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Ecological and conservation aspects of bycatch fishes: An evaluation of shrimp fisheries impacts in Northeastern Brazil

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Fishes accidentally caught, commonly known as bycatch, usually have no economic importance and are not reported in official statistics, being frequently discarded at sea (Crowder and Murawski, 1998). This bycatch contributes to alterations in the ecosystem, decline of populations, catch of juveniles and endangered species, threatening many marine populations (Pascoe, 1997). Despite significant efforts carried out towards the mitigation of the bycatch (Hazen et al., 2018), basic biological information is lacking for many non-target species, hampering the assessment of the real impact of this incidental catch and application of sustainable management actions in an ecosystem viewpoint.

Length-weight relationships (LWR) may be used to infer body condition indices, to estimate the fish weight from a known length and *vice versa* (Froese, 2006) and is often used as an input parameter in stock assessment and ecological modeling (Vaz-dos-Santos and Rossi-Wongtschowski, 2013).

In the Northeastern of Brazil, the shrimp fisheries are predominantly artisanal, carried out mainly by motorized artisanal trawling boats and, in some cases, beach seine nets (Dias Neto, 2011). This activity is focused on shallow waters and has great social-economic importance, since approximately 100,000 persons depend directly or indirectly of this fishery for their living (Santos et al., 2006). Previous studies focusing on the bycatch species in the northeast of Brazil (Silva-Június et al., 2013; Eduardo et al., 2019; Lira et al., in press) provided valuable biological and population information of a variety of species. However, many species still lack basic knowledge that is required for management and conservation actions, such as length-weight relationships and size at first gonadal maturity and also indicators of the ecological roles of the fish species, especially those related to the balancing of the marine food web which may influence the composition of this ecosystem (Elliott et al., 2007).

In this study, we provide LWR information and a review of literature addressing the size at first maturity, conservation status, and trophic and functional guilds of thirty-three fishes captured incidentally in a shrimp fishery in Northeast Brazil. We expect that this information may contribute to the general biological knowledge and hence to the sustainable management and conservation of these bycatch fish species.

The study was conducted in the municipality of Lucena (6° 53′50” S and 34° 51′01” W) on the coast of the state of Paraíba, Northeastern Brazil (Figure 1).

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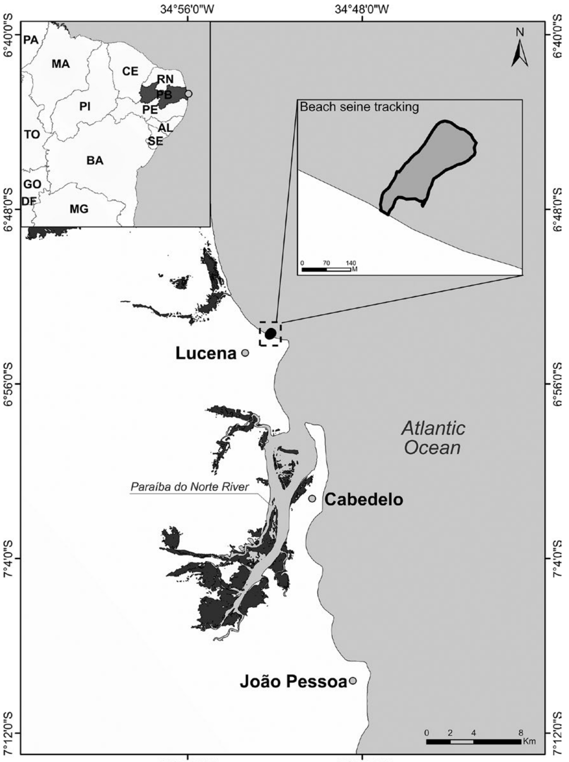

Figure 1. Map of the study area, coast of the state of Paraiba, Brazil.

Specimens were collected monthly from December 2016 to November 2017 using one of the local beach seines (out of 8), representative of the overall fleet, which is the predominant fishing modality in the region to catch shrimp. This net (side length of body mesh: 2 cm, side length of cod-end mesh: 1.5 cm, entrance dimensions horizontal x vertical: 120 × 6 m) was deployed from a small, non-motorized craft. Two trawls (50 minutes from the moment of the deployment of the net to the end of the operation) were performed monthly. Trawls were carried out from 6 m deep to the surf zone and a maximum distance of 500 m from shore.

