Bycatch of Asteroidea from shrimp trawl fishery in the southwestern Atlantic Ocean – Brazil

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Abstract. Shrimp trawling is considered a significant negative impact on the marine ecosystem, especially on the benthic community. Sea stars (Echinodermata: Asteroidea) are one of the most affected groups by unintentional catches. This study was performed at the Santana Archipelago, a Marine Protected Area in the northern region of Rio de Janeiro State, between 2008-2009. Sea stars accidentally caught by trawling were collected during open and closed season of the shrimp fisheries *(Xiphopenaeus kroyeri)* at depths of 5-60 m. A generalized linear zero-inflated model was applied to test for differences in capture between fishing seasons and depths. A total of 158 sea star specimens were captured. These specimens were identified as *Asterina stellifera, Astropecten acutiradiatus, Astropecten brasiliensis, Astropecten cingulatus, Luidia alternata alternata, Luidia clathrata, Luidia ludwigi scotti, Luidia senegalensis.* The sea stars *A. brasiliensis* and *L. senegalensis* are currently considered as vulnerable species in the Brazilian official list of threatened species. The higher capture of sea stars was shown in deepest areas, and there was no significant difference in the number of specimens between seasons. This is the first study about asteroids accidentally captured by shrimp trawling.

Keywords. Benthos; Echinoderms; Fishing; *Xiphopenaeus kroyeri*.

INTRODUCTION

Marine biodiversity is a component that enormously influences our social and economic development; however, it has been often threatened by impacts of different anthropogenic origins (Costanza, 1999; Tittensor *et al.,* 2010). Among these impacts, pollution and commercial fishing are responsible for a huge loss of biodiversity across the seas (Halpern *et al.,* 2008; Costello *et al.,* 2010). For instance, in addition to overfishing that endangers fish stocks and biodiversity (Murawski, 2000; Coll *et al.,* 2016), bycatch is one of the most destructive practices that come from commercial fishing, as it contributes to decrease the richness and abundance of marine species (Coll *et al.,* 2016; Mendonça *et al.,* 2019).

Bycatch can be characterized as the set of captured species other than those target species (Clucas, 1997). The most significant effect of shrimp trawling bycatch is the mortality of the benthic fauna that affects its species composition and abundance and, hence, the maintenance of coastal ecosystems (Dayton *et al.,* 1995; Hall, 1996; Smith, 2001; Escolar *et al.,* 2009). The high bycatch mortality rate (Davies *et al.,* 2009; Eayrs, 2007) and the death of invertebrates affect benthic communities' structure by disturbing food chains and sedimentary structures (Jones, 1992; Alverson *et al.,* 1994). Many benthic invertebrates have been indicated as bioconstructors and bioturbators of the substrate involved in organic matter and nutrient cycle and, therefore, play an important role in ecosystem maintenance (Mermillod-Blondin *et al.,* 2005; Soares-Gomes *et al.,* 2009).

Benthic invertebrates, fishes, and turtles are usually captured as bycatch during trawling activities (Dayton *et al.,* 1995; Hall, 1996; Hall *et al.,* 2000). Nevertheless, most available studies found in the literature focused mainly on commercial

species, while bycatch of non-commercial invertebrates is usually neglected, such as mollusks, cnidarians, poriferans, and echinoderms (Kelleher, 2005).

The bottom trawl fishing has been indicated as the main modality responsible for the decrease of the echinoderm population density (Bergman & Hup, 1992). Among echinoderms, sea stars are one of the most affected taxa since many of them inhabit sandy and/or muddy bottoms all over the world (Probert *et al.*, 1997; Bergmann *et al.*, 2002; Blom *et al.*, 2009; Escolar *et al.*, 2009; Ventura *et al.*, 2013). Captured sea stars experience various physical injuries such as crushing and autotomy because of bottom trawling (Micael *et al.*, 2009; Ventura *et al.*, 2013).

