Sustainability of capture of fish bycatch in the prawn trawling in northeastern Brazil

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The prawn fishery produces more discards than any other type of catch and captures a large quantity of immature individuals. This research aimed to assess the sustainability of capture of fish bycatch in prawn trawling. Each species was assessed according to two groups of criteria: (1) their relative vulnerability to capture by trawl and mortality due to this fishery (2) recovery capacity of the specie after a possible collapse of the population. Within each group, each species was ranked (1-3), being 1 the highest value, meaning the species is highly susceptible to capture or has a low resilience. A total of 8,894 individuals were caught, belonging to 28 families. The species with capture least sustainable were *Stellifer rastrifer* and *Isopisthus parvipinnis*. These latter species are highly susceptible since they are either benthic or demersal, and their diet may include benthic organism. *Chirocentrodon bleekerianus* and *Anchoa tricolor* were the most likely fishes to be sustainable since they are pelagic, they are least susceptible to capture by trawls, and also have a greater capacity to recover, as most individuals have bred before capture. Due to the fishery's multi-specific nature, it is difficult to implement mitigation measures for specific species. Thus, the creation of fishing exclusion zones should be considered as the most appropriate management measure.

A pesca de arrasto de camarão produz mais descarte do que qualquer outra pescaria e captura uma grande quantidade de indivíduos imaturos. Esta pesquisa visa determinar a sustentabilidade da captura da ictiofauna acompanhante na pesca de arrasto de camarão. Cada espécie foi analisada de acordo com dois grupos de critérios: (1) vulnerabilidade à captura pela rede de arrasto e mortalidade ocasionada por esta pescaria; e (2) capacidade de recuperação da população para minimizar. Dentro de cada critério as espécies foram classificadas de 1 a 3, sendo 1 o valor mais alto, indicando que a espécie é altamente susceptível à captura ou tem baixa capacidade de recuperação. Um total de 8.894 indivíduos foram capturados, pertencendo a 28 famílias. As espécies com captura menos sustentável foram *Stellifer rastrifer* e *Isopisthus parvipinnis*. Estas espécies são altamente susceptíveis, pois são bentônicas ou demersais e suas dietas incluem organismos bentônicos. *Chirocentrodon bleekerianus* e *Anchoa tricolor* foram as espécies que apresentaram a captura mais sustentável. Por serem pelágicas, são menos susceptíveis à captura por arrastos de fundo, além disto, apresentaram uma grande capacidade de recuperação, pois a maior parte dos indivíduos capturados encontrava-se acima do seu tamanho de primeira maturação sexual. Devido à natureza multiespecífica da pescaria é difícil implementar medidas mitigatórias específicas. Assim, a criação de zona de exclusão de pesca deve ser considerada como a medida de manejo mais adequada.

Key words: Demersal fish, Recovery, Sandy beach, Susceptibility, Vulnerability.

Introduction

Due to the technological advances and the increase in the number of fishing fleets, fish stocks are undergoing intense pressure and, consequently, overexploitation (Isaac *et al*., 2006). Prawn trawling has become quite prominent in recent years - it is practiced along almost the entire Brazilian coast and promotes economic and social development in the regions where it is carried out (Branco, 2005). However, this kind of fishery is extremely heterogeneous as a result of the low selectivity of the fishing gear used (Klippel *et al*., 2005).

As a result of the use of trawls, prawn fishing is a major threat to marine environments. Among the main consequences of this fishery are direct and indirect impacts

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on ecosystems and biodiversity (Kinieb, 1991), physical alterations in the seabed (*e.g.*, due to the removal of rocks and corals and the flattening of the bottom's natural topography) (Pilskaln *et al.*, 1998) and changes in chemical cycles, carbon mineralization patterns and biogeochemical flows (Riemann & Hoffman, 1991).

The prawn fishery produces more discards than any other type of catch, and it is the source of more than one-third of the world's total bycatch (Alverson *et al.*, 1994). The total amount of discards is approximately five times the production of prawn, and it is one of the major problems related to the use of marine resources (Clucas, 1997). Another important characteristic of this activity is the capture of immature individuals (Branco, 1999; Branco & Verani, 2006).

A significant part of the fauna caught in trawl fisheries is returned to the sea either because it has no economic importance or they are small (even if they are target species). Large quantities of individuals are returned to the sea dead and for this reason are called discard or reject (Branco, 1999). Bycatch is the portion of the catch that is returned to the sea for economic, legal or personal decisions along with the non-target species captured from fishing (McCaughran, 1992).

Although fish constitutes the main component of incidental capture, many species are often captured but they are not quantified in the fishing statistics (Coelho *et al.*, 1986). The bycatch composition consists mainly by juvenile individuals which represent a considerable loss for future food biomass and can potentially affect the sustainability of fish stocks (Tischer & Santos, 2001).

Little is known about the life cycle of the bycatch species. Furthermore, many individuals are often caught before reaching the size of first sexual maturity (Pina & Chaves, 2009). Research on prawn fishery bycatch has been limited to recording and quantifying species (Vianna & Almeida, 2005). Only two studies have been focused on the sustainability of the bycatch (Stobutzki *et al.*, 2001; Feitosa *et al.*, 2008), but only Stobutzki *et al.* (2001) evaluated the impacts of a prawn fishery.

A population can vary in size length throughout time and is directly connected to fertility stages and to the environment, the latter which can make species undergo changes from one year to another (Nikolskii, 1969). Such information makes it possible to conduct studies to determine the equilibrium of a given population.

