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VULNERABILITY OF FISH TO TRAP FISHING IN NORTHEASTERN BRAZIL

Vulnerabilidade de peixes à pesca com armadilhas no Nordeste do Brasil

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ABSTRACT

In Northeastern Brazil, the trap fishing occurs mainly in rocky bottoms and a high diversity of fishes is caught. These characteristics, associated with the growing fishing effort, threat the maintenance of the biodiversity of these environments, since this fishing is not monitored, as a result of the deficiency in public management in monitoring small-scale fishing and in promoting research projects aimed at this objective. Due to the lack of detailed information on trap fisheries, this exploitation is prone to be assessed for impacts using semi-quantitative methods, built for data-poor situations. Our objective was to estimate the degree of vulnerability to trap fishing for the captured species through productivity-susceptibility analysis (PSA), based on data observed during fisheries monitoring and data obtained from the literature. Thus, it was possible to generate the necessary information to assist in the elaboration of management policies for this fishery in Northeastern Brazil. The Haemulidae family was the most abundant among the captured individuals, with *Haemulon aurolineatum* representing 29.7% of the sample. The PSA indicated that, although all species have high productivity, *Pseudopeneus maculatus, Lutjanus synagris* and *Haemulon plumierii* were the most vulnerable species, respectively. Furthermore, from 2000 to 2010 the trap fishing was directed to the *P. maculatus*; however, we verified a change in the target species, due to the biomass reduction of *P. maculatus* in the area. Therefore, it seems necessary to reassess this species building a management plan since they were classified by IUCN Red List as Least Concern – LC and according to results of the current study may not be the case anymore.

Keywords: Data-Poor; Fishing effort; Spotted goatfish

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RESUMO

No Nordeste do Brasil, a pesca com armadilha ocorre principalmente em fundos rochosos e é capturada uma grande diversidade de peixes. Essas características, associadas ao crescente esforço pesqueiro, ameaçam a manutenção da biodiversidade desses ambientes, uma vez que essa pesca não é monitorada, em decorrência da deficiência na gestão pública no monitoramento da pesca artesanal e na promoção de projetos de pesquisa voltados para esse objetivo. Devido à falta de informações detalhadas sobre a pesca com armadilhas, esta exploração é propensa a ser avaliada quanto aos impactos utilizando métodos semiquantitativos criados para situações de escassez de dados. Nosso objetivo foi estimar o grau de vulnerabilidade à pesca com armadilhas para as espécies capturadas por meio da análise de produtividade-suscetibilidade (PSA), com base em dados observados durante o monitoramento da pesca e em dados obtidos na literatura. Assim, foi possível gerar as informações necessárias para auxiliar na elaboração de políticas de gestão para essa pescaria no Nordeste do Brasil. A família Haemulidae foi a mais abundante entre os indivíduos capturados, com Haemulon aurolineatum *representando 29,7% da amostra. O PSA indicou que, embora todas as espécies apresentem alta produtividade,* Pseudopeneus maculatus*,* Lutjanus synagris *e* Haemulon plumierii *foram as espécies mais vulneráveis, respectivamente. Além disso, de 2000 a 2010 a pesca com armadilha foi direcionada ao* P. maculatus*; entretanto, verificamos uma mudança nas espécies-alvo, devido à redução da biomassa de* P. maculatus *na área. Portanto, parece necessário reavaliar essa espécie construindo um plano de manejo, uma vez que foram classificadas pela Lista Vermelha da IUCN como Pouco Preocupantes – LC, e de acordo com os resultados do presente estudo, podem não ser mais o caso.*

Palavras-chave: *escassez de dados, esforço de pesca, peixe-cabra malhado.*

INTRODUCTION

Trap fishing is a technique widely used along tropical and subtropical coastal regions and is quite old in some regions (*e.g.* the Caribbean) (Munro, 1974). In Northeastern Brazil, this fishing occur mainly in rocky bottoms and a high diversity of fishes is caught. These characteristics, associated with the growing fishing effort, threaten the maintenance of biodiversity in these environments, since this fishing is not monitored, due to the deficiency of public management in monitoring artisanal fishing and funding research projects aimed at this objective (Boehlert, 1996; Lessa *et al.*, 2009; Sanches & Sebastiani, 2009).