Individuals were identified, measured (nearest 0.1 cm total length TL) and weighed (nearest 0.01 g in total weight TW). The LWR values were estimated for species with n > 30 specimens, using the equation: $TW = a \times TL^b$, where TW is the total weight (in g); TL is the total length (in cm); *a* is the intercept of the regression curve (intercept of TW when TL is zero or initial growth coefficient) and *b* is the regression slope. This coefficient generally varies between 2.5 and 3.5, and the relation is considered isometric when $b = 3$ (all fish increase at the same rate), positive allometric when $b > 3$ (increases more in weight than predicted by its increase in length) or negative allometric when $b < 3$ (fish increases less in weight than predicted by its increase in length) (Froese, 2006; Froese et al., 2011). Prior to calculation of the LWR, outliers for each species were graphically identified and removed using TL *versus* TW plots (Froese and Binohlan, 2000). The significance of the regression was tested by ANOVA and the degree of association between TW and SL was calculated by the determination coefficient (r^2).

For each species, it was recorded information on size at first maturity (L_{50}) and maximum length (L_{max}), available in the literature. Species were classified according to estuarine use functional groups (EUFG) as proposed by Elliott et al. (2007): marine straggler (MS), marine migrants (MM) and estuarine species (ES), and by the feeding mode functional groups (FMFG), based on information contained in the literature on food strategies, according to the categories proposed by Elliott et al. (2007): zooplanktivore (ZP), detritivore (DV), piscivorous (PV), zoobenthivore (ZB), herbivore (HV) and omnivore (OV). In addition, the conservation status of the species recorded in this study were based on the International Union for Conservation of Nature (IUCN) Red List criteria, accessed by classification at the regional level (ICMBio, 2018), which comprises 10 categories: extinct (EX), regionally extinct (RE), extinct in the wild (EW), critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC), data deficient (DD) and not evaluated (NE).

A total of 10,992 individuals of 11 families and 4 orders and 33 species were analyzed (Table 1). According to the IUCN classification, 29 species were categorized as least concern (LC), 3 species as data deficient (DD) (*Menticirrhus americanus*, *Ophioscion punctatissimus* and *Bagre marinus*) and 1 species as near threatened (NT) (*Bagre bagre)*, these last two categories deserving attention for management and conservation purposes (Table 1).

All LWR were highly significant ($p < 0.01$), with the coefficient of determination (r^2) ranging from 0.901 and 0.989. The value of the parameter *(b)* ranged between 2.45 for *O. mucronatus* and 3.498 from *A. spinifer*. Except for *O. mucronatus*, all species analysed in this study had the allometric coefficient (*b*) between the expected range of 2.5 to 3.5 (Froese, 2006). The allometric coefficient (*b*) for the length-weight ratio reflects intrinsic characteristics, and adaptive process of each species, as reproductive or environmental ontogenetic variations, and mainly, between sexes (Froese, 2006).

Table 1. Family and species of 33 species captured in a shrimp fisheries in Northeastern Brazil. Number of individuals (N), TL: total length (minimum and maximum), TW: total weight (minimum and maximum), *a* and *b*: regression parameters of LWRs (confidence interval), r^2: determination coefficient, length at first maturity (L_{50}), maximum length (Lmax). IUCN classification (data deficient (DD), least concern (LC), near threatened (NT), not evaluated (NE)); feeding mode functional groups (FMFG), zoobenthivore (ZB), piscivorous (PV), zooplanktivore (ZP), herbivore (HV) and omnivore (OV)); estuarine use functional group (EUFG), marine migrants (MM), marine straggler (MS) and estuarine species (ES)). (* without information of LWRs parameters for Brazil; ** Without information of LWRs parameters for Northeastern Brazil); (female (F), male (M), unidentified (U), pooled sexes (P)).

