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Incidental capture of green turtle (*Chelonia mydas*) in gillnets of small-scale fisheries in the Paranaguá Bay, Southern Brazil

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ABSTRACT

Fishing activities are an important economic resource in the Paranaguá Bay, southern Brazil. In this area, there are reports of sea turtles interacting with small-scale fisheries. It was found that the juvenile green-turtle (*Chelonia mydas*) uses areas disturbed by fishing activity, which puts them at a higher risk of capture. The objective of this study was to evaluate the interactions of juvenile green-turtles with the gillnets used in small-scale fisheries, enabling a long-term understanding of those gillnet characteristics which increase the risk of turtle captures. The highest sea turtle capture rates occur in the early dry season, which is correlated with the larger displacement of individuals searching for available food sources. High levels of fishing effort also occur in this early dry period without a specific target resource. The highest levels of sea turtle mortality were observed during the coldest periods of the year (late rainy and early dry seasons) and can be related to the physiological needs of the sea turtles. The characteristics of gillnets that had the strongest relationships to turtle captures were soak time and mesh size. These results suggest that it is necessary to design new regulations governing aspects of fishing techniques such as soak time, net length or seasonal use of nets. Conservation initiatives aiming to reduce the risk of turtle capture must consider the economic importance of small-scale fishing practices and address the conflict that may exist between social concerns and environmental issues.

1. Introduction

Anthropogenic pressures, including fishing activities, are among the reasons why sea turtles are registered as a critically endangered species. The risk these animals face from bycatch has frequently been reported, but a lack of data makes the identification of factors that influence their survival rates difficult (FAO, 2009). Because of the insufficiency of this data for further analysis, the FAO Expert Consultation has recommended a compilation of basic information regarding accounts of shore fishing interactions with sea turtles since 2004.

The environmental impacts of industrial fishing have received a great deal of attention, as industrial fisheries are involved with international and environmental policies and rigorous trade regulations (FAO, 2007). Information regarding the impacts of small-scale fishing, however, remains scarce (Wallace et al., 2010). Further understanding of the environmental impacts of small-scale fisheries through assessments at regional scales are necessary to take appropriate conservation measures while considering the socio-economic concerns of different regions (FAO, 2009).

There are several recent studies that address interactions between sea turtles and fishing practices along the Brazilian coast, with the earliest efforts focusing on large-scale industrial fisheries (Marcovaldi et al., 2002). Therefore, the management practices created in response to this work only address long-line industrial fishing of pelagic species such as *Caretta caretta* and *Demochelys coriacea* (Thome et al., 2003; Marcovaldi et al., 2006; Kotas et al., 2004). This previous focus on large-scale industrial fisheries makes the present study, which examines the impact of small-scale fisheries on sea turtles in Brazil, a valuable contribution to the existing body of knowledge.

Additionally, many communities in the state of Paraná in Southern Brazil are dependent on small-scale fishing practices for their livelihoods (Andriguetto-Filho et al., 2006), but the

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interactions of these practices with sea turtles have not yet been addressed. One study suggests that juvenile individuals of the green turtle (*Chelonia mydas*) use the same areas as the fisheries, which in turn increases their capture risk (cf. Guebert-Bartholo et al., 2011). Since 2004, the Instituto de Pesquisas Cananéia (IPeC) has reported turtle stranding and, in some cases, interactions with gillnets in areas of concern (Guebert et al., 2008). The majority of these captures are accidental, as is expected with the unwanted bycatch of fishing practices.

It has been reported by fishermen in the region that interaction of gillnets with sea turtles is common, and monitoring efforts have reported a high sea turtle mortality rate (100 individuals/year approx.) (Bartholo-Guebert et al., 2011). Nevertheless, there is a lack of data in these records, as they are unable to identify the cause of death. Considering this context, it is evident that there is still a lack of robust evidence about the timing and manner of the interaction between fisheries and turtles. The main goal of this study is to evaluate the interactions of juvenile green-turtles with gillnets of small-scale fisheries in a growing region of Southern Brazil and, by doing so, to enable the long-term monitoring necessary to advance our understanding about how gillnet characteristics increase the risk of turtle captures. In terms of local populations of sea turtles, we also propose solutions to reduce their capture rates.