A trap fishing monitoring in Northeastern Brazil indicated that reef species from the Scaridae, Labridae, Acanthuridae, Lutjanidae and Mullidae families, which were caught as bycatch during lobster fishing and were discarded, or consumed on a small scale, became the target around the year 2000 (Ribeiro, 2004). Initially, trap fishing was mainly aimed at catching lobsters and other crustaceans, but the decline of the lobster has forced a change in this fishery, both in its range and in its fishing gear, which increased the fishing effort on reef fish species. In the same way, the decline of the snapper fishery (Southern red snapper – *Lutjanus purpureus*) also boosted the increasing trend in the productivity of trap fishery targeting reef fish (Asano-Filho; Furtado-Junior & Brito, 2002). Although detailed fishing statistics for the activity is lacking all over the Brazilian area, Ribeiro (2004) estimated that the number of traps annually employed on the adjacent coast of Pernambuco ranged from 150 traps day-1 in April to 4500 traps day-1 in September, October, and January in 2013.

When considering the catch volume, the trap fishing is the second most important (Lessa; de Nóbrega & Bezerra, 2004), despite the regular capture of species evaluated by the ICMBio (2018) as Vulnerable (VU). Furthermore, the capture of Data Deficient (DD) species is known, but the impact on them is unknown, which prevents any management action. Overall, incomplete knowledge about the context of Northeastern Brazil, where small-scale fishing is widely distributed but under monitored, also occurs in many other tropical countries (Longhurst & Pauly, 1987; Musiello-Fernandes; Zappes & Hostim-Silva, 2017; Jimenez *et al.*, 2019).

Due to the lack of detailed information on trap fishing, this exploitation is prone to be assessed for impacts using semi-quantitative methods, built for data-poor situations (Stobutzki; Miller & Brewer, 2001; Hobday *et al.*, 2011). Thus, for the impacts of the bycatch species, the Ecological Risk Assessment for Effect of Fishing (ERAEF) was set up in which a first level (Scale Intensity Consequence Analysis – SICA) is based on a probability-consequence framework, using the biology of species and the fishing gear attributes, whereas the second level the Productivity and Susceptibility Analysis (PSA), assess the vulnerability of species based on life history (productivity) and catch probability (susceptibility) (Hobday *et al.*, 2011). Productivity and Susceptibility Analysis (PSA) have been used for predicting the biological risk for fish populations caught (Hordyk & Carruthers, 2018), showing vulnerable species that require more urgent monitoring. The vulnerability index to fishing provides the basis for the development of fishery policies (Patrick *et al.*, 2010; Griffiths; Duffy & da Silva, 2017; Lucena-Frédou *et al.*, 2017).

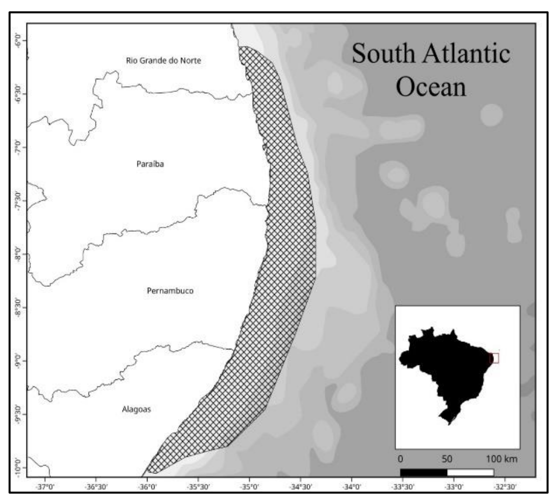
Recently, several works have been developed based on data-poor methodologies in Brazil (Jimenez *et al.*, 2019, 2021; Leduc *et al.*, 2021). However, for trap fishing in Northeastern Brazil, studies are still scarce and relatively old, focusing only on ornamental species (Lessa; de Nóbrega & Bezerra, 2004; Feitosa *et al.*, 2008; Beatriz & Marques, 2010).

In this sense, our objective is to assess the trap fisheries in Northeastern – Brazil using a data-poor approach to estimate the vulnerability to fishing of the species caught in trap fishing through the productivity-susceptibility analysis and finally, generate information necessary for building management policies for this fleet in Northeastern – Brazil.