In Brazil, shrimp trawling causes a huge impact on the benthic community (*e.g.*, Graça-Lopes *et al.*, 2002; Branco *et al.*, 2015; Costa *et al.*, 2016; Mendonça *et al.*, 2019). Therefore, precautionary measures have been considered in certain government instances to minimize the impacts of bycatch from shrimp trawling. Currently, the main Brazilian regulation on shrimp fishing is related to its closed season (Normative Instruction IBAMA No. 189/2008). The closed season is a strategy in which there is a prohibition to fish for the target species during their period of reproduction and recruitment (Franco *et al.*, 2009). The shrimp fishing closed season occurs annually from 1 March to 31 May in Brazil's southeastern and southern marine regions. The closed season of commercial fishing aims at the conservation of shrimp resources only (Franco *et al.*, 2009) and does not consider the biology of the bycatch species.

Xiphopenaeus kroyeri (Heller, 1862), the seabob shrimp, is one of the most traded species off the Brazilian coast (D'Incao *et al.*, 2002; MPA, 2011). Further, the very small mesh size used for fishing *X. kroyeri* are poorly selective because large proportions of *X. kroyeri* considered too small for sale are also caught (Silva *et al.*, 2012). Some devices are currently used to increase selectivity during shrimp trawling, such as the bycatch reduction devices (BRDs) and the turtle excluder devices (TED) (Broadhurst *et al.*, 2006; Eayrs, 2007; Willems *et al.*, 2016). Another measure used to reduce bycatch income is the protection of predetermined areas where fisheries are forbidden (Broadhurst *et al.*, 2006; Eayrs, 2007).

Evaluating captured organisms, estimating the volume of unintentional catches, and assessing the impacts on discarded organism populations are essential measures to minimize bycatch impacts and monitor these organisms' capture (Kelleher, 2005). Therefore, knowledge about biodiversity associated with the fishing activity is important to support conservation measures (Costa & Di Beneditto, 2009).

Sea stars have been reported previously near the coastal region of Macaé, Brazil (Mincarone *et al.*, 2016); however, there is no study available to date on how they can be affected by bottom trawling. Shrimp trawling is an important economic resource for Macaé, which has a Fishermen community operating in the region (Silva *et al.*, 2016). This study presents the first survey of the unintentionally captured sea stars during the bottom trawling of the shrimps *X. kroyeri* from the Santana Archipelago, Macaé (RJ), to observe their distribution patterns and abundance at different depths during open and closed fishing seasons.

MATERIAL AND METHODS

Study site

The present study was conducted at the Santana Archipelago, located about five miles from the coast of Macaé, a municipality in the North of the state of Rio de Janeiro (Fig. 1). The Santana Archipelago is a Marine Protected Area (MPA) created by Municipal Law No. 1216/89 (Macaé, 1989). The protection area is inserted in the Campos Basin, the largest oil hub in Brazil (Silvestre & Dalcol, 2009). The local upwelling biologically influences the shrimp population of *X. kroyeri* (Davanso *et al.*, 2017; Silva *et al.*, 2015).

Data collection

The surveys were conducted from the Santana Archipelago on a shrimp fishing boat equipped with a handmade trawl net (mesh size 20 mm and 15 mm in the cod) with opening between doors of 3.5 m. From March 2008 to April 2009, including the closed season of the shrimp fishery, 13 trawling were carried out at depths of 5, 15, 35, 45, and 60 m. Trawls were deployed for at least 15 minutes at a constant speed of 3.3 km/h. All the specimens of trawling were stored in isoprene boxes with tags.

