UNIVERSIDADE FEDERAL RURAL DE PERNAMBUCO

DEPARTAMENTO DE PESCA E AQUICULTURA

LUCAS VINÍCIUS SANTOS SILVA

BIOLOGIA REPRODUTIVA E ECOLOGIA TRÓFICA DO PEIXE *Larimus breviceps*
(Acanthuriformes: Sciaenidae) NO LITORAL DA PARAÍBA

Recife

2021

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Trabalho de Conclusão de Curso apresentado como requisito parcial para a obtenção de título de bacharel em engenharia de pesca pelo curso de Bacharelado em Engenharia de Pesca da Universidade Federal Rural de Pernambuco – Campus Sede.

Orientadora: Profª. Drª. Flávia Lucena Frédou

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Lucas Vinícius Santos Silva

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"Fogo nos racistas".

- Djonga

RESUMO

O Boca-mole *Larimus breviceps* é uma das principais espécies capturadas como bycatch provenientes da pesca de camarão no Brasil. Apesar disso, estudos sobre a biologia e impactos da pesca na espécie ainda são escassos (e.g., maturação ovariana macroscópica e microscópica, desenvolvimento ovocitário, variação sazonal na dieta, atributos morfométricos, isótopos estáveis). No presente estudo descrevemos os principais aspectos da biologia reprodutiva e ecologia trófica de *L. breviceps* na Paraíba, nordeste do Brasil. Um total de 970 indivíduos (549 fêmeas e 421 machos) foram capturados entre dezembro de 2016 e novembro de 2017 com uma rede de arrasto de praia. O comprimento total (CT) variou de 4,2 a 23 cm. A proporção sexual foi significativamente diferente (1 fêmea: 0,77 macho) para meses agrupados e para fevereiro, março, julho e outubro (p<0,05). As gônadas foram descritas por análises macroscópicas e microscópicas. Os ovários eram formados por oogonia, ovócito pré vitelogênico, vitelogênico, maturo e atrésico. Logo depois, cinco estágios foram definidos: imaturo, desenvolvimento inicial, desenvolvimento avançado, matura e regressão. O período de maior atividade reprodutiva ocorreu entre novembro e março e indivíduos imaturos ocorreram durante o ano todo. O comprimento médio de primeira maturidade (L_{50}) foi de 11,1 cm CT. Para o estudo de alimentação, uma subamostragem foi realizada, com 479 estômagos analisados. O comprimento total dos indivíduos variou entre 6,3 e 19,2 cm. Nove categorias alimentares foram defenidas e Sergestidae foi caracterizada como presa principal (Iai = 83%). A composição da dieta mostrou um padrão diferente para juvenis e adultos. Diferenças significativas de 45 indivíduos (27 juvenis e 19 adultos) foram encontradas para o índice de achatamento corporal e o índice de achatamento do pendúnculo caudal, significando que adultos são nadadores mais rápidos do que juvenis. Um total de 40 indivíduos (estação seca = 20; estação chuvosa = 20) foram selecionados para análise de isótopos estáveis. Diferenças foram encontradas nos valores de $\delta^{13}C$ na estação seca, na qual juvenis se alimentam de presas mais ricas em $\delta^{13}C$ do que adultos. Foi encontrado um nível trófico entre a terceira e a quarta posição, classificando a espécie como carnívora predadora. As informações do presente estudo contribuem com o conhecimento geral da espécie e podem ser utilizadas para futuros desenvolvimentos de práticas de manejo que asseguram a sustentabilidade da exploração de espécies marinhas.