MATERIAL AND METHODS

To standardize the effort, two fishing tackles were made with the same materials and dimensions (structure made with mangrove wood, with 52 cm of height, 117 cm of width and 168 cm of depth, trap opening with 36 cm of diameter with 6 cm PVC netting). The accompanied fleet was from the state of Pernambuco and the sampling area was defined by the fishermen based on fleet dynamics (Figure 1). Nine samples were collected, seasonally, between October 2016 and September 2017. The collected species were identified through specific literature (Carpenter & De Angelis, 2002; Sampaio & Nottingham, 2008; Lessa *et al.*, 2009). The productivity and susceptibility analysis were calculated for most abundant species, according to Stobutzky *et al.* (2001), adapting the attributes used according to the fishing gear and the species to be analyzed. We estimated the productivity and susceptibility indexes by nine attributes, which are explained as follows:

Figure 1 – Operating area to the trap fishing fleet Northeastern Brazil



Productivity attributes

Age at maturity (t50): The average age where 50% of the population has reached the age of first sexual maturity.

*Maximum age (tmax):*Maximum age was estimated from the Inverse Von Bertalanffy Growth Function (Mackay and Moreau, 1990), using asymptotic length (L_∞) for each species.

Von Bertalanffy Growth Parameter (K): Reflects how the species invests energy in growth. Fast growth rates mean higher population growth, i.e. productivity.

Length at maturity (L_{50}):Length at which 50% of the individuals attain sexual maturity for the first time.

Maximum Length (L_{max}):As trap fishing has a lack of information regarding the monitoring of captures and their observed biological data, we used the asymptotic length of the Von Bertalanffy Growth Function as the maximum length for the species as a way to standardize the data to be used.

Susceptibility attributes

Vertical overlap (VO):The use of water column species in relation to fishing gear. In trap fishing, the equipment is thrown into the water and submerge to remain in contact with the sea floor. Benthic species are most susceptible for this fishing.

Horizontal overlap (HO): Distribution and fishing area. Endemic species are more susceptible to fishing than species with greater distribution.

Lmean/L_{50}: Proportion that shows the rates of juvenile caught for each specie. Populations that suffer more from juvenile exploitation lose their ability to recover, making them more vulnerable to fishing.

Commercial Value: When the abundance of a target species decreases in an area, other species that compete for the same resource tend to increase their abundance. This increases the accidental capture of species of little commercial value or unfit for consumption, which are discarded frequently. Therefore, the fishing area defined by the fishing fleet tends to vary according to the abundance of commercially valuable species, making it impossible for the population to recover.

For each attribute, data from the literature were used to determine the productivity and susceptibility indices for all species separately (Meester, 1998; Vianna & Verani, 2002; da Silva, 2004; Lessa; de Nóbrega & Bezerra, 2004; Santana; Morize & Lessa, 2006; Shinozaki-Mendes *et al.*, 2007; Veras *et al.*, 2009; Marques & Ferreira, 2010; Shinozaki-Mendes *et al.*, 2013; Santos, 2015; Anbalagan *et al.*, 2016; Lessa *et al.*, 2016; Aschenbrenner *et al.*, 2017; Vasconcelos-Filho; Lessa & Santana, 2018), based on the evaluation criteria (Table I). We use the same weight for all attributes to avoid any interference in the result. The data quality index was estimated for each attribute and averaged, based on it's source data from the same population (3-good), data from another population (2-moderate) or data from another phylogenetically close species (1-poor). The vulnerability index was calculated following the literature method (Hobday *et al.*, 2011) and the degrees of vulnerability were estimated as high (> 1.89), moderate (between 1.89 and 0.94) and low (< 0.94). The vulnerability index was estimated from the Euclidean Matrix Distance:

$$V = \sqrt{(p - p_0)^2 + (s - s_0)^2}$$

A generalized linear model (GLM) was calculated to assess which attributes had the highest degree of significance in vulnerability. After estimating the main attributes that showed a significant difference in the GLM, we recalculated the PSA only with these attributes to assess whether the vulnerability scores have changed (2^{nd} Vulnerability). The Principal Component Analysis (PCA) was calculated to identify which species were grouped and which attributes (used in 2^{nd} Vulnerability) had greater weight in the groups.