In this context, the aim of this research was to assess the bycatch fish species' resilience and susceptibility to trawls and verify their susceptibility and resilience as bycatch within a prawn fishery in northeastern Brazil.

Material and Methods

Study Area. São Cristóvão Beach, the study area, is located in the Rio Grande do Norte State (4°55'29.83"S 36°57'2.91"W), northeastern Brazil. This beach is located in a shallow bay (Fig.1) and the bottom is sandy/muddy. This region is characterized by a semi-arid climate with prevailing hot/dry
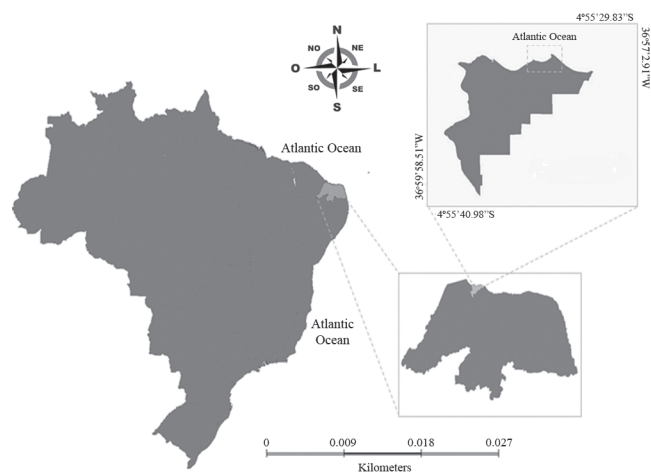

Fig. 1. Map of northwestern Brazil showing location of study area in São Cristóvão beach.

(June to January) and rainy seasons (February to May); the average annual precipitation is less than 750 mm (Idema, 2002, 2003). The tide follows a semidiurnal pattern that displays a daily disparity; the average sea level is of 133.1 cm and the quadrature and spring tidal range is of 127.79 cm and 284.55 cm, respectively (Garcia Júnior, 2006). Northeast-east winds stand out in this region, with higher speeds in the summer; a maximum of 8.5 m/s is reached in October and a minimum of 0.7 m/s during the winter month of April (Idema, 2003).

Sampling. Sampling was carried out monthly from February 2010 through January 2011, during spring tide, in shallow areas (6m), parallel to the shoreline and in direction of the current for 30 minutes. A 15 m long and 8.60 m wide bottom trawl, with a 4 cm opening, was pulled by a prawn boat with a 46-HP 6-cylinder engine at a speed of 2.5 knots. Fish collected were kept in a Styrofoam box and then brought to the laboratory, where they were stored in a freezer and later identified, weighed and measured (total length). The samples are deposited at the Biologia e Dinâmica Populacional de Peixes Marinhos Laboratory Collection under the numbers 1-50.

Data Analysis. Fish species were analyzed according to biological and ecological characteristics (Figueiredo & Menezes, 1978, 1980, 2000; Menezes & Figueiredo, 1980, 1985; Carvalho Filho, 1999; Froese & Pauly, 2011). Only those species with abundances greater than 0.5% of the total number of fishes were analyzed. The method proposed by Stobutzki *et al.* (2001) and adapted by Feitosa *et al.* (2008) was modified and used to assess the sustainability of fish bycatch in a prawn fishery.

Two sustainability criteria were used: (1) vulnerability to capture and mortality by trawling, and (2) the species' resilience after potential population collapse. Values ranging from 1 to 3 were assigned for each sustainability index, where one means the species is highly susceptible to capture and/ or has a low capacity to recovery (Table 1). The values obtained

for each group of criteria were plotted on a graph that indicated the species which capture was more or less sustainable. When specific information about a certain species was not available, the same value given to the other species of the family or genus was attributed. If the information for species or genus of this family was not available, the value 1 was assigned as a precautionary approach (Stobutzki *et al.*, 2001).

The day/night catchability proposed by Stobutzki *et al.* (2001) was not considered in this study due to the scarcity of the target species (prawns). As a result, nowadays the prawn fishery occurs for 24 hours (Tomáz *et al.*, 2003).

It was observed that the species analyzed in this research showed a preference for the same type of habitat. Thus, this criterion did not directly interfere in the analysis. A similar situation was observed for the depth criterion. Since trawling was always conducted in depths < 40 m, this did not influence species' capture and was therefore removed from the analysis. As all captured taxa were dioecious, therefore hermaphroditism did not interfere directly in the analysis of species recoverability and was therefore ignored.

The criteria used to analyze species' susceptibility to capture and to mortality associated with trawling were applied as follows: a) Water-column position: as the prawn trawls are usually operated near the bottom, benthic and demersal species are more likely to be captured than pelagic ones (Stobutzki *et al.*, 2001). b) Survival: this criterion was described in a study by Wassenberg & Hill (1989) and Hill & Wassenberg (1990) on the survival of bycatch caught in trawls. After being trawled, individuals were observed and the researchers recorded whether they were alive or dead. Survival was divided into three categories, based on species frequency: survival probability ≤ 33.3%; 33.3 < survival probability < 66.6%; and survival probability ≥ 66.6%. c) Diet: this criterion is related to the occurrence of species' main food items in the areas where trawling occurs. Species that feed on benthic and/or demersal organisms have a greater susceptibility to trawling than those that feed on pelagic organisms.

Five criteria were analyzed to evaluate population resilience: 1) maturity, 2) maximum size, 3) relationship between yield and fishing effort (catch per unit effort - CPUE), 4) reproductive strategy and 5) mortality.

