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Papers

Artisanal fishery with surface gillnets and megafauna strandings

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Abstract
Bycatch is an issue of worldwide relevance involving conflicts between conservation and fishery interests. In Brazil, this conflict has been highlighted in relation to the regulation of small-scale fishery with surface gillnets. To promote management and transformation of this conflict, we analyzed the relationship between catch unloadings from small-scale fishing with surface gillnets and strandings of marine megafauna. We used fishery monitoring data and beach monitoring data in São Paulo between 2015 and 2021, relating to *Chelonia mydas*, *Caretta caretta*, *Lepidochelys olivacea*, *Pontoporia blainvillei* and *Sotalia guianensis*. The analyses included (i) overview of catches unloadings from small-scale fishing with surface gillnets and strandings that resulted in the death of each of these species over the course of the year; (ii) correlation tests between those variables for the northern, central, and southern regions; and (iii) performing regression analyses for municipalities within these regions, exhibiting statistically significant positive correlations. The fisheries harvest period was found not to overlap with the stranding distribution. In correlation tests, only strandings of *C. mydas* in the northern and southern regions, *S. guianensis* in the southern region and *P. blainvillei* in the central region showed relationships with fishing landings. The regression analysis was significant for *C. mydas* and *S. guianensis*. At the municipal level, the results were statistically significant for *C. mydas* in São Sebastião, Ubatuba, Ilha Comprida and Cananéia and for *S. guianensis* in Cananéia. However, the regression explained a small part of the mortality and other impact factors were pointed out. Non-prohibitive management measures, participatory studies, and direct methods for evaluating the interaction between fisheries and megafauna associated with environmental factors should be implemented, along with analyses on other impacts on megafauna.

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INTRODUCTION

Gillnets are one of the oldest types of fishing gear and are widely used in both artisanal and industrial fishing (HE et al., 2021). They have low operating costs and hence are accessible to small-scale fishers (KING, 2007). There are some types of gillnets, such as set gillnets, fixed gillnets, trammel nets and drift gillnets. Gillnets can be used at the sea surface, in the middle of the water column or close to the sea bottom and can either be anchored or left to drift. Fishing with a surface gillnet can take place without an anchorage system but requires monitoring by the fishers while the net drifts with the currents. Gillnets can also be "launched" actively to concentrate and encircle shoals of fish (HE et al., 2021).

The catch return of gillnets is influenced by the characteristics of this gear and the strategy for using it. Gillnets generally have a high level of selectivity, which is regulated through their mesh size, the place where they are used and the characteristics of the target fish (HE et al., 2021). Several studies have pointed out the importance of ethnoknowledge regarding the selectivity of gillnet fishing: for example, fishers' different strategies regarding the distribution of species according to the environment and types of habitats (CLAUZET et al. 2005; SILVA; SILVA, 2020). However, despite the selective power of gillnet fishing, bycatch of megafauna also occurs (AFONSO; CHAVES, 2021).

In the 1980s, the Food and Agriculture Organization of the United Nations (FAO) started a debate about bycatch in drift gillnets (NORTHRIDGE, 1991) that resulted in more restrictive rules for this type of fishing. In Brazil, the first regulation dealing with gillnets was ordinance IBAMA no. 121-N of 1998, which limited the overall net size to a length of 2.5 km. In 2007, IBAMA normative instruction no. 166 came into force for regulating the use of gillnets in Brazil. Even without evidence of efficacy, this rule established that the upper edge of surface gillnets should be suspended two meters below the sea surface and that these gillnets must not be operated when the water column is less than twice the vertical height of the net (BRASIL, 2007). In practice, this rule made small-scale fishing with surface gillnets unviable and has led to conflicts between the fishery sector, environmental management, and conservation bodies. In 2021, this conflict stemming from normative instruction no. 166/2007 was identified as one of the most evident problems on the coastline of the state of São Paulo, according to the actors involved (PRADO et al., 2022a).

The aim of this study was to analyze the relationship between landings from small-scale surface gillnets fishing and strandings of megafauna along the coast of the state of São Paulo, Brazil. The goal is to contribute to the debate surrounding this management issue. In contrast to other states, São Paulo has established a data collection system on fishing landings since 1969. Moreover, data on strandings along this coastline have been available from the Sistema de Monitoramento da Biota aquática (SIMBA) since 2015. The existence and analysis of these data provides support for decision-making in relation to this fishing activity.

