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Bycatch and discard rates assessment of the gillnet fishery in the southern Brazil

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A R T I C L E I N F O

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A B S T R A C T

The fisheries discard patterns are an important element to be considered in stock assessment, fisheries management, and conservation measures. Using data collected by scientific observers on board, we analysed the bycatch and discard rates of the pelagic and bottom gillnet fishing in southern Brazil. Bottom gillnet was responsible for discarding from 77 taxa; 35 % of the discarded biomass was composed of teleost fishes, 33 % of elasmobranchs, and 22 % of other taxa. Pelagic gillnet, targeting the *Pomatomus saltatrix*, resulted in the discard of 13 species and taxa not identified at the species level, such as Cnidaria and Malacostraca. The most discarded fish species was *Brevoortia pectinata*, constituting 94.8 % of the total discarded biomass. The discard rate of bottom gillnets targeting *Micropogonias furnieri* was higher (20 %) than that of those targeting the demersal species (6 %), such as *Cynoscion guatucupa* (formely *Cynoscion striatus*) and *Umbrina canosai*. The high biomass proportion and numerous discarded species emphasize the need for effective management through temporal and spatial fishing restrictions. Our findings suggest potential measures, including the closure of fishing areas in coastal waters.

1. Introduction

The incidental catch and subsequent discards of marine animals are among the main environmental impacts of modern fisheries (Moore et al., 2021; Montevecchi, 2023). Worldwide, more than 9.1 million tons were discarded per year between 2010 and 2014, and the total amount and discard rates widely varied between fishing gears and regions (Roda et al., 2019). In the most updated and comprehensive studies on global discards, revealed that the bottom trawling fisheries were responsible for the large amount and the higher discard rates (Roda et al., 2019; Gilman et al., 2020). The gillnet fisheries presented a substantial variation in the amounts and discard rates between the different modalities, but also were responsible for a large amount of discarded biomass, estimated at 800 million kg annually, with a general 10.1 % discard rate. The diversity of gillnet fisheries makes it important to estimate the discard rates for each gillnet modality since the composition and proportion of discarded catches can vary according to the target species, region, and seasonality (Davies et al., 2009).

In Brazil, an assessment of discarded catches from the blackfin goosefish (*Lophius gastrophysus*) gillnet fishery in the outer shelf and upper slope of southeastern and southern Brazil revealed that 1.02 non-target organisms were discarded for each monkfish caught, leading to a discard rate of 50 % (Perez and Wahrlich, 2005). In the same region, but in shallower waters, another study assessed the catch composition of bottom gillnet targeting the whitemouth croaker (*M. furnieri*), in which 0.27 non-target organisms were discarded for each croaker caught (Schroeder et al., 2014b).

In southern Brazil, the industrial gillnet fishing begun in the 1960's for pelagic species and from the 1980's for demersal species (Haimovici and Mendonça, 1996) and have increased their contribution to the total landings through the years (Vasconcellos et al., 2014; Haimovici and Cardoso, 2017). In more recent years, *ca.* 70 vessels operate with pelagic gillnets targeting the bluefish *P. saltatrix*, during the autumn and winter months (Vasconcellos et al., 2014); other *ca.* 280 vessels operate with bottom gillnets targeting the withemouth croaker, caught mainly in the spring and summer, and the stripped weakfish, *C. guatucupa*, and the Argentine croaker, *U. canosai*, throughout the year, but mainly in autumn and winter (Vasconcellos et al., 2014; Pio et al., 2016). Although

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gillnet fleets have high selectivity to the size of the organisms, they catch a wide range of non-target species, including marine turtles (Monteiro et al., 2016), marine mammals (Fruet et al., 2011; Prado et al., 2013), seabirds (Cardoso et al., 2011; Fogliarini et al., 2019) and elasmobranchs (Vooren and Klippel, 2005).

The discard pattern is an important element of decision for stock assessment and to subsidize the fisheries management and conservation measures. In this study on the bycatch composition and discard rates of the pelagic and bottom gillnet fishing in southern Brazil, we analysed the catch composition and the discard rates in a relatively large number of fishing sets with both bottom and surface gillnets targeting different species. We also explored the relationships between the discard rates and the distance of the coast, depth, latitude, and season of the sets.