2. Materials and methods

The Paranaguá Estuary Complex (PEC) is situated in the mid-northern part of Paraná state (Southern Brazil) and is comprised of several small bays which meet the larger Paranaguá Bay (Fig. 1). The PEC is a large interconnected subtropical estuary made up of two main water bodies and is connected to the open sea via three channels (Lana et al., 2000), which give rise to an ocean shore and an estuarine shore (Angulo and Aráujo, 1996). A wide variety of rich habitats exist on the estuarine side, including salt marshes, mangroves, swamps, seagrass patches, rocky shores and tide banks (Netto and Lana, 1997). The external area (ocean shore) of the PEC is made up of beaches and sandbanks with a lack of vegetation (Lana et al., 2000), which extend for 2 km and have depths of no more than 2 m (Netto and Lana, 1997).

In this area, small-scale fishing villages are found along the shore sides of rivers and estuaries, and these villages harvest around 70 target-species of economic importance (Andriguetto-Filho et al., 2009). Although the yields of small-scale fishing are generally not highly valued, they are of regional importance (Andriguetto-Filho et al., 2006). It is possible to differentiate between the fishing techniques of estuarine fishermen and shore fishermen; the origin and permanence of this wide variety of practices can be explained historically by both natural and social factors (Andriguetto-Filho et al., 2009). Estuarine fishermen use tools like the wooden plank boat, long-lines, the *gerival* or *tarrafinha* (a kind of beam trawl developed locally for capturing juvenile white shrimp), drift gillnets, encircling gillnets, anchored gillnets and trammel nets. Shore fishermen, whom are generally employed by others, use a diversity of equipment (canoes with propulsion systems, trawl nets, trammel nets, drift, encircling and anchored gillnets with different mesh sizes) (Andriguetto-Filho et al., 2006, 2009). Therefore, in order to analyze the relative impacts of these methods, the estuary and shore sites must be treated separately.

In this study, three small-scale fishing estuarine villages (Ponta do Poço, Maciel, Ilha do Mel,-Fig. 1) and three shore villages (Shangri-lá, Barrancos, Pontal do Sul, -Fig. 1) of the Paranaguá Bay were monitored from July 2007 until June 2008. Data were collected from reports of researchers aboard fishing vessels, interviews with fishermen and anecdotal information; in some analyses, however, it was not possible to use all of this information. The

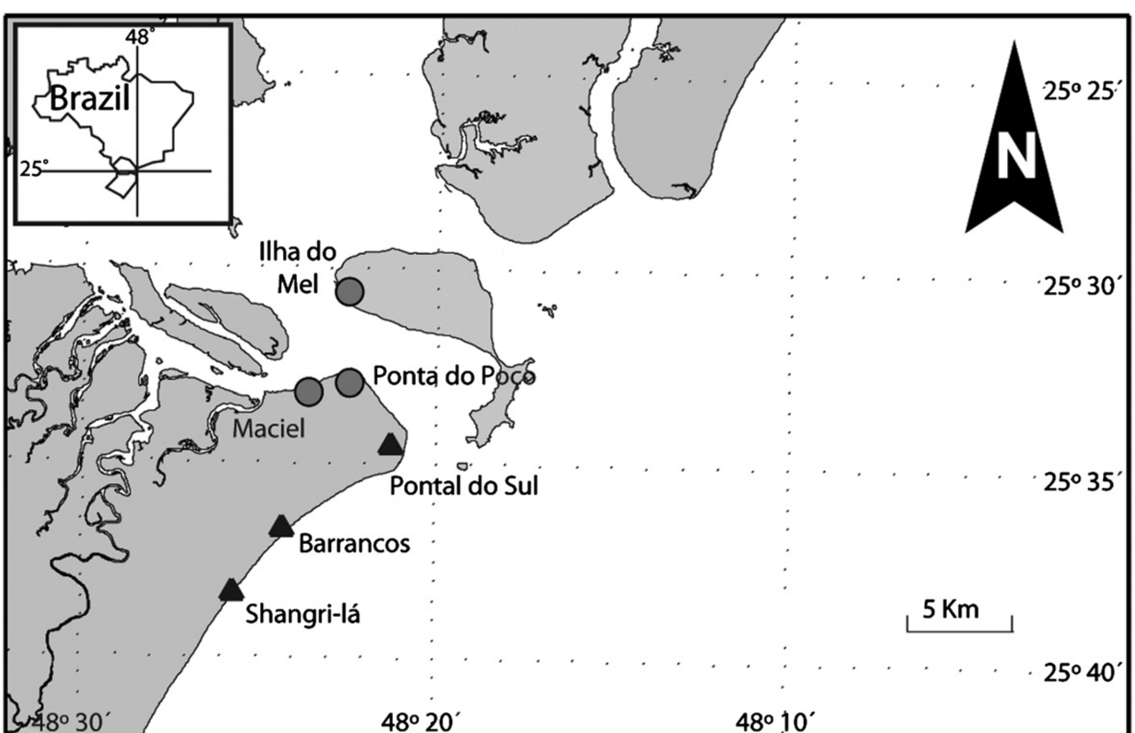

Fig. 1. The Paranaguá Estuary Complex (25°20′S–25°35′S e 48°00′W–48°30′W) and locations of the fishing areas of interest in the Paranaguá Bay. Triangles are the shore sites; circles are the estuarine sites.