METHODOLOGY

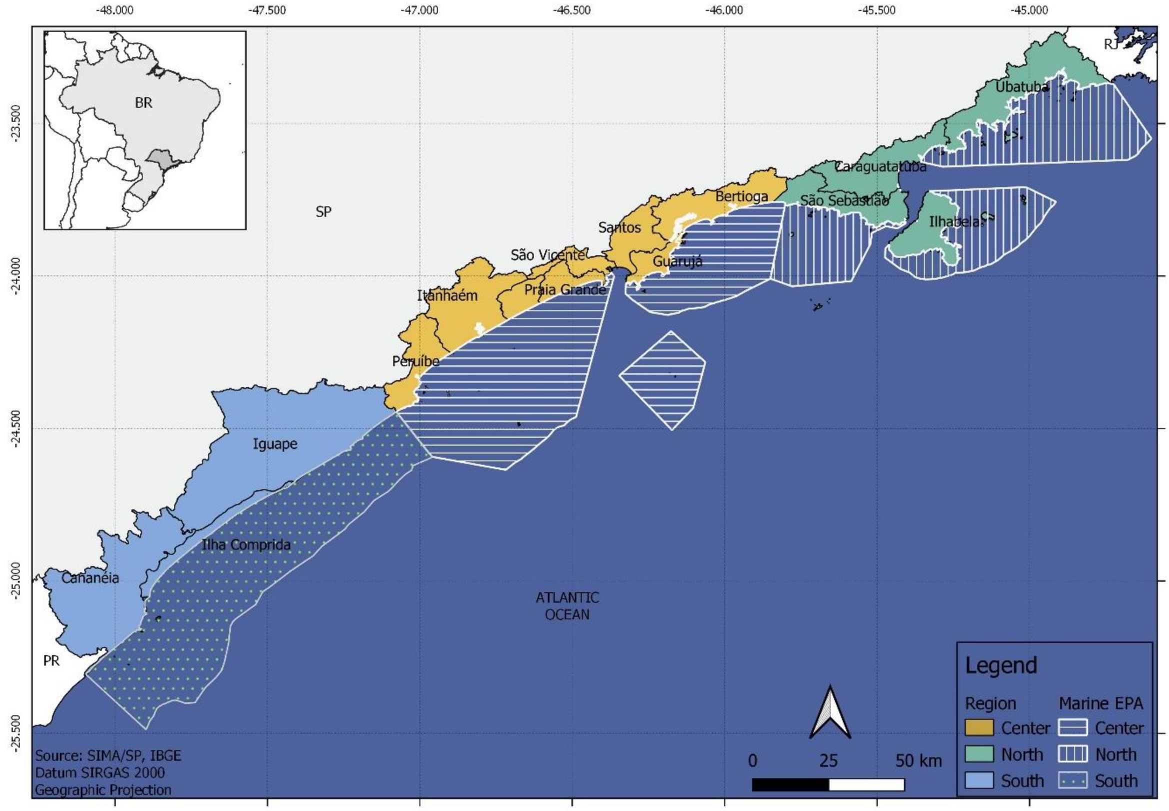
Information was extracted from the public database of the Programa de Monitoramento Pesqueiro de São Paulo (PMAP-SP), which monitors coastal fishing landings (IP, 2022), and the public available database of the Beach Monitoring Program (PMP), which monitors coastal animal strandings (SIMBA, 2022). The temporal period selected for analysis was between August 2015 and September 2021, as this timeframe had available data in both databases. The research question guiding this stage of the analysis was: "Is there a correlation between the small-scale fishery activities using drift gillnets at the water surface and the number of megafauna strandings resulting in death along the coast of the state of São Paulo, taking into account the spatial overlap and temporal variation throughout the year?"

From the PMAP-SP database, the following parameters were selected: small-scale fishing, surface gillnets, municipality, year, month, and number of landings. From the PMP, the following were selected: number of individuals stranded, species, number of dead individuals, municipalities, geographical coordinates, and date. Among the species, the five species with the largest numbers of strandings were selected, namely: green sea turtle (*Chelonia mydas*), loggerhead sea turtle (*Caretta caretta*), olive ridley sea turtle (*Lepidochelys olivacea*), Franciscana dolphin (*Pontoporia blainvillei*) and Guiana dolphin (*Sotalia guianensis*). In situations in which the records grouped two municipalities, the geographical coordinates were used to identify which of them was the location of the stranding.

Firstly, a temporal analysis was conducted to provide an overview of landings from small-scale fishing using surface gillnets at the sea surface and to identify strandings resulting in the death of individuals for each species. These findings were graphically represented, displaying monthly means and standard errors. This approach aimed to identify any periods characterized by elevated levels of strandings, species mortality, and higher numbers of landings.

Subsequently, correlation analysis was also performed, grouping the municipalities into the northern, central, and southern regions of the São Paulo state. This division was done in accordance with the geomorphological characteristics of the coastline (SOUZA, 2012) and corresponded to the municipalities adjacent to the marine environment protection areas of north, central and south of São Paulo (Figure 1).

Figure 1 - Coastline of the state of São Paulo, highlighting the Marine Environment Protection Areas and municipalities in the northern, central, and southern regions.



Source: The authors (2023).

