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PRÓ-REITORIA DE PESQUISA E PÓS-GRADUAÇÃO
PROGRAMA DE PÓS-GRADUAÇÃO EM RECURSOS PESQUEIROS E AQUICULTURA

AVALIAÇÃO DA VULNERABILIDADE DAS ESPÉCIES CAPTURADAS PELA PESCA DE ARRASTO DE PRAIA DE CAMARÃO NA COSTA DA PARAIBA

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Dissertação julgada adequada para a obtenção do título de Mestre em Recursos Pesqueiros e Aquicultura. Defendida e aprovada em 30/08/2022 pela seguinte Banca Examinadora.

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Dedicatória

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"[...]e me ocorreu que a ambição voraz dos seres humanos nunca é saciada quando os sonhos são realizados, porque há sempre a sensação de que tudo poderia ter sido feito melhor e ser feito outra vez."

(John Green – A culpa é das estrelas)

Resumo

No Brasil, não existem estatísticas oficiais de pesca para avaliar quantitativamente o estado das espécies alvo e das capturas acessórias. Uma vez que a segurança alimentar está em jogo, são necessários instrumentos apropriados para manter a sustentabilidade da pesca. Um modelo "pobre de dados" amplamente utilizado, apesar das críticas sobre a sua subjetividade, é a Análise de Produtividade e Susceptibilidade (PSA). Neste estudo, utilizamos a PSA para avaliar o impacto de uma pesca de camarão do nordeste do Brasil que é relevante do ponto de vista socioeconómico para a população local, mas que se sabe ter impactos ecológicos adversos. O status de vulnerabilidade (alta, média ou baixa) de 30 espécies foi determinado pelo PSA e comparado com três outras abordagens semiquantitativas que avaliam o risco do estoque ou de extinção. Os resultados obtidos com o PSA e outros métodos foram parcialmente convergentes, destacando-se seis capturas acessórias e uma espécie alvo para a qual as medidas de gestão ou coleta de dados devem ser priorizadas. Este estudo mostrou que o PSA, quando comparado com outros métodos semiquantitativos, pode constituir uma avaliação preliminar valiosa para a gestão de pescarias com dados pobres. A utilização integrada de vários métodos é aconselhável no diagnóstico dos recursos haliêuticos. No entanto, é essencial compreender as peculiaridades de cada técnica para apreciar a sua aplicabilidade e viabilidade.

Palavras-chave: Modelos “data-limit”; Enfoque ecossistêmico, Fauna acompanhante, Brasil.

Abstract

In Brazil, there are no official fisheries statistics to quantitatively assess the status of target and bycatch species. Since food security is at stake, appropriate tools are needed to maintain fisheries sustainability. One widely used "data-poor", despite the critics on its subjectivity, is Productivity and Susceptibility Analysis (PSA). In this study, we use PSA to assess the impact of a northeastern Brazil shrimp fishery which is socioeconomically relevant for the local population but is known to have adverse ecological impacts. The vulnerability status (high, medium, or low) of 30 species was determined by the PSA and compared with three other semi-quantitative approaches that assess stock or extinction risk. The results obtained from the PSA and other methods were partially convergent, highlighting six bycatch and one target species for which management measures or data collection should be prioritized. This study showed that PSA when compared with other semi-quantitative methods, can constitute a valuable preliminary assessment for managing poor-data fisheries. The integrated use of various methods is advisable in diagnosing fishery resources. However, it is essential to understand the peculiarities of each technique to appreciate its applicability and feasibility.

Key words: Data-limit models; Ecosystem approach, Bycatch, Brazil.

Lista de Figuras

Lista de Tabelas

SUMÁRIO

1 – INTRODUÇÃO

A pesca é uma das atividades humanas mais antigas e uma das principais fontes de proteína visando suprir as necessidades do ser humano (SOUZA et al. 2019). Apesar da pesca artesanal no Brasil apresentar variações espaciais de acordo com a região (SILVA e GARCÍA, 2013), ela tem uma grande importância socioeconômica, fornecendo alimento e renda para muitas comunidades ao longo da costa (SILVANO, 2004).

A pesca de camarão no Brasil é realizada de forma industrial, semi-industrial e artesanal, predominantemente motorizada com arrasto simples ou duplo. No entanto, também pode ser realizada com uso de armadilhas fixas, redes de emalhe e arrasto manual, como o arrasto de praia (DIAS-NETO, 2011). Na região Nordeste, a pesca do camarão apresenta características mistas: semi-industrial nos estados de Alagoas e Sergipe; e majoritariamente artesanal nos demais estados, com barcos motorizados medindo entre 4 e 13 m e embarcações não motorizadas que atuam em áreas menos profundas e mais próximas ao continente (SANTOS, 2010).

Em Lucena, na Paraíba, a pesca de camarão era realizada através das duas modalidades, o arrasto de praia, executado por pescadores locais e o arrasto de portas (motorizado), com parte da frota composta por pescadores do município vizinho Cabedelo (MOURA et al., 1999). Porém, devido a conflitos entre pescadores que migravam de outros municípios para a pesca a motorizada, foi implementada a Portaria nº 833/190 para o estado da Paraíba, determinando, em todo o estado, a proibição da pesca com arrasto motorizado até três milhas náuticas a partir da costa, inviabilizando os arrastos motorizados nesta região (MOURA et al.,2003). Atualmente, a pesca de camarão na região é realizada apenas por arrasto de praia (CRAVEIRO et al., 2019).

O município de Lucena tem a pesca artesanal como uma atividade muito relevante para a realidade socioeconômica da população (SILVA, 2012). Apesar de grande importância econômica e social, a pesca de arrasto é considerada umas das atividades econômicas que mais prejudicam o ambiente marinho, provocando alteração nos vários aspectos do funcionamento ecossistêmico e de suas populações (MELNYCHUK et al., 2017; HIDDINK et al., 2017). Isso porque a rede de arrasto é um aparelho de pesca eficiente, mas pouco seletivo, capturando inúmeras espécies não-alvo, captura conhecida como captura incidental, tradução usual para o termo inglês *bycatch*.

A pesca de arrasto, ocasiona tanto impactos diretos (como a remoção de espécies não-alvo) quanto indiretos (como modificação do habitat e da densidade de predadores e presas) sobre o ecossistema (STOBUTZKI et al., 2002). Alguns autores estimaram a proporção da produção de camarão em relação à captura da fauna acompanhante em vários estados do Nordeste, concluindo que, embora a relação mais comum seja a paritária, podem ocorrer variações consideráveis, como: 1: 3,28 no estado do Ceará (BRAGA et al., 2001); 1:1 no Piauí (SANTOS et al., 2002) e 1:0,39 em Pernambuco (SILVA-JÚNIOR et al., 2019). Além disso, uma vez que as espécies alvo e grande parte da fauna acompanhante são associadas ao fundo, elas são impactadas significativamente por essa modalidade de pesca que atua principalmente perturbando mecanicamente o fundo. O revolvimento do fundo provocado pela elevação do sedimento lamoso nas áreas de arrasto, aumenta a turbidez da água e pode interferir na dinâmica dos organismos que habitam a coluna d ‘água (HIDDINK et al., 2017).

Segundo Passarone (2020), a pesca de arrasto de praia em Lucena e o arrasto de fundo motorizado em outros estados na região Nordeste compartilham muitos aspectos: maior captura de fauna acompanhante em relação ao camarão (1 Kg de camarão para 2,3 Kg de ictiofauna) e alta taxa de captura de juvenis, apresentando potenciais riscos ao recrutamento de diversas espécies que utilizam a região costeira como áreas de abrigo e berçário. Entretanto, a pesca de arrasto de praia captura uma riqueza, ou seja, um número de espécies maior (PASSARONE, 2020).

De uma maneira geral, o estado da Paraíba apresenta carência de informações sobre a biologia e pesca dos camarões marinhos e sua fauna acompanhante, principalmente acerca da modalidade de arrasto de praia (PASSARONE, 2020). Nascimento (2018) destaca que a conservação desta pescaria é necessária não apenas para devolver e restaurar o equilíbrio das populações desses organismos, como também para a continuidade da atividade pesqueira, saberes e cultura pesqueira que essas comunidades possuem. Assim, informações e ferramentas adequadas para avaliar e gerenciar os impactos dessa pesca são necessárias, particularmente em situações com poucos dados, visando a manutenção da atividade, essencial como fonte de renda e alimento.

No Brasil, a pesca artesanal representa 65% da produção total de pescado, engloba 957 mil pescadores artesanais entre homens e mulheres (MPA, 2011) e, apesar de ser reconhecida como uma importante atividade socioeconômica, a falta de estatística pesqueira, somada a grande diversidade e descentralização dos desembarques, dificulta a avaliação da real dimensão dessa atividade (LUCENA-FREDOU et al., 2021).

A gestão local eficaz dos recursos pesqueiros requer avaliações específicas e informações locais (AYERS; KITTINGER, 2014). No entanto, a pesca local e de pequena escala tem sido amplamente negligenciada por abordagens de gestão em todo o mundo durante o desenvolvimento de políticas ambientais e econômicas e, à medida que a escala das avaliações aumenta, a oportunidade de capturar as características locais e regionais do estoque diminui (MORENO-BÁEZ et al., 2010), predominando a carência de dados, inviabilizando a avaliação dos estoques. Isto é comum na pesca artesanal de países em desenvolvimento. Por exemplo, avaliações baseadas em dados de captura e esforço muitas vezes não podem ser realizadas para estas pescarias, devido à falta de informações históricas e/ou confiáveis (MICHELI et al., 2014). Essa divergência é parcialmente explicada por restrições econômicas na coleta de dados, mas também reflete o número de espécies e a diversidade de habitats e pescarias (FITZGERALD et al., 2018). Este problema é particularmente importante para artes de pesca que costumam ser pouco seletivas, na qual muitas espécies não-alvo são capturadas e descartadas, ou acidentalmente mortas durante as operações. Os impactos da pesca em espécies não-alvo têm se tornado cada vez mais reconhecidos, priorizando o gerenciamento mais amplo da pesca com base no ecossistema (*Ecosystem-Based Fisheries Management* – EBFM) em detrimento às avaliações tradicionais de uma única espécie (PIKITCH et al., 2004; COLLIE et al., 2014).

Uma abordagem que vem sendo amplamente utilizada por vários gestores dentro da família pobre em dados e considerando o EBFM é a Análise de Produtividade e Susceptibilidade ou *Productivity and Susceptibility Analysis* (PSA). A PSA é uma análise de risco semiquantitativa, que tem o objetivo de se estimar a vulnerabilidade de um estoque com base em sua produtividade biológica e susceptibilidade em relação a uma pescaria (STOBUTZKI et al., 2002; HOBDAY et al., 2011; LUCENA-FRÉDOU et al., 2017). Ela é considerada um primeiro passo em situações com poucos dados para identificar as principais espécies em risco (HOBDAY et al., 2011).

Considerando que a pesca de arrasto de praia tem relevância socioeconômica no nordeste do Brasil e que seu efeito sobre a fauna acompanhante já foi identificado como não negligenciável por Passarone (2020), este estudo teve o objetivo de avaliar a vulnerabilidade das espécies capturadas pela pesca de arrasto de praia direcionado ao camarão, usando a PSA como ferramenta, não apenas sobre as espécie-alvos, mas também na fauna acompanhante. Os resultados que serão apresentados podem fornecer informações para indicar prioridades de manejo que possam auxiliar na gestão local e que ela seja capaz de oferecer a sustentabilidade dos recursos pesqueiros, de forma que não traga impactos negativos para os pescadores artesanais da localidade.

1.2 – OBJETIVOS

1.2.1 – Geral

Analisar e avaliar a vulnerabilidade das espécies capturadas pela pesca de arrasto de praia direcionado ao camarão no município de Lucena-PB.

1.2.2 – Específicos

- Determinar as espécies mais vulneráveis capturadas pela pesca de arrasto na praia;
- Elencar prioridades de manejo relacionadas as espécies mais vulneráveis ou com carência de dados que possam auxiliar na gestão local.

2. Artigo Científico a ser submetido Regional Studies in Marine Science

VULNERABILITY ASSESSMENT OF SPECIES CAUGHT BY THE SHRIMP TRAWL FISHERY IN NORTHEASTERN BRAZIL

Freitas, A.J.R; Passarone, R.; Lira, A.; Pelage, L; Lucena-Frédou, F.

ABSTRACT

In Brazil, there are no official fisheries statistics to quantitatively assess the status of target and bycatch species. Since food security is at stake, appropriate tools are needed to maintain fisheries sustainability. One widely used "data-poor", despite the critics on its subjectivity, is Productivity and Susceptibility Analysis (PSA). In this study, we use PSA to assess the impact of a northeastern Brazil shrimp fishery which is socioeconomically relevant for the local population but is known to have adverse ecological impacts. The vulnerability status (high, medium or low) of 30 species was determined by the PSA and compared with three other semi-quantitative approaches that assess stock or extinction risk. The results obtained from the PSA and other methods were partially convergent, highlighting six bycatch and one target species for which management measures or data collection should be prioritized. This study showed that PSA when compared with other semi-quantitative methods, can constitute a valuable preliminary assessment for managing poor-data fisheries. The integrated use of various methods is advisable in diagnosing fishery resources. However, it is essential to understand the peculiarities of each technique to appreciate its applicability and feasibility.

Keywords: Data-limit models; Ecosystem approach, Bycatch, Brazil.

