FISH BYCATCH OF THE LAULAO CATFISH *Brachyplatystoma vaillantii* (VALENCIENNES, 1840) TRAWL FISHERY IN THE AMAZON ESTUARY

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ABSTRACT

This study aimed to analyse the composition and seasonal variation in the fish bycatch of the *Brachyplatystoma vaillantii* trawl fishery in the Amazon Estuary in 2009 by monitoring the trips of 48 vessels. The bycatch represented 29% of the catches, totalling 22,228 specimens and 52 taxa, distributed in 22 families (the principal families were Ariidae, Pimelodidae, and Sciaenidae). *Brachyplatystoma rousseauxii*, *Plagioscion squamosissimus*, and *Sciades herzbergii* together contributed 69% of the bycatch and were considered consistent bycatch species. Although a higher proportion of bycatch was captured during the rainy season, the seasonal difference was not significant. A multidimensional scaling (MDS) ordination analysis and an analysis of similarity (ANOSIM) indicated that the species composition of the bycatch was similar across the seasons. However, larger numbers of *B. rousseauxii* and *P. squamosissimus* were captured during the rainy season, whereas *S. herzbergii* predominated during the dry season. The marine migrants and estuarine species guilds showed the greatest richness, whereas freshwater migrants were the most numerous. Among the feeding guilds, the zoobenthivores were the most diverse, whereas the piscivores were the most abundant. The results indicate that fishing pressure primarily affects small- (20-30 cm) and medium-sized (30-50 cm) individuals, although the catch of *P. squamosissimus* was composed primarily of adults. However, the catches of both *B. rousseauxii* and *B. vaillantii* were composed primarily of juveniles.

RESUMO

Este estudo objetivou analisar a composição e variação sazonal da ictiofauna acompanhante da pesca de arrasto de *Brachyplatystoma vaillantii* no estuário amazônico, em 2009, através do monitoramento de viagens de 48 embarcações. A ictiofauna acompanhante representou 29% das capturas, totalizando 22.228 indivíduos e 52 táxons pertencentes a 22 famílias, sendo estas as principais: Ariidae, Pimelodidae e Sciaenidae. *Brachyplatystoma rousseauxii*, *Plagioscion squamosissimus* e *Sciades herzbergii* representaram juntas 69% da captura e foram consideradas constantes. Embora o maior percentual de captura tenha ocorrido no período chuvoso, as diferenças sazonais não foram significativas. Análises de ordenação (MDS) e de similaridade (ANOSIM) mostraram que a composição da captura entre os períodos é semelhante; entretanto, maiores capturas de *B. rousseauxii* e *P. squamosissimus* foram observadas no período chuvoso, enquanto *S. herzbergii* foi dominante no período seco. As guildas migrantes marinhas e espécies estuarinas apresentaram maior riqueza, enquanto as migrantes dulcícolas predominaram em percentual de indivíduos. Considerando as guildas alimentares, as zoobentívoras apresentaram a maior riqueza, enquanto as piscívoras predominaram em abundância relativa. Os resultados indicam que a pressão pesqueira atua sensivelmente sobre os indivíduos de pequeno (20-30 cm) e médio (30-50 cm) porte, embora a captura de *P. squamosissimus* seja composta predominantemente por adultos. A captura de *B. rousseauxii* e *B. vaillantii*, entretanto, foi composta predominantemente por juvenis.

Descriptors: Industrial fishing, Diversity, Juveniles, Catfish.
Descritores: Pesca industrial, Diversidade, Juvenis, Bagre.

INTRODUCTION

In the early 1990s, when fisheries throughout the world began to approach the theoretical limits of fish production and competition for limited resources grew alarmingly, the need for the more rational exploitation of fishery resources became increasingly apparent. The capture of bycatch has a number of negative effects from an ecological perspective. Bycatch also causes economic and biological losses (ALVERSON; HUGHES, 1996; HALL; MAINPRIZE, 2005). One of the major problems associated with bycatch, as the result of non-selective fishing practices, is that bycatch may include juveniles of commercial and non-commercial species or individuals of threatened, protected or endangered species (ALVERSON et al., 1994; KENELLY, 1995; LEWISON et al., 2004). Another negative aspect is the discarding of fish (SAILA, 1983; ALVERSON et al., 1994; STOBUTZKI et al., 2003), which constitutes a serious problem for managers because it represents an unquantified mortality variable in fisheries (ALVERSON; HUGHES, 1996). Consequently, populations that are subject to bycatch can decline over short timescales, often without previous detection (CASEY; MYERS, 1998).

From an ecological perspective, the capture of bycatch can produce several negative effects on the ecosystem, including loss of biodiversity and changes in habitat and densities of predators and prey (LEWISON et al., 2004; STOBUTSKI et al., 2003; CLUCAS, 1997; MURRAY et al., 1992).