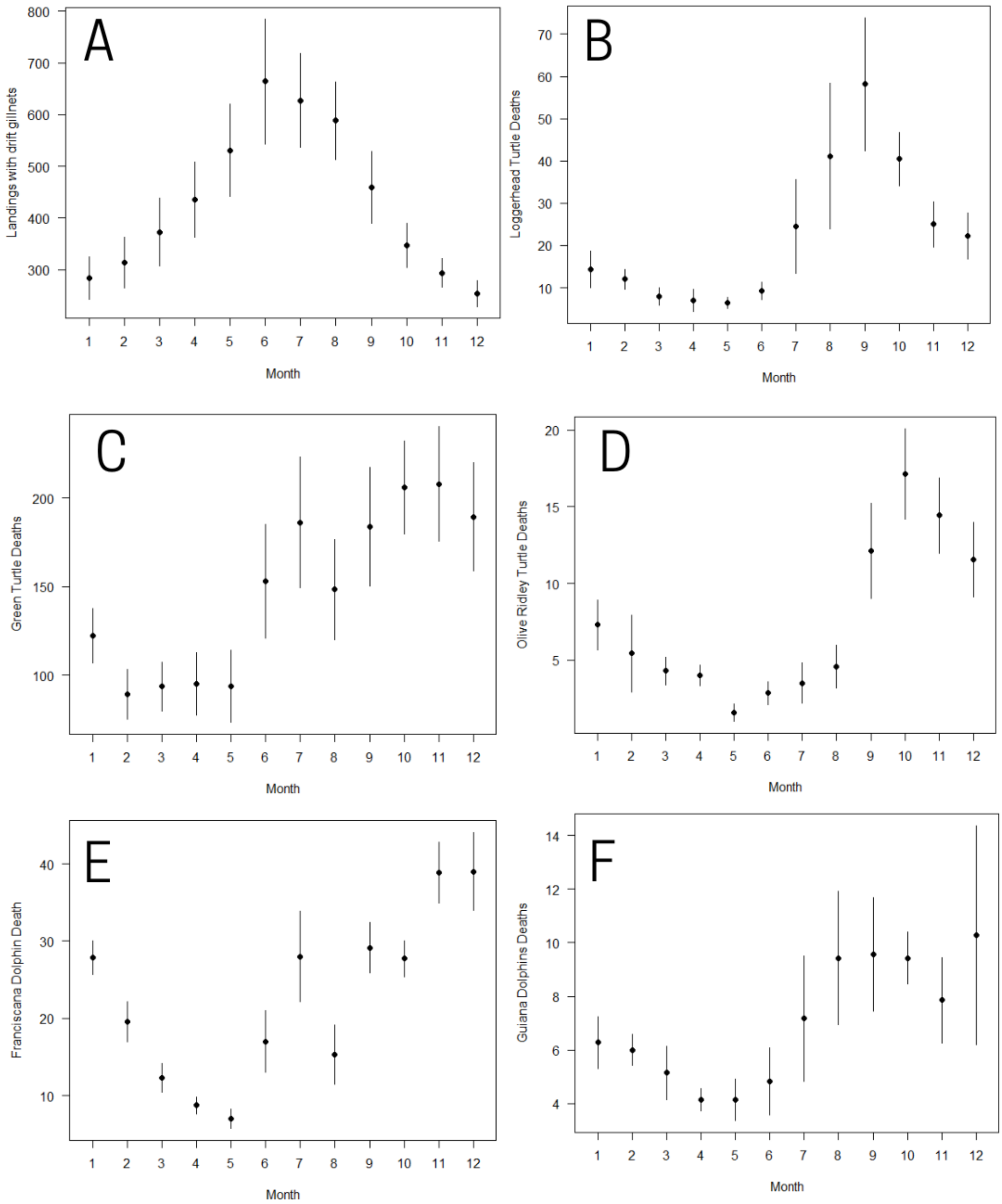
For statistical analysis, the data were normalized by adding a value of 1.0 and transforming it into the base 10 logarithm (PINO, 2014). After this normalization, the assumptions of normal distribution of the data and homoscedasticity of residuals were fulfilled. Pearson correlation tests were then performed (ZAR, 2010) between the numbers of strandings and landings for each region. The results from the correlation tests were classified into categories, ranging from null to perfect, as follows: null ($0 < r < 0.1$), weak ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.6$), strong ($0.6 < r < 0.9$), very strong ($0.9 < r < 1$) and perfect ($r = 1$). These correlations could be either positive or negative (CALLEGARI-JACQUES, 2009). In regions with positive correlations, regression analysis was performed. In regions in which the regression analysis was statistically significant ($p \leq 0.05$), regression analysis was then performed for each municipality that made up the region. Through this, it was assessed which species would be most affected by use of surface gillnets in each region or municipality.

RESULTS

Overview of the coast

The number of landings from artisanal fishing using surface gillnets over the years ($\bar{x}$ =450.2 S.D.= 208.2) presented increases in the colder months, especially between May and August, with a peak in June (Figure 2a), that coincided with the harvests of mullet (*Mugil liza*) and serra Spanish mackerel (*Scomberomorus brasiliensis*). The evaluation revealed that none of the five megafauna species examined experienced the highest number of strandings in the month of June. (Figure 2). However, there were higher numbers of strandings for both *C. mydas* and *P. blainvillei* in July. Among the turtles, it was found that *C. mydas* suffered the highest average number of strandings per year ($\overline{x}$ =154.69 S.D.= 77.41), followed by *C. caretta* ($\overline{x}$ =22.10 S.D.= 26.60) and *L. olivacea* ($\overline{x}$ =6.85 S.D.= 6.34). *C. caretta* showed highest mortality between August and October, with a peak in September. *C. mydas* showed highest mortality between September and December, with peaks in October and November. *L. olivacea* showed highest mortality between September and December, with a peak in October. Among the cetaceans, *P. blainvillei* showed the highest numbers of strandings between September and December, with the peak number of strandings in December ($\overline{x}$= 21.77 S.D.= 12.89). *S. guianensis* showed increased numbers of strandings from August onwards each year, with the peak in December ($\overline{x}$= 7.20 S.D.= 5.17).