Maturity is related to the probability that most individuals be captured after reaching the size of first maturity established for certain species (Stobutzki *et al.*, 2001). If the fishery has been capturing individuals larger than the size of first maturity, respective populations will have a greater possibility to recover in case of decline (Robert & Hawkins, 1999). Maximum size was used as a relative indicator of its resilience. Large sized species tend to live longer, grow slowly and mature late; thus, their populations recover at a slower pace than those that grow to smaller sizes (Robert & Hawkins, 1999). Relationship between yield and fishing effort: the catch per unit effort (CPUE) is usually not proportional to the abundance of the resource or species (Jennings *et al.*, 2001). However, if a certain species has little ability to recover and is removed from the environment in large quantities, it can be susceptible to becoming at risk of extinction (Fonteles-Filho, 1989). In this study all valor analyzed were distributed in three ranges to facilitate the classification between the weights (1, 2 and 3) used herein (Table 1). The unit used for this criterion was individuals/hours of trawling. Reproductive strategy: species able to disperse for long distances are less vulnerable to a possible risk of extinction (Robert & Hawkins, 1999). Thus, the resilience of r-strategist species is greater than that of k-strategist species. Mortality refers to the resilience of a given population directly related to the mortality index (Sparre & Venema, 1997). Mortality was calculated using the following formula: Mortality index = $(Lmax - Lmed)/(Lmed - Lmin)$, where: Lmax - maximum length reported in the literature; Lmed - average total length of individuals captured; Lmin - minimum length of individuals observed in the sample. Considering the minimum and maximum values found for the 17 species analyzed, three mortality index classes were determined; this corresponds to the 1-3 weights, as indicated in Table 1.

In order to calculate the rates of susceptibility or total removal,

Table 1. Criteria used to assess susceptibility of bycatch species to capture and mortality due the trawling. For each criterion, the weighting score and definition was established on the tree ranks.

Criteria	Weighting score	1	2	3
Susceptibility				
Water column position	3	Demersal or benthic	Benthopelagic	Pelagic
Survival	3	Survival probability ≤ 33.3%	33.3% < survival probability ≤ 66.6%	Survival probability > 66.6%
Diet	3	Feed on demersal or benthopelagic organisms	Feed on benthopelagic organisms	Feed on pelagic organisms
Resilience				
Maturity	3	Mature individuals < 50%	-	Mature individuals >50%
Maximum size	3	Maximum size ≥ 33.8 cm	10.6 cm < maximum size < 33.8 cm	Maximum size ≤ 10.6
CPUE	3	CPUE ≥ 42.7 individuals/hours of trawling	1.4 inds/h of trawling < CPUE < 42.7 inds/hours of trawling	CPUE ≤ 1.4 inds/hours of trawling
Reproductive strategy	2	Viviparous	Demersal spawning/Parental care	Pelagic spawning
Mortality index (Z)	1	Mortality index ≥ 17.9	0.67 < Mortality index < 17.9	Mortality index ≤ 0.67

$$Si = \sum_{j=1}^{n} (wj.Ri) / \sum_{j=1}^{n} wj$$

the following equation was used (Stobutzki *et al.*, 2001):

where, Si refers to the ranking of total susceptibility or recovery of species I, wj = weight of criterion j, and Ri = weight of species I for criterion j, and n = total number of criteria for each axis.

Statistical analysis. The data were log-transformed (ln(TL)) and the Liliefors test was used to evaluate data normality (BioStat 5.0 software - Instituto de Desenvolvimento Sustentável Mamirauá). Parametric tests and multivariate analysis were also used. The Z test (BioStat 5.0 software) was applied to check the probability of fish being caught before or after reaching the size at first maturity, while the factorial correspondence analysis (FCA) (Multivariate Statistical Package - MVSP 3.1 software) was used to determine and describe the correlation between species and each criterion evaluated. The significance level applied was 0.05.

Results

A total of 8,894 individuals were caught as bycatch, which belonged to 58 species, 48 genera, and 28 families (Table 2). This study shows that prawn trawling is not selective, as most of the individuals caught were imature. They belong to the following families: Sciaenidae (5 spp), Haemulidae (2 spp), Pristigasteridae (2 spp), Ariidae (2 spp), Engraulidade (3 spp), Carangidae (2 spp) and Polynemidae (1 spp). *Pomadasys corvinaeformis* (Steindachner, 1868), *Cathrops spixii* (Agassiz, 1829), *Stellifer rastrifer* (Jordan, 1889) and *Pellona harroweri* (Fowler, 1917) represented more than 50% of the individuals captured. All species identified as frequent were abundant in catches, with the exception of *Isopisthus parvipinnis* (Cuvier, 1830) and *Anchoa tricolor* (Spix and Agassiz, 1829), which were present in less than half of the sampling months (Table 2).

The information provided by the susceptibility criterion was specific to each species. The values obtained for this criterion ranged from 1.0 to 1.7. *Polydactylus virginicus* (Linnaeus, 1758) and *Chirocentrodon bleekerianus* (Poey, 1867) showed the lowest and highest values for susceptibility, respectively. Thus, it can be stated that *P. virginicus*, followed by *Menticirrhus americanus* (Linnaeus, 1758), *P. corvinaeformis*, *S. rastrifer* and *I. parvipinnis* showed great susceptibility to the fishing gear used, while *C. bleekerianus*, *Larimus breviceps* Cuvier, 1830, *Conodon nobilis* (Linnaeus, 1758), *Anchoa spinifer* (Valenciennes, 1848), *Cetengraulis edentulus* (Cuvier, 1829) and *A. tricolor* were the least susceptible to the trawl (Fig. 2). B*agre marinus* (Mitchill, 1815) and *A. tricolor* had the highest (Z = 17.9) and lowest (Z = 0.7) values for the mortality index, respectively (Table 3).