2. Material and methods

2.1. Data collection

Data were collected by scientific observers in 16 commercial fishing trips held by 11 vessels of the industrial gillnet fleet that lands at the Rio Grande port between August 2013 and August 2015 (Table 1). A total of 143 bottom gillnet sets were sampled (29° 40'S and 34°01'S latitude), 111 targeting the demersal fishes (*U. canosai* and *C. guatucupa*) and 32 targeting the *M. furnieri*, and 36 with pelagic gillnets targeting *P. saltatrix*, all carried out on the southern shelf of Brazil between 9 and 115 m deep. For each set, the onboard observers recorded the length (m), height (m), and mesh size between opposing nodes (mm) of the net. In addition, they recorded date, time, depth, latitude and longitude at the beginning and end of the set (Table 1).

2.2. Identification and quantification of discarded catch

Along the retrival of each haul, scientific observers identified at the lowest possible taxonomic level the composition of the catch and recorded the numbers of specimens retained and discarded. The specimens of both categories were placed into baskets and weighted. When identification on board was not possible, the organisms were photographically registered, and the final identification was carried out in the laboratory using bibliographical references (Buckup and Bond-Buckup, 1999; Figueiredo et al., 2002; Fischer et al., 2011; Bernardes et al., 2005; Cardoso and Haimovici, 2015).

The retained and discarded total catch per species and hauls was estimated by multiplying the weight of a complete basket with individuals of a given species by the total number of baskets of this species in the catch (Perez et al., 2013; Schroeder et al., 2022). For less frequent species, the weight of individuals was directly measured.

The biomass of megafauna components such as Magellanic penguin (*Spheniscus magellanicus*), franciscana (*Pontoporia blainvillei*), and green turtle (*Chelonia mydas*) was not recorded on board. The biomass of penguins was estimated by multiplying the numbers in the hauls by the average weight of those transported to the laboratory. For franciscanas, it was estimated by multiplying the number of individuals caught by the average biomass of specimens sampled in the region by the Ecology and Conservation of Marine Megafauna - EcoMega Laboratory (FURG). For the turtles, onboard observers recorded the curvilinear carapace length (CCL), and it was converted in biomass using the relationship between standard CCL and mass for green turtles (Colferai, 2015).

Table 1
Summary of fishing data and characteristics of the bottom and pelagic industrial gillnet fishing fleet based in the Rio Grande, Rio Grande do Sul state, Brazil. Demersal fishes represent the species *U. canosai* and *C. guatucupa*. Average ± standard deviation.

Fishing gear	Bottom gillnet		Pelagic gillnet
Fishing target	***Micropogonias furnieri***	**Demersal fishes**	***Pomatomus saltatrix***
Number of fishing boats	5	2	4
Min-Max boats length (m)	18–20	18–20	10–22
Horsepower (Hp)	260	260	170–250
Storage capacity (tons)	35	35	10–35
Min-Max mesh size (mm)	90–140	90–140	90
Number of fishing trips	5	5	6
Number of sets	32	111	36
Average number of sets per trip	6±2	22±7	6 ±4
Average number of fishing days	6±2	12±2	3±1
Average net length (km)	16±7	9±4	3±1
Min-Max net length (km)	9–19	4–18	0.4–3
Average net height (m)	3±0.3	2±0.4	11±1
Min-Max net height (m)	3–4	2–3	10–15
Average net area (km^2)	0.05±0.01	0.02±0.01	0.01±0.009

2.3. Catch per unit effort and discard rate

The catch per unit of effort (CPUE) was calculated for each gillnet set according to the relationship below:

$$CPUE_i = \frac{RC_i + DC_i}{LL_i}$$

Where RC_i is the retained catch of the set *i*, DC_i is the discarded catch of the set and LL_i is the linear length of the net used in the set. The discard rate (*D*) was calculated as Alverson et al. (1994):

$$D_i = \frac{DC_i}{RC_i + DC_i}$$

The discard rates were compared between fishing methods (pelagic and bottom gillnets), target species, depth, and season. To compare depths and seasons, the bottom gillnet sets for the different target species were grouped. For pelagic gillnet, the rates were compared between the two fishing seasons: autumn and winter.

The discard rates were analyzed spatially by using maps. The set positions were plotted at the midpoint between the start and the end of the set. The bottom and pelagic gillnet maps were generated using Quantum GIS software.

2.4. Statistical analysis

The discard rates were compared using the Wilcoxon-Mann-Whitney (WMW) test for the pelagic gillnet sets. Differences were considered significant for p-value < 0.05. For the bottom gillnet, the discard rates were compared using the Kruskal-Wallis's (K-W) test followed by the Dunn test using the PMCMR (Pohlert, 2014) dunn.test packages (Dinno, 2016) available in R software (R Core Team, 2016) version 3.3.1. Furthermore, possible relationships between total CPUE and discard rate were evaluated using Spearman's correlation test (Zar, 2024).