2.1 – INTRODUCTION

Most assessment of fisheries resources are carried out using "data-rich" quantitative stock assessment models (FERNANDES et al., 2017). However, in tropical developing countries, fisheries stocks tend to be poorly documented and managed due to the unavailability or incomplete official fisheries statistics (HONEY et al., 2010), which hampers the application of traditional assessment models. This data-poor context, with a subsequent lack of stock assessment, is the current situation faced by Brazil.

The Food and Agriculture Organization of the United Nations - FAO (FAO, 2020), in its report "The State of World Fisheries and Aquaculture", criticized Brazil for not providing statistical data to the institution since 2014 and, in its latest report, continued to express concern about Brazil's failure to respond to questionnaires (FAO, 2022). In the absence of valuable statistics and legislation, the management of fisheries resources is negatively affected, which has repercussions at all levels of the country's fisheries organizations (RESENDE et al., 2003). The lack of commitment, investment and long-term financial resources poses significant threats to the sustainability of Brazilian small-scale fisheries (ARAUJO et al., 2017, PREVIERO; GASALLA, 2020).

The scarcity of official statistics compromises the possibility of monitoring the stocks exploited by small-scale fisheries (SSFs) since most of these fisheries do not have the resources to develop a detailed assessment of local stocks (PRINCE, 2010). In Brazil, SSFs represent 65% of the total fish production, comprising almost 1 million artisanal fishers (MPA, 2011), and, despite being recognized as an essential socioeconomic activity, given the complete absence of monitoring, no proper management of this activity are currently available (LUCENA-FREDOU et al., 2021).

Data-limited approaches - such as Ecological Risk Assessment (ERA) methods - have been widely used to estimate risk in data-poor context, often integrating expert knowledge with available quantitative or empirical data (GEORGESON et al., 2020; HOBDAY et al., 2007; ZHOU et al., 2013; ZHOU et al., 2016). Assessing ecological sustainability in fisheries has become increasingly important with the widespread adoption of Ecosystem-Based Fisheries Management (EBFM), which requires a holistic approach beyond the direct impacts of the species targeted by fisheries.

A widely used ERA tool in fisheries is the semi-quantitative Productivity and Susceptibility Analysis (PSA) (STOBUTZKI et al., 2002; HOBDAY et al., 2011; LUCENA-FRÉDOU et al., 2017; PREVIERO; GASALLA, 2019; LIRA et al., 2022). PSA aims to estimate the vulnerability of a stock based on its biological productivity and susceptibility to a fishery (STOBUTZKI et al., 2002; HOBDAY et al., 2011; LUCENA-FRÉDOU et al., 2017). It is considered a preliminary assessment in data-poor contexts to identify the main species at risk (HOBDAY et al., 2011; WILLIAMS et al., 2018).

Trawling is considered one of the most degrading economic activities in the marine environment, drastically altering ecosystems' abiotic and biotic components (MELNYCHUK et al., 2017; HIDDINK et al., 2017). Indeed, the lack of size selectivity inherent to this fishing activity results in the capture of many non-target species, known as "by-catch". In Brazil, trawling encompasses several fleets (industrial, semi-industrial and artisanal) and modalities (motorized and non-motorized) (DIAS-NETO, 2011), which impact the biota and the seabed differently.

In Lucena, a municipality located in Paraíba, Northeast Brazil, artisanal fishing is one of the main economic activities. In particular, shrimp fishing is carried out using beach seining and is primarily carried out by artisanal and subsistence fishers, being of great socioeconomic importance for the local population (SILVA, 2012; NASCIMENTO et al., 2018;). Ensuring the sustainability of this fishery is necessary not only to avoid the decline of stocks but also to perpetuate a fishing activity with a traditional and cultural dimension (NASCIMENTO et al. 2018).

Although considered artisanal and non-motorized, the beach seine modality catches a higher species richness than that observed in the motorized fishery in the region and nearby, and a high catch rate of juveniles, presenting potential risks to the recruitment of several species that use the coastal region as a shelter and nursery area (PASSARONE, 2020). Therefore, the potential impacts of this fishery should not be overlooked.

In this context, this study aims to assess the vulnerability and potential risk of target and bycatch species caught by the shrimp trawl fishery in Lucena. The results of this assessment could be used to prioritize management actions for the most vulnerable species, and to contribute for applying PSA towards the sustainable development of the small-scale fishery

2.2 – METHODS

2.2.1 – Study Area

The municipality of Lucena is located on the northern coast of the state of Paraíba (Figure 1) within a low sedimentary plateau of a barrier formation characteristic of the northeastern coast. Its coastal plain comprises terraces of fluviomarine accumulation (MADRUGA, 1985).

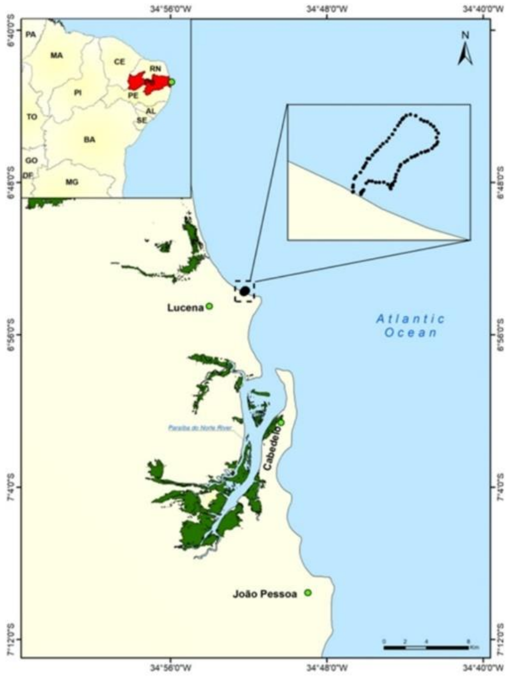

Figura 1. Municipality of Lucena-PB, Brazil. Adapted from Passarone et al., (2019).

Until 1992, shrimp fishing in Paraíba was carried out by beach seining, mainly in the municipality of Lucena, and by motorized trawls (SILVA, 1986; MOURA et al., 2003). Given the conflicts between fishers migrating from other municipalities for motorized fishing, and state Ordinance No. 833/190 for the state of Paraíba, which prohibited motorized trawl in all the Paraiba state up to three nautical miles from the coast (MOURA et al., 2003), were implemented, Currently, shrimp fishing in the region is conducted only by beach seining (CRAVEIRO et al., 2019).

2.2.2 – Data sampling

The fish specimens were collected monthly from December 2016 to November 2017 with two trawls per month, and an average duration of 50 minutes each, except for the month of May (there was no collection) and the month of June (it was not possible to perform the second trawl, because environmental factors made fishing impossible). A 120m beach net, designed for local commercial fishing, was used for collection (width at the sleeve 4m, cod-end 6m; 2cm mesh size at the sleeve and 1.5cm at the cod-end with two stakes at the ends). The maximum recorded depth in the trawled area was 6.0 meters.

The total capture of shrimp was registered on site. For bycatch, the entire sample was preserved and forwarded to the laboratory in collections where the number of specimens was equal to or less than 30 kg. When the sample exceeded 30 kg, only a random subsample (30 kg) was sent to the laboratory. In these cases, an estimate of the total sample weight was performed on-site using a monoblock with a known weight (30 kg). The samples were frozen for later analysis in the laboratory and then identified to the lowest taxonomic degree possible, according to specialized taxonomic keys (WHITEHEAD, 1985; SZPILMAN, 2000; MARCENIUK, 2005). The total length (TC in cm) and the total weight (PT in g) of each organism were measured.

2.2.3 – Data analysis

Selected species

Species were selected for analysis according to the following criteria:

(1) species identified by Passarone (2020) in the study area as being abundant and frequent, according to the methodology of Garcia and Vieira (2001). This methodology categorizes as abundant the species that has a percentage capture (PN) greater than the ratio 100/S (where S is the absolute richness of the species) and frequent the species that has a frequency of occurrence (FO) greater than 50% in a given season.

(2) species that have commercial importance, according to local knowledge, empirical and official statistics.

(3) elasmobranchs, since they are long-lived species with low reproductive rate and, in general, have a high vulnerability to fishing (SIMPFENDORFER et al., 2011); and

(4) species listed through the regional assessment conducted by the Chico Mendes Institute for Biodiversity Conservation (ICMBio, 2018) using the criteria of the International Union for Conservation of Nature (IUCN), considering the three threatened categories (critically endangered (CR), endangered (EN) and vulnerable (VU)) and the categories near threatened (NT) and data deficient (DD). Indeed, species classified as NT or DD are considered priorities for research on conservation status, according to the Ordinance of the Ministry of Environment (MMA) No. 43/2014

2.2.4 – Calculating the vulnerability

Vulnerability (v) is a function of the productivity (P) and susceptibility (S) attributes, which corresponds to a measure of the extent to which fishing mortality for a species exceeds its biological capacity to renew itself (STOBUTZKI et al., 2002). When combined, P and S attributes produce a unique score capable of quantifying the risk of a stock. Three risk categories were defined for each attribute using the tertile method, ranging from 1 (high productivity or low susceptibility; low risk) to 3 (low productivity or high exposure; high risk). This score was assigned to each of the attributes (productivity and susceptibility, Table 1 and 2), and the weighted average of all attributes was used to obtain an overall productivity score of (P) and (S).

The two-dimensional nature of the PSA leads directly to the calculation of an overall vulnerability score (v) for a stock, defined as the Euclidean distance from the origin in a PSA scatter plot:

$$v = \sqrt{(P - X_0)^2 + (S - Y_0)^2}$$

where X_0e $Y_0$are the origin coordinates (x, y).

The scores were plotted on a scatter plot, with P on the x-axis and S on the y-axis. The x-axis is inverted (i.e., starts at three and ends at 1) so that the region near the origin (which was at 3, 1) corresponds to the least vulnerable stocks, i.e., those with high productivity and low susceptibility. In contrast, the most vulnerable stocks are found farther from the origin.

Information on productivity and susceptibility attributes was obtained through local fisheries data and studies from regional literature. In some cases, given the lack of data, through specialized literature and Fishbase (FROESE; PAULY, 2020).

2.2.5 – Productivity attributes

Seven productivity attributes related to species' life history characteristics were selected based on available studies (PATRICK et al., 2009; HOBDAY et al., 2011, LUCENA-FRÉDOU et al., 2017, LIRA et al., 2022). The parameters considered are detailed at supplementary material (SOM 2.1) and in Table 1:

For all attributes except reproductive strategy, scores were obtained using the tertile method (more details in the Table 1 and supplementary material)

Tabela 1. Productivity attributes and rankings used to determine the vulnerability of species caught by beach seine in Paraiba, Northeast Brazil.

Attributes/Parameters	*Ranking*		
Productivity	***Low (1)***	***Moderate (2)***	***High (3)***
Intrinsic growth rate (r)	< 0.57	0.57 - 0.63	> 0.63
Maximum age (A_{MAX})	> 6.99	5.92 – 6.99	< 5.92

Maximum size (L_{MAX})	> 33.40	21.50 - 33.40	< 21.50
Von Bertalanffy's growth coefficient (k)	< 0.41	0.41 - 0.48	> 0.48
Average size of first maturity (L_{50})	> 15.73	11.68 – 15.73	< 11.68
Reproductive strategy	> 4	1 – 4	< 1
Estimated natural mortality (M)	< 0.70	0.70 - 0.97	> 0.97

2.2.6 – Susceptibility attributes

As for the productivity attributes, the susceptibility parameters were based on available studies (PATRICK et al., 2009; HOBDAY et al., 2011; LUCENA FRÉDOU et al., 2017; NOEGROHO et al., 2021; LIRA et al., 2022) and adapted to the present study case, when necessary. The parameters used are detailed at supplementary material (SOM 2.2) and in Table 2:

Tabela 2. Susceptibility attributes and rankings used to determine the vulnerability of species caught by beach seine in Paraiba, Northeast Brazil. Percentage of adults in the catch (aults (%); Frequency of occurrence (FO); Fishing mortality (F); Natural mortality (M); Overlap area (OA); Potential spawning rate (SPR).

Attribute	***Ranking***		
Susceptibility	***Low (1)***	***Moderate (2)***	***High (3)***
(% > L50)	>0.25	0.04-0.25	<0.04
Commercial category	subsistence consumption/discarded	commercial	target species / abundant and frequent
(F/M)	< 0.5	0.5 - 1.0	>1.0
SPR	> 0.4	0.4 - 0.2	< 0.2
Shoaling/aggregation	decreases the catch	not affect the catch	increases the catch
OA	(DE +L)	(DE + A/R)	(PE/ RE)
FO	scare and rare	scarce and frequent/ high abundant and rare	High abundant and frequent

2.2.7 – Measuring uncertainty when assigning weights to attributes

The attribute weights of productivity and susceptibility are subjective and may affect the results and consequently reduce the accuracy of the models. The weights of each attribute are usually defined on a scale from one to three. However, following Lucena-Frédou et al. (2017), a standard weight of two was given to all productivity and susceptibility attributes, except for r, k and Lmax, which were given a value of three (they are considered critical attributes for species resilience), considering that the differences between species are mainly explained by these parameters (LUCENA-FRÉDOU et al., 2016). Potential redundancy among attributes was not assessed since, in previous studies (LUCENA-FRÉDOU et al., 2017; LIRA et al., 2022 among correlated attributes, no relevant changes among assigned risks and vulnerability rank were observed.