Figure 2 - Mean annual distribution and standard error for (A) number of fishing landings using surface gillnets and for (B-F) number of strandings of (B) *Caretta caretta*, (C) *Chelonia mydas*, (D) *Lepidochelys olivacea*, (E) *Pontoporia blainvillei* and (F) *Sotalia guianensis*.

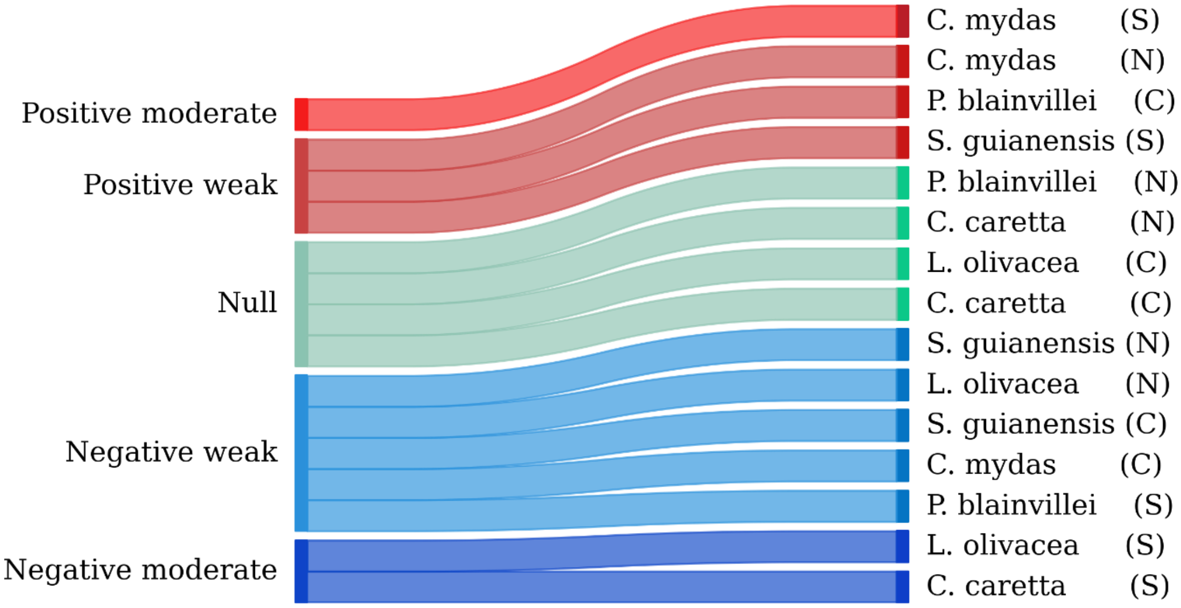


Source: The authors (2023).

Regional analyses

The correlation tests between lethal strandings and landings from small-scale fishing using surface gillnets in the northern, central, and southern regions showed a moderate positive correlation only for *C. mydas* in the southern region (r = 0.355). There were weak positive correlations in the southern region for *S. guianensis* (r = 0.264), in the central region for *P. blainvillei* (r = 0.256) and in the northern region for *C. mydas* (r = 0.280). Any strong, very strong or perfect correlation was observed (Figure 3).