An estimated seven million tons of bycatch are discarded by fisheries worldwide each year (KELLEHER, 2005). Off the coast of northern Brazil, approximately 30 thousand tons of bycatch are discarded annually by marine and estuarine fisheries, in particular by trawlers (ISAAC, 1998). In the Amazon Estuary, industrial trawling is one of the most important fishery activities in terms of both the volume of the catch landed and the income derived from this activity (IBAMA, 2007). One of the principal targets of the industrial trawler fleets of northern Brazil is the laulao, *Brachyplatystoma vaillantii* (Valenciennes, 1840), a freshwater catfish of the Pimelodidae family, which is widely distributed in the river basins of northern South America (MEES, 1974).

The fishery for large migratory catfishes, such as the laulao catfish, is conducted in almost the entire Amazon basin. Brazilian, Colombian and Peruvian fishermen jointly exploit an area that extends from Tefé, in the Middle Solimões River, to Iquitos, in Peru. The main landing ports are located in Pará State and in Letícia, Colombia (BARTHEM; GOULDING, 1997; FABRÉ; ALONSO, 1998; FABRÉ et al., 2000; PARENTE et al., 2005). Nearly ten thousand tons of fish are landed per year in Leticia.

In Brazil, the peak of laulao captures occurred in the 1970s, when approximately 29 thousand tons were landed. This period also corresponded to the peak of tax incentives and investments in fishing equipment. During the ‘80s, however, the relative laulao catfish stock showed signs of depletion (BARTHEM; GOULDING, 1997), and the stock was classified as overfished (BARTHEM; PETRERE, 1995). Currently, the stock shows signs of recovery. Between 2007 and 2010, the fishery landed an average of approximately 24,400 tons per year (MPA, 2012). During this period, approximately 2,300 tons of this species were exported, generating an income of more than US$ 2 million (MDIC/ALICEWEB, 2007-2010). Isaac (1998) estimated that approximately 12% of the *B. vaillantii* catch is discarded as bycatch.

The objective of the present study was to contribute to the discussion of the impact and potential management of bottom trawl fisheries. Specifically, the study analysed the composition and seasonal variation of the fish fauna captured as bycatch during industrial trawling for laulao catfish in the Amazon Estuary.

Material and Methods

Study Area

The Amazon Estuary has megathermic weather, with a relative humidity above 80% and a mean air temperature of 25ºC. The region has two distinct seasons: rainy (January to June) and dry (July to December) (MARTORANO et al., 1993). The average annual rainfall is 2,214 mm (MORAES et al., 2005).

Data Collection

Approximately 20% of the trips of the Amazonian laulao trawling fleet (48 vessels) were monitored between January and December, 2009. This fleet conducts pair trawling in the Amazon Estuary between latitudes 00°03.7’N and 01°40.7’N and longitudes 48°5.7’W and 49°54.4’W (Fig. 1). Overall, 575 trawl hauls were examined. In each case, five baskets of fish were sampled randomly. Prior to landing, the specimens were identified, and the total (TL), fork (FL), and standard (SL) lengths were measured.

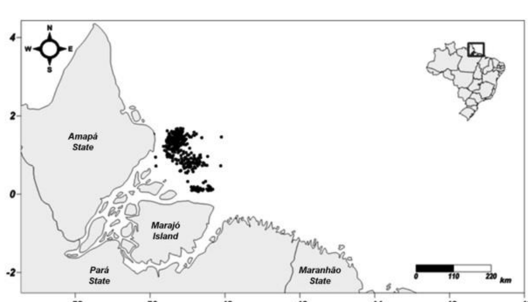

Fig. 1. Operational area of the industrial trawler fleet that targets *B. vaillantii* off the northern coast of Brazil in 2009.

Data Analysis

Catch Composition and Frequency of Occurrence

The composition of the catches was evaluated in terms of their species richness, relative frequency, and frequency of occurrence (%F). These parameters were calculated for the entire study period and separately for the rainy and dry seasons, which were defined as in Martorano et al. (1993). The seasonal variation in the proportion of bycatch was evaluated using a chi-square test at a 5% significance level. Between-season differences in species richness were tested with a one-way ANOVA. Shapiro-Wilk and Cochran tests were used to test the normality and homoscedasticity of the data, respectively. If necessary, the data were log(x+1) transformed.

The frequency of occurrence of the different species was classified according to the scheme of Dajoz (1973), in which a frequency of occurrence (%F) value of 50% or above is considered to be constant, 25-50% accessory, and less than 25% occasional. A multidimensional scaling (MDS) ordination analysis was used to evaluate the similarities in the structure of the fish assemblage between seasons. An analysis of similarity (ANOSIM) was used to test whether the groups found by MDS were statistically different (CLARKE, 1993).

Ecological Guilds

The available data on the ecology of the identified fish species in transitional environments was used to classify the species according to two functional features (based on Elliot et al., 2007): (1) the way the fish uses the estuary over the course of its life cycle, i.e., the Estuarine Use Functional Group, or EUFG, and (2) its feeding preferences and strategies, known as the Feeding Mode Functional Group, or FMFG.

All species were allocated to one of the environmental guilds (EUFGs) defined by Elliott et al. (2007): Marine Stragglers (MS), Marine Migrants (MM), Estuarine Species (ES), Freshwater Migrants (FM), and Freshwater Stragglers (FS). These guilds were defined primarily in terms of the type, frequency, and period of use of the estuarine environment and the abundance of the species in the estuary.