following seasonal periods were classified according to rainfall: early dry period (July to September), late dry period (October to December), early rainy period (January to March) and late rainy period (April to June) (Barletta et al., 2008).

Due to the high variety of fishing gear used in the area, data was collected only for fishing events that used gillnets (trammel net, encircling gillnet, anchor set gillnet and trawl net). For each of these events, the following information was recorded: net length, net height, mesh size, twine thickness, soak time (the interval during which fishing gear is in the water), approximate depth of fishing sites, and approximate distance to coast of the fishing sites. Trammel nets (locally called *feiticeira*), which have three layers of net, were not included in the analyses due to the difficulty of comparing them with single layer nets. Data on the physical conditions and curved carapace lengths (CCL) measurements (for size frequency classification) of sea turtles in the incidental bycatch were also collected.

An ANOVA was used to evaluate the differences between the size classes of captured turtles on a temporal scale (between seasons) and on a spatial scale (between estuary and shore sites). Data were transformed and tested for normality with the Shapiro–Wilk Test and for homoscedasticity using Levene's Test. Relationships between the green-turtle captures and certain characteristics of fishing gear in each area were assessed using a Principal Component Analysis (PCA). For this analysis, each fishing event was considered as a sample, characteristics of fishing gear as variables and a turtle capture in any fishing event (with or without captured) was considered a factor correlating to the sample.

Fishing effort and total number of captures are shown per season for both study areas, allowing for an assessment of the cumulative impact of small-scale fisheries on sea turtles. We also performed a simple regression for each study area (estuarine and shore area) using data from each month during the seasons.

Some caveats should be taken into consideration regarding the data used in this paper. Data reported in the early rainy season may have been affected by the socio-economic activities occurring during this season (tourism, turtle-based products, higher vessel traffic, restricted areas designated for fishing), all of which may be reflected in the low numbers of reported capture events. These factors may have masked the true amount of capture events and lead to an underestimated number of captures in this seasonal period. However, it is still possible to evaluate captures of sea turtles in small-scale fisheries of the region using the data presented in this study.