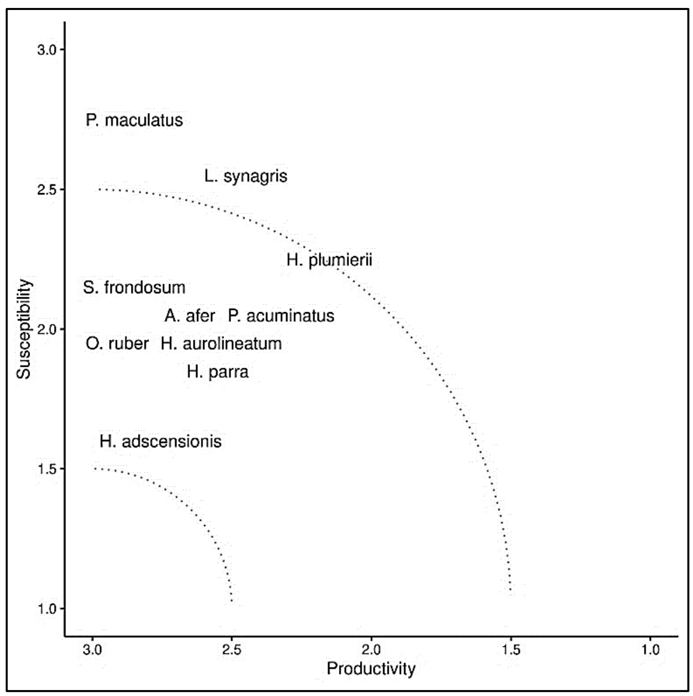
Table I – Evaluation criteria for productivity and susceptibility analysis attributes. The definition of the criteria was based on the characteristics of the fishing gear and the biology of the species that directly influence the susceptibility of catch and the population's ability to recover (productivity)

Productivity			
Attributes	High (3)	Moderate (2)	Low (1)
Age at Maturity	1 to 5	5 to 15	15 to 30
Maximum Age	5 to 10	10 to 25	25 to 60
Maximum Size	20 to 100	100 to 300	300 to 500
Size at Maturity	< 40	40-200	> 200
Von Bertalanffy (k)	> 0.25	0.15 to 0.25	< 0.15
Susceptibility			
Horizontal Overlap	> 0.50	0.25 to 0.50	< 0.25
Vertical Overlap	> 0.8	0.2-0.8	< 0.2
l50/lmean	$L_{mean} < 0.5L50$	$0.5L50 < L_{mean} < L50$	$L_{mean} > L50$
Commercial Value	Discarding	Local markets or personal use	Exportation and regional markets

RESULTS

25 species were identified totaling 528 individuals. The Haemulidae family had the highest number of individuals (n = 304) with *Haemulon aurolineatum* as the most abundant species (n = 157) (Table II). The ten most abundant species were used to calculate the PSA (*Haemulon aurolineatum, Orthopristis ruber, Lutjanus synagris, Pseudupeneus maculatus, Haemulon parra, Haemulon plumierii, Holocentrus adscensionis, Pareques acuminatos, Sparisoma frondosum* and *Alphestes afer*). The PSA (Figure 2) indicated that, although all species have high productivity and *P. maculatus, L. synagris* and *H. plumierii* were the most vulnerable species. The species *P. maculatus, L. synagris, H. plumierii* and *S. frondosum* were also the most susceptible species and only *P. acuminatus* presented moderate data quality (Table III).

Figure 2 – PSA plot for the most abundant species in the present study, calculated from the Euclidean Distance Matrix. The vulnerability increases directly proportional to the distance from the central axis (3,1)



The GLM show that only Age of first maturity, Maximum age, Horizontal overlaping, Lmean/L50 ratio and Use of habitat was the most significant attributes for Vulnerability. The new PSA calculated showed a difference in the vulnerability indexes (Table III).

The principal component analysis did not show a clear definition of the groups, but the target species remained separate from the others (Figure 3). The first principal component explained 60% of the grouping and had a greater contribution from the attribute "Horizontal overlap" (63%). The second component explained 22% of the cluster, with the "$L_{mean} - L_{50}$" ratio being the attribute with the greatest contribution.