Therefore, the sensitivity analysis in this study was focused on weight allocation (LUCENA-FRÉDOU et al., 2017; DUFFY; GRIFFITHS, 2019; LIRA et al., 2022). Due to a lack of information, stocks with little data may receive overestimated vulnerability scores (FUJITA et al., 2014). To assess the effect of subjectivity, which may lead to uncertainties in the results, random weight allocations (1 to 3) were performed for all productivity and susceptibility attributes through 5000 simulations, assessing the sensitivity of the scores with the different weights in ranking species vulnerability and risk. The standard deviation of the vulnerability values and the empirical probability of being ranked as low, moderate, or high vulnerability were calculated for each species. All analyses were performed using the R environment (R version 4.1.1, 2021).

2.2.8 – Comparing vulnerability results with IUCN extinction risk and other approaches

Nevertheless, PSA's semi-quantitative and subjective aspect can threaten the method's credibility (HOBDAY et al., 2011; LIRA et al., 2022). This problem can be minimized by comparing PSA vulnerability results with other assessment approaches for species (OSIO et al., 2015). Hence, in our study, the PSA results were compared with three methods:

i) IUCN Red List: assesses the relative risk of extinction and the status of threatened species using the quantitative and qualitative criteria obtained through the Ministry of Environment (MMA) (ICMBio, 2018), considering the categories: 1- Critically Endangered (CR), 2- Endangered (EN), 3- Vulnerable (VU), 4- Near Threatened (NT), Least Concern (LC) and 5- Data Deficient (DD);

ii) Reference point from traditional stock assessment (RP-SA) (HOENIG, 1983; JENSEN, 1997): which considers the relationship between fishing (F) and maximum sustainable productivity (Fmsy). They were classified as "not overfished" when F < Fmsy and "overfished" when F > Fmsy. Except for shrimp, where local estimates of mortality and exploitation rates were available, the proxy of Fmsy was obtained by the ratio with M (Fmsy = 0.87 M (teleost) and Fmsy = 0.41 M (Chondrichthyes), according to Zhou et al. (2012). The mortality estimates (Z, M and F) were obtained as described in the susceptibility section;

iii) Sustainability reference point (FROESE, 2004): To maintain sustainable fisheries and avoid growth and recruitment overfishing, Froese (2004) proposed three simple length-based indicators called Pmat, Popt and Pmega, where: Pmat and Popt refer to the percentage of adult and optimum size fish present in the catch respectively. Pmega refers to the percentage of mega spawners, fish with a length greater than the optimal length (Lopt) + 10% of Lopt (≥1.1Lopt). Also, according to Froese (2004), target length classes should be within the range of ± 10% of the Lopt value for fishery sustainability and optimal biological yield. Is the length at which the biomass of a cohort is maximised (BEVERTON 1992). The Lopt Catch composition was obtained for a total of twenty-eight species that had a sample number greater than 30.

For comparison between methods, we established the following equivalences:

- High risk in PSA should be equivalent to overfishing in RP-AS; and to red list extinction levels CR, VU and EN and to Popt values less than 50%;
- Moderate risk in PSA is equivalent to no overfishing in RP-SA, IUCN Red List levels DD, and NT and Popt values between 50% and 80%;
- Low risk in PSA should be equivalent to no overfishing in RP-SA, the IUCN LC level and Popt values above 80% (Table 3).

Tabela 3. Risk categories.

PSA	**IUCN**	**RP-SA**	***Popt***
High	CR, VU e EN	overfished	0 to 50%
Moderate	DD e NT	not overfished	51 to 80%
Low	LC	not overfished	81 to 100%

The different approaches were compared individually (two by two) with the PSA. Subsequently, they were jointly compared to each other.

2.3 – RESULTS

2.3.1 – Vulnerability Index

A total of 30 species were analyzed (Table 4). Productivity indices ranged from 1.00 to 3.00, and susceptibility indices from 1.57 to 2.71. Ten species, including the target species *Penaeus schmitti*, were classified as high risk (V ≥ 1.83). Ten species, including the other two target species (*Penaeus subtilis* and *Xiphopenaeus kroyeri*,) were categorized as moderate risk (V ≤ 1.76 ≥ 1.31) and ten others as low risk (V ≤ 1.29) (Table 4, Figure 4).

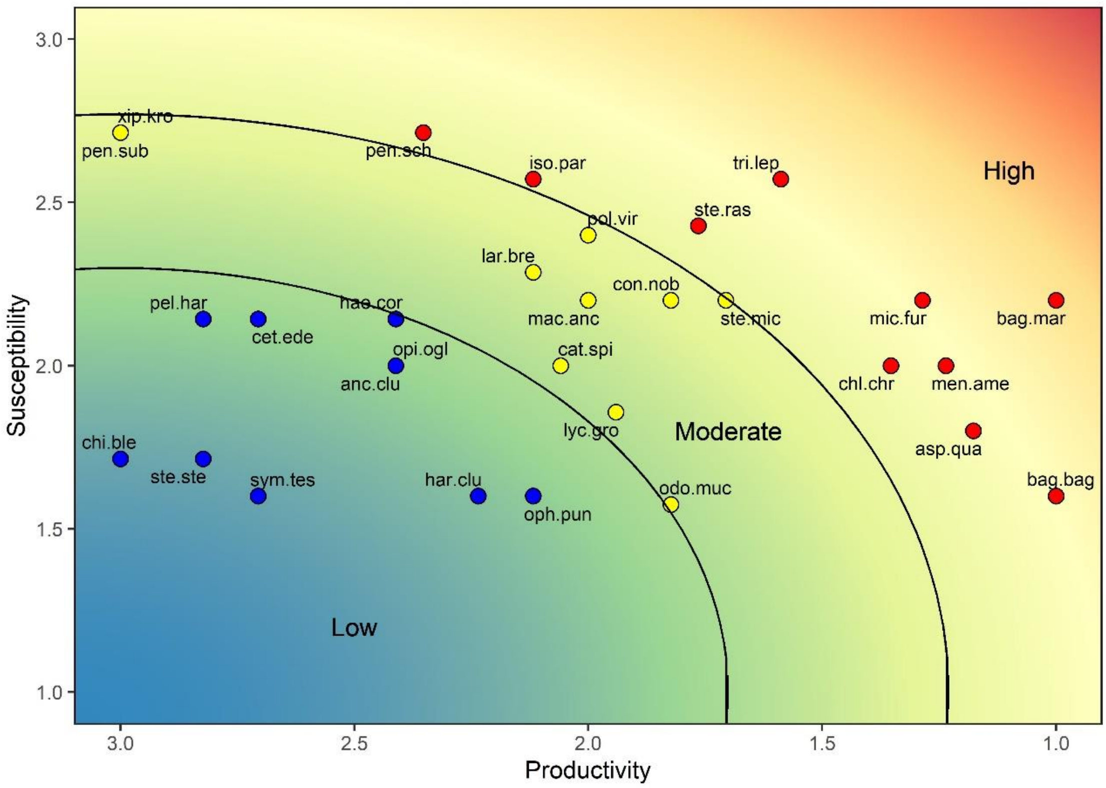

Figura 2. Results of productivity and susceptibility scores of the species captured by the shrimp trawl fishery in Lucena-PB. The tertile method was used to separate the categories. The colour scale represents the vulnerable values, with blue being the lowest and red the highest. A code represents the species (See Table 4).

Table 4. Productivity (P), susceptibility (S) and vulnerability (v) scores defined by tertile method, risk classification and ranking obtained through the PSA of target and non-target species. IUCN classifications: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD). Traditional Stock Assessment Reference Point (RP-SA): 1- Not overfished; 2- Overfished; NA = Uncertain. Popt: indicates the percentage of individuals caught in the Lopt ±10 range.

Family	**Species**	**Code**	**P**	**S**	**V**	**Rank**	**Risk**	**IUCN**	**RP-SA**	**Popt (%)**
Ariidae	*Bagre marinus*	*bag.mar*	1.00	2.20	2.33	1	High	DD	NA	0
Achiridae	*Trichiurus lepturus*	*tri.lep*	1.59	2.57	2.11	2	High	LC	2	1.72
Sciaenidae	*Micropogonias furnieri*	*mic.fur*	1.29	2.20	2.09	3	High	LC	NA	NA
Ariidae	*Bagre bagre*	*bag.bag*	1.00	1.60	2.09	4	High	NT	NA	1.72
Sciaenidae	*Menticirrhus americanus*	*men.ame*	1.24	2.00	2.03	5	High	DD	NA	1.22
Ariidae	*Aspistor quadriscutis*	*asp.qua*	1.18	1.80	1.99	6	High	LC	NA	2.08
Carangidae	*Chloroscombrus chrysurus*	*chl.chr*	1.35	2.00	1.93	7	High	LC	NA	0.37
Sciaenidae	*Stellifer rastrifer*	*ste.ras*	1.76	2.43	1.89	8	High	LC	2	20.94
Penaeidae	*Penaeus schmitti*	*pen.sch*	2.35	2.71	1.83	9	High	DD	1	0.09
Sciaenidae	*Isopisthus parvipinnis*	*iso.par*	2.12	2.57	1.80	10	High	LC	2	5.63
Sciaenidae	*Stellifer microps*	*ste.mic*	1.71	2.20	1.76	11	Moderate	LC	NA	0
Polynemidae	*Polydactylus virginicus*	*pol.vir*	2.00	2.40	1.72	12	Moderate	LC	NA	2.07
Penaeidae	*Penaeus subtilis*	*pen.sub*	3.00	2.71	1.71	13	Moderate	LC	1	0
Penaeidae	*Xiphopenaeus kroyeri*	*xip.kro*	3.00	2.71	1.71	14	Moderate	DD	1	0.11
Haemulidae	*Conodon nobilis*	*con.nob*	1.82	2.20	1.68	15	Moderate	LC	NA	0
Sciaenidae	*Macrodon ancylodon*	*mac.anc*	2.00	2.20	1.56	16	Moderate	LC	NA	0
Sciaenidae	*Larimus breviceps*	*lar.bre*	2.12	2.29	1.56	17	Moderate	LC	2	0.93
Ariidae	*Cathorops spixii*	*cat.spi*	2.06	2.00	1.37	18	Moderate	LC	2	15.79
Engraulidae	*Lycengraulis grossidens*	*lyc.gro*	1.94	1.86	1.36	19	Moderate	LC	2	27.24
Pristigasteridae	*Odontognathus mucronatus*	*odo.muc*	1.82	1.57	1.31	20	Moderate	LC	NA	0
Haemulidae	*Haemulopsis corvinaeformis*	*hae.cor*	2.41	2.14	1.29	21	Low	LC	2	6.06
Engraulidae	*Cetengraulis edentulus*	*cet.ede*	2.71	2.14	1.18	22	Low	LC	2	61.39
Engraulidae	*Anchovia clupeoides*	*anc.clu*	2.41	2.00	1.16	23	Low	LC	NA	40.36

Clupeidae	*Opisthonema oglinum*	*opi.ogl*	2.41	2.00	1.16	24	Low	LC	NA	0
Clupeidae	*Pellona harroweri*	*pel.har*	2.82	2.14	1.16	25	Low	LC	1	29.25
Sciaenidae	*Ophioscion punctatissimus*	*oph.pun*	2.12	1.60	1.07	26	Low	DD	NA	3.49
Clupeidae	*Harengula clupeola*	*har.clu*	2.24	1.60	0.97	27	Low	LC	NA	12.21
Sciaenidae	*Stellifer stellifer*	*ste.ste*	2.82	1.71	0.74	28	Low	LC	1	60.85
Pristigasteridae	*Chirocentrodon bleekerianus*	*chi.ble*	3.00	1.71	0.71	29	Low	LC	1	49.73
Cynoglossidae	*Symphurus tessellatus*	*sym.tes*	2.71	1.60	0.67	30	Low	LC	NA	NA

2.3.2 – Measuring uncertainty

Overall, only ten of the thirty species (33.33%) remained in the same risk category when the different weights were assigned (Figure 5A). Four species among those ten remained at low risk: *Chirocentrodon bleekerianus, Harengula clupeola, Stellifer stellifer and Symphurus tessellatus*. Nine species had more than an 80% chance of remaining at high risk: *Bagre bagre, Bagre marinus, Chloroscombrus chrysurus, Micropogonias furnieri, Menticirrhus americanus, Trichiurus lepturus* (100% chance regardless the simulation); *Aspistor quadriscutis, Stellifer rastrifer* (more than 96% chance) and *Isopisthus parvipinnis* (84% chance) (Figure 5B). It is worth noticing that the lines representing the standard deviation range show that the species at the extremes same risk level remain even after the simulations (Figure 5B). Regarding the target species, *Penaeus schmitti* has more than a 70% chance of staying in the high-risk category. In contrast, *Penaeus subtilis* and *Xiphopenaeus kroyeri* have a 65% probability of remaining in the moderate risk category.