The effect of environmental variables, of the sets CPUE, and the gear characteristics upon the discard rates (D) was analyzed with the Beta Regression model with a *logit* function (Ferrari and Cribari-Neto, 2004). Environmental variables included were the average depth from the beginning to the set end, the distance from the set's midpoint to the shoreline, and season. The variables of the gear characteristics included were mesh size (only for bottom gillnet), height, and length of the net at each set. The discard rates (D) values are continuous and restricted to the [0,1] interval, and it was assumed that they followed the Beta distribution. In some sets, there was no discard, that is, D = 0, while in others, D = 1. For the response variable (D) to be restricted to the range of the beta regression model 0<D<1, the discard rates were transformed as follows:

$$D_i = \frac{DC_i + 0,001}{RC_i \quad + \quad DC_i + 0,002}$$

The model with the lowest value of AIC (Akaike information criterion) was chosen (Akaike, 2011).

The explanatory variables were standardized as follows:

$$Z_i = \frac{X_{i-}\mu}{\sigma}$$

Where Z_i corresponds to the standardized variable in the set, X_i is the explanatory variable in the set, μ is the mean of the variable set, and σ is the standard deviation of the variable set. The beta regression models were performed using the Betareg package (Cribari-Neto and Zeileis, 2010) available in the R software (R Core Team, 2016) version 3.3.1.

3. Results

3.1. Catch composition and total discarded

In the 36 sets of pelagic gillnets, 13 species were recorded among discards. These included seven teleost fishes, three elasmobranchs, one marine mammal, one seabird, one sea turtle, and taxa not identified at the species level, such as Cnidaria and Malacostraca (Fig. 1a, b, Table S1). The discarded biomass was comprised by 95 % of the menhaden *B. pectinata*, 3 % of other teleosts and 2 % of other taxa (Fig. 1a). The total catch was 27 tons (t), of which 5 t (19 %) were discarded. The average discarded biomass was 146 kg (95 % C.I.: 64–229) per set, 18 % (95 % C.I.: 12–24 %) (Fig. 2).

In all the bottom gillnet sets, 77 taxa were recorded among discards. These included 39 teleost fishes, 23 elasmobranchs, 11 crustaceans, two sea turtles, one marine mammal, one seabird, and cnidarians not identified at the species level (Fig. 1c, Table S1). Teleosts amounted to 35 %, among which 23 % of menhaden, the most discarded species. Elasmobranchs comprised 33 % of the total discarded biomass, among which 13 % of angel shark *Squatina occulta.* In bottom gillnets, undetermined Cnidaria and Malacostraca accounted for approximately 19 % and 9 % of the discarded biomass, respectively. In pelagic gillnets, Cnidaria and Malacostraca comprised 0.1 % and less than 0.1 %, respectively (Fig. 1a, b, Table S1).

In the 32 bottom gillnet sets targeting *M. furnieri*, the total catch was 43 t of marine organisms, and from these, 5 t were discarded. The average discard rate per set was 20 % (95 % C.I.: 13–27) (Fig. 2), and the average discarded biomass was 155 kg (C.I.: 97–213). In the 111 sets targeting *C. guatucupa* and *U. canosai*, the total catch was 192 t, and from these, 9 t were discarded. The average discard rate per set was 6 % (95 % C.I.: 5–7) (Fig. 2), and the average discarded biomass was 80 kg (95 % C.I.: 59–101.6). The average discard rate per target species was significantly higher in the bottom gillnet targeting *M. furnieri* (20 %, 95 % C.I.: 12–24) than those targeting the demersal fishes (6 %, 95 % C.I.: 4–8) (K-W, p-value < 0.05).