Family / Species	N	TL (cm) Min-Max	TW (g) Min-Max	Regression parameters			L_{50} (cm)	L_{max} (cm)	IUCN	FMFG	EUFG	Ref.
				a (95% CI)	*b* (95% CI)	r^2						
Clupeidae												
Harengula clupeola (Cuvier, 1829)	213	7.5-16.1	3.6-45.6	0.007 (0.005-0.009)	3.167 (3.049- 3.285)	0.929	U 14.3	P 22.5	LC	ZP	MS	1; 1; 2; 3
Opisthonema oglinum (Lesueur, 1818)	746	3.9-15	2.1-31.3	0.006 (0.005-0.007)	3.093 (3.157-3.029)	0.923	U 19.5	P 38.0	LC	ZP	MS	4; 5; 6; 3
Engraulidae												
Anchoa filifera ** (Fowler, 1915)	92	5.3-9.1	0.8-4.84	0.004 (0.003-0.007)	3.109 (2.898-3.321)	0.905	x	P 12.8	LC	ZB	ES	5; 7; 8
Anchoa spinifer (Valenciennes, 1848)	48	5.7-18.9	1-48.1	0.002 (0.001-0.002)	3.498 (3.360-3.637)	0.982	x	M e P 24	LC	PV	MM	5;9; 3
Anchovia clupeoides (Swainson, 1839)	135	8.4-16.7	2.7-37.4	0,002 (0,001-0,004)	3.343 (3.154-3.531)	0.902	x	M e P 30.0	LC	ZP	MM	10; 2; 3
Cetengraulis edentulus (Cuvier, 1829)	1207	7.4-14.6	2.0-27.5	0.002 (0.001-0.002)	3.498 (3.432-3.564)	0.901	U 14.7	M e P 18.2	LC	ZP	MM	11; 12; 2; 3
Lycengraulis grossidens (Spix and Agassiz, 1829)	488	6.4-23.5	1.2-115.1	0.003 (0.003-0.003)	3.279 (3.237-3.332)	0.98	F 11.2; M 13.3	P 23.5	LC	PV	ES	14; 15; 16; 17
Pristigasteridae												
Chirocentrodon bleekerianus (Poey, 1867)	920	3.3-16.4	0.2-15.7	0.004 (0.003-0.005)	3.069 (3.005-3.132)	0.909	U 7.6	P 16.1	LC	PV	MS	11; 18; 19; 8
Odontognathus mucronatus Lacepède, 1810	103	6-15.5	1.5-13.5	0.018 (0.013-0.025)	2.454 (2.309-2.599)	0.917	x	M e P 19.2	LC	HV	MS	20, 21, 8
Pellona harroweri (Fowler, 1917)	519	4.1-15.5	0.5-34.6	0.006 (0.005-0.007)	3.125 (3.083-3,167)	0.977	U 7.0	P 13.4	LC	ZB	MS	11; 5; 22; 23
Carangidae												
Chloroscombrus chrysurus (Linnaeus, 1766)	266	2.7-16	0.1-16.2	0.007 (0.006-0.009)	3.033 (2.935-3.131)	0.934	U 15.5	P 48.3	LC	ZB	MS	24; 5; 25; 3

CONTINUED TABLE 1.

Selene brownii (Cuvier, 1816)	36	4-14.3	0.5-37.5	0.014 (0.010-0.019)	2.914 (2.737-3.091)	0.97	x	P 29.0	LC	ZB	MS	5; 26; 27
Selene vomer (Linnaeus, 1758)	88	2.4- 24.4	0.1-161.8	0.012 (0.010-0.013)	3.012 (3.086-2.938)	0.987	U 24.1	P 48.3	LC	PV	MS	11; 28; 29; 3
Ephippidae												
Chaetodipterus faber (Broussonet, 1782)	47	3.2-26.3	0.74-530.8	0.023 (0.018-0.030)	3.141 (3.012-3.269)	0.982	F 14.4; M 9.8	M e P 91.0	LC	OV	MM	30; 31; 32; 33
Haemulidae												
Conodon nobilis (Linnaeus, 1758)	154	4.3-17.3	0.2-67.1	0.006 (0.004-0.009)	3.284 (3.114-3.453)	0.906	U 16.0	P 34.2	LC	ZB	MM	11; 34; 34; 3
Haemulopsis corvinaeformis (Steindachner, 1868)	418	5.3-18.6	1.7-93	0.007 (0.006-0.008)	3.202 (3.151-3.253)	0.974	F 11.8; M11.0	P 25.0	LC	ZB	MS	35; 35; 36; 37
Polynemidae												
Polydactylus virginicus (Linnaeus, 1758)	578	3.5-25	0.3-169.4	0.003 (0.002-0.003)	3.368 (3.313-3.422)	0.962	x	P 33.0	LC	ZB	MM	38; 39; 3
Sciaenidae												
Isopisthus parvipinnis (Cuvier, 1830)	709	3.7-24.5	0.4-130.9	0.005 (0.005-0.006)	3.126 (3.082-3.169)	0.966	F 14.5; M 13.2	M e P 25.0	LC	PV	MM	40; 28; 41; 40
Larimus breviceps Cuvier, 1830	986	4.2-23	0.68-167.7	0.005 (0.005-0.006)	3.238 (3.197-3.278)	0.961	F 13.5; M 13.3	P 31.0	LC	ZB	MM	40; 5; 42; 43
Macrodon ancylodon (Bloch and Schneider, 1801)	97	5.8-24.9	1.7-95.4	0.015 (0.011-0.021)	2.712 (2.595-2.829)	0.957	U 22.1	P 45.0	LC	PV	MM	44; 28; 45; 46
Menticirrhus americanus (Linnaeus, 1758)	83	5.4-24.8	1.25-160.7	0.006 (0.005-0.007)	3.116 (3.044-3.189)	0.989	U 18.1	M e P 50.0	DD	ZB	MM	11; 28; 47; 48
*Ophioscion punctatissimus*** Meek and Hildebrand, 1931	85	4.8-19.5	1.1-108.4	0.004 (0.003-0.006)	3.358 (3.215-3.501)	0.963	x	M e P 25.0	DD	ZB	MM	49; 50; 51
Stellifer brasiliensis (Schultz, 1945)	96	4.9-16.9	0.6-54.1	0.004 (0.003-0.005)	3.297 (3.157-3.438)	0.959	F 9.4; M 8.7	P 17.0	LC	ZB	MM	52; 18; 9; 3
Stellifer microps (Steindachner, 1864)	533	5-13.5	0.6-22.5	0.006 (0.005-0.007)	3.153 (3.068-3.239)	0.908	F 8.2; M12.5	M e P 20.0	LC	ZB	ES	40; 53; 54; 55
Stellifer rastrifer (Jordan, 1889)	449	4.1-18.1	0.53-56.1	0.005 (0.004-0.006)	3.298 (3.223-3.373)	0.943	U 9.5	P 17.0	LC	ZB	MM	11; 44; 9; 9