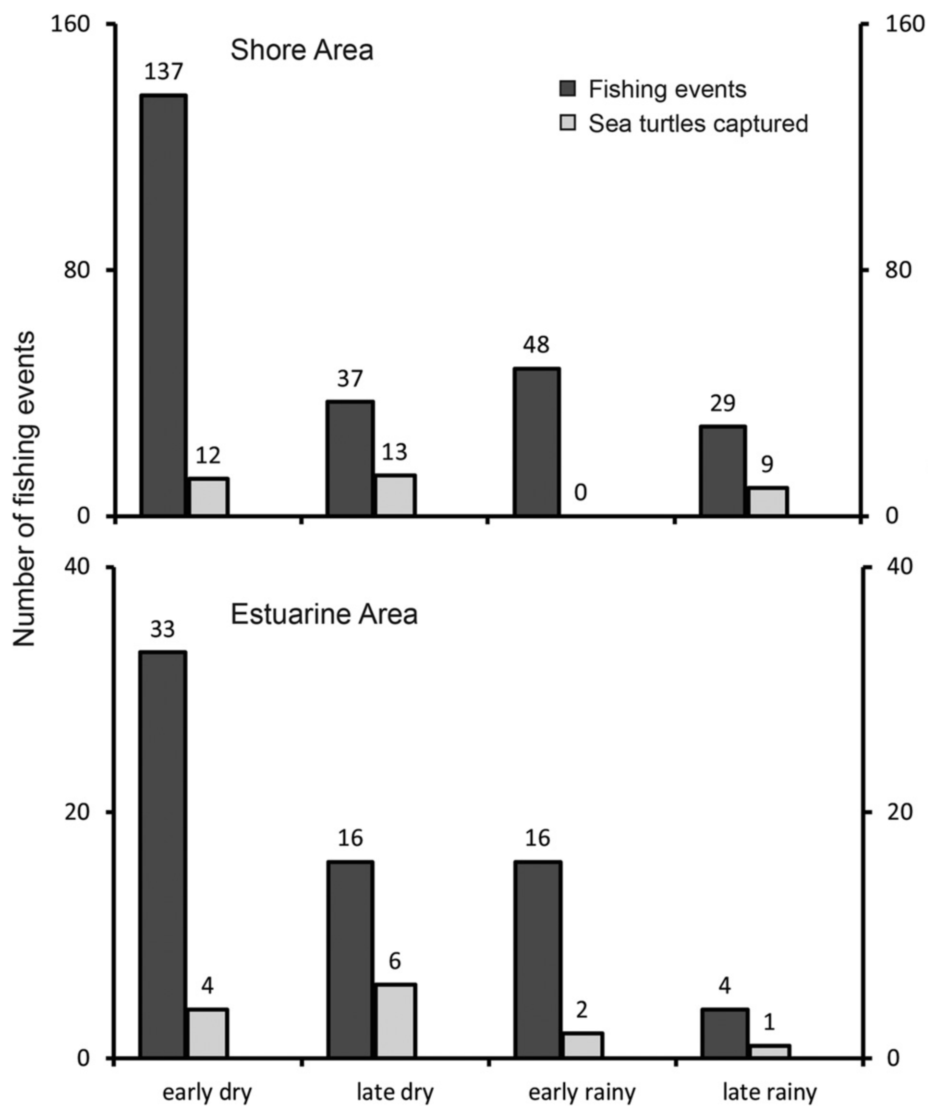

Fig. 2. Fishing effort of gillnets of small-scale fisheries and sea turtle captures by season period and area in Paranaguá Bay, southern Brazil.

3. Results

3.1. Fisheries characterization and summary of sea turtle captures

A total of 374 fishing events were recorded during this study, of which 49 had interactions with the species *Chelonia mydas* (capture rate of 13%). More specifically, events involving the use of gillnets ($n = 320$, 86% of total events recorded) had the highest frequency of sea turtle capture ($n = 49$).

Anchored gillnets were the most frequently used fishing gear in this region throughout the year, followed by drift gillnets and encircling gillnets. Drift gillnets were observed during the months of January and February, while trammel nets were used during the months of June to October. The use of trawl nets began in September, but was discontinued during the period of January through June; the beach trawl net and the cast nets were characterized by use during two months, May and June, in which *Mugil* spp. are the fishing targets. Particularly in the estuarine area, the beam trawl nets were used in December, and the long line was used in January, even though the uses of both techniques were less frequent in comparison with the others.

There was a total of 251 gillnet fishing events with 34 sea turtle captures in the studied shore area, while in the estuarine area there were 91 fishing events with 13 captures (Fig. 2). The highest fishing effort was recorded during the early dry season at both areas (total of 170 fishing events and 16 captures), and the lowest effort was recorded during the late rainy season (total of 33 fishing events with 10 captures; Fig. 2). There was no relation between the number of fishing events and number of captures at either the shore area ($F_{(1,10)} = 0.17$; $R^2 = ,016$; $p = 0.69$) or the estuarine area ($F_{(1,10)} = 0.29$; $R^2 = ,023$; $p = 0.60$).

A 63% mortality rate (31 individuals) was recorded among the sea turtle capture events in this study. Mortality was highest during the late dry season ($n = 14$), peaking during the month of November ($n = 9$). Survival was recorded for 4 individuals. For the early dry season, a mortality of 8 individuals was recorded, peaking during the month of September ($n = 4$), but there was also an equal number of survivors (8). The lowest numbers of captures ($n = 2$) were recorded in the months of the early rainy season, and both of these captured individuals survived. In the late rainy season, there were 12 captures recorded, of which 9 were dead. Captures peaked in April ($n = 4$), and 4 individuals survived, with the most surviving