Concerning the ability to recover, *S. rastrifer* and *I.*

parvipinnis had the lowest values, although *A. tricolor*, *C. bleekerianus*, *P. harroweri*, *Stellifer stellifer* (Bloch, 1790), and *Selene vomer* (Linnaeus, 1758) presented the greatest resilience (Fig. 2). The mean and minimum lengths recorded for *S. rastrifer* and *I. parvipinnis* were below their size at first maturity. The probability that individuals of these species be caught before having bred for the first time is of 38.5% and 45.6% for *S. rastrifer* and *I. parvipinnis*, respectively. The opposite was observed for *C. spixii*, *S. stellifer* and *C. bleekerianus*, with probabilities of 85.1%, 98.8% and 94.4%, respectively (Table 3). Based on all these information's, it can be said that the species with capture most likely to be sustainable are *C. bleekerianus* and *A. tricolor*, while *S. rastrifer* and *I. parvipinnis* are the least likely.

The correspondence analysis for resilience and susceptibility showed that *P. harroweri*, *C. bleekerianus*, *A. tricolor*, *S. stellifer* and *C. spixii* were associated with the maturity criterion. In relation to survival, this criterion had a positive influence on *C. spixii* and *B. marinus* (Fig.3). Diet and position in the water column were essential to the low susceptibility of *C. edentulus* and *A. spinifer* to the fishing gear. Negative relationships were observed for *C. spixii* and *B. marinus* with diet and position in the water column criterion; *C. edentulus*, *P. harroweri*, *C. bleekerianus*, *A. tricolor* and *A. spinifer* with the survival criterion; *B. marinus*, *P. corvinaeformis*, and *M. americanus* with maturity (Fig.3). The cumulative percentage of variation for the two axes was of 89.39%.

Discussion

The methodology used in this study was applied to classify bycatch fish species according to potential risk of extinction as a result of the incidental capture. Such an analysis is influenced by fish length, the proportion of young and immature individuals, fish maximum length, size at first maturity, and mortality rate. All species analyzed were susceptible to trawling in different levels.

The results presented showed that benthopelagic and demersal or benthic species were more vulnerable to the prawn fishery's gear; it catches mainly species with this pattern of distribution in the water column because the trawling happens close to the substrate. Therefore, those fish that inhabit rocky or pelagic areas are not considered vulnerable to trawling (Jennings *et al.*, 2001). Benthic or demersal species suffer habitat damage due to the impacts caused by bottom trawls. Essential habitat loss for given species may cause population decline (and, in some cases, extinction) (McCaughran, 1992).

Many bycatch species have no economic value and are discarded in the sea. Survival rate of these individuals is questionable because of the physiological effects that decompression causes when they are removed from great depths and brought rapidly to the surface (Nguyen, 2009). Species with the highest resistance to this practice belong to families Ariidae, Sciaenidae, and Haemulidae. The survival rate surpasses 33.3% in these three families. In addition, the low depth of the study area (6 m) is a positive factor for their survival

Table 2. Bycatch species at the São Cristóvão beach, with the respective common names, families, percentage abundance (%) and frequency (in months). Legend: * All common names were obtained from Fishbase; PA - Percentage Abundance; F - Frequency.