Table II – Biometric data and frequency of species captured by trap fishing, from samples collected (9) from standardized traps, over a year

Species	N of individuals	Frequency	TL (mean)	Weight (mean)
Haemulon aurolineatum	157	29.73	16.94	64.16
Orthopristis ruber	85	16.10	18.66	90.61
Lutjanus synagris	73	13.83	18.58	101.49
Pseudupeneus maculatus	64	12.12	19.62	91.41
Haemulon parra	37	7.01	18.11	86.56
Haemulon plumieri	22	4.17	22.73	179.47
Holocentrus adscensionis	20	3.79	11.01	16.91
Pareques acuminatus	13	2.46	12.40	23.80
Sparisoma frondosum	10	1.89	20.17	152.42
Alphestes afer	8	1.52	20.47	146.26
Cantherhines pullus	4	0.76	12.55	37.18
Chaetodipterus faber	4	0.76	17.17	128.09
Diplectrum formosum	4	0.76	18.88	69.49
Monacanthus setifer	4	0.76	14.60	51.96
Mulloidichthys martinicus	4	0.76	24.03	153.52
Anisotremus virginicus	3	0.57	21.83	181.84
Calamus pennatula	3	0.57	21.93	184.17
Lutjanus analis	3	0.57	31.37	422.40
Acanthurus bahianus	2	0.38	20.05	206.48
Acanthurus coeruleus	2	0.38	19.95	198.27
Remora remora	2	0.38	53.70	375.39
Acanthurus chirurgus	1	0.19	10.50	19.54
Aluterus schoepfii	1	0.19	35.70	307.77
Diodon holocantus	1	0.19	17.00	118.43
Sparisoma chrysopterum	1	0.19	23.10	

DISCUSSION

The trap fishing is one of the most productive in Pernambuco accounting for 13.4% of the overall landings (Lessa; de Nóbrega & Bezerra, 2004). However, changes in the fishing strategies occurred throughout the years as traps were launched in the year 2000' in depths from 18 to 60 meters, with a submersion time from 2.5 to 3 days (Lessa *et al.,* 2009; Marques & Ferreira, 2010). Our result showed that the fleet has been setting its traps in deeper areas between 30 and 100m deep, with a submersion time between 2 and 6 days, pointing to an increasing in fishing effort after 13 years.

Still comparing to the REVIZEE Program (from 1998 to 2000) in fishing operations using the same gear and vessels displaying identical features, *P. maculatus* was the most abundant species (45.6%), followed by *L. synagris* (14.5%), whereas one of the least abundant species was *H. aurolineatum* (6.9%). Contrasting, in the present study *H. aurolineatum* was the most abundant species (29.7%) and *L. synagris* corresponds to 13.83% of catches, followed by *P. maculatus* (12.12%). These changes in proportions indicate a reduction in the abundance of the previously main target species (*P. maculatus*), a species intended primarily for export (Santana; Morize & Lessa, 2006; Cunha; de Carvalho & de Araújo, 2012).

Table III – The productivity (P), susceptibility (S) and vulnerability (V) indexes for the ten most abundant species caught by the trap fishing fleet. After the GLM, we eliminate 4 of the 9 attributes used to calculate the PSA and calculate a second vulnerability index

Species	Productivity	Susceptibility	1^{st} Vuln	2^{nd}Vuln	Quality
Haemulon aurolineatum	2.6	2	1.08	1	2.6
Orthopristis ruber	2.8	1.75	0.78	0.67	2.4
Lutjanus synagris	2.4	2.5	1.62	1.34	3
Pseudupeneus maculatus	2.8	2.75	1.76	1.67	3
Haemulon parra	2.6	1.75	0.85	0.67	3
Haemulon plumierii	2.2	2	1.28	1.12	3
Holocentrus adscensionis	3	1.5	0.5	0.67	3
Pareques acuminatus	2.4	1.75	0.96	1	1.2
Sparisoma frondosum	2.8	2	1.02	1	3
Alphestes afer	2.6	1.75	0.85	1	3