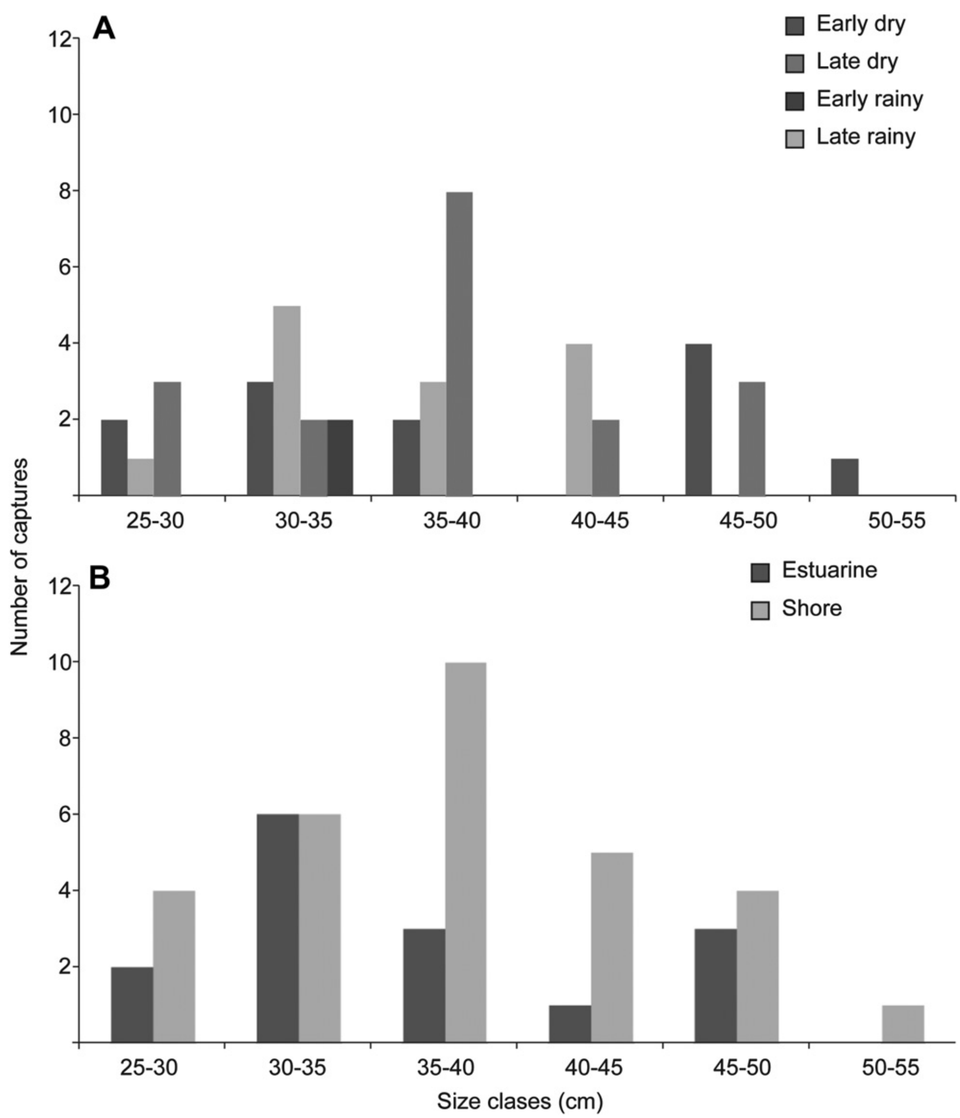

Fig. 3. Size class frequencies of green-turtles captured by fishing gear A. by season and B. by area in Paranaguá Bay, southern Brazil ($n = 45$).