Family	Scientific name	Common name*	PA	F
Haemulidae	*Pomadasys corvinaeformis* (Steindachner, 1868)	Roughneck grunt	18.03	11
Ariidae	*Cathorops spixii* (Agassiz, 1829)	Madamango sea catfish	15.64	11
Sciaenidae	*Stellifer rastrifer* (Jordan, 1889)	Rak estardrum	15.35	8
Pristigasteridae	*Pellona harroweri* (Fowler, 1917)	American coastal pellona	9.88	11
Sciaenidae	*Stellifer stellifer* (Bloch 1790)	Little croaker	9.67	10
Pristigasteridae	*Chirocentrodon bleekerianus* (Poey, 1867)	Dogtooth herring	7.41	8
Sciaenidae	*Larimus breviceps* Cuvier, 1830	Shorthead drum	6.21	12
Sciaenidae	*Menticirrhus americanus* (Linnaeus, 1758)	Southern kingcroaker	3.06	12
Haemulidae	*Conodon nobilis* (Linnaeus, 1758)	Barred grunt	2.00	12
Polynemidae	*Polydactylus virginicus* (Linnaeus, 1758)	Barbu	1.38	12
Engraulidae	*Anchoa spinifer* (Valenciennes, 1848)	Spicule anchovy	1.36	11
Carangidae	*Selene setapinnis* (Mitchill, 1815)	Atlantic moonfish	1.23	11
Sciaenidae	*Isopisthus parvipinnis* (Cuvier, 1830)	Bigtooth corvina	0.99	5
Engraulidae	*Cetengraulis edentulus* (Cuvier, 1829)	Atlantic anchoveta	0.83	7
Engraulidae	*Anchoa tricolor* (Spix & Agassiz, 1829)	Piquitinga anchovy	0.81	4
Carangidae	*Selene vomer* (Linnaeus, 1758)	Lookdown	0.63	10
Ariidae	*Bagre marinus* (Mitchill, 1815)	Gafftopsail sea catfish	0.62	9
Trichiuridae	*Trichiurus lepturus* Linnaeus, 1758	Largehead hairtail	0.44	9
Diodontidae	*Chilomycterus spinosus* (Linnaeus, 1758)	Striped burrfish	0.37	9
Sciaenidae	*Stellifer brasiliensis* (Schultz, 1945)	Cangoá	0.36	4
Aphipiidae	*Chaetodipterus faber* (Broussonet, 1782)	Atlantic spadefish	0.30	10
Paralichthydae	*Citharichthys macrops* Dresel, 1885	Spotted whiff	0.29	3
Cynoglossidae	*Symphurus tessellatus* (Quoy & Gaimard, 1824)	Tongue fish	0.26	10
Ariidae	*Genidens barbus* (Lacépède, 1803)	White sea catfish	0.25	1
Ariidae	*Bagre bagre* (Linnaeus, 1766)	Coco sea catfish	0.24	3
Sciaenidae	*Bairdiella ronchus* (Cuvier, 1830)	Ground croaker	0.20	6
Carangidae	*Chloroscombrus chrysurus* (Linnaeus, 1766)	Atlantic bumper	0.19	7
Gerreidae	*Eucinostomus melanopterus* (Bleeker, 1863)	Flagfin mojarra	0.19	4
Pristigasteridae	*Opisthonema oglinum* (Lesueur, 1818)	Atlantic thread herring	0.16	5
Triglidae	*Prionotus punctatus* (Bloch, 1793)	Bluewing searobin	0.16	6
Dasyatidae	*Dasyatis guttata* (Bloch & Schneider, 1801)	Long nosestingray	0.13	4
Lutjanidae	*Lutjanus synagris* (Linnaeus, 1758)	Lane snapper	0.13	4
Haemulidae	*Genyatremus luteus* (Bloch, 1790)	Torroto grunt	0.12	4
Dactylopteridae	*Dactylopterus volitans* (Linnaeus, 1758)	Flying gurnard	0.11	6
Paralichthydae	*Citharichthys spilopterus* Günther, 1862	Bay whiff	0.10	3
Tetraodontidae	*Sphoeroides greeleyi* Gilbert, 1900	Green puffer	0.10	5
Achiridae	*Trinectes paulistanus* (Miranda Ribeiro, 1915)	Slipper sole	0.09	4
Gymnuridae	*Gymnura micrura* (Bloch & Scheneider, 1801)	Smooth butterfly ray	0.08	4
Sparidae	*Archosargus probatocephalus* (Walbaum, 1792)	Sheepshead	0.08	3
Achiridae	*Achirus declivis* Chabanaud, 1940	Plainfin sole	0.07	2
Gerreidae	*Diapterus rhombeus* (Cuvier, 1829)	Caitipa mojarra	0.07	2
Sciaenidae	*Nebris microps* Cuvier, 1830	Smalley ecroaker	0.07	3
Ariidae	*Notarius grandicassis* (Valenciennes, 1840)	Thomas seacatfish	0.04	1
Engraulidae	*Anchoa filifera* (Fowler, 1915)	Long finger Anchovy	0.04	1
Carangidae	*Uraspis secunda* (Poey, 1860)	Cottonmouth jack	0.03	2
Sparidae	*Archosargus rhomboidalis* (Linnaeus, 1758)	The sea bream	0.03	1
Cynoglossidae	*Symphurus plagusia* (Bloch & Schneider, 1801)	Duskycheek tonguefish	0.02	2
Sciaenidae	*Paralonchurus brasiliensis* (Steindachner, 1875)	Banded croaker	0.02	2
Sphyraenidae	*Sphyraena guachancho* Cuvier, 1829	Guachanche barracuda	0.02	2
Synodontidae	*Synodus intermedius* (Spix & Agassiz, 1829)	Sand diver	0.02	1
Acanthuridae	*Acanthurus chirurgus* (Bloch, 1787)	Doctorfish	0.01	1
Batrachoididae	*Thalassophryne nattereri* Steindachner, 1876	Niquin	0.01	1
Carangidae	*Trachinotus falcatus* (Linnaeus, 1758)	Permit	0.01	1
Haemulidae	*Haemulon aurolineatum* Cuvier, 1830	Tomtate grunt	0.01	1
Mullidae	*Pseudupeneus maculatus* (Bloch, 1793)	Spotted goatfish	0.01	1
Scombridae	*Scomberomorus cavalla* (Cuvier, 1829)	King mackerel	0.01	1
Serranidae	*Rypticus randalli* Courtenay, 1967	Plain soapfish	0.01	1
Tetraodontidae	*Sphoeroides testudineus* (Linnaeus, 1758)	Checkered puffer	0.01	1

because they do not undergo decompression problems.

Bagre marinus, *C. spixii*, and *P. corvinaeformis* showed the highest correlation with survival. When individuals were dredged they reached the vessel still alive. However, despite their resistance to stress, *B. marinus* and *C. spixii* were most affected by trawling because their dependence to the substrate.

Regarding feeding habit, it was detected that the bycatch

Table 3. Lengths of first capture and maturity, probabilities of caught below the length at maturity and breeding, mean and maximum length, and the mortality index of bycatch species at the São Cristóvão beach (RN). Legend: ** not found in the literature, size of sexual maturity. n - Number of individuals, L' - length at first capture, L(50) - length at first maturity, Prob. - probability, Z - mortality index.