The feeding guilds (FMFGs) were defined according to the available literature (KRUMME et al., 2004; ELLIOTT et al., 2007). The species were classified as zooplanktivore (ZP), detritivore (DV), herbivore (HV), piscivore (PV), zoobenthivore (ZB), omnivore/opportunist (OV/OP), and piscivore/zoobenthivore (PV/ZB). The latter two categories were included based on data collected in the present study. The FMFGs were identified by combining the data available on the predominant diet and feeding site. If few data were available for a species, trophic preferences were inferred from the information gathered by the Fishbase project (FROESE; PAULY, 2010). The guilds were based on the percentage of both species and number of individuals, following Selleslagh et al. (2009).

Body Length and Catch Probability

The cumulative frequency of the body lengths of the target and principal bycatch species was adjusted to a logistic model to estimate the length at which the catch probability is 50% (P_{50}). The P_{50} values were compared with those for first sexual maturity (L_{50}) available in Vásquez et al. (2009) for *B. vaillantii*, Fabré et al. (2000) for *Brachyplatystoma rousseauxii*, and Barbosa et al. (2012) for *Plagioscion squamosissimus*.

Results

Catch Composition

A total of 75,714 specimens were collected during the study period. The bycatch represented 29% of the catches, totalling 22,228 specimens and 52 taxa, of which 41 were identified to species level, representing 22 families (Table 1). Species richness was similar between seasons, with 47 species observed in the rainy season and 42 in the dry season (ANOVA, $p > 0.05$). The Sciaenidae, Pimelodidae, and Ariidae families together represented 44% of the total number of species and 91% of the specimens collected (Table 1).

Overall, 47% of the species captured were classified as occasional ($F < 25\%$), whereas *Pellona flavipinnis* and *Lithodoras dorsalis* were classified as accessory. Only *B. rousseauxii*, *P. squamosissimus*, and *Sciades herzbergii* were considered to be consistent and essential members of the bycatch from industrial laulao trawling. Individuals of these three species represented 39.9%, 17.4%, and 11.2%, respectively, of the total bycatch (Table 1), together constituting approximately 69% of the sample.

Taxa recorded exclusively in only one of the two seasons were relatively rare. Five taxa (*Cathorops spixii*, *Genyatremus luteus*, *Mugil* sp., *Plagioscion auratus*, and *Stellifer* spp.) were captured exclusively in the dry season and ten in the rainy season (*Colomesus psittacus*, *Oligoplites* sp., *Scomberomorus brasiliensis*, *Acanthocybium solandri*, *Hypostomus punctatus*, *Eigenmannia virescens*, *Polydactylus virginicus*, *Trinectes paulistanus*, *Dasyatis geijskesi*, and jururema). A total of 37 taxa occurred throughout the study period.

Although the bycatch represented a higher percentage during the rainy season than during the dry season, the difference was not significant (chi-square, P > 0.05). Among the principal species, the highest relative frequency of *S. herzbergii* occurred during the dry season (14.4%), whereas *B. rousseauxii* (46.1%) and *P. squamosissimus* (23%) were captured in higher numbers during the rainy season (Table 1).

A MDS ordination analysis found no evidence of distinct species groups between seasons (Fig. 2). The *R* value for the ANOSIM was also relatively low (*R* = 0.113). This value indicates that between- and within-group similarity is high.

Table 1. Absolute and relative frequency (total and by seasons), minimum (Min) and maximum (Max) lengths (in centimetres - cm) and ecological guilds of species captured as bycatch of laulao trawling in the Amazon estuary. Total Length (*); Fork Length (**); Feeding Mode Functional Group (FMFG); Zooplanktivore (ZP); Detritivore (DV); Herbivore (HV); Piscivore (PV); Zoobenthivore (ZB); Piscivore/Zoobenthivore (PV/ZB); Estuarine Use Functional Group (EUFG); Marine Stragglers (MS); Marine Migrants (MM); Estuarine Species (ES); Freshwater Migrants (FM); and Freshwater Stragglers (FS).