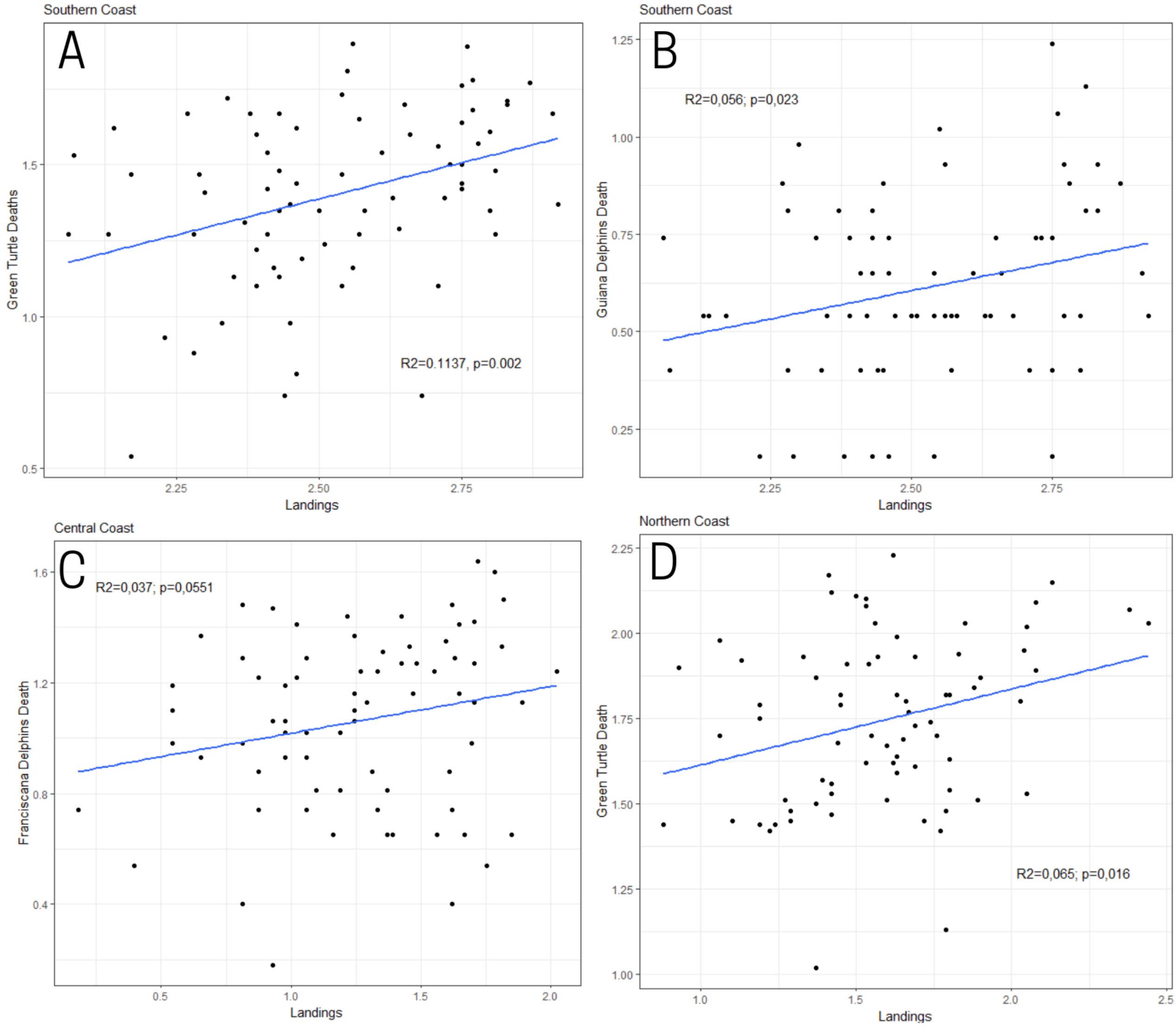
Figure 3 - Correlation between lethal strandings of megafauna and the number of fishing landings using surface gillnets in the northern (N), central (C) and southern (S) regions of the São Paulo coast.



Source: The authors (2023).

The regression analysis (Figure 4) showed statistically significant results for *C. mydas* in the northern region (p = 0.016) and southern region (p = 0.002) and for *S. guianensis* also in the southern region (p = 0.023). However, for *P. blainvillei*, this test did not present a statistically significant result (p = 0.055). In all cases, the value of the coefficient of determination (R^2) was less than 0.15, which means that less than 15% of the lethal strandings can be explained by the number of landings from surface gillnets, according to the linear model.

Figure 4 - Linear regression model between megafauna strandings and small-scale fishing landings using surface gillnets, for: (A) *Chelonia mydas* in the southern coastal region, (B) *Sotalia guianensis* in the southern coastal region, (C) *Pontoporia blainvillei* in the central coastal region and (D) *Chelonia mydas* in the northern coastal region.