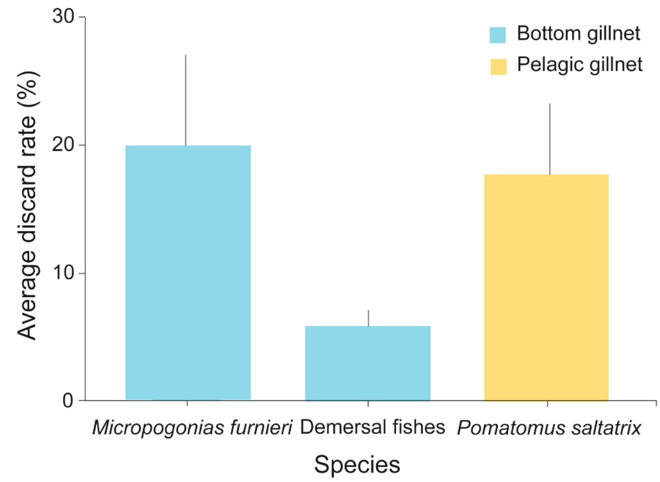

Fig. 2. Average discard rate of gillnet fishing by target species. Demersal fishes represent the species *U. canosai* and *C. guatucupa.* Vertical lines denote the standard deviations.

3.2. Discard rates by depth and season

Regarding depth, the highest discard rates were observed between 0 and 20 m in both fisheries (Fig. 3a). For the bottom sets, a gradual decrease was observed between the stratum from 0 to 20 m to the greatest depths sampled, between 80 and 100 m (Fig. 3a). The depth range covered by pelagic gillnets did not allow an analysis on the discards by depth.

Regarding seasons, the average discard rates did not differ significantly between autumn and winter for the pelagic gillnets (Fig. 3b). For the bottom gillnet sets, the average discard rates were higher during the summer than in the other seasons (WMW, p-value < 0.0001) (Fig. 3c). The average discard rates in the sets carried out during the winter were lower than those in the other seasons (p-value < 0.0001) (Fig. 3c).

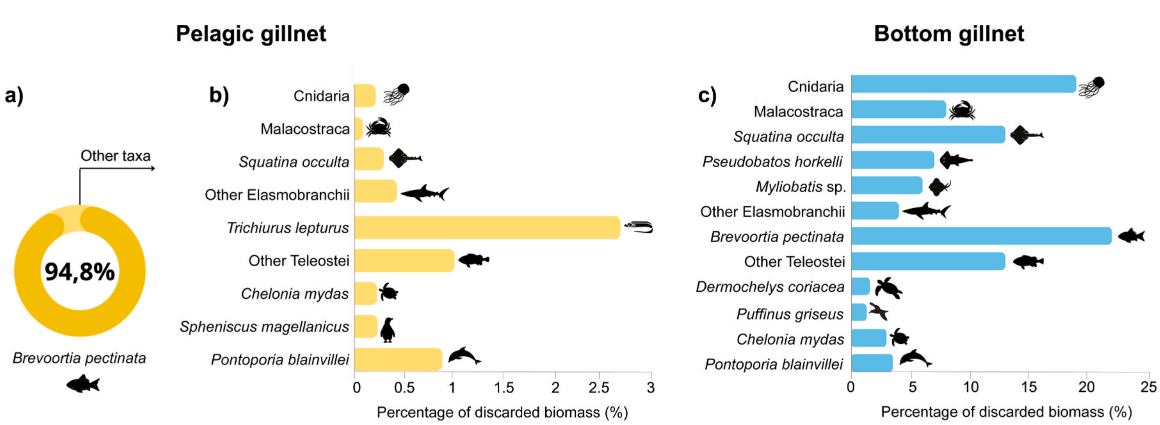

Fig. 1. Composition of discarded biomass by gillnet fishing fleet based in Rio Grande, Rio Grande do Sul, Brazil. (a) Representation of the percentage of discarded biomass of the *B. pectinata* captured by pelagic gillnet, (b) Representation of the percentage of discarded biomass of the other taxa captured by pelagic gillnet, and (c) Representation of the percentage of discarded biomass of the bottom gillnet.