Family	Scientific name	Absolute Frequency			Relative Frequency			Length Ranges (cm)		Guilds		
		Total	Rainy	Dry	Total	Rainy	Dry	Min	Max	FMFG	EUFG	Source
Achiridae												
	Achirus sp.	10	8	2	0.04	0.07	0.02	17.0*	30.0*	-	-	
	Apionichthys dumerili Kaup, 1858	14	7	7	0.06	0.06	0.06	16.0*	42.0*	-	FM	Froese & Pauly (2010)
	Trinectes paulistanus (Miranda Ribeiro, 1915)	8	8	-	0.04	0.07	-	20.0*	40.0*	ZB	MM	Froese & Pauly (2010)
Ageneiosidae												
	Ageneiosus inermis (Linnaeus, 1766)	90	56	34	0.40	0.50	0.31	17.0**	53.0**	PV/ZB	FS	Froese & Pauly (2010);
Ariidae												
	Amphiarius rugispinis (Valenciennes 1840)	285	31	254	1.28	0.28	2.29	15.0**	47.0**	ZB	ES	Mendes & Barthem (2010); Espírito Santo et al. (2005)
	Aspistor quadriscutis (Valenciennes, 1840)	1122	286	836	5.05	2.56	7.55	14.0**	63.0**	ZB	ES	Barros et al. (2011); Froese & Pauly (2010); Mendes & Barthem (2010)
	Bagre bagre (Linnaeus, 1766)	538	188	350	2.42	1.69	3.16	18.0**	63.2**	PV/ZB	MM	Froese & Pauly (2010); Léopold (2004)
	Cathorops spixii (Agassiz, 1829)	1	-	1	0.00	-	0.01	27.0**	27.0**	ZB	ES	Barletta & Blaber (2007)
	Notarius grandicassis (Valenciennes, 1840)	370	210	160	1.66	1.88	1.44	16.0**	72.0**	ZB	ES	Froese & Pauly (2010); Léopold (2004); Krumme et al. (2004)
	Sciades herzbergii (Bloch, 1794)	2498	898	1600	11.24	8.05	14.45	10.0**	130.0**	ZB	ES	Krumme et al. (2008); Giarrizzo & Saint-Paul (2008); Barletta & Blaber (2007); Krumme et al. (2004)
	Sciades parkeri (Traill, 1832)	425	140	285	1.91	1.26	2.57	10.0**	140.0**	PV/ZB	ES	Froese & Pauly (2010)
	Sciades proops (Valenciennes, 1840)	84	16	68	0.38	0.14	0.61	17.0**	76.0**	PV	ES	Barros et al. (2011); Froese & Pauly (2010)
Aspredinidae												
	Aspredo aspredo (Linnaeus, 1758)	264	144	120	1.19	1.29	1.08	15.0*	50.0*	DV	ES	Froese & Pauly (2010); Espírito Santo et al. (2005); Léopold (2004); Camargo & Isaac (1998)
Auchenipteridae												
	Pseudauchenipterus nodosus (Bloch, 1794)	38	8	30	0.17	0.07	0.27	15.0**	53.0**	ZB	FS	Barros et al. (2011); Krumme et al. (2004)

Table 1. Cont.

Family	Scientific name	Absolute Frequency			Relative Frequency			Length Ranges (cm)		Guilds		
		Total	Rainy	Dry	Total	Rainy	Dry	Min	Max	FM FG	EUFG	Source
Batrachoididae												
	Batrachoides surinamensis (Bloch & Schneider, 1801)	22	10	12	0.10	0.09	0.11	31.0*	62.0*	PV/ ZB	ES	Barletta & Blaber (2007); Krumme et al. (2004)
Carangidae												
	Oligoplites sp.	1	1	-	0.00	0.01	-	33.0**	33.0**	-	-	
Centropomidae												
	Centropomus sp.	6	1	5	0.03	0.01	0.05	30.0**	68.0**	-	-	
Dasyatidae												
	Dasyatis geijskesi Boeseman, 1948	22	22	-	0.10	0.20	-	30.0*	97.0*	ZB	MS	Froese & Pauly (2010); Espírito Santo et al. (2005); Léopold (2004)
Doradidae												
	Lithodoras dorsalis (Valenciennes, 1840)	548	324	224	2.47	2.91	2.02	12.0**	60.2**	HV	FS	Froese & Pauly (2010)
Ephippidae												
	Chaetodipterus faber (Broussonet, 1782)	4	2	2	0.02	0.02	0.02	32.0*	46.0*	ZB	MM	Krumme et al. (2004)
Haemulidae												
	Genyatremus luteus (Bloch, 1790)	5	-	5	0.02	-	0.05	23.0*	36.0*	ZB	MM	Barletta & Blaber (2007); Krumme et al. (2004)
Loricariidae												
	Hypostomus punctatus Valenciennes, 1840	2	2	-	0.01	0.02	-	39.0*	50.0*	DV	FS	Froese & Pauly (2010)
Mugilidae												
	Mugil incilis Hancock, 1830	58	7	51	0.26	0.06	0.46	23.1**	54.0**	-	MS	Barros et al. (2011)
	Mugil sp.	6	-	6	0.03	-	0.05	30.0**	47.0**	-	-	
Pimelodidae												
	Brachyplatystoma filamentosum (Lichtenstein, 1819)	221	192	29	0.99	1.72	0.26	2.0**	188.0**	PV	FM	Espírito Santo et al. (2005); Barthem & Goulding (1997)
	Brachyplatystoma platynemum Boulenger, 1898	67	10	57	0.30	0.09	0.51	12.0**	66.0**	PV	FS	Froese & Pauly (2010)
	Brachyplatystoma rousseauxii (Castelnau, 1855)	8887	5147	3740	39.98	46.15	33.7 7	10.0**	170.0**	PV	FM	Espírito Santo et al. (2005); Barthem & Goulding (1997)
	Hypophthalmus marginatus Valenciennes, 1840	47	21	26	0.21	0.19	0.23	12.2**	44.0**	ZP	FM	Froese & Pauly (2010); Junk (1985)
	Pimelodella cristata (Müller & Troschel, 1848)	7	4	3	0.03	0.04	0.03	10.0**	28.2**	ZB	FS	Froese & Pauly (2010)
	Pinirampus pirinampu (Spix & Agassiz, 1829)	9	1	8	0.04	0.01	0.07	37.0**	67.0**	PV	FS	Froese & Pauly (2010)
Polynemidae												
	Polydactylus virginicus (Linnaeus, 1758)	3	3	-	0.01	0.03	-	33.0**	50.0**	ZB	MM	Barletta & Blaber (2007)
Pristigasteridae												
	Pellona flavipinnis (Valenciennes, 1837)	509	273	236	2.29	2.45	2.13	4.0**	72.7**	PV	FM	Froese & Pauly (2010); Léopold (2004)
Sciaenidae												
	Ctenosciaena gracilicirrhus (Metzelaar, 1919)	633	93	540	2.85	0.83	4.88	15.0*	83.1*	ZB	MS	Froese & Pauly (2010)
	Cynoscion acoupa (Lacepède, 1801)	96	65	31	0.43	0.58	0.28	32.0*	99.0*	PV/ ZB	MM	Krumme et al. (2004)
	Macrodon ancylodon (Bloch & Schneider, 1801)	88	5	83	0.40	0.04	0.75	14.0*	53.0*	PV/ ZB	MM	Camargo & Isaac (2004); Krumme et al. (2004)
	Micropogonias furnieri (Desmarest, 1823)	509	67	442	2.29	0.60	3.99	13.5*	89.0*	ZB	MM	Krumme et al. (2004)