Continued table 1.

Stellifer stellifer (Bloch, 1790)	528	5.6-13.2	1.6-31.7	0.005 (0.004-0.006)	3.299 (3.207-3.391)	0.904	U 7.5	P 15.0	LC	ZB	ES	11; 21; 56; 57
Trichiuridae												
Trichiurus lepturus Linnaeus, 1758	752	18.5-83.9	2.4-380.8	0,0001 (0.00009-0.00015)	3.368 (3.300-3.436)	0.927	U 71.1	P 234.0	LC	PV	MS	1; 58; 59; 3
Ariidae												
Aspistor quadriscutis (Valenciennes, 1840)	48	5.3-35.2	1.01-369.5	0.003 (0.002-0.004)	3.285 (3.112-3.458)	0.97	x	P 50.0	LC	ZB	MS	60; 61; 62
Bagre bagre (Linnaeus, 1766)	58	6.7- 37.4	1.9-353.6	0.005 (0.003-0.008)	3.032 (2.880-3.184)	0.966	F 15.9; M 21.2	P 55.0	NT	ZB	MM	63; 5; 64, 65
Bagre marinus (Mitchill, 1815)	198	4-24.6	0.3-86.4	0.002 (0.001-0.003)	3.352 (3.507-3.197)	0.903	U 33.0	P 60.0	DD	ZB	MM	11; 66; 67; 67
Cathorops spixii (Agassiz, 1829)	152	5-25.7	0.5-147.3	0.002 (0.002-0.003)	3.410 (3.343-3.477)	0.985	U 12.0	P 30.0	LC	ZB	ES	11; 60; 3; 3
*Cathorops agassizii*** (Eigenmann and Eigenmann, 1888)	120	5.2-26.9	0.91-137.7	0.004 (0.003-0.005)	3.217 (3.112-3.322)	0.969	U 14.0	P 22.5	LC	ZB	ES	68, 12; 68; 57
Tetraodontidae												
*Lagocephalus laevigatus*** (Linnaeus, 1766)	40	3.3-10.8	0.57-21.7	0.017 (0.011-0.026)	3.011 (2.745-3.277)	0.933	x	P 100.0	LC	HV	MM	69; 70; 71