Species	n	L' (cm)	L(50)	Pro. L < L(50)	Prob. of breeding	Lmean ± E.P. (cm)	Max. length (cm) according to references	Z
Pomadasys corvinaeformis	1604	4.2	15.8	p = 0.476	p = 0.524	8.18 ± 0.0376	25 (Figueiredo & Menezes, 1980)	5.2
Cathorops spixii	1391	7.7	12	p = 0.149	p = 0.851	13.98 ± 0.0822	30 (Froese & Pauly, 2008)	3.6
Stellifer rastrifer	1365	5.0	9.5	p = 0.385	p = 0.615	8.5 ± 0.0329	20 (Figueiredo & Menezes, 1980)	4.3
Pellona harroweri	879	3.1	7	p = 0.382	p = 0.618	10 ± 0.0592	16 (Figueiredo & Menezes ,1978)	1.9
Stellifer stellifer	860	4.6	7.5	p = 0.012	p = 0.988	9.5 ± 0.0393	15 (Cervigón, 1993)	2.1
Chirocentrodon bleekerianus	659	4.9	7.6	p = 0.056	p = 0.944	8.46 ± 0.0453	11.1 (Figueiredo & Menezes, 1978)	1.7
Larimus breviceps	552	3.0	14	p = 0.312	p = 0.688	11.4 ± 0.1393	30 (Figueiredo & Menezes, 1980)	3.2
Menticirrhus americanus	272	4.2	18.1	p = 0.386	p = 0.614	11.16 ± 0.2269	50 (Cervigón, 1993)	6.6
Conodon nobilis	178	5.6	16	p = 0.375	p = 0.625	8.96 ± 0.1992	33.6 (Cervigón *et al.,* 1992)	7.9
Polydactylus virginicus	123	4.3	**	p = 0.401	p = 0.599	10.9 ± 0.2876	32 (Motomura, 2004)	4.2
Anchoa spinifer	121	5.6	**	p = 0.444	p = 0.556	12.4 ± 0.2066	24 (Figueiredo & Menezes, 1978)	2.7
Selene setapinnis	109	3.6	20.5	p = 0.496	p = 0.504	7.88 ± 0.2406	40 (Figueiredo & Menezes, 1980)	8.5
Isopisthus parvipinnis	88	5.3	15.9	p = 0.456	p = 0.544	10.4 ± 0.6345	25 (Figueiredo & Menezes, 1980)	3.9
Cetengraulis edentulus	74	9.2	14,7	p = 0.496	p = 0.504	11.3 ± 0.1438	16,6 (Froese & Pauly, 2008)	3.5
Anchoa tricolor	71	7.8	7.6	p = 0.312	p = 0.688	11.1 ± 0.1170	10 (Figueiredo & Menezes, 1978)	0.7
Selene vomer	56	3.3	24.1	p = 0.452	p = 0.548	6.5 ± 0.2449	50 (Figueiredo & Menezes, 1980)	14.6
Bagre marinus	55	8.0	33	p = 0.480	p = 0.520	11.4 ± 0.3820	69 (IGFA, 2001)	17.9

fishes feed mainly on benthic or demersal and benthopelagic organisms. They are thus more susceptible to dredging than pelagic species, as the preference for this kind of food directly influences their position in the water column (Wootton, 1989)

and, consequently, their susceptibility to the gear used.

The criteria diet was a positive aspect for *I. parvipinnis*, *S. vomer*, *S. setapinnis*, and *C. edentulus* since they feed on benthic crustacean, but also small fishes, or zooplankton
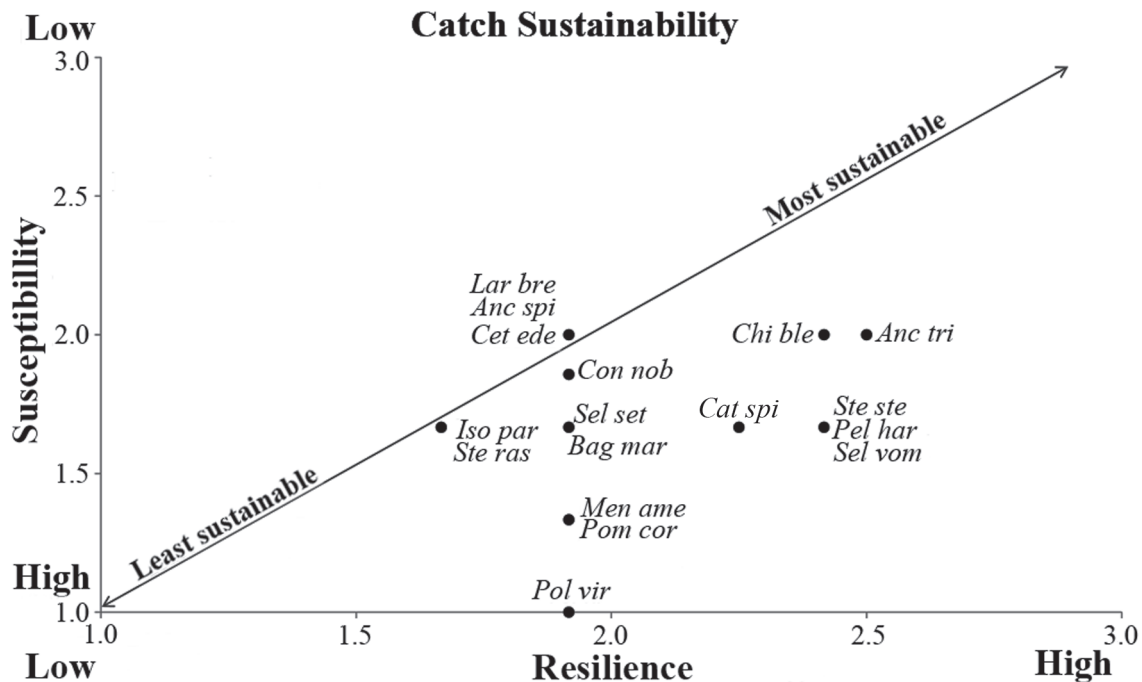