Table 1. Cont.

Family	Scientific name	Absolute Frequency			Relative Frequency			Length Ranges (cm)		Guilds		
		Total	Rainy	Dry	Total	Rainy	Dry	Min	Max	FMFG	EUFG	Source
Sciaenidae												
	Nebris microps Cuvier, 1830	4	2	2	0.02	0.02	0.02	27.0*	34.0*	ZB	MM	Froese & Pauly (2010); Espírito Santo et al. (2005)
	Plagioscion auratus (Castelnau, 1855)	1	-	1	0.00	-	0.01	35.0*	35.0*	PV	FS	Barros et al. (2011); Froese & Pauly (2010)
	Plagioscion squamosissimus (Heckel, 1840)	3879	2572	1307	17.45	23.06	11.80	7.0*	90.0*	PV	FM	Espírito Santo et al. (2005); Léopold (2004)
	Plagioscion surinamensis (Bleeker, 1873)	371	240	131	1.67	2.15	1.18	10.0*	140.0*	PV	FM	Froese & Pauly (2010)
	Stellifer spp.	155	-	155	0.70	-	1.40	27.0*	58.0*	-	-	
Scombridae												
	Acanthocybium solandri (Cuvier, 1832)	2	2	-	0.01	0.02	-	37.0**	37.0**	PV	MM	Froese & Pauly (2010); Espírito Santo et al. (2005)
	Scomberomorus brasiliensis Collette, Russo & Zavala-Camin, 1978	1	1	-	0.00	0.01	-	44.0**	44.0**	PV	MM	Froese & Pauly (2010); Espírito Santo et al. (2005)
Sternopygidae												
	Eigenmannia virescens (Valenciennes, 1836)	3	3	-	0.01	0.03	-	25.5**	35.7**	ZB	FS	Barletta & Blaber (2007)
Tetraodontidae												
	Colomesus psittacus (Bloch & Schneider, 1801)	1	1	-	0.00	0.01	-	45.0*	45.0*	ZB	ES	Giarrizzo et al. (2010); Krumme et al. (2007); Barletta & Blaber (2007); Krumme et al. (2004)
Trichiuridae												
	Trichiurus lepturus Linnaeus, 1758	3	1	2	0.01	0.01	0.02	44.0*	92.0*	PV	MS	Barletta & Blaber (2007)
Not identified												
	Rays	146	22	124	0.66	0.20	1.12	11.0*	180.0*	-	-	
	Caldeirada	19	14	5	0.09	0.13	0.05	17.0**	43.0**	-	-	
	Jurubeba	102	7	95	0.46	0.06	0.86	15.0**	46.0**	-	-	
	Jururema	17	17	-	0.08	0.15	-	20.0**	35.0**	-	-	
	Lambe-lambe	12	9	3	0.05	0.08	0.03	10.0*	48.0*	-	-	
	Tuiuiu	15	12	3	0.07	0.11	0.03	29.0*	44.0*	-	-	
Total		**22228**	**11153**	**11075**	**100**	**100**	**100**	-	-	-	-	

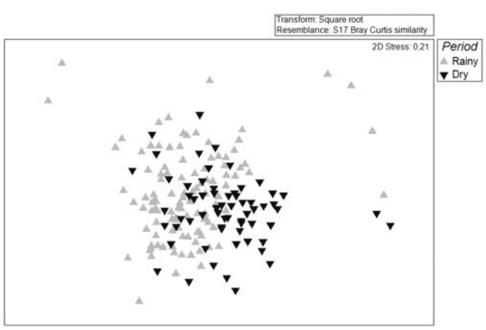

Fig. 2. Results of a MDS ordination analysis with the rainy and dry seasons as factors.

