceanic areas off southeast-south Brazil, REVIZEE and TAMAR cruises, 2002–2008

onboard. This information raised the hypothesis that summer is also a parturition season for *P. violacea* on the southern Brazilian coast. Females with mid-term and near-term embryos were found mainly during summer, which can be explained by the fact that maturation occurs in late spring (Forselledo et al., 2008). Conversely, Mollet et al. (2002) suggested two or more pupping seasons per year for this species, without a specific timeframe of occurence.

No relationships between the sea surface temperature (SST) and the catches were observed. However, there was a clear pattern of low CPUE during winter; in general, the CPUE values were higher during the other seasons. Forselledo et al. (2008) observed in the same area that the highest CPUE occurred in summer (1.4 stingrays/1000 hooks), when the mean SST was high (25°C). Lowest values were found in winter (0.1 stingrays/1000 hooks), at minimum temperatures of 9.3°C. According to Domingo et al. (2005), the highest CPUE values obtained from the longline fishery in the South Atlantic took place in autumn, with 6.4 stingrays/1000 hooks. The lowest values occurred in spring, with 1.6 stingrays/1000 hooks. Therefore, the CPUE values decrease from autumn to spring, following a reduction in the mean SST. It seems to be a southward movement of pelagic stingrays following the warmer waters of the Brazilian Current, i.e. above 17°C, a phenomenon that could also explain the higher concentration of individuals along the Uruguayan latitudes in summer (Domingo et al., 2005; Forselledo et al., 2008).

Therefore, mitigating measures at locations where there are known to be by-catches of species that do not sustain fishery exploitation and that affect a stratum of the population that is sexually mature or even pregnant and ready to spawn, e.g. the stingray *Pteroplatytrygon violacea,* are shown to be very important tools in preventing overfishing – or even extinction.

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