In the laboratory, sea stars specimens were manually screened from the bycatch, fixed in 4% formaldehyde, and preserved in 70% ethanol. The sea stars were identified to species level using stereomicroscope (Olympus SZX16), optical microscope (Olympus CX31), and specific literature (*e.g.*, Tommasi *et al.*, 1970; Ventura *et al.*, 2007; Gondim *et al.*, 2014).
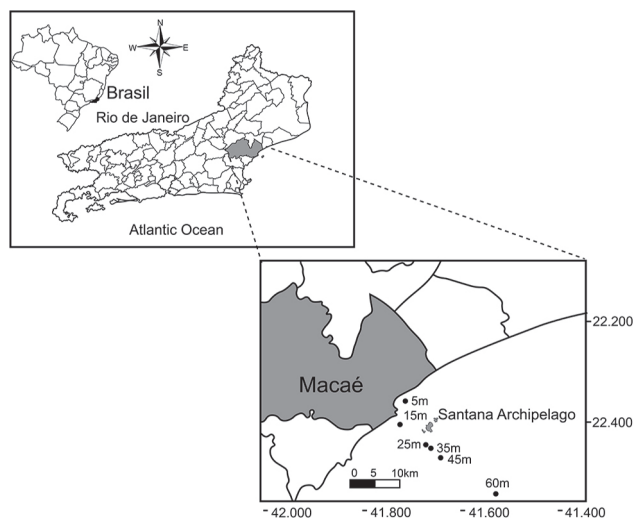

Figure 1. Map of the study area of Marine Protected of the Santana Archipelago, Macaé (RJ).

For each species, the number of specimens per sample and bathymetric range were recorded and classified according to threat category the Official National List of Endangered Species of Brazilian Fauna (ICMBio, 2018). The "vulnerable" (VU) category was applied to species that face a high risk of extinction in the wild and was established following the criteria of the IUCN (International Union for Conservation of Nature) (ICMBio, 2018). The specimens were deposited in the Echinoderm Collection of the Instituto de Biodiversidade e Sustentabilidade – NUPEM, Universidade Federal do Rio de Janeiro, Macaé, RJ (NPM-Ech).

All samplings were carried out in accordance with Brazilian state and federal laws (Instituto Chico Mendes de Biodiversidade/ICMBio №11274).

Data analysis

To verify temporal differences in sea stars bycatch across depth, we used a zero-inflated Poisson (ZIP) model. This is a mixture model because zeros are modeled as coming from the binomial process and the count process. In a first step, a global model was adjusted using depth, season (closed or fishing), and their interactions as covariates for the binomial and the count process using Poisson distribution. Depth was modeled as a third-degree polynomial predictor generated by a B-spline basis matrix. A likelihood ratio test provided evidence ($\chi^2 = 18.15$; $p < 0.001$) for a model selection using negative binomial distribution. We adjusted sequential candidate nested models dropping each predictor in turn, and applied likelihood ratio tests for model selection. The procedure was independently used to select predictors for the count and the binomial structure. The final best model was validated using graphical residuals inspection (Zuur *et al.,* 2009). To investigate differences in sea stars species composition from different events of bycatch, we used the biplot diagram from a Principal Coordinates Analysis (Gower, 1966) generated from a Bray-Curtis dissimilarity matrix. All analyses were done using the R Program (R Core Team, 2020).

RESULTS

A total of 158 sea star specimens belonging to eight species were captured from the Santana Archipelago (Table 1). The captured species were represented by three genera: *Asterina,* with four specimens (accounting for approximately 3% of the composition); *Astropecten,* with 52 specimens (accounting for approximately 33% of the composition) and *Luidia,* with 102 specimens (accounting for approximately 65% of the composition) (Table 1).

We found an increase in sea stars captured at a depth range of 25-45 m (Fig. 2); however, no significant difference was detected between the closed and open fishing seasons. The final best model retained only the predictor of depth that was modeled as a polynomial of third degree (Table 2). The first axis of the principal coordinates diagram tended to separate deeper trawls, but no very clear pattern was found (Fig. 3a). No differences in the species composition were found between seasons (Fig. 3b).