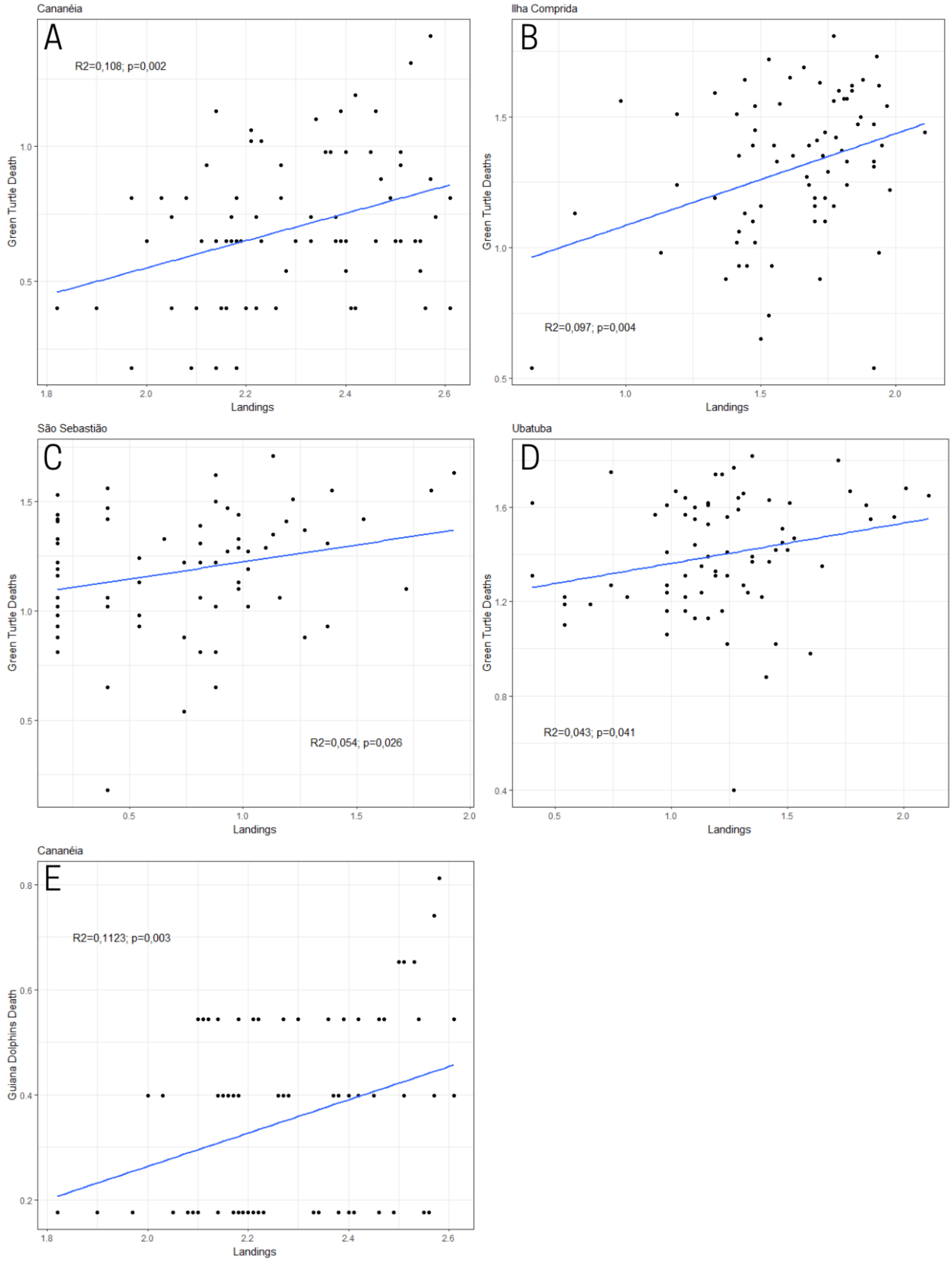


Source: The authors (2023).

Municipal analyses

In the municipal analyses, *C. mydas* presented statistically significant results in the municipalities of Cananéia (p = 0.002) and Ilha Comprida (p = 0.004) in the southern region; and in São Sebastião (p = 0.026) and Ubatuba (p = 0.041) in the northern region. Similar to regional analysis, the coefficient of determination (R^2) was less than 0.15 (Figure 5). In the other municipalities, the correlation tests did not present significant relationships. Regarding strandings of *S. guianensis*, there was a significant relationship only for the municipality of Cananéia (p = 0.003) and, again, like in the other results, the value of R^2 was low.

Figure 5 - Linear regression model between megafauna strandings and small-scale fishing landings using surface gillnets, for *C. mydas* in the municipalities of Cananéia (A) and Ilha Comprida (B) in the southern coastal region; *C. mydas* in the municipalities of São Sebastião (C) and Ubatuba (D) in the northern coastal region; and *S. guianensis* in the municipality of Cananéia (E) in the southern coastal region.



Source: The authors (2023).

DISCUSSION

Correlations

One of the main challenges in fishing planning is to be able to address its particularities and diversity of strategies (CHUENPAGDEE; JENTOFT, 2018). With a focus on small-scale surface gillnet fishing, our results showed that the distribution of the number of landings did not match with the distribution of strandings, for any of the species analyzed. Out of the 15 correlation tests performed, only four of them showed positive correlations between small-scale fishing landings using surface gillnets and strandings of animals. On the other hand, another four of the tests were null (i.e. with no indication of cause and effect between landings and strandings) and the other seven were negative, i.e. they showed an inverse relationship between the use of this gear and the strandings.

In the regression analyses, the statistically significant results accounted for only a small percentage: less than 15% of the mortality observed ($R^2 < 0.15$). This indicates that other factors could be related to these strandings. Kroetz et al. (2020) concluded that there was always more than one determination factor in incidental catch of *Dermochelys coriacea*, *C. caretta*, *Tursiops truncatus* and *Manta birostris*. Several factors have been correlated, such as the type of fishing gear, depth, temperature, and longer time for which the gear is in the water. In combination, these factors increase the chances of bycatch (KROETZ et al., 2020).

The peak period for lethal strandings of animals along the coast of southeastern Brazil shows variations, possibly due to differences in local factors. Results very similar to those presented here were obtained for all species, using the PMP database on the coastline between Santa Catarina and São Paulo, (PRADO et al., 2022b). However, analyses on other geographical areas have shown different results. In Rio de Janeiro, an analysis on strandings of *C. caretta* and *L. olivacea* found that the peak was in September, and for *C. mydas* it was between July and August (TAGLIOLATTO et al., 2019). In the municipality of Ilha Comprida, SP, an analysis on strandings of *P. blainvillei* found that the peak was between August and October, and that the peak for *S. guianensis* was in September (DESVAUX, 2013). In Espírito Santo, the peak for strandings of *P. blainvillei* was between January and March, and the peaks for *S. guianensis* were in March, August and November (MAYORGA et al., 2020).

SPECIES WITH SIGNIFICANT RESULTS

Chelonia mydas, green sea turtle

This was the species with the highest number of lethal strandings. A small part of the mortality ($R^2 < 0.15$) was correlated with fish landings from surface gillnets in certain municipalities on the southern and northern coasts of São Paulo. Among marine turtles, *C. mydas* is one of the most abundant species and has the most inshore habitat (ALMEIDA et al., 2018), which increases the likelihood of interaction with fishing.