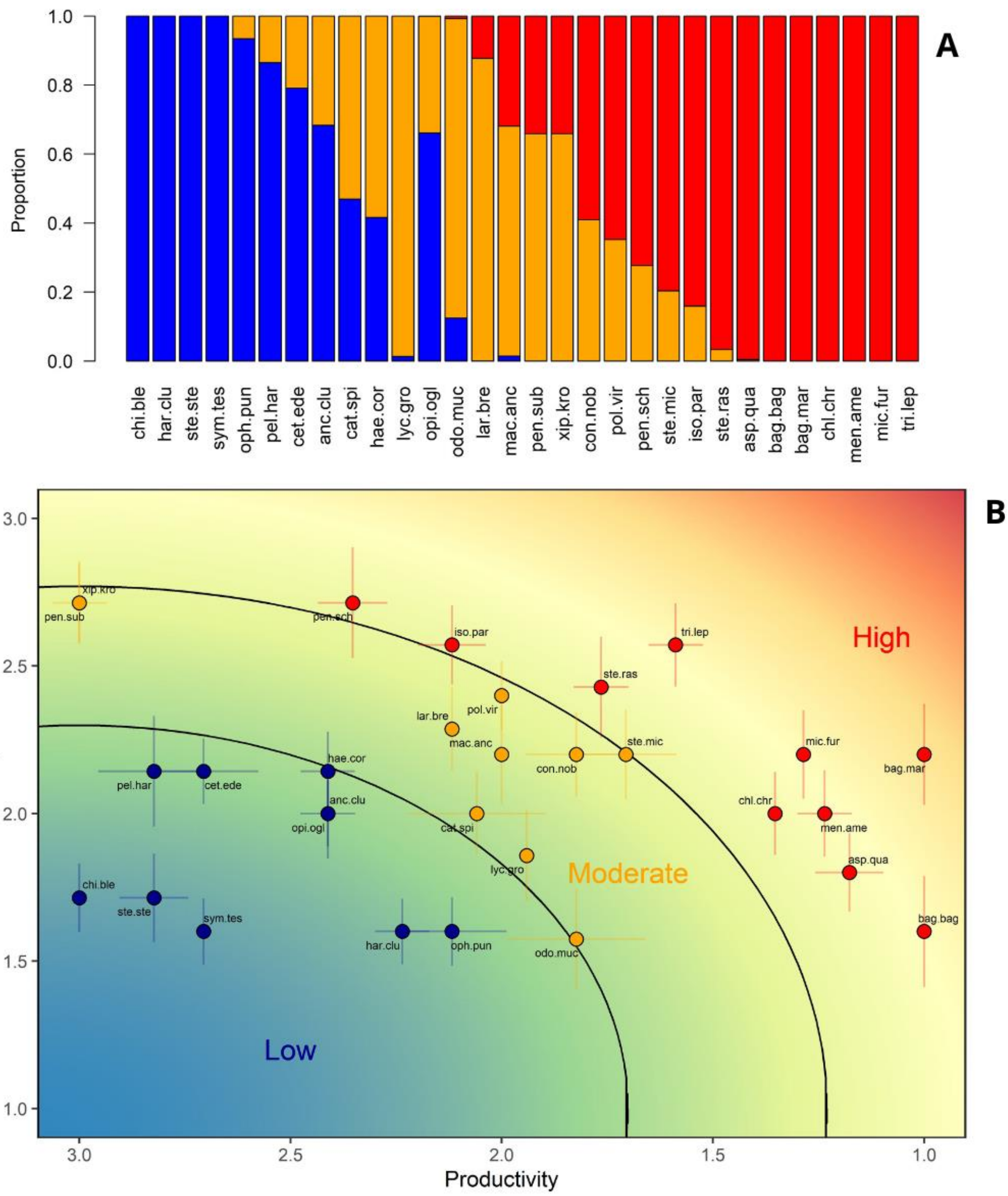

Figura 3. A) Probability of species risk being classified as low, moderate or high risk regardless of the weight used. In blue: low risk, orange: moderate risk and red: high risk. B) Productivity (P), susceptibility (S) and vulnerability (v) scores of species caught by the shrimp fishery using beach seine in Lucena-PB. The range lines for each point show the standard deviation obtained from uncertainty simulations (5000 simulations). The colour scale represents the vulnerability values, with blue being the lowest and red the highest. The species are represented by a code formed by the species name (Table 4).

2.3.3 – Comparing with other approaches

Considering the IUCN red list, no species was classified as Critically Endangered (CR), Endangered (EN) or Vulnerable (VU) (Table 4, Figure 6). Most species (approximately 80%) (Figure 6) were assessed as of Low Concern (LC), including some considered by the PSA to be at high risk (*A. quadriscutis, I. parvipinnis, T. lepturus, M.*

furnieri, *S. rastrifer* and *C. chrysurus*) (Table 4). *Bagre marinus*, two target species (*P. schmitti* and *X. kroyeri*) and the species *M. americanus* and *Ophioscion punctatissimus* were assessed as DD. *B. bagre* was considered Near Threatened (NT) (Table 4).

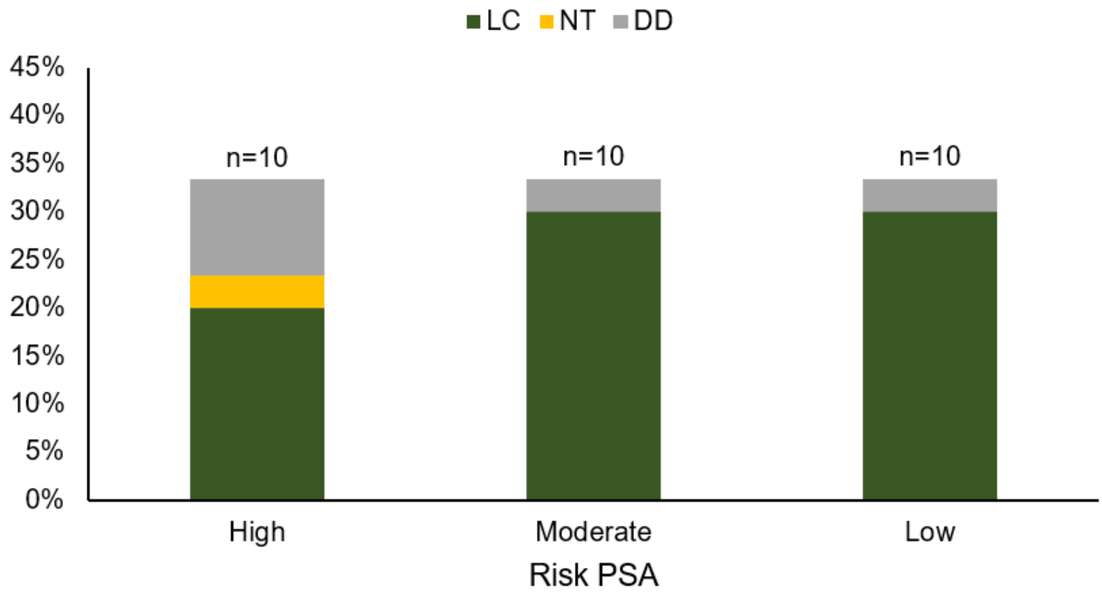

Figura 4. Comparison of species caught by shrimp trawl fisheries considering the IUCN Red List approach by risk categories (Near Threatened (NT); Least Concern (LC) and Data Deficient (DD)) versus PSA risk categories (low, moderate, and high are the PSA vulnerability risks).

The Lopt was calculated only for species with more than thirty individuals captured, hence twenty-eight species (out of thirty) were analyzed. None of the species had more than 62% of specimens caught within the ideal length range, and seven species had all their catches outside the range, including the target species *P. subtilis* (see Table S1).

Most species were not caught within the optimal range, and many had their peak size frequency smaller the L_{50}. Ten species had only between 0.09% and 5% of the individuals caught within the optimal range (*B. bagre*, *C. chrysurus*, *L. breviceps*, *T. lepturus*, *M. americanus*, *X. kroyeri*, *P. schmitti*, *O. punctatissimus*, *A. quadriscutis*, *Polydactylus virginicus*). Seven species had no individual captured within the optimal range, so they were not represented graphically (more details see supplementary material, Figure S1, Table S1). Only two species (*S. stellifer* and *Cetengraulis edentulous),* considered as low risk by the PSA, had percentages corresponding to moderate risk according to the Lopt method (>60%). The other twenty-six were deemed high risk by the Lopt method, even those considered medium and low risk by the PSA (Table 4).

Due to a lack of data, only fourteen of the thirty species studied could be analyzed in the RP-SA approach. Eight were classified as overexploited, and six as not overexploited (Table 4). Eight of the fourteen species had equivalent results between the PSA and RP-AS methods (Figure 8, Table 4). The three species (*T. lepturus*, *I. parvipinnis* and *S. rastrifer*) that were at high risk by the PSA were considered overfished by the RP-SA.

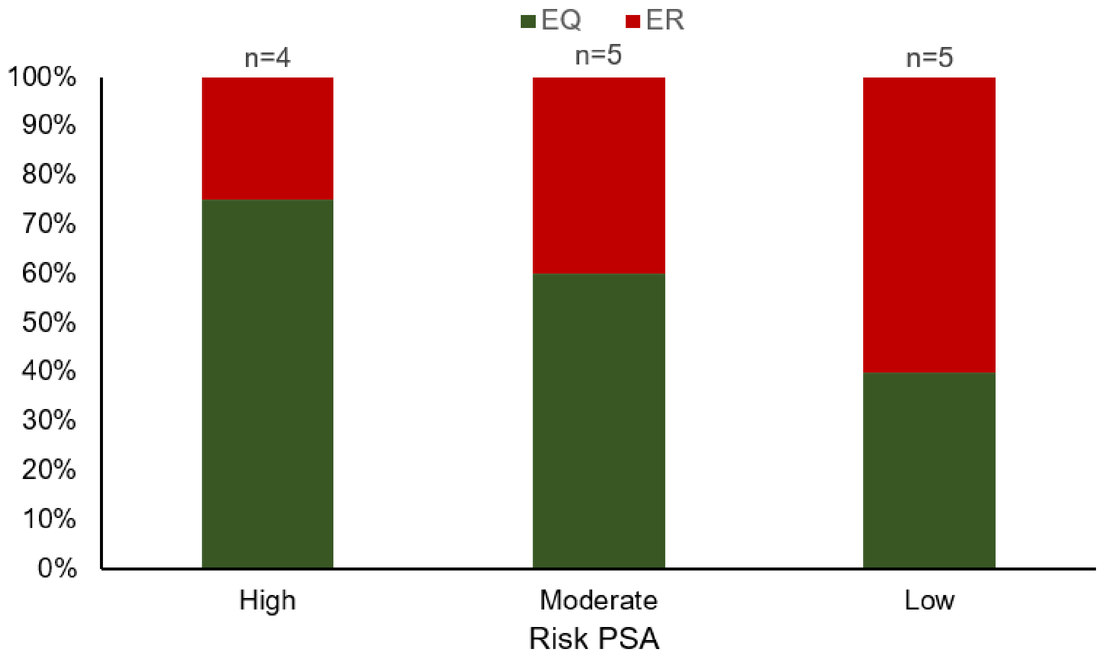

Figura 5. Comparison of species caught by shrimp fisheries considering the Traditional Stock Assessment Reference Point (RP-SA) vs PSA approach. EQ: Similar status between PSA and RP-SA results (high risk and overfishing; moderate or low risk and not overfished); ER: Misclassifications between PSA and RP-SA results.

For only fourteen species, a comparison between the three approaches was possible. The results did not converge between the three methods for any species. However, some similarities were observed. Analysis of the catch composition data shows that only two species, *S. stellifer* (60.85%) and *C. edentulus* (61.39%), had more than 50% of individuals caught within the Lopt ±10 range. The PSA category (low risk) of *S. stellifer* was equivalent to the risk category estimated with the other approaches. Conversely, the low-risk PSA category of *C. edentulus* was comparable only to the IUCN category (Table 4). The target species, *P. schmitti*, had a 0.09% Popt percentage in accordance with its high-risk category attributed in the PSA. Conversely, *P. subtilis* and *X. kroyeri* obtained Popt percentages of 0% and 0.11%, while they were assessed as moderate risk species by the PSA, LC and DD, respectively by IUCN; and are not overfished according to RP-SA (not equivalent) (Table 4). The PSA risk category of *P. subtillis* differed from the categories assessed by other approaches (Table 4).

The species *I. parvipinnis, T. lepturus* and *S. rastrifer* were considered high risk by the PSA, overfished by the RP-SA and have low percentages of individuals caught at ideal length (5.63%, 1.72% and 20.94%, respectively), but were not included in the red list risk category (Table 4). The species *L. breviceps, L. grossidens* and *C. spixii* have 0.93%, 27.24% and 15.79%, respectively, of individuals caught at ideal length (high risk), are overfished according to the RP-SA, but are considered of Least Concern (LC) by the IUCN. The three species do not correspond with the PSA results (Table 4). *Haemulopsis corvinaeformis* and *C. edentulus* were considered low-risk species by the PSA and of Least concern (LC) by the IUCN; however, they were considered as overfished by the RP-SA and showed low percentages of ideal length, namely 6.06 % (high risk) and 61.39% (moderate risk) respectively (Table 4). Finally, the categories of *P. harroweri, S. stellifer* and *C. bleekerianus* were the same in all approaches except for Popt.

2.4 –DISCUSSION

Assessing the sustainability of various bycatch species in trawl fisheries is a major challenge for researchers and hence managers, especially for regions and fisheries that are poorly studied, such as in Northeast Brazil. The flexibility and minimal data requirements of PSA enabled this method to be used in a diversity of fisheries worldwide and applied to a wide range of taxonomic groups (STOBUTZKI et al., 2001; LUCENA FRÉDOU et al., 2017; FARUQUE; MATSUDA, 2019; LIRA et al., 2022). Although the usefulness of PSA is more limited than fully quantitative methods, such as the Sustainability for Fishing Effects model (ZHOU; GRIFFITHS, 2008), it is more widely applicable in situations where information is limited (LUCENA-FRÉDOU et al., 2017). Thus, this methodology, like all assessment methodologies, has advantages and disadvantages.