Fig. 2. Classification of bycatch species according to criteria indicating susceptibility to capture and resilience. The combination of these criteria provides a graphic that indicates the species with the most sustainable catch. Legend: Pom cor - *Pomadasys corvinaeformis*, Cat spi - *Cathorops spixii*, Ste ras - *Stellifer rastrifer*, Pel har - *Pellona harroweri*, Ste ste - *Stellifer stellifer*, Chi ble - *Chirocentrodon bleekerianus*, Lar bre - *Larimus breviceps*, Men ame - *Menticirrhus americanus*, Con nob - *Conodon nobilis*, Pol vir - *Polidactylus virginicus*, Anc spi - *Anchoa spinifer*, Sel set - *Selene setapinnis*, Iso par - *Isopisthus parvipinnis*, Cet ede - *Cetengraulius edentulus*, Anc tri - *Anchoa tricolor*, Sel vom - *Selene vomer*, Bag mar - *Bagre marinus*.
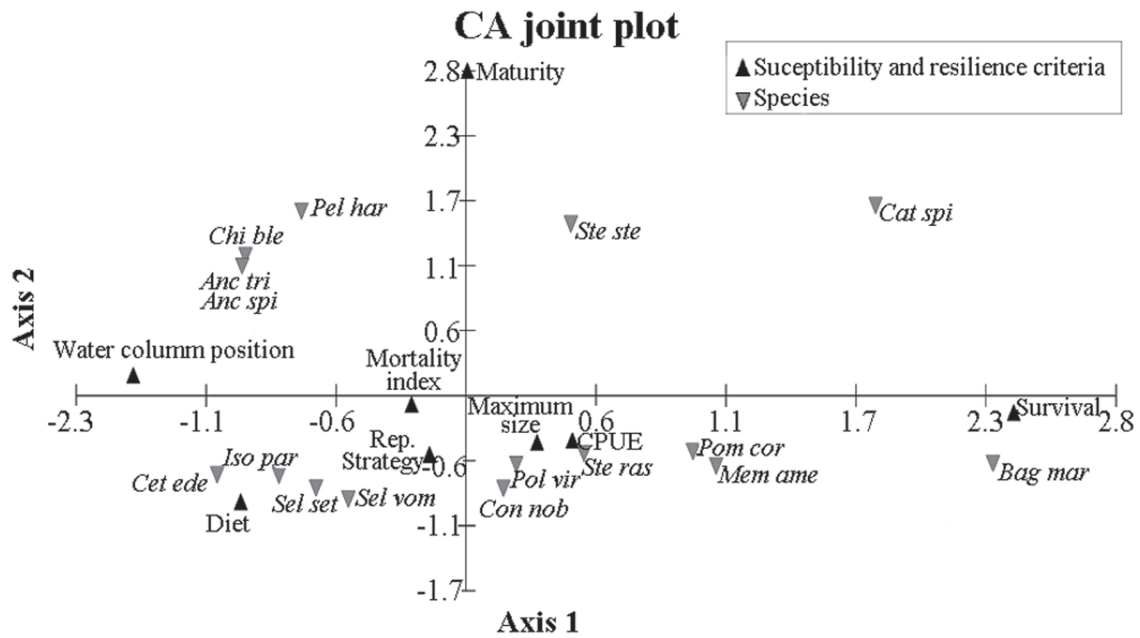
Fig. 3. Correspondence analysis showing the correlation among species and criteria used to evaluate the susceptibility and resilience. Legend: Pom cor - *Pomadasys corvinaeformis*, Cat spi - *Cathrops spixii*, Ste ras - *Stellifer rastrifer*, Pel har - *Pellona harroweri*, Ste ste - *Stellifer stellifer*, Chi ble - *Chirocentrodon bleekerianus*, Lar bre - *Larimus breviceps*, Men ame - *Menticirrhus americanus*, Con nob - *Conodon nobilis*, Pol vir - *Polidactylus virginicus*, Anc spi - *Anchoa spinifer*, Sel set - *Selene setapinnis*, Iso par - *Isopisthus parvipinnis*, Cet ede - *Cetengraulius edentulus*, Anc tri - *Anchoa tricolor*, Sel vom - *Selene vomer*, Bag mar - *Bagre marinus*, Rep - reproductive.

for the latter species (Carvalho-Filho, 1999). Conversely, *S. stellifer* and *C. spixii* was negatively related with this criterion, since their diet is composed mainly of polychaeta and crustacean (carcinofagous), but can feed on fishes, algae and mollusk (Menezes e Figueiredo, 1980; Le Bail *et al.*, 2000), which live in sandy-muddy bottoms. Overall, position in the water column, survival and diet were fundamental criteria in classifying the different species, such as *P. harroweri*, *L. breviceps* and *B. marinus*.