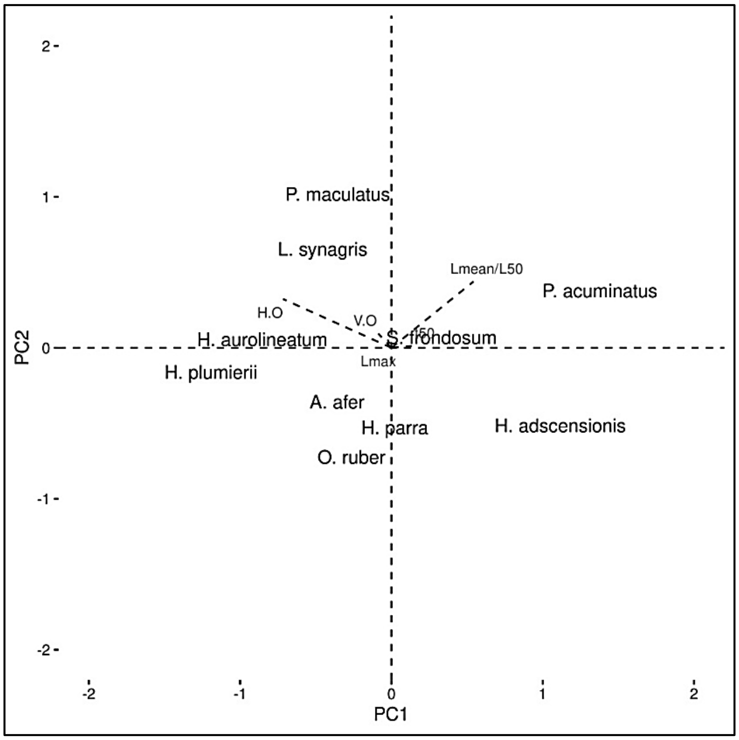
Changes in species abundance over more than a decade follow the pattern in which the target species – which was one of the less productive and more susceptible species (*P. maculatus*) – ended up being replaced by another relatively more productive and equally susceptible one (*H. aurolineatum*), supposedly due to the reduction in the dominance of other species that compete for resources (as is the case of *P. maculatus*). The depletion of target species, in addition to forcing a change of route in the fishing fleet, also causes a severe impact on the ecological balance of the area, causing an increase in species dominance and disturbances in the food web.

Armstrong, Hilborn and Hilborn (1998) suggested that one of the main characteristics of overfishing is the decline and replacement of target species, as recorded in this study. Concerns were raised because *L. synagris* was found to be the least productive among all the analyzed species. Therefore, concerns were raised once it has been the second and third most captured in 1998-2000 (Lessa; de Nóbrega & Bezerra, 2004) and on the present study, respectively. This maintenance of capture rates is not only due to the population's ability to sustain and recover, but mainly to the increase in fishing effort. The average weights of the main species captured by trap fishing (*P. maculatus, L. synagris* and *H. aurolineatum*) had a reduction in the average weight per individual, when comparing the results of this study with previous data. In the case of *L. synagris*, this reduction reached almost 50% when comparing the REVIZEE data with those of this study (from 196 g to 101.5 g).

The general context of this exploration with the decline of the most abundant species follows the pattern of baseline change (Pauly & Zeller, 2014), with the capture of juveniles pointing to a situation of growth overfishing where specimens are not left to grow to maturity (Hilborn & Walters, 1992).

The number of species caught in this study was less than previous studies (Marques & Ferreira, 2010). This reduction may have occurred due to many aspects like enviromental degradation and fishery overexploitation. Despite changes in fleet strategy, the fishing gears used over the last decade have been similar. This reduction in the number of species may be one effect of fishing effort in reef areas and along with other aspects (e.g. reduction of target species captures and decrease of their mean weight) may be another sign of overfishing. Furthermore, catches composed of vulnerable species (ICMBio) as *Sparisoma frondosum* and *Sparisoma axillare*, or near threatened as *Lutjanus analis* and *L. synagris* in regional assessments (Teixeira, 2014), deserve great attention. Thus, this fishing modality must be closely monitored, and surveillance measures enforced. Plans are in place to *S. frondosum* and *S. axillare*, allowing them to be sustainably used and managed (Ordinance 129 – MMA of 27/4/2018).