DISCUSSION

In the present study, the most abundant genus was *Astropecten. Astropecten* has also been recorded in bycatches of commercial crustaceans in Scotland and India (Bergmann *et al.,* 2002; Prabhu *et al.,* 2013), as well as in bycatches of the commercial gastropod *Zidona dufresnei* (Donovan, 1823) in Uruguay (Riestra *et al.,* 2006). In Brazil,

Table 1. Sea stars species collected at Environmental Protection Area of the Santana Archipelago. Being "N", number of individuals; "Depth. (m)", depth in meters and "NPM-Ech", catalog number in the NPM-EchNUPEM/UFRJ Biodiversity Institute.

Taxa	Number of captured individuals per trawls													Total	Depth (m)	Voucher (NPM-Ech)
	1	2	3	4	5	6	7	8	9	10	11	12	13			
Asteroidea																
Asterinidae																
Asterina stellifera (Möbius, 1859)				1								3		4	25	024, 056
Astropectinidae																
Astropecten acutiradiatus Tortonese, 1956								2		6	1	1	2	12	25-45	041, 046, 048, 051, 059, 067
Astropecten brasiliensis Müller & Troschel, 1842												3		3	35	066
Astropecten cingulatus Sladen, 1883	4	1		10	3	5	5			1	4		4	37	15-35	003, 004, 008, 021, 022, 023, 028, 029, 033, 034, 038, 039, 053, 054, 068, 069, 070, 071
Luidiidae																
Luidia alternata alternata (Say, 1825)											1	1		2	35	055, 063
Luidia clathrata (Say, 1825)	2	2		13	2	4	3			3	5	9		43	25-60	002, 012, 013, 019, 020, 027, 032, 037, 047, 052, 060, 061, 062
Luidia Ludwigi scotti Bell, 1917			1	5	3	1						4	2	16	35-60	009, 014, 015, 020, 025, 057, 058, 064
Luidia senegalensis (Lamarck, 1816)	1	4	5	8	1	1	3	1	8	3	2		4	41	05-45	001, 005, 006, 007, 010, 011, 016, 017, 018, 026, 031, 035, 036, 040, 042, 043, 044, 045, 049, 050, 065
Total	7	7	6	36	10	11	11	3	8	13	12	18	16	158		

previous studies have reported *A. brasiliensis, A. cingulatus, A. stellifera, L. clathrata* and *L. senegalensis* in bycatches of the seabob shrimp *X. kroyeri* in the state of Santa Catarina (Branco & Verani, 2006; Branco *et al.*, 2015). Additionally, a study carried out in the municipality of Campos dos Goytacazes (RJ) has recorded *A. brasiliensis, A. cingulatus* and *L. clathrata* in bycatches of the commercial trawling of *A. longinaris* and *X. kroyeri* commercial shrimps (Costa & Di Beneditto, 2009), corroborating the results found in this study.

According to Ventura *et al.* (2013), bottom trawling is one of the main activities that increase extinction vulnerability in sea stars. Among the species identified in this study, *A. brasiliensis* and *L. senegalensis* are classified as "vulnerable" in the official list of endangered species in Brazil (ICMBio, 2018).

Our results showed that the deepest bathymetric regions presented the highest abundance of captured sea stars. Interestingly, some of the most abundant species reported in those depths in Brazil, especially from the genus *Luidia,* occur naturally in deeper bathymetric regions

far away from high hydrodynamic areas, probably because of the bottom composition (Ventura & Fernandes, 1995). No significant variation between the sampled periods (closed and fishing season) was observed in this study since the distribution of sea stars species is usually related to temperature and salinity, which vary depending on the bathymetric range rather than seasonality (Ventura & Fernandes, 1995). The sea star reproductive season is also variable and influenced by environmental factors, and different populations of the same species can breed at different times (Mercier & Hamel, 2013).