Because green sea turtles mainly lay their eggs on isolated oceanic islands, they are less impacted by the disorderly occupation of onshore coastal areas, with less predation of their eggs and females than other species of marine turtles (ALMEIDA et al., 2018; LIMA et al., 2021). After conservation efforts, *C. mydas* has now ceased to be on the list of Brazilian species threatened with extinction (BRASIL, 2022).

The types of fishing that interact most with *C. mydas* are surface gillnet, set gillnet, floating trap net, fish-weir fishing, and trawling (AWABDI et al., 2021; BAHIA; BONDIOLI, 2010; PINGO *et al.*, 2017). In the estuarine region of Cananéia, *C. mydas* was the species present in more than 90% of incidents with turtles between 2003 and 2008 (BONDIOLI et al., 2008). It was also the species most bycatch in fish-weir fishing (BAHIA; BONDIOLI, 2010). However, fish-weir fishing is non-lethal gear, such that turtles that are caught can be released alive (BAHIA; BONDIOLI, 2010; BONDIOLI et al., 2008).

Sotalia guianensis, Guiana dolphin, and Pontoporia blainvillei, Franciscana dolphin

The Guiana dolphin, *S. guianensis*, is one of the most common dolphin species along the Brazilian coast. Its habitats are close to the shore and generally associated with estuarine and bay environments. Interactions between this species and gillnet fishing have been reported along the entire coast of Brazil (PINHEIRO; CREMER, 2003). Currently, *S. guianensis* is classified as vulnerable (BRASIL, 2022).

In the present analysis, *S. guianensis* showed a weak positive correlation in the southern coastal region of São Paulo and the linear regression model was statistically significant only for the municipality of Cananéia, for which other surveys have indicated that there is a stable population of this species. The estimated size of this population in Cananéia is between 366 and 451 individuals, with a high likelihood of survival and little variation between the seasons, thus indicating that food is available for them throughout the year (MELLO et al., 2019). Low variation in the number of individuals in dolphin pods has also been observed (SANTOS; ROSSO, 2007). Other data have also shown that there is a positive relationship between the presence of Guiana dolphins and use of fish-weir fishing and a negative relationship with use of gillnets (GODOY et al., 2020).

The Franciscana dolphin, *P. blainvillei*, presented a weak positive correlation between strandings and landings from the artisanal fleet using surface gillnets in the central region of the coast, but the linear model did not show a statistically significant result. Nonetheless, despite the low relationship found in the present analysis, *P. blainvillei* is classified in Brazil as critically endangered with extinction (BRASIL, 2022). Bycatch of this species by small-scale gillnetting fleet has been reported (BERTOZZI, 2009; BERTOZZI; ZERBINI, 2002; SECCHI et al., 2022; ZAPPES et al., 2018), and in paired trawling (MONTEALEGRE-QUIJANO; FERREIRA, 2010).

In São Paulo, monitoring of bycatch that occurred during fishing operations by six vessels in the municipality of Praia Grande between 1998 and 2001 recorded 31 catches of *P. blainvillei* through using gillnets (BERTOZZI; ZERBINI, 2002). Monitoring of the gillnetting fleet of the municipalities of Ubatuba, Praia Grande, Mongaguá and Itanhaém between 2004 and 2005 registered 14 bycatches, among which 12 were in Praia Grande and two in Mongaguá (BERTOZZI, 2009). These large differences between municipalities and regions are in line with our results and highlight the difficulty in making extrapolations. The hypothesis that other factors such as urban, industrial, and port development may explain the larger numbers of strandings in certain places can be raised.

Desvaux (2013) analyzed the cause of death among cetaceans stranded in Ilha Comprida between 2010 and 2011. Among these incidents, 29% of the cases involving Franciscana dolphins and 28% of those involving Guiana dolphins showed evidence of interaction with fishing, without information on the gear involved. In the present study, the correlation between surface gillnets and strandings was 5.6% ($R^2 = 0.056$) for Guiana dolphins and 3.7% ($R^2 = 0.037$) for Franciscana dolphins.

In monitoring of fishing on the coasts of Rio de Janeiro and Espírito Santo, to quantify bycatch of cetaceans between 2017 to 2019, 15,929 landings were surveyed. Among these, cetaceans were caught in 24 (0.15%) (PATIRI, 2020). Among the animals caught, 13 were Guiana dolphins, eight were Franciscana dolphins and three were not identified. The eight Franciscana dolphins were caught using bottom gillnets.

OTHER THREATS

In a review of anthropic threats to cetaceans that covered 103 articles published over a 30-year period (1986-2016), it was found that the majority of these studies addressed pollution (54.4%), followed by bycatch (19.4%), vessel traffic (10.7%), collision with vessels (3.9%), hunting (3.9%), barrage construction (1.9%) and others (5.8%) (MAREGA-IMAMURA et al., 2020). On the coast of São Paulo, among such threats, we can cite port activities with intense dredging actions and maritime traffic (HAUSER-DAVIS et al., 2020). In addition, there are the activities of the oil and gas sector and the impact of highly urbanized areas with industrial and touristic activities. These activities amplify discharges of effluents and chemical residues, which have other direct and indirect impacts on marine fauna (DOMIT *et al.*, 2022; HAUSER-DAVIS et al., 2020).