Ecological Guilds

Overall, the largest environmental guild in terms of the number of species (Fig. 3a) was that of the marine migrants (26.8%), followed by the estuarine species (24.4%). The same pattern was observed during the rainy season. In the dry season (Fig. 3a), however, estuarine species dominated (27.3%), followed by marine migrants (21.2%), freshwater stragglers (21.2%), and freshwater migrants (21.2%).

In contrast, freshwater migrants predominated (64.1%) in terms of the number of individuals captured during the study period (Fig. 3b), followed by estuarine species (23.3%). The same pattern was observed in both seasons, although the percentage of marine (visitors and migrants) and estuarine species increased during the dry season in comparison with the rainy season (Fig. 3b).

The zoobenthivores (ZB) were the richest feeding guild in terms of the number of species (43.6%), followed by the piscivores, PV (30.8%). These two guilds also predominated in both seasons, representing 41.7% and 30.6% of the species, respectively, in the rainy season and 38.7% and 32.3% in the dry. The species that feed on fish and zoobenthos (PV/ZB) were also prominent in both seasons (Fig. 4a). In terms of the number of individuals captured, however, the piscivores predominated (64.8%) throughout the study period, representing 76.5% of the catch during the rainy season and 52.5% during the dry season (Fig. 4b).

Body Length and Catch Probability

The standard length (SL) of the *B. vaillantii* specimens ranged from 2.6 to 91.7 cm, with a high frequency (83%) of individuals between 20 and 40 cm. The estimated catch probability (P_{50}) for this species was 25.27 cm (Fig. 5). A similar pattern was recorded for *B. rousseauxii* (SL: 9.5-153.4 cm), with approximately 36% of individuals in the 40-50 cm class (Fig. 5). The P_{50} value estimated for *B. rousseauxii* was 35.96 cm. In the case of *P. squamosissimus*, total length (TL) ranged from 7 to 90 cm, with most individuals in the 50-60 cm class and P_{50} estimated as 43.94 cm (Fig. 5). Similarly, *S. herzbergii* presented fork lengths (FL) between 10 and 130 cm but primarily between 30 and 50 cm (42%). The P_{50} value for this species was 40.34 cm (Fig. 5).

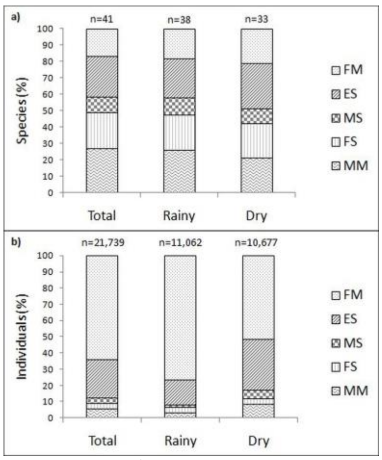

Fig. 3. Percentage of (a) species and (b) individuals present in the bycatch of the *B. vaillantii* trawler fleet by environmental guild. Marine Stragglers (MS), Marine Migrants (MM), Freshwater Stragglers (FS), Freshwater Migrants (FM), Estuarine Species (ES), and numbers (n) of (a) species and (b) individuals.

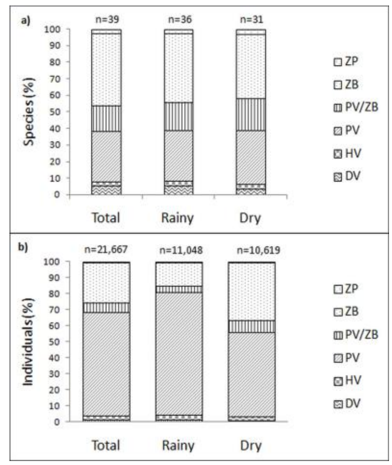

Fig. 4. Percentage of (a) species and (b) individuals present in the bycatch of the *B. vaillantii* trawler fleet by feeding guild. Zooplanktivore (ZP), Zoobenthivore (ZB), Piscivore/Zoobenthivore (PV/ZB), Piscivore (PV), Herbivore (HV), Detritivore (DV), and numbers (n) of (a) species and (b) individuals.