Some authors recently described some caveats of PSA, such as subjective interpretations, false positives, and the influence of weight assignment (LUCENA-FRÉDOU et al., 2017; DUFFY; GRIFFITHS, 2019). Many of these limitations have been previously recognized, and several alternatives to minimize these limitations have been suggested, such as adding or removing attributes, using alternative methods to calculate the overall vulnerability score, or comparing PSA with other assessment methods (PATRICK et al., 2009; ZHOU et al., 2016; HORDYK; CARRUTHERS, 2018). In our study, these weaknesses and uncertainties were mitigated by testing the effect on risks and rank when assigned different weights to attributes and comparing PSA results with three other approaches (IUCN List, RP-AS and Popt). The IUCN Red List categories of threatened species assess the relative extinction risk and status of threatened species using comprehensive quantitative and qualitative criteria. The RP-SA is a biological indicator and uses the ratio of fishing mortality (F) to maximum sustainable yield (Fmsy). Popt is one of the length-based sustainability indicators suggested by Froese (2004) and evaluates length composition data in relation to reference points. This indicator provides the information needed to develop a practical management approach to assess growth and recruitment overfishing. Although these approaches use different methodologies, some may use data involved in calculating some PSA attributes (e.g., length composition), making the comparison somewhat redundant.

Despite being a non-motorized modality, the beach seine fishery in Lucena is still causing impacts that cannot be ignored, such as the high capture rate of juveniles, presenting potential risks to the recruitment of several species (PASSARONE, 2020). This fishery recorded a total of 119 species, with a ratio of 1:2.3kg (shrimp: fish) and a bycatch proportion comparable with motorized trawl fishing in other states in the Northeast region. In addition, this modality captured a higher species richness than that observed in other nearby states (PASSARONE, 2020).

In this study, a total of 30 species caught by the beach seine fishery in Lucena were analyzed according to their relevance in the catch, commercial importance, and risk of extinction, also including elasmobranchs. Ten species were considered as at high risk of vulnerability, and among them, nine have more than 80% probability of remaining at high risk after the 5000 simulations: *B. bagre, B. marinus* (NT and DD), *M. furnieri* (commercial importance), *C. chrysurus, I. parvipinnis, S. rastrifer, M. americanus, T. lepturus, A. quadriscutis* (abundant). According to Hordik and Carruthes (2018), the extreme ranges correlate well with exploitation risk, but the uncertainty in risk for the intermediate values is high. Several similarities with the present study were observed in for the bottom shrimp trawling off Sirinhaém, Northeast Brazil (LIRA et al., 2022). Indeed, the authors also attributed a high-risk category to the species *B. bagre, B. marinus, A. quadriscutis, M. furnieri, T. lepturus, S. rastrifer* and *M. americanus*.

Not all species assessed by the PSA were included in the comparative analysis with the other methods, as only fourteen had sufficient data to apply the RP-AS and twenty to carry on the Popt approach. Most species did not have their catches within the optimal length range. The shrimps *P. subtilis* and *X. kroyery* showed moderate risk in the

PSA and are overexploited according to the RP-SA but were not caught within the optimal range of Popt. The other target species, *P. schmitti,* is not overfished but presented high risk according to the PSA and is considered Data Deficient (DD) by the IUCN. It also showed only 0.09% of the individuals caught within the optimum length range. In studies developed in Northeast Brazil, the shrimps *P. subtilis* and *P. schmitt* had most of their catches at a size below the length at first maturity, indicating that the catch occurs before the animal reaches sufficient size to contribute to the stock (SILVA et al., 2016, 2018). In the state of Pernambuco (Northeast Brazil), the same shrimp species have moderate risk, and, according to studies in the region, the stocks are not overexploited (LOPES et al., 2014; SILVA et al., 2015, 2018; LIRA et al., 2021, 2022). Special attention must be paid to *X. kroyeri* and especially *P. schmitti* stocks due to their classification as DD by the IUCN. However, as already reported in Northeast Brazil (PASSARONE, 2020; LIRA et al., 2021, 2022), the greatest impacts of this fishery are not on the target shrimps, but on bycatch species.

B. bagre, I. parvipinnis, M. americanus, Aspistor quadriscutis and M. furnieri were classified as high risk by the PSA and are not being caught in their optimum size range. Additionally, *I. parvipinnis* is overfished, according to the RP-SA. Except for *B. bagre* and *M. americanus,* classified by the IUCN as Near Threatened and Data Deficient, the other species are assessed as Least Concern. *Polydactylus virginicus, O. oglinum, Conodon nobilis, Macrodon ancylodon, L. grossidens,* and *L. breviceps* had their vulnerability assessed as a moderate risk by the PSA, with the last two mentioned species being overfished according to the RP-SA and of Least Concern by the IUCN. According to Verba et al. (2020), these species are overexploited or fully exploited within the Brazilian Exclusive Economic Zone, mainly considering the fishery combined effect with the climate change.

In our study, the diagnostics of the four methods did not converge completely for any species. Although some of the data used by IUCN, stock assessment methods and the PSA are similar, the criteria used to derive risk, status, and vulnerability are different (LIRA et al., 2022), which may contribute to some divergences in the results. The PSA points out the species at the highest risk of vulnerability, which deserve special attention from managers, as they are subject to overfishing or must be a priority in data collection (DUFFY et al., 2019). PSA results are relevant for a particular fishery, while the IUCN category is a global or regional assessment that does not consider "stock units" and local threats specificities.

Regarding Popt results, most of the catch was outside the ideal length range. This high proportion of juveniles may be related to the fact that several fish species use this shallow fishing ground as a nursery (PINHEIRO-SOUSA et al., 2015). In Lucena, Passarone et al. (2020) also observed the predominant capture of individuals below the length of first maturity (89% of individuals). This is a characteristic of shrimp trawling and can affect species recruitment (SILVA-JÚNIOR et al., 2015). Beach seine catches (with selective gear and within a nursery ground) are not likely to be representative of the whole stock since the fishery targets only a small part of the population. However, the PSA approach assesses species vulnerability by considering the productivity component inherent to the species and the susceptibility related to the fishing gear, in this case, the beach seine.

Therefore, convergent results between the different approaches (PSA, IUCN Red List, RP-AS and Popt), proved that the analysis is an efficient methodology for assessing fisheries with little data, especially compared with other methods, and can thus be used as a framework for management measures. In our case study, this complementarity of approaches allows to draw some conclusions related to priorities for conservation actions and investigations. Our study highlighted that management priority should be given to species classified with high risk by PSA and as NT and DD (priorities by the MMA ordinance No. 43/2014): *M. americanus, B. bagre*, *B. marinus* and *P. schmitti*. Scrutiny should be given to *P. schmitti* because it is one of the fishery's target species that is considered as high risk. Finally, the vulnerability of *T. lepturus, I. paripinnis* and *S. rastrifer* must be emphasized since, except for the IUCN, they were deemed as high-risk species by all approaches.

It is essential to highlight the great socioeconomic importance of beach seining in Lucena, not only for fishers but for the local population, which is involved in the fishing operations in exchange for bycatch for their consumption (PASSARONE, 2020). According to Silva and García (2013), shrimp is the most prized product for Lucena fishers, as it represents a much greater profit than small fish, preferably used for consumption. Thus, the social aspect of this fishery and its role in food security cannot be neglected, as for many other small-scale fisheries in developing countries. Nascimento et al. (2019) pointed out that there is no evidence of increased fishing effort over the years for the region as there is a lack of incentive to engage future generations due to the infrastructure problems and financial insecurity faced by fishers. However, according to Passarone (2020), the non-regulation of this activity poses an ecological threat since the lack of monitoring hampers the control of fishing effort and the monitoring of bycatch composition and proportion, hindering the comprehension of the global effect of these fisheries on the ecosystem.

Besides considerations on local management priorities, this study also addressed the use of different methods to evaluate a stock/species/fishery. Knowing the technique and evaluating its peculiarities is important to understand its applicability and feasibility. Data-limited models need to be investigated for their pertinence and conclusions considered with caution, especially if they analyses the stock and consider only a part of it. However, their integrated use is advisable in the diagnosis of fishery resources. A study conducted by Oceana on commercial fish stocks shows that we do not know the situation of 94% of our stock (OCEANA, 2021). Little is known about the main national fish resources, and this lack of information prevents to guarantee stock sustainability and fisheries' economic benefits.

4– REFERENCES

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3 – CONSIDERAÇÕES FINAIS

A pesca de arrasto de camarão em Lucena (Paraíba) é pouco conhecida, mas precisa ser investigada dada a sua amplitude e relevância socioeconômica como fonte de renda e alimento. Segundo Passarone (2020), a não regulamentação desta atividade representa uma ameaça a sustentabilidade dos recursos pesqueiros, visto que a falta de monitoramento inviabiliza o controle do esforço de pesca.

Os resultados da PSA neste estudo provaram que a análise é uma metodologia eficiente para a avaliação de pescarias com poucos dados, principalmente quando comparadas com outros métodos de origens diferentes, mas que em vários casos, relativamente convergiram e que podem ser usadas como estrutura para medidas de manejo. Algumas espécies acessórias estão mais vulneráveis que as próprias espécies alvo, assim necessitando de uma atenção diferenciada, devendo ser levadas em consideração nas tomadas de decisões, destacando as espécies: *M. americanus, B. bagre, B. marinus, P. schmitti, T. lepturus, I. paripinnis* e S. *rastrifer,* por estarem com alto risco em mais de uma abordagem e/ou já terem sido citadas em outros estudos a sua necessidade de atenção redobrada.

Além das considerações sobre prioridades de manejo local, este estudo também abordou aspectos sobre o uso de diferentes métodos para avaliar um estoque/espécie/pescaria. É importante conhecer o método e avaliar as suas peculiaridades para compreender sua aplicabilidade e viabilidade. Os modelos de dados limitados precisam ser investigados quanto a sua pertinência e considerar com cautela suas conclusões, principalmente se analisam estoque e consideram apenas uma parte dele. Entretanto, o seu uso integrado é aconselhável no diagnóstico dos recursos pesqueiros. Um estudo realizado pela Oceana sobre os estoques pesqueiros de interesse comercial, mostra que desconhecemos a situação de 94% dos nossos estoques (OCEANA, 2021). Pouco se sabe sobre os principais recursos pesqueiros nacionais e esta ausência de informações certamente é um risco para nortear o seu uso sustentável e otimizar os benefícios econômicos desta atividade.

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5 – ANEXO I – MATERIAL SUPLEMENTAR

VULNERABILITY ASSESSMENT OF SPECIES CAUGHT BY THE SHRIMP TRAWL FISHERY OFF THE COAST OF PARAIBA

SOM 1. Details of equations

Details of the equations used in estimating some of the productivity and susceptibility attributes.

SOM 2. Attribute details

Details of the estimates of the productivity and susceptibility attributes used in this study.

SOM 3. Froese sustainability recommendations

Details of the equation used in estimating Lopt

Result of the analysis of optimal length catch composition (Popt)

Table S1. Result of the analysis of ideal length catch composition (Popt). The values were estimated from the Froese length-based indicator (2004). For shrimp, the carapace length was considered.

Frequency distribution and optimal length range (Lopt)

Figura S1. Length frequency data of species caught by the beach seine trawl shrimp fishery in Lucena-PB from December 2016 to November 2017, where Lm (red) indicates the first maturity size, Lopt (grey) indicates the length range in which the maximum yield can be obtained (the bar size corresponds to the frequency of individuals present in the Lopt ±10 range) and Linf (green) the asymptotic length.

Total mortality

Figure S2. Figura S2. Catch curve converted into linear length to estimate total mortality (Z ± SE) (Chapman and Robson, 1960; Pauly, 1983) of fish species with representative length frequency distribution caught by the shrimp trawl fishery of Lucena.

Length frequency distribution

Figure S3. Length frequency distribution of bycatch species that included most of the size spectra (including juveniles and adults) and shrimp species caught by the shrimp fishery in Lucena-PB. The blue dashed and solid red lines represent the first maturity size (L_{50}) and asymptotic length ($L\infty$), respectively.

Productivity Data

Table S2. Input data for productivity attributes used for species caught by beach net fishery in Lucena-PB

Susceptibility data

Table S3. Input data for susceptibility attributes used for species caught by the beach trawl fishery in Lucena-PB.

SUPPLEMENTARY MATERIAL

SOM 1. DETAILS OF EQUATIONS

Details on life history parameter estimates for the species used in this study, when not found in the literature.

I. Intrinsic growth rate (r): This parameter was estimated from the equation proposed by Mertz (1970), using the life table. The estimation of r from this simple approach generally leads to errors of at most 10% around the true value (Stearns, 1992). The life table with survivors by age groups was calculated based on the natural mortality (M) estimates developed by Gislason et al. (2010):

$$Mt = 0.55KL_{\infty}^{1.44}exp^{-1.61logL}$$

Lt corresponds to the length referring to an age (t) (projected from 0 to 100) estimated from Von Bertalanffy (1938):

$$Lt = L_{\infty}\left[1 - e^{-k(t-t_0)}\right]$$

to is the theoretical age when size equals zero.

The probability of survival from each age to the next age (Sp) was estimated from the natural mortality by age as indicated above.