In the case of Franciscana dolphins, these effluents may cause immunosuppression, endocrine changes, neurological diseases, allergies, and cancer. In addition, other factors such as marine litter, sound pollution and climatic changes also have an impact on this population (DOMIT *et al.*, 2022).

In the Iguape-Cananéia estuary, the impact of reduction of salinity has shown a negative correlation with the presence of Guiana dolphins (GODOY et al., 2022). There has also been damage caused by dredging, ships and port activities in São Paulo, Bahia and Rio Grande do Norte (PAIS *et al.*, 2018).

For green sea turtles, pollution due to marine litter is one of the most evident threats to their conservation. Plastic was found among the stomach contents of the majority of stranded individuals that were found dead in Peruíbe, SP (EDRIS et al., 2018) and in Rio Grande do Sul (PETRY et al., 2021). Climatic changes also have an impact and an increase in temperature of the order of 2 °C, that may influence the determination of the sex of embryos and cause feminization (POLOCZANSKA et al., 2009). Furthermore, climatic changes may alter the availability of food resources and the circulation of sea currents and winds (ALMEIDA et al., 2018).

These impacts need to be taken into consideration in analyses of bycatch. In the surveys analyzed here, there were no assessments of the cumulative and synergic effects of these impacts.

Contributions to management and conservation

Considering the recommendations in the literature regarding the importance of fishery management be based on the specific features and diversity of artisanal fishing (CHUENPAGDEE; JENTOFT, 2018), the present study provides contributions by using the existing public data to evaluate the specific correlation between surface gillnetting and bycatch.

However, this study also demonstrates the lack of direct information on the interactions between non-target species and fishing activities. Data of this nature needs to be obtained in a standardized manner and should extend along the entire coast (OTT et al., 2002), including data on species, fishing gear, locality, period of interaction and determination of the cause of death, among others.

The data from Fishing Activity Monitoring Program between 2015 and 2021 show that surface gillnets fisheries were mostly small-scale. This accounted for 4.76% of the production of the São Paulo state. However, this accounted for 30.94% of the production units, which shows the large number of people involved in this activity (IP, 2022). Despite this importance, the small-scale sector is poorly represented and needs to have greater participation in fishery governance. In Brazil, more than 90% of fishery workers belong to the small-scale category, involved in either subsistence or commercial activity (CAMPOS; CHAVES, 2016). However, the industrial sector has always been prioritized in terms of government support and participation in decision-making (GONÇALVES-NETO et al., 2021).

The absence of socioeconomic and ethnoecological data on fishing communities and adoption of top-down management approaches have given rise to conflicting and ineffective conservation measures (GONÇALVES et al., 2022). This is made worse by the lack of spaces for dialogue integrating different forms of knowledge and worldviews (TOOMEY et al., 2017). Unfortunately, the Brazilian gillnet regulations through IBAMA normative instruction no. 166 (BRASIL, 2007) have these characteristics.

Concomitantly with adoption of spaces and means for constructive participation, drastic conservation measures should always be avoided whenever possible (SECCHI et al., 2022). Adaptive changes to operational, technological or managerial mechanisms are preferable. In this regard, studies on and implementations of simple technologies for avoiding bycatch should be encouraged. These should include the use of sound-emitting devices in nets (BORDINO et al., 2002), use of illumination in gillnets (ORTIZ et al., 2016) or nocturnal fishing (OTTONI-NETO et al., 2011), among other techniques. Adoption of sociotechnical solutions should also be stimulated (AYERS; LEONG, 2022).

The most successful mitigation strategies often emerge through collaboration between fishers, managers also megafauna and fishery researchers (SECCHI et al., 2022; ZAPPES et al., 2018), while paying attention to the asymmetries of power between the different interested parties (TOOMEY et al., 2017). The existence of spaces for discussion and collective construction, with a view to achieving compatibility between conservation of megafauna and maintenance of traditional fishing activities, has been shown to be essential for transforming this and other conflicts into scenarios of greater fairness and sustainability.

FINAL REMARKS

The results show that it is not possible to establish a direct relationship between the surface gillnets use and the presence of dead megafauna individuals stranded on beaches of São Paulo state. Even when this relationship was statistically significant, it only explained a small proportion of the mortality, which indicates that other factors need to be analyzed together with the type of fishing gear used. There were differences between the results from analyses on the entire coastline, regions, and municipalities, which showed that the extrapolation of the results was inappropriate. In addition to these results, it is necessary to consider the socioeconomic importance of this type of fishing gear for artisanal fisheries. Thus, we recommend that measures for collaborative and adaptive management should be adopted, concomitantly with the monitoring of activities, to better assess the interaction between fishing and megafauna.

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AUTHORS CONTRIBUTION

Mayra Jankowsky conceived and designed the study, collected information, developed the statistical analysis and its scripts, interpreted the data, wrote, revised, and edited the manuscript. Ivan Machado Martins designed the study, developed the statistical analysis, interpreted the data, wrote, revised, and edited the manuscript; Deborah Santos Prado designed the study, interpreted the data, wrote, revised and edited the manuscript; Jocemar Tomasino Mendonça designed the study, interpreted data, wrote and revised the manuscript.