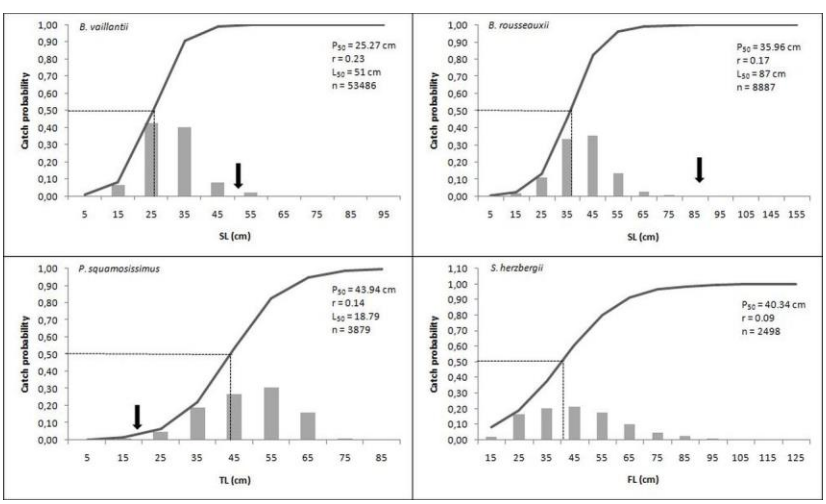

Fig. 5. Catch probability estimated for *B. vaillantii* and the principal bycatch species. The dashed lines indicate the length at which catch probability is 50% (P_{50}), the arrows indicate the estimated length of first sexual maturity (L_{50}), r is the slope of the logistic curve, and n is the number of individuals measured. The L_{50}values for *B. vaillantii*,*B. rousseauxii* and *P. squamosissimus* were obtained from Vásquez et al. (2009), Fabré et al. (2000) and Barbosa et al. (2012), respectively.

DISCUSSION

In recent decades, many technological advances have been made in an effort to reduce bycatch, but the capture and discarding of unwanted species remains a major problem for commercial fisheries worldwide (FAO, 2010). Industrial trawling for shrimp and demersal finfish represents more than half of the overall estimate of discarded bycatch (KELLEHER, 2005).

The industrial trawling fleets of the coast of northern Brazil operate primarily in the mouth of the Amazon River. These operations target primarily *B. vaillantii* (pair trawling), and pink (*Farfantepenaeus subtilis*, *F. brasiliensis*, and *F. notialis*) and white shrimp (*Litopenaeus schimitti*), using double rigs (PETRERE et al., 2007). In both cases, undersized specimens of the target species and any fish with no commercial value are discarded as bycatch (BARTHEM; GOULDING, 1997; BARTHEM, 2000).

During the peak of the industrial harvesting of *B. vaillantii,* in the 1970s, approximately 30% of the catch was rejected (ARAÚJO-LIMA; RUFFINO, 2003). In 1979, 20% of the total catch of this species was discarded, representing approximately 3,253 tons or 11 million specimens (DIAS-NETO et al., 1985). The results of the present study indicate that the fish bycatch of the industrial laulao trawler fleet in the Amazon Estuary is approximately 29% of the total catch (individuals). The number of taxa recorded in this study (52) was similar to those recorded in studies of the bycatch of shrimp trawling operations (SANTOS et al., 1998; CASTRIOTA et al., 2001; VIANNA et al., 2004; GOMES; CHAVES, 2006; BRANCO; VERANI, 2006).

The three principal families in terms of both species richness and the percentage of individuals captured were the Ariidae, Pimelodidae, and Sciaenidae, which are the most diverse within the study region (BARTHEM, 1985). Species representing the principal bycatch families in the present study are commercially important in northern Brazil (ESPÍRITO SANTO et al., 2005) and represent approximately 14% of the total catch landed in Pará State, the equivalent of approximately 13,400 tons (SEPAQ, 2008). Of these species, *B. rousseauxii*, *P. squamosissimus*, and *S. herzbergii* together represent approximately 69% of the total catch and were considered to be consistent and essential components of the bycatch of the industrial *B. vaillantii* fleet. Pinheiro and Lucena Frédou (2004) have recorded similar results for the laulao trawling fleet in the Amazon Estuary, although the catfish *Sciades couma* was the dominant bycatch species in this case, followed by *B. rousseauxii* and *P. squamosissimus*.

The composition of the bycatch was similar between seasons, as confirmed by MDS and ANOSIM, with approximately 71% of the taxa occurring in both periods. There was some variation in catch volume, however, with limnic species, such as *B. rousseauxii* and *P. squamosissimus*, more common during the rainy season, and marine species (e.g., *S. herzbergii*) predominating during the dry season. This pattern is typical of the Amazon Estuary, in which freshwater fish species predominate during the period of maximum fluvial discharge (rainy season), whereas marine species are more common during the dry season (BARTHEM, 1985). This difference occurs because the increased discharge during the rainy season tends to displace the more saline water of marine origin (EGLER; SCHWASSMANN, 1962), allowing freshwater species, such as *B. rousseauxii* and *P. squamosissimus*, to range into coastal areas. In the dry season, in contrast, the intrusion of seawater produces an increase in salinity in the inner portion of the estuary, forcing the freshwater species further upriver into the Amazon and Tocantins basins and enabling marine species, such as *S. herzbergii*, to range into the estuary (BARTHEM, 1985).

In terms of the number of species, the marine migrants and estuarine species were the most diverse environmental guilds. However, freshwater migrants were dominant in numbers, due primarily to the abundance of *B. rousseauxii* and *P. squamosissimus*. In the case of the feeding guilds, the zoobenthivore group was predominant in terms of the number of species, while the piscivores predominated in relative abundance, representing approximately 65% of the total individuals captured.