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$$Sp = e^{-Mt}$$

Fecundity (Fc) was considered proportional to weight (Lt3) assuming a sex ratio of 1:1. Thus, these values (Sp and Fc) were used to estimate the net reproduction rate (R0) and generation time (G), incorporating age (t). Finally, the intrinsic growth rate (r) was obtained from the relationship between (R0) and (G):

$$r = \frac{\log R_0}{G}$$

As cited in Lira et al. (2022), the r estimates obtained here are useful for comparative purposes among the species considered, but their use as an absolute stand-alone estimate should be taken with caution, given the limitations of the approach employed.

II. Maximum age (A_{MAX}): When the attribute was not available, Amax was estimated from the empirical equation of Taylor (1960):

$$A_{max} = k + \left(\frac{2.996}{t_0}\right)$$

where k is the Von Bertalanffy growth coefficient and $t_0$is the theoretical age in years that the fish would be at length zero. $t_0$was estimated by the empirical equation of Froese and Binohlan (2003):

$$\log_{10}(-t_0) = -0.3922 - (0.2752 \times \log_{10}(L_\infty)) - (1.038 \times \log_{10}(k))$$

III. Von Bertalanffy's growth coefficient (k): When the attribute was not available, k was estimated using the empirical equation of Le Quesne and Jennings (2012):

$$K = 2.15 \times {L_\infty}^{-0.46}$$

Where L∞ is the asymptotic estimated by Froese e Binohlan (2000) based on the maximum total length reported for the species:

$$\log_{10}(L_\infty) = 0.444 + 0.9841 \times \log_{10}(L_{\max})$$

IV. Average size of first maturity (L_{50}): When the attribute was not available, it was estimated according to Binohlan and Froese (2009) based on the maximum total length observed for the species:

$$\log L_{50} = -0.1189 + 0.9157 \times \log L_{max}$$

<u>V. Estimated natural mortality (M):</u> We use the mean (M) of nine different empirical relations per application developed by Jason cope (https://github.com/shcaba/Natural-Mortality-Tool). All relations are described below:

Then_nls, Then_lm e Then_VBGF by Then *et al.* (2014) and Hamel_Amax (Owen Hamel (in. prep; owen.hamel@noaa.gov):

$$\log(M) = 1.717 - 1.01\log(t_{max})$$

$$M = 4.889 t_{max}{}^{-0.916}$$

$$M = 4.118 k^{0.73} L_{\infty}^{-0.33}$$

$$M = {}^{5.4}/_{A_{max}}$$

ZM_CA_pel e ZM_CA_dem by Alverson and Carney (1975); Zhang e Megrey (2006):

$$M = {}^{3K}/_{(e^{akt_{max}} - 1)}$$

$$M = \frac{\beta k}{e^{(t_{mb} - t_0)} - 1}$$

Jensen_VBGF1 and Jensen_VBGF2 by Jensen (1996, 1997, 2001):

$$M = 1.5k$$

$$M = 0.21 + 1.47k$$

Pauly_lt por Pauly (1980):

$$\log M = -0.0066 - 0.279\log L_{\infty} + 0.6543\log k + 0.4634\log T$$

Where, t_{max} is the maximum age, k and $L\infty$ are von Bertalanffy growth coefficient and asymptotic size respectively, and T water temperature.

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SOM 2. ATTRIBUTE DETAILS

2.1 Productivity Attributes

I. Intrinsic growth rate (r): This represents the theoretical growth rate of a population in the absence of fishing effort. It was estimated from life history parameters for each species using the approach of Fortuna et al. (2014). The lower the r, the lower the productivity (SOM 1).

II. Maximum age ($AMAX$): the maximum age recorded in the literature, inversely related to the mortality rate (M) (HOENIG, 1983). The lower it is, the higher the productivity (SOM 1).

III. Maximum size ($LMAX$): maximum length recorded in the literature, which is used as an indicator of productive capacity. Larger species tend to live longer and have slower growth and late maturity, consequently having lower productivity (ROBERTS; HAWKINS, 1999).

IV. Von Bertalanffy growth coefficient (k): Von Bertalanffy equation parameter measures the speed with which a fish reaches its maximum size. Long-lived species with low productivity tend to have low values of k (FROESE; BINOHLAN, 2000) (SOM 1).

V. Average size of first maturity ($L50$): the average size at which 50% of individuals are apt for reproduction, inversely proportional to productivity. Large, slow-growing, low-productivity species tend to mature relatively later and be less resilient to fishing, making them more vulnerable to overfishing (HUTCHINGS; REYNOLDS, 2004) (SOM 1).

VI. Reproductive strategy: this attribute provides a proxy of natural mortality in the early periods of a species' life cycle and was based on Winemiller's (1989) parental investment index. The index is a score ranging from 0 to 14 according to egg care (e.g., whether they are laid in nests or the water column) (0-2), parental care time (0-4), and gestation period or nutritional contribution (0-8). In our study, the sum of the points defines whether the individual has high (0), moderate (1-3) or low (>4) productivity.

VII. Estimated natural mortality (M): Natural mortality is directly proportional to productivity. Species with high mortality rates need to compensate for this mortality with a high productivity level to maintain the population. Natural mortality was calculated from available data on the species biology, and various methods were tested with the help of the online natural mortality calculation tool (https://github.com/shcaba/Natural-Mortality-Tool). Natural mortality for each species was defined as an average value calculated from the combination of the mortality values generated by each method for each species.

2.2 Susceptibility attributes

I. Percentage of adults (% > L50): Proportion of individuals above L_{50} size, considered adults, present in the catches. For this, we used data from length frequency distributions of beach net catches calculated only for species sampled that included most of the species' size spectra (including juveniles and adults) (Figure S3). Following Lira et al. (2022), we chose to consider the highest susceptibility in the direction of the highest proportion of individuals caught below L_{50} (juveniles) since our species are mainly short life cycle species, small body size, with high reproductive capacity and rapid growth and sexual maturation (r-strategist pattern). Scoring was defined using the tertile method.

II. Commercial category: Fish stocks with a higher value are more susceptible to overfishing (PATRICK et al., 2009). Scores were obtained by researching species prices locally, in literature or by considering that species may be discarded or used for consumption only. Target species and those species that are not considered targets but were frequent and abundant in the collections were considered high risk; commercial species were classified in the moderate risk category; those species that are consumed or discarded were deemed low risk.

III. Fishing mortality/natural mortality ratio (F/M): this ratio indicates the relative impact of fishing pressure (HUYNH et al., 2018). For conservationist reasons, the value of natural mortality should be considered the upper limit for fishing mortality (THOMPSON, 1993) so that for the species to remain at a safe level, it is recommended that the value of the F/M ratio does not exceed 1. The F values were obtained through the equation $F = Z - M$, where the total mortality (Z) was estimated by calculating the catch curve (PAULY, 1983; WETHERALL, 1986) through the FSA (Simple Fisheries Stock Assessment Methods) package (OGLE et al., 2020), only for species with representative length frequency distribution (Figure S2).

IV. Length-Based Stock Potential Ratio (LB-SPR): The potential spawning ratio (SPR) is the reproductive proportion naturally or unfished that remains in the stock under the current degree of exploitation (HORDYK et al. 2015b). This biological reference point has been tested in the literature to determine the influence of fishing pressure on the reproductive capacity of the stock (HORDYK et al., 2015 a, b; GOODYEAR, 1993). For the sustainability of a fishery, a 40% SPR rate is considered the target reference point and an SPR lower than 20% is harmful to the stock (PRINCE et al., 2015). SPR can be used as an alternative reference point for biomass at maximum sustainable yield (BMSY) (PONS et al., 2019). This method requires data on (i) representative length distribution, (ii) M/k ratio; (ii) asymptotic length ($L\infty$); (iii) length at which 50% (L50) and 95% (L95) of a fish population are mature (Hordyk et al., 2015; Hordyk et al. 2016; Prince et al., 2015). This information is available in this study and used in the attributes and calculations described above.

V. Shoaling/aggregation: This attribute comprises the behaviors of the species. Individual responses may include, for example, the herding effect or avoidance of gear that would affect catchability (PATRICK et al., 2010). If fish behavior decreases the catchability of the gear, it is considered low risk; if behavior responses do not affect the catchability of the gear substantially, it is regarded as medium risk; and if fish behavior increases the catchability of the gear, it is regarded as high risk (PATRICK et al., 2009; NOEGROHO et al., 2021). The scores considered the behavioral responses of the fish caught in the literature.

VI. Overlap Area (OA): This attribute combines information on the susceptibility of the species to fishing gear based on ecological niche characteristics (adapted from Patrick et al., 2010 and Lira et al., 2022), such as geographic and water column distribution (demersal (DE), pelagic (PE) or reef associated (RE)) and sediment type the species is frequently associated with (mud (M), sand (S) and rocks (R)). If bottom trawls target mainly demersal species, and those shrimp fishing areas are mainly concentrated in regions of non-consolidated substrate (mostly mud), we considered high-risk demersal species frequently associated with muddy substrates (DE + M), medium-risk demersal species associated with sandy or rocky substrates (DE + S/R) and low risk pelagic or coral reef-associated species (PE/RE). An extensive literature review assessed the vertical distribution and sediment-associated information, including articles, books, and reports, and the FishBase repository (FROESE and PAULY, 2019).

VII. Frequency of occurrence (FO): The species were classified according to their frequency and abundance based on Garcia and Vieira (2001). The species with a catch rate (PN%) greater than the ratio 100/S, where S is the number of species in the set, were classified as abundant. The species with a frequency of occurrence (FO%) greater than 50% in the set were classified as frequent. Therefore, it was considered high risk the highly abundant and frequent species (PN% > 100/S and FO% > 50), as the moderate risk the scarce and frequent species (PN% < 100/S and FO% > 50) and high abundant and rare (PN% > 100/S and FO% < 50); and categorized as the low risk the low scare and rare species (PN% < 100/S and FO% < 50).

SOM 3. FROESE SUSTAINABILITY RECOMMENDATIONS

Sustainability reference point (FROESE, 2004): The optimum length is typically slightly greater than the length at first maturity (FROESE; BINOHLAN, 2000). The goal would be to catch all fish (100%) within this ideal size range. Although this is rarely achievable in practice, calculating the length at which this would occur (Lopt) provides a reference point for growth overfishing (KELL et al. 2017). In this study, we will use only the Popt (percentage of fish present between the length range 0.9 × Lopt and 1.1 × Lopt). Find the Popt requires information on the catch length composition for the fishery and an estimate of Lopt, obtained by using the formula below (BEVERTON 1992):

$$Lopt = L\infty \times \left[\frac{3}{\left(3+\frac{M}{K}\right)}\right]$$

Where L∞ is the asymptotic length, K is the Von Bertalanffy growth coefficient, and M is the natural mortality.

3.1 RESULT OF THE ANALYSIS OF OPTIMAL LENGTH CATCH COMPOSITION (POPT)

Table S1. Result of the analysis of ideal length catch composition (Popt). The values were estimated from the Froese length-based indicator (2004). For shrimp, the carapace length was considered.

SPECIE	Lopt (cm)	+10% (cm)	-10% (cm)	Popt (%)
Cetengraulis edentulus	11,64	12,80	10,48	61,39
Stellifer stellifer	9,19	10,11	8,27	60,85
Chirocentrodon bleekerianus	10,32	11,35	9,29	49,73
Anchovia clupeoides	11,26	12,38	10,13	40,36
Pellona harroweri	11,49	12,64	10,34	29,25
Lycengraulis grossidens	16,11	17,72	14,50	27,24
Stellifer rastrifer	12,44	13,68	11,20	20,94
Cathorops spixii	20,37	22,41	18,33	15,79

Harengula clupeola	14,19	15,61	12,78	12,21
Haemulopsis corvinaeformis	17,00	18,70	15,30	6,06
Isopisthus parvipinnis	17,00	18,70	15,30	5,63
Ophioscion punctatissimus	15,79	17,36	14,21	3,49
Aspistor quadriscutis	33,82	37,20	30,44	2,08
Polydactylus virginicus	20,64	22,70	18,57	2,07
Bagre bagre	37,18	40,89	33,46	1,72
Trichiurus lepturus	82,08	90,28	73,87	1,72
Menticirrhus americanus	26,35	28,99	23,72	1,22
Larimus breviceps	21,04	23,15	18,94	0,93
Chloroscombrus chrysurus	16,78	18,46	15,10	0,37
Xiphopenaeus kroyeri	2,42	2,67	2,18	0,11
Penaeus schmitti	2,98	3,27	2,68	0,09
Bagre marinus	33,82	37,20	30,44	0,00
Conodon nobilis	23,21	25,53	20,89	0,00
Macrodon ancylodon	29,99	32,99	26,99	0,00
Odontognathus mucronatus	18,50	20,34	16,65	0,00
Opisthonema oglinum	21,16	23,28	19,05	0,00
Stellifer microps	14,93	16,42	13,43	0,00
Penaeus subtilis	3,07	3,38	2,77	0,00