Figure 3 – Principal Component Analysis with productivity and susceptibility attributes (2nd Vulnerability) for 10 most important species caught by trap fishing in Northeastern-Brazil



In all, the Ecological Risk Assessment-ERA is a useful approach for evaluating the fishing effects on ecosystems and over limited stock data species, supplying the basis for drawing fisheries resource management policies. The vulnerability of species, derived from an ecological risk analysis methodology, can indicate the stock reduction, resulting from unmonitored fishing (Arrizabalaga *et al*., 2001; Griffiths; Duffy & da Silva, 2017). In this regard, a common limitation of the Productivity and Susceptibility Analysis (PSA) application is the difficulty in incorporating the effects of other fisheries operating in the same region. There is also a high sensitivity regarding the inclusion or exclusion of species evaluated, since this causes changes in species ranking (Neat *et al*., 2011). As an example, accidental catches of species without commercial value that are commonly discarded in trap fisheries as well as the presence of very distant taxa such as crustaceans and cephalopods. Even so, the PSA is an important tool for assessing possible fishing impacts in fisheries that are difficult to quantify (Lucena-Frédou *et al*., 2017) indicated that the PSA risk assessment results for several species of the study area agreed with those of the IUCN assessment methods. This means that despite limitations, the PSA is a fairly robust method for ecological risk assessment.

The PCA groups species with systematic and morphological similarities, as is the case of the families Mullidae, Lutjanidae, and Haemulidae, displaying similar body shapes, are crucial for fish trapping. Although this fishery is a multi-specific modality, the body shape and aggregation characteristics are critical to the trap's catchability (Ribeiro, 2004; Marques & Ferreira, 2010). Ultimately, one of the most important issues raised here is the lower diversity of species obtained in fish-trap in the current study when compared to the study carried out by (Marques & Ferreira, 2010). They obtained 41 species in the same area, in contrast to the 25 species recorded 10 years after even attaining deeper waters. The pressure caused by overfishing reduces the abundance of species more sensitive to human stresses and the ecological effects on the habitat are difficult to estimate. Preservation actions in areas that are already suffering from fishing efforts (e.g. Marine Protection

Areas – MPA) are crucial for the recovery of populations of species that are directly and indirectly affected (Roberts *et al.*, 2017; Oliveira *et al.*, 2018).

Only five attributes were significant for estimating the vulnerability. The vulnerability indices calculated for nine and five attributes presented higher risks for most species after removing the attributes that did not show a significant difference. Hordyk and Carruthers (2018) point out that considering a high number of attributes used in PSA, the risk of false negatives is also high. The order of the most vulnerable species has not undergone significant changes, but the categorization has. Choosing the right attribute is important when developing ecological risk analysis for management measures as it affects the prioritization of ecological groups based on the vulnerability of the species caught.

Furthermore, from 2000 to 2010 the trap fishery was directed to the *P. maculatus* (Ribeiro, 2004; Vieira; Souza & Teixeira, 2009; Vasconcelos & Osório, 2010; Marques & Ferreira, 2010), however, in the present study, we verified a change in the target species, due to the decrease in weight and number of captured individuals. Therefore, it seems necessary to re-assess this species and build a management plan since it is deemed Least Concern – LC, which according to the results in the current study may not be the case anymore.

CONCLUSION

The reduction in the abundance of the target species of trap fishing is an indication of non-sustainability. The species with the highest economic value (*L. synagris* and *P. maculatus*) had their participation in captures and average weight per individual reduced in 13 years, demonstrating that populations have been suffering from overexploitation, which can cause depletion or, in the worst case, local extinction of the species.

The use of semi-quantitative methods for ecological risk analysis has been demonstrating effectiveness throughout recent studies, but there are still points to be discussed. The number of attributes analyzed to estimate vulnerability is an important point for the approach of the methodology. The use of parametric analysis methods can be a useful tool in solving possible excesses in the PSA, which can avoid bias in the results.

Despite the PSA pointing out the vulnerability of species to fishing effort, it is still necessary to produce quantitative data for a deeper understanding of the scenario of fish stocks. Even so, the analysis carried out in this study proved several aspects that the captured species have been demonstrating overfishing, reinforcing the need for small-scale fishing management and the recovery of possible affected areas.

The results presented herein, show the need for more effective management measures and planning policies concerning the trap fishing on the study area, to avoid irreparable damage to the ichthyofauna present in these marine environments and further population declines of the species with high commercial value.

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