1- (da Costa et al., 2018); 2- (de Paiva et al., 2008); 3- (Vasconcelos-Filho and Oliveira, 1999); 4- (Petermann and Schwingel, 2016); 5 - (Cervigón et al., 1992); 6- (Vasconcelos-Filho, 1979); 7- (Muto et al., 2014); 8- (Passos et al., 2013); 9- (Nizinski and Munroe, 2002); 10- (Bigelow et al., 1963); 11- (Silva Júnior at al., 2013); 12- (Giarrizzo et al., 2006); 13- (Vasconcelos-Filho and Oliveira, 2001); 14- (Ramos, 2006); 15- (Kullander and Ferraris, 2003); 16- (Bortoluzzi et al., 2006); 17- (Mai and Vieira, 2013); 18 - (Barreto et al., 2018); 19 - (Corrêa et al., 2005); 20- (Freire et al., 2009); 21- (Santos et al., 2011); 22- (Muto et al., 2008); 23 - (Andrade, 2016); 24- (de Queiroz et al., 2018); 25- (Silva and Lopes, 2002); 26- (Bomfim, 2014); 27- Marinesp.ecies.org; 28- (Cervigón, 1993); 29- (Daros, 2014); 30- (Soeth et al., 2019); 31- (Robins and Ray, 1986); 32- (Vasconcelos-Filho et al, 2009); 33- (Riede, 2004); 34- (Pombo et al., 2014); 35- (Eduardo et al., 2018); 36-(Denadai et al., 2013) ; 37- (Paiva et al., 2009); 38- (Motomura, 2004); 39- (Lopes and Oliveira-Silva, 1998); 40-(Silva-Júnior et al., 2015); 41- (Lira et al., 2013a); 42- (de Moraes et al, 2004); 43- (Bessa et al., 2014) 44- (Camargo and Isaac, 2005); 45- (Bezerra Figueiredo et al., 2014); 46- (Militelli and Macchi, 2004); 47- (Lira et al., 2013b); 48- (Schmidt and Dias, 2012); 49- (Chao, 1978); 50- (Zahorcsak et al., 2000); 51- (Spach et al., 2004); 52- (Rodrigues-Filho et al., 2011); 53- (Chao, 1978); 54- (Giarrizzo and Krumme, 2007); 55- (Barletta and Blaber, 2007); 56- (Pombo et al., 2013); 57- (Dantas et al., 2015); 58- (Claro, 1994); 59- (Vasconcelos-Filho et al., 2010); 60- (Taylor and Menezes, 1978); 61- (Mendes and Barthem, 2010); 62- (de Andrade-Tubino et al., 2008); 63- (Véras and Almeida, 2016); 64- (Le Bail et al., 2000) 65- (Mourão et al., 2014); 66- (IGFA, 2001); 67- (Mendoza-Carranza, 2013); 68- (Dantas et al., 2012); 69- (Shipp, 1981); 70 -(Denadai et al., 2012); 71- (de Andrade, 2015).

The classification in functional guilds is widely used to investigate the composition, and spatial-temporal distribution of ichthyofauna (Akin et al., 2005; Ferreira et al., 2019). This approach can be used to simplify the understanding of complex ecosystems by generating information about the hierarchical structure and connectivity (Garrison and Link, 2000; Angel and Ojeda, 2001; Franco et al., 2008; Nicolas et al., 2010) investigating anthropic stressors, including the effect of fishing (Auster and Link, 2009). According to the feeding mode functional groups (FMFG), 19 species were classified as zoobenthivore (ZB), 7 species as piscivorous (PV), 4 species zooplanktivore (ZP), 2 species herbivore (HV), and 1 species omnivore (OV). The predation of detritivores organisms and the interaction with sedimentary organic matter carried out by zoobenthivores play an important role between primary consumers and higher trophic levels in the food web (Duarte and Andreata, 2003).

Lycengraulis grossidens, Chirocentrodon bleekerianus, Pellona harroweri and *Stellifer rastrifer* were caught above the maximum size described in the literature. We observed the predominant catch of specimens below the length of first maturation (89% of the individuals) (Table 1). The high catch of juveniles is characteristic of shrimp trawling. In Pernambuco, near to the study site, Silva Júnior et al. (2013) observed that 64% of the individuals caught are below the size of first maturation (L_{50}). The low selectivity of the fishing gear (Branco and Verani, 2006) and in our case the very shallow fishing zone may contribute to high juvenile catches, due to the lower swimming capacity at this stage, when compared to the adult specimens. In this study, according to the estuarine use functional group (EUFG), 16 species were categorized as marine migrants (MM), 11 species as marine straggler (MS) and 6 estuarine (ES) (Table 1). The high percentage of juveniles may also be related to the migratory behaviour of the species living in the adjacent open sea, migrating to the coastal and estuarine waters during spawning, using these areas for shelter and feeding (Pinheiro-Sousa et al., 2015), emphasizing the importance of the connectivity between the coastal and marine environment (Vasconcelos-Filho et al., 2009).

Overall, this study increases the knowledge on coastal fish, normally captured as bycatch, providing biological information useful for further studies in ecology, conservation, and fisheries assessment and management.

Thus, given the high catch of juveniles, species marine migrant and zoobenthivores in Lucena-PB, northeast Brazil, the present study reiterates the need for new approaches which appraise the species susceptibility, for a better evaluation of fishing impacts, such as, to improve the management measures, considering non-target species as a way of guaranteeing biodiversity and ecosystem stability.

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