3.2 FREQUENCY DISTRIBUTION AND IDEAL LENGTH RANGE (Lopt)

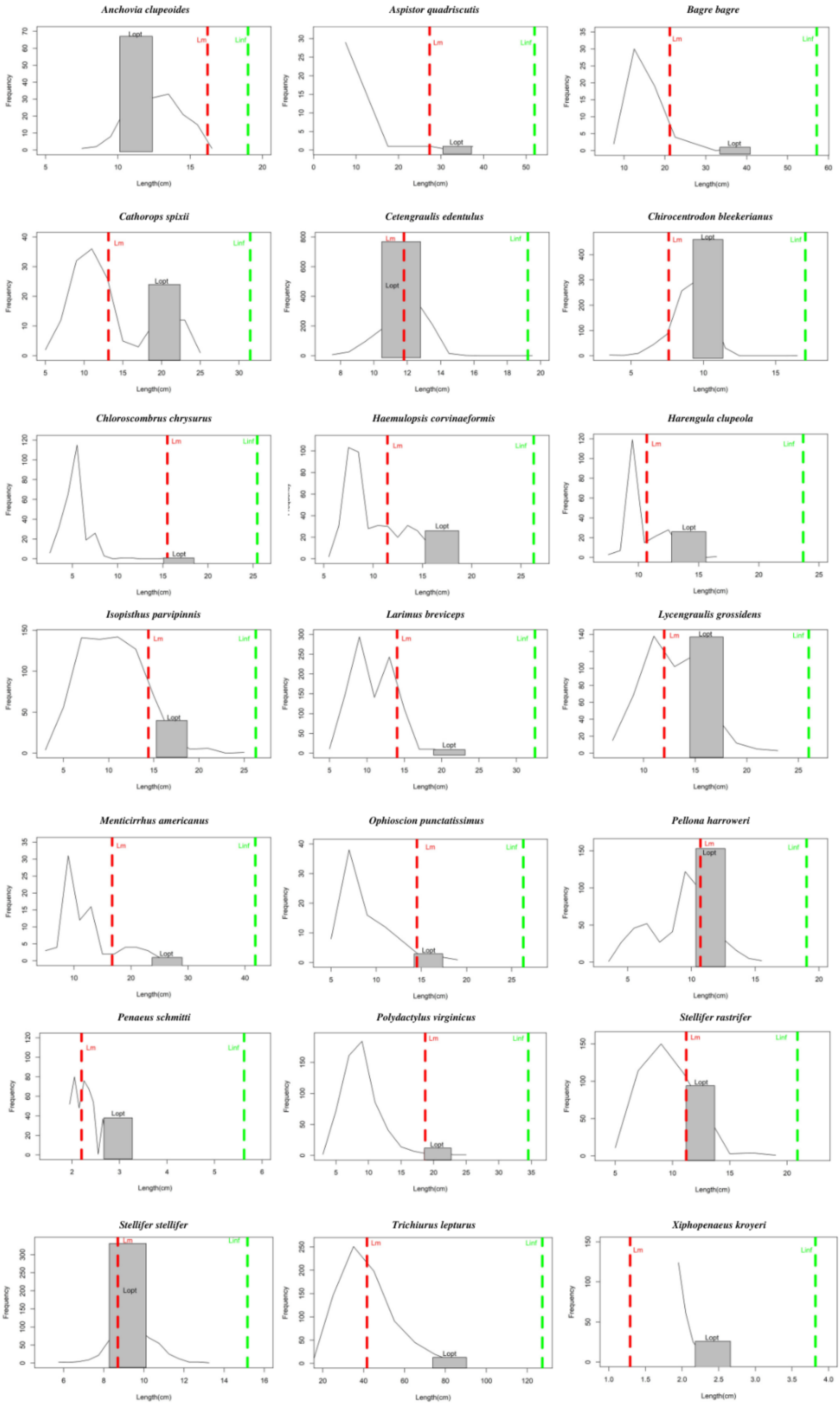
Anchovia clupeoides
Aspistor quadriscutis
Bagre bagre
Cathorops spixii
Cetengraulis edentulus
Chirocentrodon bleekerianus
Chloroscombrus chrysurus
Haemulopsis corvinaeformis
Harengula clupeola
Isopisthus parvipinnis
Larimus breviceps
Lycengraulis grossidens
Menticirrhus americanus
Ophioscion punctatissimus
Pellona harroweri
Penaeus schmitti
Polydactylus virginicus
Stellifer rastrifer
Stellifer stellifer
Trichiurus lepturus
Xiphopenaeus kroyeri
Lopt
Lm
Linf
Frequency
Length(cm)

Figura S1. Length frequency data of species caught by the beach seine trawl shrimp fishery in Lucena-PB from December 2016 to November 2017, where Lm (red) indicates the first maturity size, Lopt (grey) indicates the length range in which the maximum yield can be obtained (the bar size corresponds to the frequency of individuals present in the Lopt ±10 range) and Linf (green) the asymptotic length.

TOTAL MORTALITY

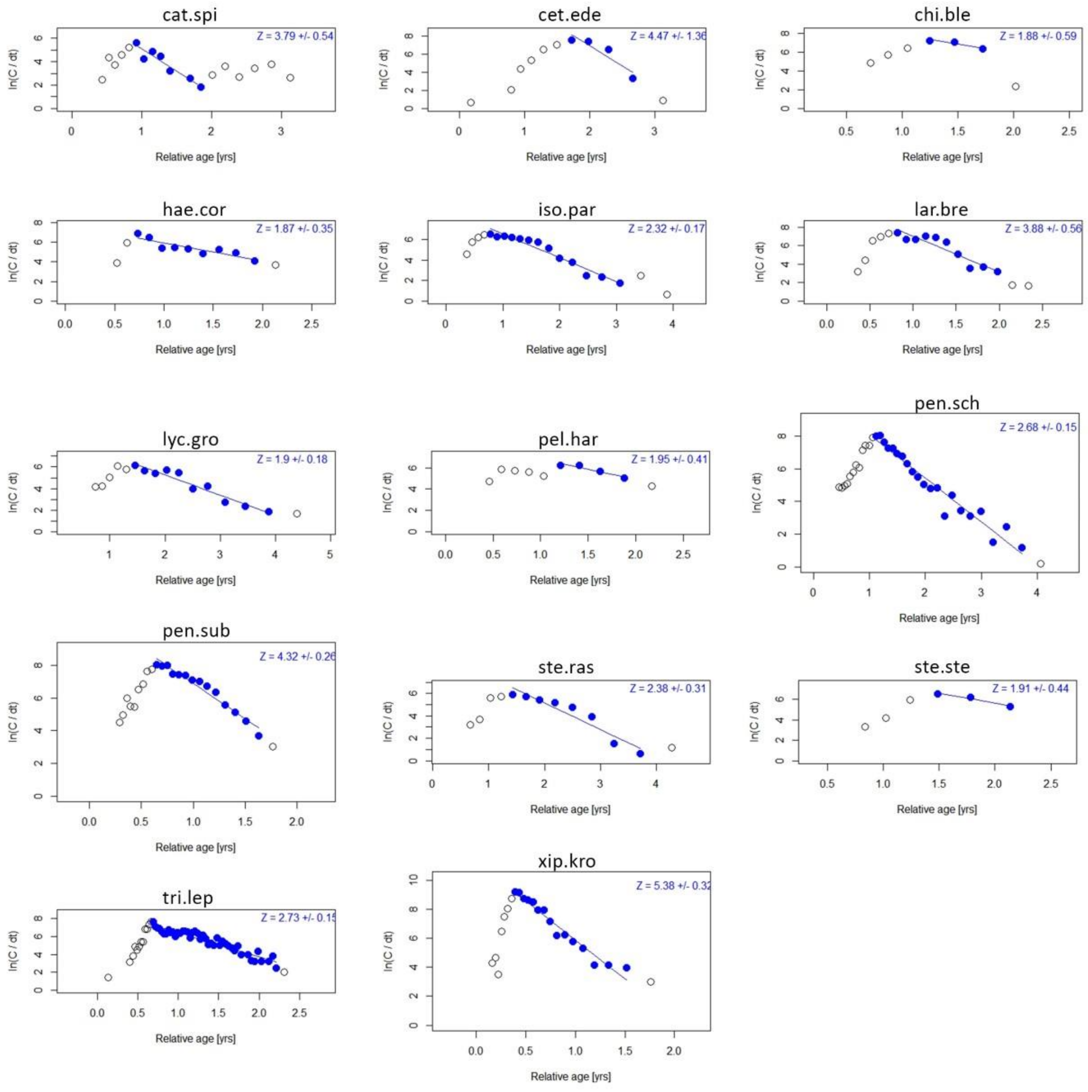

Figura S2. Catch curve converted into linear length to estimate total mortality (Z ± SE) (Chapman and Robson, 1960; Pauly, 1983) of fish species with representative length frequency distribution caught by the shrimp trawl fishery of Lucena. A code represents species (See table 4).

LENGTH FREQUENCY DISTRIBUTION

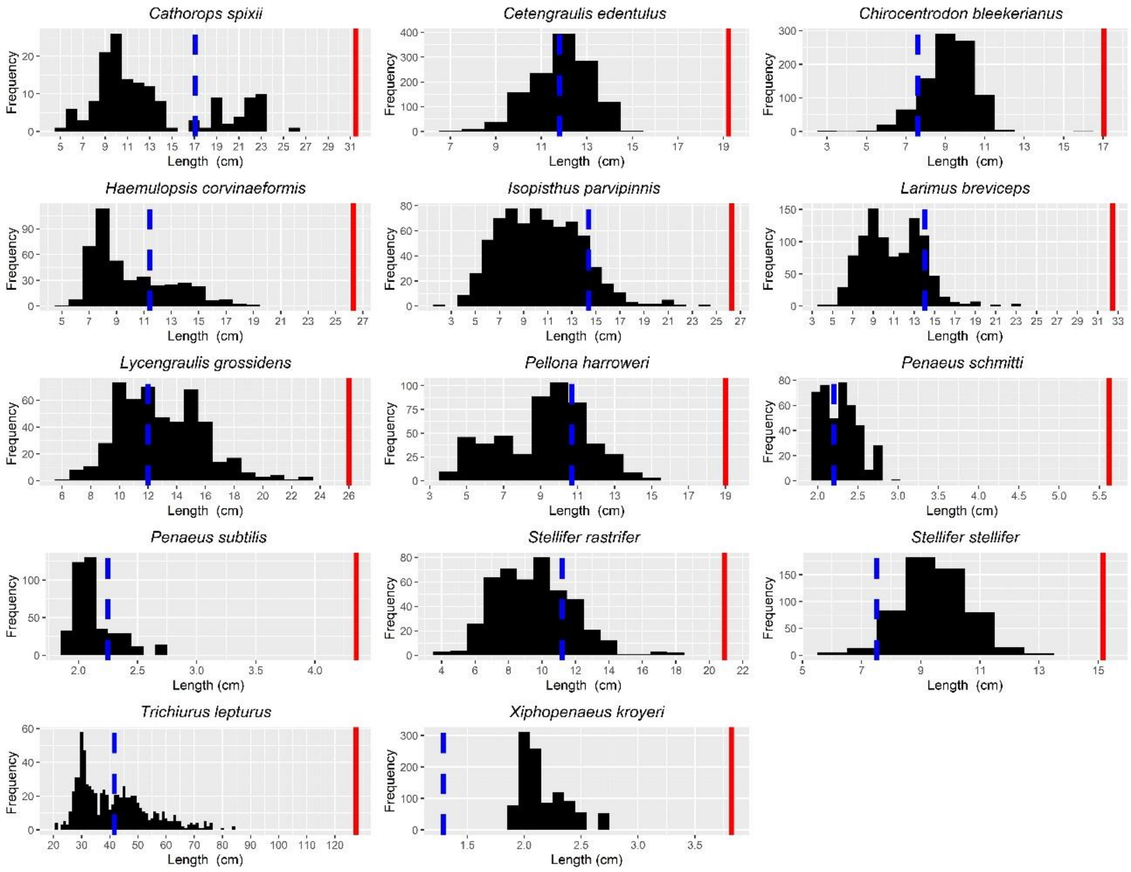

Figura S3. Length frequency distribution of bycatch species that included most of the size spectra (including juveniles and adults) and shrimp species caught by the shrimp fishery in Lucena-PB. The blue dashed and solid red lines represent the first maturity size (L50) and asymptotic length (L∞), respectively.

PRODUCTIVITY DATA

Table S2. Input data for productivity attributes used for species caught by beach net fishery in Lucena-PB. Von Bertalanffy length coefficient (k); maximum size (Lmax); first maturity length (L50); intrinsic growth rate (r); and maximum size (Amax). Values in Red were estimated using the equations: L∞ (logL∞=0.444+0.9841×logLmax by Froese and Binohlan (2000)); k (k=2.15 x L∞^ (-0.46) by Le Quesne and Jennings (2012)); t0 (log-t0=-0.3922-(0.2752×logL∞) -(1.038×logk) by Froese and Binohlan (2003)); Amax (Amax=k+(2.996/t0) by Taylor (1960)); L_{50} ($logL_{50}$=-0.1189+0.9157×$logL_{max}$ by Binohlan and Froese (2009)).