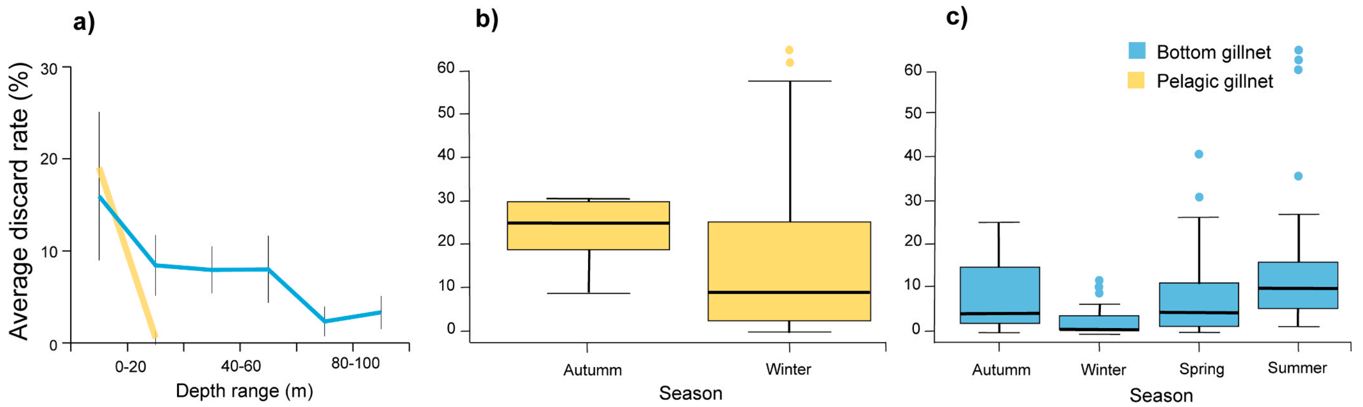

Fig. 3. Average discard rate by depth range (a) and season (b and c). Yellow represents pelagic gillnet and color blue represents bottom gillnet fishing. Vertical lines denote the 95 % confidence interval.

3.3. Spatial distribution of the discard rates and its relationships

The spatial distribution of the discard rates from pelagic gillnets did not show large differences among regions and depths sampled, except for one set carried out close to the coast and slightly north of 33°S (Fig. 4a). On the other hand, southernmost bottom gillnet sets, close to the Uruguayan coast, and some sets at north from 30ºS presented higher discard rates than the rest (Fig. 4b). In addition, the distribution of the discard rates in the bottom gillnet sets revealed higher discard rates to the south, close to Uruguay, and in one set north of 30º S (Fig. 4b).

The Spearman correlation coefficients (ρ) between the discard rate and the total CPUE (tons/km^2) was negative and moderate for the bottom gillnet sets ($\rho = -0.45$, p-value = 2.352e-08) and positive and weak for the pelagic gillnet sets ($\rho = -0.06$, p-value = 0.72) (Table 2). As the correlation was at most moderate, the CPUE variable was included in the models.

For the pelagic gillnet, the model with the best fit (AIC = −61.2) presented as variables the distance from the coast (km) and the net length (km) (Table 2). The hauls within the shortest distance from the coast (0–20 km) presented the highest discard rate (17 %) (Fig. 5a). Regarding the net length, the rates were higher (22 %) in nets with a length of over 2 km (Fig. 5b). For the bottom gillnet, the model with the best fit (AIC = −555) presented as explanatory variables the total CPUE and the net height (m) (Table 2). The highest discard rates (15 %) occurred in the lower classes of total CPUE values (10–40 tons/km^2) compared to the other categories (Fig. 5c). As for the net height, the discard was higher in nets with 3.5 m (45 %) (Fig. 5d).

4. Discussion

The present study is one of the first attempts to quantify the gillnet fisheries discards along southern Brazil based on scientific onboard observers sampling. It shows that many species are incidentally affected by these fisheries, and the discard rates presented a significant heterogeneity among fishing modalities, target species, net characteristics, seasons, and depths.

In the pelagic gillnet sets, the overall average discard rate was 18 %, of which 95 % of the discards were composed of menhaden *B. pectinata.* Schools of this species have been abundant in the Patos Lagoon estuary and nearby costal pelagic waters (Fischer et al., 2011). This species spawns in coastal waters near the Patos lagoon estuary, and its larvae are transported to the estuarine region (Weiss and Krug, 1977), moving back in autumn as juveniles to coastal areas (Malanski, 2011). It is also incidentally caught and discarded by small scale gillnets in the estuary as it has almost no commercial value (Loebmann and Vieira, 2006). Although it may be occasionally consumed by fishers and local population, the lack of commercial values is the main motivation for the species to be discarded by the industrial gillnet fisheries targeting bluefish during winter in the coastal waters (De Rezende et al., 2019).