Shrimp fishing is forbidden during the closed season (IBAMA, 2008). If we assume that the shrimp fishing occurs during the spawning events of these sea
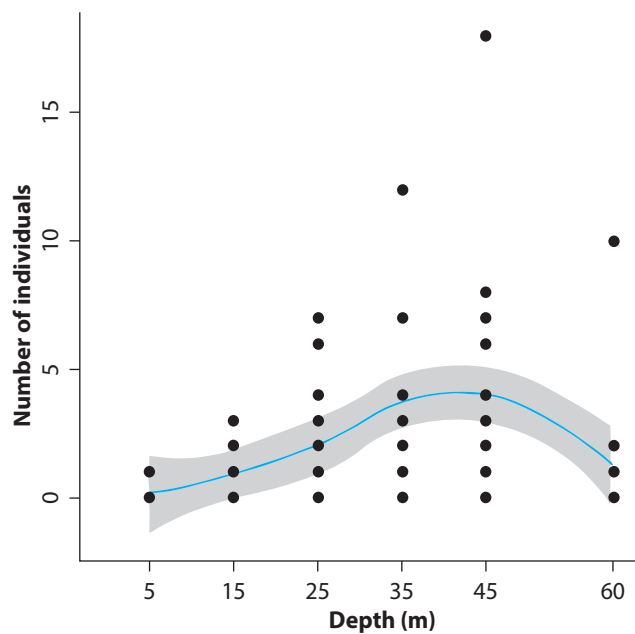
Table 2. Summary results of the best model using depth as predictor for the counts of seas stars captured in 78 trawls. Coefficients of the count and binomial structure (hurdle) of a zero inflated model using negative binomial distribution are presented.

Count model coefficients	Estimate	Std. Error	z value	p value
Intercept	-2.517	1.687	-1.493	0.136
bs(Depth)1	5.480	3.238	1.693	0.091
bs(Depth)2	3.973	1.396	2.845	0.004
bs(Depth)3	3.917	1.798	2.179	0.029
Log(theta)	0.733	0.551	1.330	0.183
Zero hurdle model coefficients				
Intercept	-1.197	0.638	-1.876	0.061
bs(Depth)1	-0.152	2.022	-0.075	0.940
bs(Depth)2	6.028	1.737	3.47	< 0.001
bs(Depth)3	0.032	0.920	0.034	0.973

Figure 2. Number of sea stars captured in each of the 78 trawls from 5 m to 60 m depth. The shaded area corresponds to 95% confidence band using a loess smooth curve.
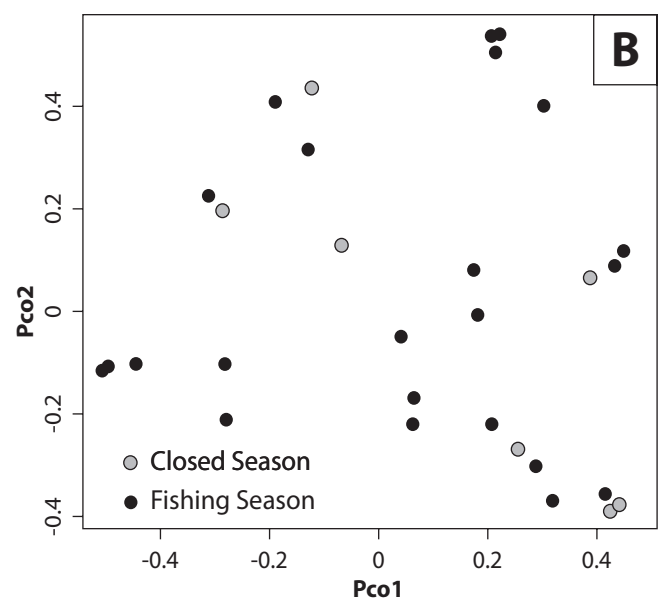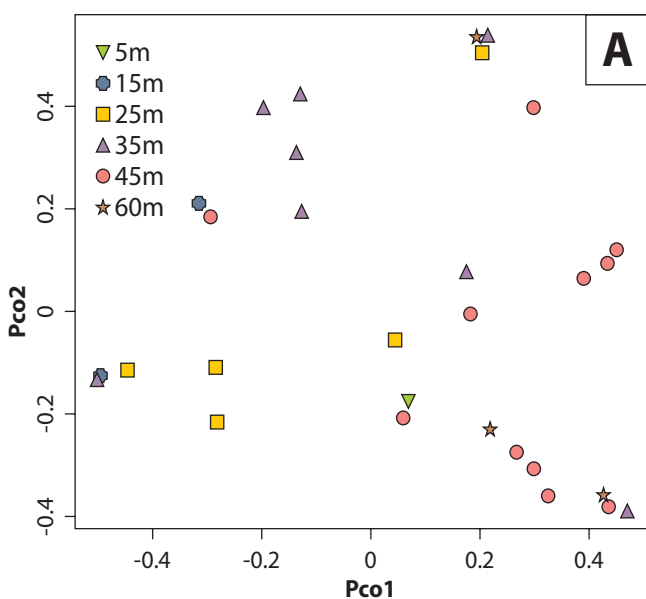