Order	Family	Specie	Cod.sp	IUCN	Lmax	L∞	k	t0	Amax	L50	r	Referencias
Clupeiformes	Engraulidae	*Anchovia clupeoides*	*anc.clu*	LC	24	19.00	0.60	-0.29	4.70	16.2	0.62	42;41; 43
Siluriformes	Ariidae	*Aspistor quadriscutis*	*asp.qua*	LC	50	51.99	0.35	-0.41	8.17	27.3	0.58	41;44
Siluriformes	Ariidae	*Bagre bagre*	*bag.bag*	NT	55	57.11	0.33	-0.40	8.54	21.2	0.56	45;44;46;5
Siluriformes	Ariidae	*Bagre marinus*	*bag.mar*	DD	50	51.99	0.35	-0.41	8.17	39	0.54	44;11
Siluriformes	Ariidae	*Cathorops spixii*	*cat.spi*	LC	30	31.45	0.44	-0.36	6.45	13.14	0.64	3;4
Clupeiformes	Engraulidae	*Cetengraulis edentulus*	*cet.ede*	LC	18.2	19.23	0.55	-0.32	5.11	11.8	0.63	2;44;6
Clupeiformes	Pristigasteridae	*Chirocentrodon bleekerianus*	*chi.ble*	LC	16.1	17.05	0.58	-0.31	4.82	7.6	0.67	13;44;7
Carangiformes	Carangidae	*Chloroscombrus chrysurus*	*chl.chr*	LC	48.3	25.45	0.35	-0.51	9.42	15.5	0.39	8;44
Perciformes	Haemulidae	*Conodon nobilis*	*con.nob*	LC	34.2	35.78	0.41	-0.37	6.85	14.3	0.63	14;44;9
Perciformes	Haemulidae	*Haemulopsis corvinaeformis*	*hae.cor*	LC	25	26.29	0.48	-0.35	5.92	11.45	0.66	10;44
Clupeiformes	Clupeidae	*Harengula clupeola*	*har.clu*	LC	18	23.68	0.43	-0.41	6.56	10.7	0.51	17;15;44
Acanthuriformes	Sciaenidae	*Isopisthus parvipinnis*	*iso.par*	LC	25	26.29	0.48	-0.35	5.92	14.4	0.63	18;44;19
Carangiformes	Sciaenidae	*Larimus breviceps*	*lar.bre*	LC	31	32.48	0.43	-0.37	6.55	14.04	0.62	45;44;19
Clupeiformes	Engraulidae	*Lycengraulis grossidens*	*lyc.gro*	LC	23.5	26.00	0.42	-0.69	6.44	12	0.53	12;16;44;20
Acanthuriformes	Sciaenidae	*Macrodon ancylodon*	*mac.anc*	LC	45	47.10	0.43	-0.33	6.00	21.13	0.72	21;18;44;22
Acanthuriformes	Sciaenidae	*Menticirrhus americanus*	*men.ame*	DD	50	41.80	0.29	-0.52	9.81	16.7	0.40	23;18;44;24
Acanthuriformes	Sciaenidae	*Micropogonias furnieri*	*mic.fur*	LC	53.1	60.00	0.05	-2.11	57.00	34.1		25;26;44;27
Clupeiformes	Pristigasteridae	*Odontognathus mucronatus*	*odo.muc*	LC	19.2	28.80	0.35	-0.49	8.07	11.4	0.43	28;29;44
Acanthuriformes	Sciaenidae	*Ophioscion punctatissimus*	*oph.pun*	DD	25	26.29	0.48	-0.35	5.92	14.5	0.63	30;44;31
Anguilliformes	Clupeidae	*Opisthonema oglinum*	*opi.ogl*	LC	38	31.80	1.46	-0.06	3.50	21.3	2.70	1;45;44;32
Clupeiformes	Clupeidae	*Pellona harroweri*	*pel.har*	LC	18	19.02	0.55	-0.32	5.08	10.7	0.63	45;44;31
Decapoda	Penaeidae	*Penaeus schmitti*	*pen.sch*	DD	6.5	5.62	0.42	-0.68	6.45	2.2	0.52	
Decapoda	Penaeidae	*Penaeus subtilis*	*pen.sub*	LC	7.6	4.35	0.86	-0.30	3.18	2.25	1.30	
Perciformes	Polynemidae	*Polydactylus virginicus*	*pol.vir*	LC	33	34.54	0.42	-0.37	6.74	18.7	0.62	33;44;31

Acanthuriformes	Sciaenidae	*Stellifer microps*	*ste.mic*	LC	20.5	24.96	0.30	-0.63	9.36	12.1	0.30	34;30;44;19
Acanthuriformes	Sciaenidae	*Stellifer rastrifer*	*ste.ras*	LC	32.1	20.90	0.37	-0.49	7.61	11.2	0.28	35;44;31
Acanthuriformes	Sciaenidae	*Stellifer stellifer*	*ste.ste*	LC	14.3	15.17	0.62	-0.30	4.57	7.5	0.61	36;44;37
Pleuronectiformes	Symphurus tessellatus	Symphurus tessellatus	*sym.tes*	LC	22	23.18	0.51	-0.34	5.58	12.9	0.63	35;44
Pleuronectiformes	Achiridae	*Trichiurus lepturus*	*tri.lep*	LC	234	127.40	0.40	-0.25	7.25	41.6	0.72	38;39;44;40
Decapoda	Penaeidae	*Xiphopenaeus kroyeri*	*xip.kro*	DD	3.3	3.82	0.96	-0.27	2.85	1.29	2.80	

1 (Lessa et al., 2004); 2 (Joyeux et al., 2009); 3 (Taylor e Menezes, 1978); 4 (Dantas, 2012); 5 (Passarone et al., 2019); 6 (Souza-Conceição et al., 2005); 7 (Corrêa et al., 2005); 8 (de Queiroz et al., 2018); 9 (Lira et al., 2019); 10 (Eduardo et al., 2018); 11 (Lima et al., 2016); 12 (Goulart et al., 2007); 13 (Soeth et al., 2019); 14 (Pombo et al., 2014); 15 (Lieske and Myers, 1994); 16 (Kullander and Ferraris, 2003); 17 (da Costa et al., 2018); 18 (Cervigón, 1993); 19 (Silva Júnior et al., 2015); 20 (Mai and Vieira, 2013); 21 (Ikeda, 2003); 22 (Cardoso et al., 2018); 23 (Giannini and Paiva-Filho, 1992); 24 Haluch et al., 2011; 25 (Santos, 2015); 26 (Nakamura et al., 1986); 27 (Santos et al., 2015); 28 (Silva-Júnior, 2004); 29 (Freire et al., 2009); 30 (Chao, 1978); 31 (Conceição, 2017); 32 (Simoni, 2019); 33 (Motomura, 2004); 34 (Sarmento, 2015); 35 (Barreto et al., 2018); 36 (Dias et al., 2017); 37 (Trindade-Santos and Freire, 2015); 38 (Al-Nahdi et al., 2009); 39 (Claro, 1994); 40 (Barreto et al., 2017); 41 (Carpenter, 2002); 42 (Giarrizzo et al., 2006); 43 (Giarrizzo, 2007); 44 (Viana et al., 2016); 45 (Cervigón et al., 1992); 46 (Véras and Da Silva Almeida, 2016).

SUSCEPTIBILITY DATA

Table S3. **Input data for susceptibility attributes used for species caught by the beach trawl fishery in Lucena-PB.** Percentage of adults in the catch (aults (%); Frequency of occurrence (FO); Total mortality (Z); Fishing mortality (F); Natural mortality (M); Potential spawning rate (SPR). For the attributes Trade, Aggregation and the AO: 1 (low risk); 2 (moderate risk); 3 (high risk).

Order	**Family**	Specie	Cod.sp	Adultos (%)	FO	Z	F	M	F/M	SPR	Comercial	Agregação	OA	Referências
Clupeiformes	Engraulidae	*Anchovia clupeoides*	*anc.clu*	0,01	Frequente e abundante			1,24			1	2	1	47;
Siluriformes	Ariidae	*Aspistor quadriscutis*	*asp.qua*	0,04	Frequente e pouco abundante			0,56			1	1	3	49;
Siluriformes	Ariidae	*Bagre bagre*	*bag.bag*	0,12	Pouco frequente e pouco abundante			0,54			1	1	3	51;
Siluriformes	Ariidae	*Bagre marinus*	*bag.mar*	0	Frequente e abundante			0,56			1	1	3	50;
Siluriformes	Ariidae	*Cathorops spixii*	*cat.spi*	0,36	Pouco frequente e abundante	3,79	3,07	0,72	4,28	0,02	1	1	3	48;
Clupeiformes	Engraulidae	*Cetengraulis edentulus*	*cet.ede*	0,15	Frequente e abundante	4,47	3,39	1,08	3,14	0,28	1	3	1	48;
Clupeiformes	Pristigasteridae	*Chirocentrodon bleekerianus*	*chi.ble*	0,97	Frequente e abundante	1,88	0,74	1,14	0,65	0,53	1	3	1	53;63

Carangiformes	Carangidae	*Chloroscombrus chrysurus*	*chl.chr*	0	Frequente e abundante			0,55			1	2	1	48;
Perciformes	Haemulidae	*Conodon nobilis*	*con.nob*	0,03	Frequente e abundante			0,67			1	1	3	48;
Perciformes	Haemulidae	*Haemulopsis corvinaeformis*	*hae.cor*	0,24	Frequente e abundante	1,87	1,09	0,78	1,39	0,15	1	1	2	48;
Clupeiformes	Clupeidae	*Harengula clupeola*	*har.clu*	0,35	Frequente e abundante			0,86			1	2	1	48;64
Acanthuriformes	Sciaenidae	*Isopisthus parvipinnis*	*iso.par*	0,04	Frequente e abundante	2,32	1,54	0,78	1,96	0,07	1	2	3	19;65
Carangiformes	Sciaenidae	*Larimus breviceps*	*lar.bre*	0,14	Frequente e abundante	3,88	3,17	0,71	4,49	0,02	1	1	3	19;
Clupeiformes	Engraulidae	*Lycengraulis grossidens*	*lyc.gro*	0,49	Frequente e abundante	1,90	1,12	0,77	1,45	0,24	1	2	1	20;70
Acanthuriformes	Sciaenidae	*Macrodon ancylodon*	*mac.anc*	0,06	Frequente e abundante			0,74			1	2	3	19;66
Acanthuriformes	Sciaenidae	*Menticirrhus americanus*	*men.ame*	0,17	Frequente e abundante			0,51			1	1	3	57;
Acanthuriformes	Sciaenidae	*Micropogonias furnieri*	*mic.fur*	0	Pouco frequente e pouco abundante			0,13			2	2	3	54;
Clupeiformes	Pristigasteridae	*Odontognathus mucronatus*	*odo.muc*	0,07	Pouco frequente e abundante	2,30	1,72	0,59	2,94		1	2	1	53;63
Acanthuriformes	Sciaenidae	*Ophioscion punctatissimus*	*oph.pun*	0,18	Frequente e abundante			0,95			1	1	1	53;
Anguilliformes	Clupeidae	*Opisthonema oglinum*	*opi.ogl*	0	Frequente e abundante	4,82		2,20			1	2	1	48;64
Clupeiformes	Clupeidae	*Pellona harroweri*	*pel.har*	0,04	Frequente e abundante	1,95	0,86	1,09	0,79	0,46	1	2	3	70;64
Decapoda	Penaeidae	*Penaeus schmitti*	*pen.sch*	0,775	Frequente e abundante	4,68	3,56	1,12	3,18	0,06	3	3	3	62;
Decapoda	Penaeidae	*Penaeus subtilis*	*pen.sub*	1	Frequente e abundante	4,82	3,75	1,07	3,50	0,10	3	3	3	61;
Perciformes	Polynemidae	*Polydactylus virginicus*	*pol.vir*	0,02	Frequente e abundante			0,85			1	2	3	48;67
Acanthuriformes	Sciaenidae	*Stellifer microps*	*ste.mic*	0,02	Frequente e abundante			0,61			1	1	3	53;
Acanthuriformes	Sciaenidae	*Stellifer rastrifer*	*ste.ras*	0,07	Frequente e abundante	2,38	1,63	0,76	2,16	0,11	1	2	3	53;
Acanthuriformes	Sciaenidae	*Stellifer stellifer*	*ste.ste*	0,98	Frequente e pouco abundante	1,91	0,71	1,20	0,59	0,61	1	2	3	59;69
Pleuronectiformes	Cynoglossidae	Symphurus tessellatus	*sym.tes*	0,79	Frequente e pouco abundante			1,00			1	1	3	54;
Pleuronectiformes	Achiridae	*Trichiurus lepturus*	*tri.lep*	0,29	Frequente e abundante	2,71		0,66		0,05	3	2	3	48;68
Decapoda	Penaeidae	*Xiphopenaeus kroyeri*	*xip.kro*	0,857	Frequente e abundante	4,96	3,30	1,66	1,99	0,08	3	3	3	58;

19 (Silva Júnior et al., 2015); 20 (Mai and Vieira, 2013); 47 (Vasconcelos-filho, 1999); 48 (Vasconcelos Filho and Oliveira, 1999); 49 (Denadai et al., 2004); 50 (Segura-Berttolini and Mendoza-Carranza, 2013); 51 (Barletta and Blaber, 2007); 52 (Riede, 2004); 53 (Passos et al., 2013); 54 (Paiva et al., 2009); 55 (Reis-Filho et al., 2010); 56 (Mourão et al., 2014); 57 (Turra et al., 2012); 58 (Lopes et al., 2017); 59 (Rodrigues-Filho et al., 2011); 60 (Paiva et al., 2013); 61 (Silva et al., 2015); 62 (Silva et al., 2018); 63 (Corrêa, 2005); 64 (Figueiredo & Menezes, 1978); 65 (Romero et al., 2018); 66 (Yamaguti, 1967); 67 (Vaske-junior, 2019); 68 (Bernardes et al., 2007); 69 (Zanlorenzi, 2015); 70 (Lopes et al., 2012).

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