Variations can be related to the way the trawls are maneuvered - although they operate on the bottom, pelagic species can be caught during hauling. Thus, this study recorded pelagic species that were captured as bycatch: *A. spinifer*, *A. tricolor*, *C. bleekerianus*, *C. edentulus*, and *P. harroweri*. Additionally, an overlap between the depth that trawling takes place and species' spatial distribution in the water column may influence susceptibility to capture. If the habitat presents unfavorable conditions, some pelagic species will try to find areas with better living conditions (Woottom, 1989). Since these are school-forming species, migration contributes to their vulnerability to the fishing gear (Jennings *et al.*, 2001).

Species with late maturation are highly vulnerable to a possible risk of extinction (Roberts & Hawkins, 1999; Jennings *et al.*, 2001; Hutchings & Reynolds, 2004). Due to the high capture rate of individuals that had spawned at least once, *P. harroweri*, *C. bleekerianus*, *A. tricolor*, *S. stellifer*, and *C. spixii* showed a positive relationship with maturity. *Pomadasys corvinaeformis*

was negatively related to maturity, as most of the individuals captured were young. It was also verified that during the sampled period all of the abovementioned species - with the exception of *P. corvinaeformis* - had mean lengths greater than their size at maturity. In case of a population collapse this reproduction condition could improve the resilience process.

It is important to highlight that losses in life history parameters such as growth, fecundity and compensatory changes in survivorship help indicate the population's capacity to sustain (or not) a fishery. Issues like increases in the size at first maturity, decreases in the age at maturity and increases in fecundity correlated with increases in the size at maturity can be considered compensatory changes (Stearns & Crandall, 1984).

Large-sized species can often be linked to factors related to vulnerability, such as late maturity and a high probability of being caught by trawls (Reynolds *et al.*, 2005; Hutchings & Reynolds, 2004). However, in this study maximum size did not have a strong influence on species' resilience because none of the species captured attain large sizes.

It is difficult for a fishery to attain equilibrium when the fishing effort was reduced in a short period after overexploitation (King, 2007). The population can decrease if the natural mortality rate, combined with fishing mortality, reduces the stock's levels and this continues even when fishing stops (Woottom, 1989). When the number of organisms caught is higher than the number produced, it can be said that the stock is being overfished (Fonteles-Filho, 1989). However *Stellifer rastrifer*

and *B. marinus* presented extreme CPUE values (42.7 individuals/hour of trawling and 1.4 individuals/hour of trawling, respectively) and were not listed as least sustainable.

Among the species sampling in the present research, only *B. marinus* and *C. spixii* display demersal spawning and parental care (Fávaro *et al.*, 2005). These reproductive strategies have a negative influence on populations' ability to recover, as egg development depends on oral incubation (Carvalho-Filho, 1999; Fávaro *et al.*, 2005). Besides, all individuals of *B. marinus* were captured before reaching the size at first maturity; this might have happened because of this species' present late maturity (Pinheiro *et al.*, 2006). The sum of these two parameters might have promoted this species' low resilience.

If a large number of individuals of reproductive age are fished, recruitment levels may fluctuate. In terms of recruitment, overfishing may occur when a stock is fished down to a level in which recruitment alone cannot replace the number of individuals lost (Jennings *et al.*, 2001). In this case, it becomes extremely necessary to maintain a number of mature adults in a level that assures the population's continuity (King, 2007). Disequilibrium in recruitment may also result in an imbalance in age structure - it will increase the number of immature individuals in the fish stock, which will lead to a decrease in the size at sexual maturity (Fonteles-Filho, 1989). When the catchability of a given species remains high, there is a great probability that the size of the stock will decrease and the species will become at risk. This includes schooling and aggregating species, which are highly vulnerable even when stock abundance remains low (King, 2007).

When fishing mortality rates decrease after a collapse, it is expected that the population recover faster (Hutchings & Reynolds, 2004). An experiment conducted by Hutchings (2000) proved that populations which underwent a decrease in fishing mortality had their stock restored to 39% of the original size when compared to populations that remained constant or which mortality rate increased; in the last case only 29% of the original size was recovered. Thus, the mortality due to fishing might have to be reduced for a given population to recover.

Bagre marinus and *A. tricolor* had the highest and lowest mortality index values (17.9 and 0.7, respectively) among the species analyzed. High mortality rates are recorded when there is a considerable difference between the length of the fish caught and the maximum size according to the literature (Sparre & Venema, 1997). Fishing generally imposes a mortality rate that is strongly size selective, which can result in some phenotypic changes (such as alterations in reproductive parameters) as fish respond to the new environmental conditions (King, 2007; Nelson & Soulé, 1987). Normally, commercial trawling is performed in deeper areas, over 10 m (Somers, 1994), and more distant from the coast. However, in São Cristóvão Beach trawling is practiced in shallow waters and very close to coast.

Prawn trawling is clearly anthropogenic. The incidental capture of non-target species has been conducted unsustainably, as most of the organisms are caught before reaching their size at first maturity. Such a removal of species from the ecosystem can cause biodiversity losses and the local extinction of some species. Non-target species that are caught incidentally by fishing gear can be classified as vulnerable. Even at very low abundances, these species will continue to be caught, because the fishing gear is not selective. As a result of the fishery's multi-specific nature, it is difficult to implement mitigation measures for specific species. In this case it is suggest the creation of fishing exclusion zones with the purpose of promoting species' natural recovery without the interference of mortality caused by fishing.

Acknowledgments

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