Estuarine substrates are ideal environments for many organisms due to the relatively rich deposits of organic matter and inorganic nutrients (MCLUSKY, 1989). Muddy sediments dominate the inner continental shelf of the Amazon estuary (BARRETO et al., 1975), providing a considerable abundance and diversity of resources (LOWE-MCCONNELL, 1962) to a rich fauna of benthic invertebrates, which feed primarily on organic debris (DAY et al., 1989). As a result, a substantial variety of fishes that feed on these organisms are attracted to these environments (HARRISON; WHITFIELD, 2004), especially species with demersal habits, which show a high productivity in the region (ISAAC et al., 1998).

In the present study, trawling had a clear effect on populations by capturing large quantities of juveniles, as indicated by the numbers of small- (20-30 cm) and medium-sized (30-50 cm) individuals in the catches. These captures primarily affected the stocks of *B. rousseauxii* and *B. vaillantii*. The catch of *B. rousseauxii* was composed primarily (99%) of immature individuals. Approximately one-third (32%) of the catch consists of young, non-migrating individuals (< 40 cm), whereas 67% are young individuals with lengths between 40 cm and 80 cm. Barthem (2000) has observed that *B. rousseauxii* juveniles and pre-adults (1-3 years) are common in the estuary, whereas adults are rare or absent. Alonso and Pirker (2005) have reported that large numbers of *B. rousseauxii* are harvested commercially before beginning their reproductive cycle.

Although the fish in question belonged to the target species, most of the catch (98%) of *B. vaillantii* consisted of immature individuals. Approximately 4% of the total catch consisted of young, non-migrating individuals (< 20 cm), whereas 14% were pre-adults with a length of 40-50 cm. These smaller and younger individuals may be relatively common in estuaries, where Alonso and Pirker (2005) observed that 56% of the catches of commercial artisanal fisheries consisted of individuals with a FL of 20-40 cm. The high mortality of juvenile *B. vaillantii* below marketable size appears to be related to the small mesh size used by the local fisheries (BARTHEM; GOULDING, 1997).

Alonso and Pirker (2005) have characterised the Amazon estuary as a nursery for both *B. vaillantii* and *B. rousseauxii*. The abundant food and space in the estuary, in addition to the low number of predators, allows rapid growth during the first years of life and increases the probability of survival. The upstream migrations, which involve distances greater than 3,000 km, begin when the individuals are two years old (BARTHEM; GOULDING, 1997).

In *P. squamosissimus*, by contrast, the catch consisted primarily (99%) of large adults. Given that this species is of commercial value, it is probable that this catch is included in the official statistics. The elimination of these individuals from the population may, nevertheless, have an equally marked impact on recruitment.

Mortality from fishery operations tends to be more harmful to K-strategist species (ALVERSON et al., 1994), as is the case for *B. vaillantii*. This species is relatively long-lived, with a life expectancy of 22 years, grows slowly (0.13 cm per year) (ALONSO; PIRKER 2005), and matures late. Alonso and Pirker (2005) concluded that *B. rousseauxii* is being harvested at its maximum limit of exploitation. Other vulnerable species include rays, which are commonly caught as bycatch (JICA, 1998), and ariid catfishes, which have well-developed parental care, such as oral incubation of eggs and embryos (REIS, 1986; YAÑEZ-ARANCIBIA; SÀNCHEZ-GIL, 1988; BARBIERI et al., 1992; CHAVES, 1994).

A number of different mitigating strategies can be considered for the bycatch problem. Hall (1999) emphasises the need for increased selectivity and the prohibition of fishing in certain areas and seasons. Selectivity can be enhanced by increasing the mesh size and by the adoption of Bycatch Reduction Devices (BRDs).

One other option is the deployment of Marine Protected Areas (MPAs). According to the Government of Canada (2005), these areas can restore the balance of marine ecosystems and provide economic, social, and cultural benefits. These MPAs may be particularly effective as long-term strategies for migratory species and those with a long life cycle and slow maturation, such as *B. vaillantii* and *B. rousseauxii*, by protecting the habitats used during the most vulnerable phases of the life cycle, thus guaranteeing higher recruitment rates. The protection of areas characterised by high bycatch rates, especially in relationship to species vulnerable to overfishing, is also recommended.

Trawling is currently prohibited in the Amazon and Pará estuaries in the area between 00°05' N and 48°00'W (Federal decree no. 6 of 07/06/04). However, this measure appears to have been ineffective for the protection of small individuals, given that a large proportion of the bycatch still consists of juveniles. In the light of this finding, the expansion of the prohibited zone during the dry season, when non-migrating juveniles are most vulnerable, would be one additional effective measure.

Bottom trawling directed to laulao remains the focus of many social conflicts due to the impact of the fishing gear and the great fishing power of the fishery (ISAAC et al., 2011). Initiatives to decrease the negative effect of this fishery have not improved the situation over time. This lack of improvement is due primarily to the limitations of on-board space, the low refrigeration capacity of the fleet, the disproportionate relationships involving the price per kilogram of the target species and of the non-target species, and the time taken for selection and separation of the bycatch individuals (IDESP, 1989; PAIVA, 1997; ISAAC; BRAGA, 1999).

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