Figure 3. (a) Biplot diagram community organization at different depths; (b) Biplot diagram community organization at different sampling times (closed season and fishing season).

stars species, it may increase their vulnerability because some species of sea stars spawn during the open fishing season (June to February). For example, *L. senegalensis* spawns in the Fall (March to June in Brazil), while *L. clathrata* spawns in the mid-to-late Spring (September to December) after increasing their gonads size reaching their maximum in late Winter (June to September) (Lawrence, 2013). In a tropical upwelling region of the Brazilian coast (Cabo Frio), *A. brasiliensis* spawns when seawater temperature drops naturally from 22°C to 14°C, in the upwelling period (springtime and November) and *A. cingulatus* has a longer spawning period that begin in the Fall, and it goes through the Winter (May to August) (Ventura, 2013). These reproductive aspects should be considered when elaborating strategies to conserve sea stars species in order to avoid shrimp fishing during their spawning events, especially when the fishing activity endangers sea stars' populations.

Fishing is an important economic activity in Macaé, and the municipality has 3,500 artisanal fishermen registered in the fishing community (Silva *et al.,* 2016). Thousands of shrimps are annually captured from the coast of Macaé (FIPERJ, 2014, 2015). A study carried out in 2011 demonstrated the impact of the bottom trawling in Macaé on shrimp carcino-bycatch of *X. kroyeri,* concluding that for each individual of *X. kroyeri* about 2.94 individuals of carcino-bycatch were caught (Costa *et al.,* 2016). Trailing sequences in the same areas are related to biodiversity loss (Jones, 1992; Dayton *et al.,* 1995), and regions impacted by constant trawling may take decades to be reestablished, as the bottom trawling causes larval growth suppression and decreases rates of fauna growth (Jones, 1992).

The attribution of fishing exclusion areas optimizes the recovery of threatened organisms by protecting the nursery and shelter areas (Sale *et al.,* 2005; Lopes & Villasante, 2018). Thus, this should be a suitable measure to be applied in the Santana Archipelago to protect sea stars and other marine invertebrates, as there is a relevant variation in reproductive periods among the different invertebrate species.

CONCLUSION

In the surrounding area of the Environmental Protection Area of the Santana Archipelago, eight species belonging to the genera *Asterina, Astropecten,* and *Luidia* were recorded, two of which (*A. brasiliensis* and *L. senegalensis*) are vulnerable species according to the official list of endangered species in Brazil. The number of individuals and species captured showed no seasonal difference (closed fishing season and fishing season). However, there was a clear bathymetric difference characterized by high abundance of asteroids in deeper regions. In agreement with previous studies performed in other Brazilian regions, the distribution patterns of sea stars found here were associated to depth, sediment composition and food availability rather than to seasonality.

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