Elasmobranchs represented a significant portion of the discarded biomass (33 %) by the bottom gillnets, particulary during the summer. In this season, the most discarded species were the guitarfish

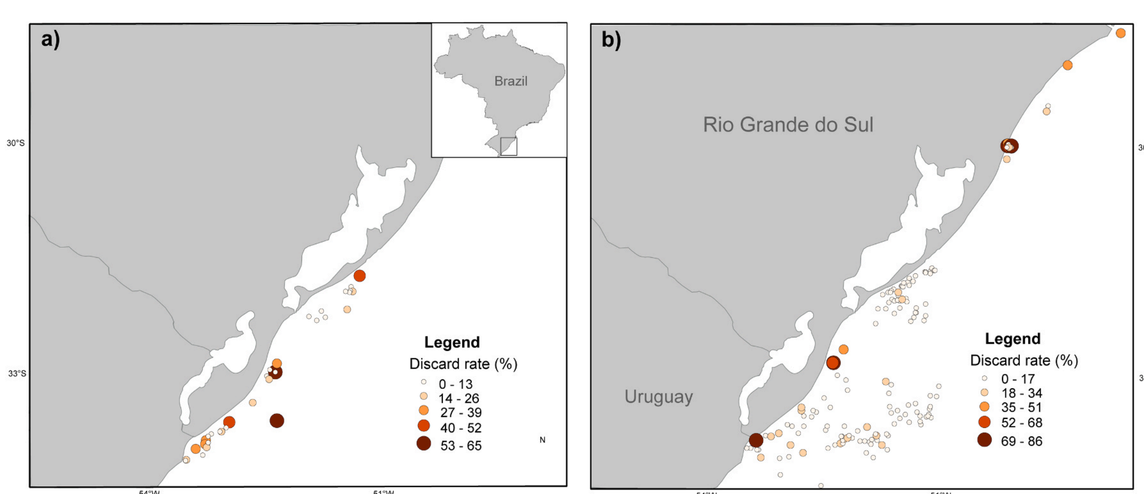

Fig. 4. Spatial distribution of discard rates of pelagic (a) and bottom (b) gillnets fishing in the southern coast of Brazil.

Table 2
Explanatory variables of the Beta regression model were selected to explain the effect of variables on discard rates in pelagic and bottom fishing sets. Significant values are indicated by "***" ($p<0.0001$), "**" ($p<0.001$) and "*" ($p<0.05$).

Fishing gear	Explanatory variables	Estimate	Standard error	Z-Value	Pr (>|z|)
Pelagic gillnet	Intercept	−2.12484	0.3032	−7.008	2.42e−12***
	Distance from the coast (km)	0.04754	0.01842	2.58	0.00988**
	Length net (km)	0.40964	0.16787	2.44	0.01468*
Bottom gillnet	Intercept	−3.93E−01	2.62E−01	−1.502	0.1332
	CPUE (tons/km^2)	−2.25E−06	9.80E−07	−2.296	0.0217*
	Net height (m)	9.43E−01	1.48E−01	6.382	1.75e−10***