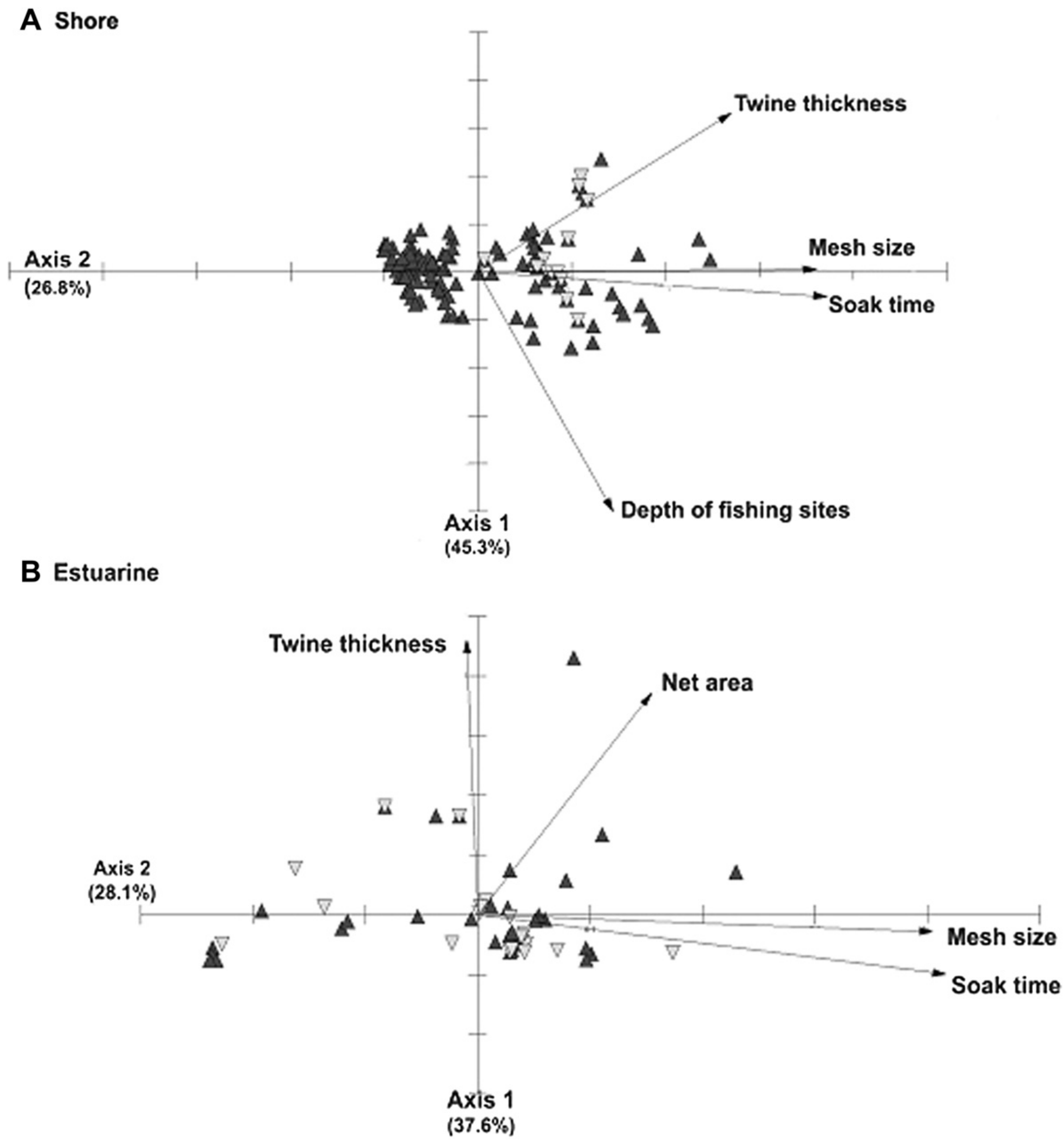

Fig. 4. Principal Component Analysis (PCA) of gillnet characteristics in small-scale fisheries and sea turtle captures by area: A. Shore B. Estuary. Black triangles: not captured, gray triangles: captured.

in June ($n = 3$). It was observed that most mortalities were recorded during the colder months (early dry and late rainy seasons, $n = 17$) and were lowest during the warmer months (late dry and early rainy seasons, $n = 14$).

3.2. Sea turtles captured in gillnets of small-scale fisheries

The following size classes of captured green-turtles in the region were measured for each season: early dry season, 39 ± 8.02 cm CCL; late dry season, 38.38 ± 5.6 cm CCL; early rainy season, 35 ± 0.0 cm CCL and late rainy season, 37.9 ± 4.96 cm CCL (Fig. 3A). With regards to the spatial variation of captures per size class, the estuary area had an average CCL of 37.93 ± 6 cm while the shore area had an average CCL of 38.69 ± 6 cm (Fig. 3B).

Despite this, no differences were found on either the temporal scale ($F = 0.2601$; $p = 0.775$) or the spatial scale ($F = 0.167$, $p = 0.846$). No distribution patterns were detected for captures in this studied area, which emphasizes the homogeneity of captures in the river mouth of Bahia de Paranaguá, as well as fails to show any preferences for area and/or size of sea turtles in bycatch.

3.3. Relation of sea turtles captures and characteristics of gillnets of small-scale fisheries

It was observed that captures of sea turtles in both estuaries and shore sites were strongly related to mesh size and soak time, two important characteristics of gillnets. In the shore area, the variation of different fishing gear types explained the two axes presented; they were responsible for 72% of the variation between the fishing events recorded in this area, while they accounted for 66% of the variation in the estuarine area. (Fig. 4A, B).

Characteristics like twine thickness and depth of fishing sites were correlated with captures in the shore areas (Fig. 4A), although they presented relatively weak correlations in comparison to other characteristics. For the estuarine area, the total net area (length*-height) and twine thickness were the two characteristics most related to sea turtle captures (Fig. 4B).