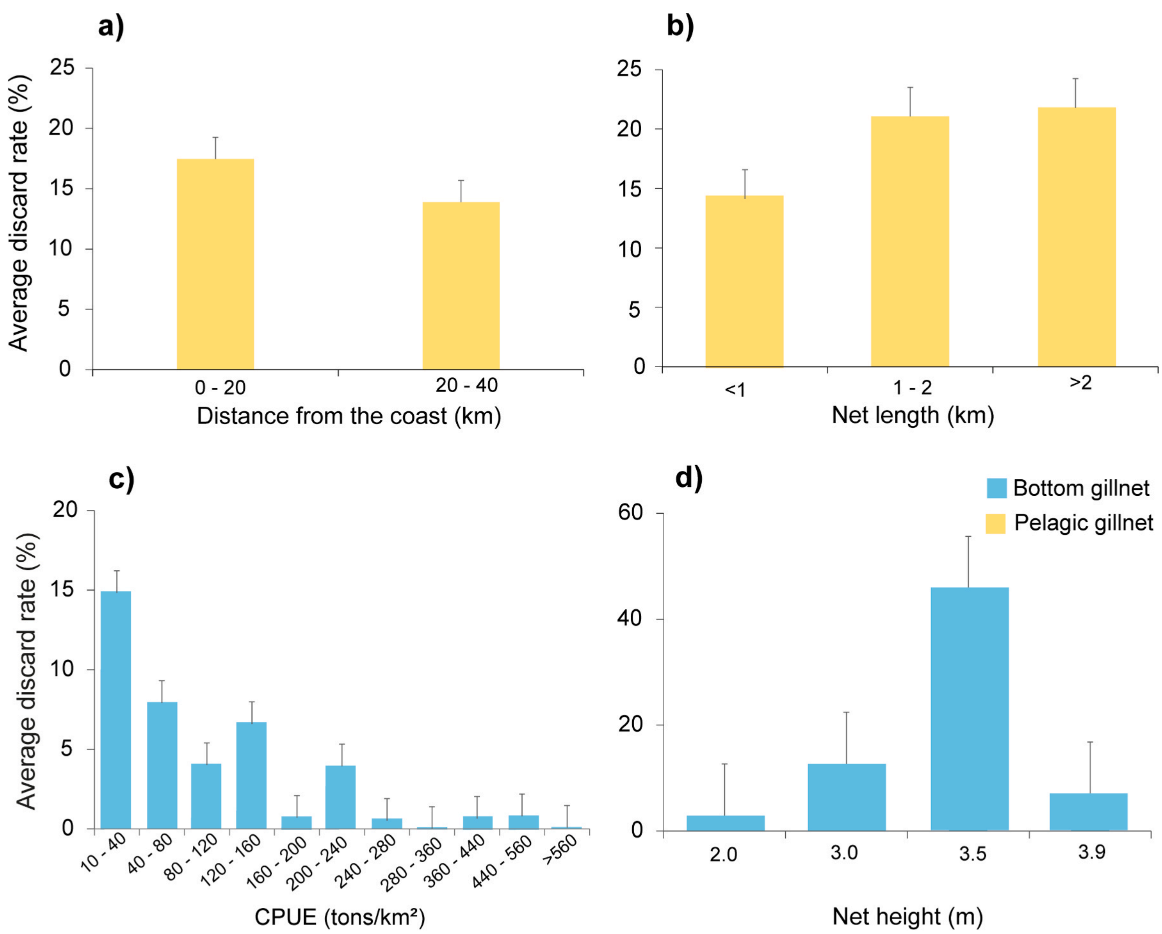

Fig. 5. The yellow color represents the average discard rate of pelagic gillnet fishing by distance from the coast (a) and net length (b). The blue color represents the average discard rate of bottom gillnet fishing by CPUE (c) and net height (d). Vertical lines represent standard deviations.

Pseudobatos horkelii and the angel sharks *S. guggenheim* and *S. occulta*. In the past, these species were important fishing resource in southern Brazil (Miranda and Vooren, 2003). However, due to the intense fishing, their populations have reduced, and their landings have been prohibited since 2004 by Normative Instruction MMA Nº5/2004 (Brasil, 2004). This prohibition remains in effect under Ordinance MMA Nº445/2014 (Brasil, 2014). On the other hand, their incidental catches can be explained by the overlap between the fishing areas and their breeding and nursery grounds (Vooren and Klippel, 2005; Miranda and Vooren, 2003). The guitarfish is distributed from the coast of São Paulo to northern Argentina, between December and February, pregnant females are concentrated in coastal waters to give birth, where the neonates remain during the first months of life (Vooren and Klippel, 2005). The three angel shark species are distributed from Rio de Janeiro to Argentina and complete their entire life cycle in the southern Brazilian continental shelf (Vooren and Klippel, 2005). *S. occulta* is a sedentary species that occupies the middle and outer shelf, while *S. guggenheim* migrates seasonally from the inner shelf and the coastal waters of southern Brazil during the summer also for reproductive activities (Miranda and Vooren, 2003). In addition, angel sharks are most commonly vulnerable during the night when they are more active, and their spatial coverage is greater (Miranda and Vooren, 2003; Mead et al., 2023).

Our findings revealed that discard rates for bottom gillnets were significantly higher during the summer, particularly in shallow waters close to the shore. This seasonal increase in bycatch is consistent with observations from other regions, where shallow coastal areas have been identified as critical zones for bycatch during specific periods (Hall et al., 2000; Lewison et al., 2004). For instance, gillnet fisheries have been responsible for bycatch of franciscana dolphins, sea turtles, and other non-target species in coastal waters of Brazil and Argentine during summer (Berninsone et al., 2020; De Oliveira et al., 2024). A similar pattern was observed in our study, where higher discard rates of bottom-set gillnets occurred in coastal areas. These findinds may be attributed to the increased presence and activity of the non-target species, which are more prevalent in these habitats during the summer. In addition, the discards mostly consisted of elasmobranchs and cnidarians during this season. Large aggregations of cnidarians have been recorded near the coast of southern Brazil during the summer (Vanucci, 1957; Cristiano, 2011). Schroeder et al. (2014a) and Rutkowski et al. (2018) have also reported that summer is the period of greatest occurrence of cnidarians in the southern and southeastern regions of Brazil. However, these studies found larger cnidarian catches in deeper waters of the outer shelf and upper slope. This difference may be explained by the lower spatial sampling coverage of our study compared to that of Schroeder et al. (2014a) and Rutkowski et al. (2018).