4. Discussion and conclusion

The temporal scale of fishing practices in this study is related to the seasonal frequencies of fishing resources along the coast of the Paraná state (Robert and Chaves, 2006). The use of anchored gillnets is frequent through the year, with the highest usage during the early dry and late dry seasons, the fishing season for the highly prized flounders (*Paralichthys* spp.) in the area (Andriguetto-Filho et al., 2006). Trammel nets, beach trawl nets, and cast nets can be found during the coldest months of the year (May, June, July), often catching large shoals of mullet fish (*Mugil* spp.) (Andriguetto-Filho et al., 2009). During the late dry and late rainy seasons, many different types of fishing gear are used (drift gillnets, encircling gillnets, anchor set gillnets, trammel nets, bottom trawl nets) due to a lack of specificity for a certain target-species (Andriguetto-Filho et al., 2006).

There was no relationship between fishing effort and sea turtle captures in each area, possibly because the fishing efforts in both areas were similar (14% and 13%, estuarine and shore respectively). However, sea turtle captures are not only related to the fishing effort deployed temporally, but also the availability of resources in the studied area during the early and late dry seasons. This observation may be associated with the larger displacement of individuals searching for their available food sources (*Halodule wrightii* in the early rainy and dry seasons, *Avicennia shaueriana* propagules in the late dry and rainy seasons and *Ulva* spp. during the late dry season) (Guebert-Bartholo et al., 2011). This explained why, in the late rainy seasonal period, the fishing effort was lower than the capture, because foraging increases the chances of sea turtles to contact and become entangled in fishing gear.

In addition, the temporal variability of captures could also be related to sea turtle behaviors such as territoriality, navigation, orientation. In northern California (USA), Avens and Lohmann (2004) related seasonal variations in these behaviors with the physiological requirements of turtles. For example, turtles migrated to the north in search of colder waters during the summer and to the south for warmer waters in winter.

As described by Avens and Lohmann (2004), measuring a similar pattern in this study is not plausible due to the different fishing styles practiced in the southern states of Brazil, different frequencies of use and different monitoring programs. However, the following registries of catch rates of green-turtles by small-scale fisheries in Brazil offer some insight into the question: Ubatuba, northern São Paulo, for the July-early dry season (Gallo et al., 2006); northern Paraná-PR, for the November late dry season (current study); and Florianópolis, Southern Santa Catarina-SC, for the March early rainy season (PROJETO TAMAR, 2005). Several hypotheses can be made based on these data. Fishing gear types and techniques with a higher success rate of sea turtle captures coincide with use in the same months. Although there is a relatively small amplitude of variation in superficial sea temperature (SST) among these areas, capture patterns could also be the result of seasonal distribution of turtles, based on physiological constraints (early dry SST: SP = 20.96 °C, PR = 18.5 °C, SC = 18.1 °C; late dry SST: SP = 23.3 °C, PR = 23.5 °C, SC = 23.2 °C; early rainy SST: SP = 25.2 °C, PR = 26 °C, SC = 25.7 °C; late rainy SST: SP = 23.3 °C, PR = 22.4 °C, SC = 21.8 °C) (NOAA, 2011). In order to confirm such hypotheses, further robust mark-recapture studies would be necessary.

Although the largest sea turtle catch was in the late rainy seasonal period, the highest rate of mortality was recorded in the coldest periods of the year (early dry and late rainy). This pattern can be explained the by physical constraints of low temperatures, which reduce the turtles' tolerance during forced swims (Lutcavage and Lutz, 1997) in relation to size and activity type of sea turtles and water temperature (Lutcavage and Lutz, 1997; Stabenau et al., 1991). These parameters should be considered when analyzing death registries, as they could differ between the early dry season and the early rainy season (Sasso and Epperly, 2006).

In the analysis of gillnets characteristics that influence sea turtle capture rates, soak time and mesh size were the most important. For the first, Guebert-Bartolho et al. (2011) have reported that the highest capture rate for green-turtles in the same region occurred with a soak time of 24h, which is a popular fishing practice in the area. Many other studies have reported that turtle mortality rate is a direct function of the time the net remains in the water (Henwood and Stuntz, 1987; Oravetz, 1999; Lezama et al., 2003; Sasso and Epperly, 2006). These data, as in other studies, confirm that soak time is a fundamental determinant of the capture rate and post-survival of sea turtles (FAO, 2004; Santora, 2003), because turtles drown due to prolonged periods spent underwater when caught in nets. These characteristics must be considered when creating a proper management plan for these animals. For example, monitoring and controlling the soak time of gillnets could reduce mortality by preventing suffocation of turtles stuck underwater for a prolonged time.

As for the second characteristic, the most prevalent mesh size of 12–16 cm can be associated with high frequency usage of these mesh nets and not with selectivity for a certain class size. Hence, in relation to the CCL, sea turtles susceptibility to capture is homogenous throughout the area and does not exhibit any selectivity for a particular size class. Another characteristic that was found to correlate with captures in both areas was twine thickness, which possibly complicates the escape of sea turtles by trapping them more thoroughly.

The depth of sites in which gillnets were recorded proved to be important in relation to sea turtles captures in shore areas; only juveniles of *Chelonia mydas* were frequently captured in shore and offshore areas when feeding. This relationship would be expected to also occur in shallower areas like those of the estuaries. Furthermore, the estuaries presented low variability in depth and a high presence of seagrass patches that serve as feeding sites for sea turtles (Guebert-Batholo et al., 2011). Here, the capture rate is not related to the design of fishing gear, but rather to the sand shoal inlets that act as natural traps for turtles who venture into these areas in search of seagrasses to eat.

The results of this study reinforce the importance of estuarine areas of the PEC as development sites for sea turtles, as reported by Guebert-Batholo et al. (2011). Due to the higher capture rates in these areas compared to shore sites, types of fishing gear observed in these areas and sea turtle diets, it is possible to conclude that probabilities of capture by fishermen are high. Conservation management plans should consider artisanal fishing practices as an economic alternative to conventional capture techniques.

During the monitoring period of the study area, 133 *C. mydas* individuals were stranded on the beach (Guebert et al., 2008). This leads us to believe that beach stranding and deaths are caused by estuarine and oceanic fishing activities as well as industrial oceanic fishing. Other deaths may result from ingestion of inorganic material, suffocation (Guebert-Bartholo et al., 2011), contact with run-off pollutants from the Port of Paranaguá (heavy metals, aromatics hidrocarbonates, HPAs and organoclorates) (Pugh and Becker, 2001; Gardner et al., 2003; Talavera-Saenz et al., 2007) or natural processes.

In this research area, this is the first study to involve the fishing villages in the issue of sea turtle bycatches. We opened the opportunity to develop future management measures for conserving the species together with fishermen.

4.1. Implications for conservation and recommendations

This study allows for an understanding of the patterns of seasonal variation and the impacts of fishing gear on the capture of sea turtles in the PEC. Such an understanding informs proposals for effective management actions in the area that will not have an undue effect on fishing activities. Considering the importance of these areas for sea turtle feeding (Guebert-Bartholo et al., 2011), a management plan is specifically needed to reduce turtle capture rates during feeding periods. In regards to this factor, it is important to consider the following points: the highest sea turtle capture rate occurs in early dry season and is related with larger displacement of individuals searching for available food sources; the highest fishing effort occurs in dry early season without a specific target resource; the highest mortality rates, in the coldest periods of the year (late rainy and early dry), can be related to the physiological needs of sea turtles. These results demonstrate that the restriction of fishing practices or closure of fishing areas should not be recommended for the study area; instead it is necessary to design regulatory measures related to fishing techniques such as soak time, net length or seasonal use of nets.

In communication with fishermen, modifications of the placement of the nets for each area were suggested. In the estuarine areas, it was suggested that nets be placed in zigzags around the seagrass meadows, allowing space for turtles to enter and leaving a net-free access route to their feeding areas. For shore areas, it was suggested that nets be placed in parallel, as opposed to their usual perpendicular placement, this arrangement tested for the reduction of sea turtle captures. To guarantee its efficiency, testing of this method should be done in conjunction with the local population of fishermen.

Estuarine environments are important habitats for the growth and development of green-turtles, but they also act as valuable fishing sites for the local community. The challenges that remain are identifying and assessing sea turtle hotspot areas in order to define the acceptable fishing styles that coincide with reducing the number of captures. Moreover, it is important to maintain relevant monitoring over long periods of time and to understand the dynamics of each factor on a broader time scale. Though these efforts, it will be possible to take appropriate measures for both sea turtle conservation and the sustainability of fishermen.

In light of this study, special attention needs to be given to those environmental management institutions in the area that address social and economic processes. These institutions are developing projects with the local population (education, culture, prevention, bycatch release), which in turn will increase the available data on this type of interaction.

Acknowledgments

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