In addition to the season and distance from the coast, the net height and CPUE also influenced the higher discard rates. In bottom gillnets, discards are primarily driven by the extensive net coverage, which can reach up to 19 km in height and span a significant portion of the water column. The variables CPUE and net height contributed the most to explaining the discard rates variability. It was inversely related to the CPUE, in other words, the sets with lower total CPUE values presented higher discards in biomass, mainly composed by cnidarians, angel sharks, and menhaden (> 55 % of discarded biomass). These sets configure lower catches that resulted in high discard rates, suggesting mistaken identification of the targeted species' presence by vessel masters. Among the monitored sets, this situation can be considered frequent, since it covered approximately 57 % of the total. As for the net height, the average discard rate was higher in hauls that used nets 3.5 m high (45 %), two of the hauls with this height concentrated more than 70 % of the discarded catch, that is, these hauls influenced the explanatory power of this variable in the model. There are no plausible reasons why a certain net height would result in higher discard rates.

For the pelagic gillnet, one variable that helped explain the discard rates was the distance from the coast. The higher discard rates were observed at shorter distances from the coast (0–20 km), which agrees with the higher discard rates at lower depths. Another variable that helped to explain the discard rates was the net length; longer nets resulted in higher discard rates, especially in events of large catches, as was the case of menhaden discards. It was not possible to assess the annual variability of the discard rates for this modality since it occurred just during austral cold months.

Our study is a contribution to the refinement and upgrade for the current regulations on the bottom and pelagic gillnet fishing in southeastern and southern Brazil described in Brasil (2011). Currently, the legal framework for the gillnet fishery lists 85 species impacted by the bottom gillnet and 35 species impacted by the pelagic gillnet. These species comprised the target catch, incidental catch and bycatch. For the bottom gillnets, this study recorded the catch of 46 species and four taxa not listed in the official regulations, while for the pelagic gillnet 7 species and two taxa not listed in the official regulations (Table S1). The inclusion of these species and taxa in the referred normative is suggested.

As shown in this and other studies, vulnerable elasmobranchs, marine mammals, penguins, and marine turtle populations are being negatively affected by gillnets, sometimes in large quantities (Secchi et al., 2004; Schroeder et al., 2014b; Monteiro et al., 2016; Fogliarini et al., 2019; Maruyama et al., 2024). The control of indirect effects of fisheries on bycatch species should be among the objectives of any management strategy (Davies et al., 2009). Although fisheries management rules restricting the number of licences and size of gillnets are in place in southern Brazil (Brasil, 2011) its compliance is hampered by its ineffective enforcement. In this complex multispecies and multifleet fisheries management context, with limited enforcement capacity, easier to enforce spatio-temporal measures such as fishing exclusion zones or seasonal closures could be more effective given the wide range of species affected by the fisheries (Dowling et al., 2016). Therefore, appropriate management measures could include the fishing areas closures at lower depths (Pio et al., 2016; Prado et al., 2021) and seasonal closures in the summer months (Haimovici et al., 2016).

5. Conclusion

The quali-quantitative analysis of the discarded catch composition is necessary to assess the impact of the gillnet fisheries on the entire vulnerable marine biological community. We have shown that the gillnet fisheries impact a greater number of species than previously known, or at least than listed in the official regulations. The higher discard rates in the shallower coastal areas and the bycatch of elasmobranchs, sea birds, marine turtles, and marine mammals, some of which are threatened by extinction, demonstrate the need for management measures that result in a decrease in fishing effort in these areas. Bottom trawl fishing in these areas has been banned since 2019 (Cardoso et al., 2021) with strong support of the community, including both local small scale and industrial fishers and conservation stakeholders. Our study can be used to establish seasonal or area fishing closures, easier to be effectively enforced by using modern localization tools and the participation of the stakeholders that minimizes the impact of fishing while keeping sustainable this economically and socially important activity.

CRediT authorship contribution statement

Manuel Haimovici: Writing – original draft, Methodology, Investigation, Conceptualization. **Carine Fogliarini:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Luiz Gustavo Cardoso:** Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Carine O Fogliarini reports financial support was provided by National Council for Scientific and Technological Development. Manuel Haimovici reports financial support was provided by National Council for Scientific and Technological Development. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rsma.2024.103753.

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