Palavras-chave

ABSTRACT

The shorthead drum *Larimus breviceps* is one of the main bycatch species of the shrimp fisheries in Brazil. However, studies addressing the biology and fisheries impacts on this species are still scarce (e.g., macroscopic, and microscopic ovarian maturation, oocyte development, seasonal variation in the diet, morphometric attributes, isotope analysis). Here, we describe the main aspects of the reproductive biology and the feeding ecology of *L. breviceps* on Paraíba, northeast Brazil. A total of 970 individuals (549 females and 421 males) were caught between December 2016 and November 2017 through a beach seine. The total length (TL) varied from 4.2 to 23.0 cm. Females dominated over males (1 female: 0.77 male). The gonads were described by macroscopic and microscopic analysis. The ovaries were composed by oogonia, pre-vitellogenic, vitellogenic, mature and atretic oocytes. Thereafter, the following stages were thus defined for females: immature, initial development, advanced development, mature and regressing. The period of highest reproductive activity occurs between November and March and immature individuals occur throughout the year. The mean length at first maturity (L_{50}) was 11.1 cm TL. To the feeding ecology study, a subsample of 419 stomachs were analyzed. The total length (TL) varied between 6.3 and 19.2 cm. Nine feeding categories were defined for *L. breviceps*. Sergestidae was characterized as the main prey (IAi=83%). The diet composition displayed a different pattern for juveniles and adults. Significant differences were found for peduncle flatness index and body flatness index in 49 individuals (27 juveniles and 19 adults); indicating that adults are faster swimmers than juveniles. A total of 40 individuals (dry season = 20; rainy season = 20) were selected for stable isotope analysis. Differences were found in $\delta^{13}C$ values for different size classes in the dry season, with juveniles feeding on preys with higher $\delta^{13}C$ levels than the adults. The shorthead drum had a trophic level between the third and fourth position, classifying the species as a carnivore predator. The information provided here contributes to the overall knowledge of this species and may be useful for further development of management practices that ensure sustainability of marine species exploitation.

Keywords

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Figure 1. Study area on the north coast of Paraíba State, northeastern Brazil. Black dots represent a real example of the fishing operation.

Figure 2. Monthly average (± standard deviation) of the total length (TL, cm) of females (red) and males (blue), of *Larimus breviceps* captured from December 2016 to November 2017 off the coast of Paraíba state, northeastern Brazil. (*, significant length differences between females and males; **, significant differences in sex ratio; $p < 0.05$; Monthly abundance, red: female; blue: male).

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Figure 4. Mean length at first maturity for females of *Larimus breviceps* captured from December 2016 to November 2017 off the coast of Paraíba state, northeastern Brazil.

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Artigo científico 2. Trophic ecology and ecomorphology of *Larimus breviceps* (Perciformes: Sciaenidae) from the Northeastern Brazil.

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Artigo científico 2. Trophic ecology and ecomorphology of *Larimus breviceps* (Perciformes: Sciaenidae) from the Northeastern Brazil.

Table 1. Ecomorphological attributes according to Gatz (1979), Watson and Balon (1984), and Winemiller (1991) (HW, Head Width; BW, Body Width; HH, Head Height; HL, Head Length; MW, Mouth Width; MH, Mouth Height; CPW, Caudal Peduncle Width; CPL, Caudal Peduncle Length; CPH, Caudal Peduncle Height; BH, Body Height; EH, Eye Height).

Table 2. Ecomorphological attributes parameters of *L. breviceps* captured from December 2016 to November 2017, off the Paraíba state coast, northeastern Brazil (sd, standard deviation).

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SUMÁRIO

INTRODUÇÃO GERAL

Regiões costeiras marinhas abrangem sistemas ecológicos chaves para várias espécies e dão suporte à reprodução, crescimento, estruturas de teia alimentar e subsistência de pescadores locais (Pauly, 1989; Soares, 1989). No Brasil, esses ecossistemas são explorados por pescadores artesanais e são caracterizados pelo múltiplo uso de apetrechos e grande diversidade de espécies alvo e de fauna acompanhante (Pauly, 2005). Uma das modalidades dessa atividade é o arrasto camaroeiro, realizado pelo arrasto motorizado e de praia (Neiva, 1988; Marrul-Filho, 2003). Estima-se que mais de 100.000 pessoas trabalhem direta ou indiretamente na pesca do camarão no Nordeste brasileiro, produzindo, em 2008, 16.146 t de camarões peneídeos nativos. Esse total representou 9,4% em relação à produção total de pescados na região (IBAMA, 2008).

No estado da Paraíba, nordeste do Brasil, a portaria IBAMA nº 833/1990 proibiu o arrasto motorizado, nas principais áreas de pesca, por ser uma atividade que altera, remove e destrói os habitats de fundo (Cabral et al., 2002). Atualmente, a pesca é realizada exclusivamente através de arrasto de praia, tendo como alvo principalmente as espécies de camarão: branco (*Penaeus schmitti*), rosa (*Penaeus subtilis*) e sete-barbas (*Xiphopenaeus kroyeri*). Apesar de limitado a áreas próximas à costa, o arrasto motorizado tem altas capturas de biomassa de fauna acompanhante (Passarone et al., 2020), provocando mortalidade incidental de muitas espécies (Hall et al., 1999) e contribuindo para o desequilíbrio ecológico do ecossistema.

Fauna acompanhante ou *bycatch* é a captura incidental de organismos aquáticos associada à pesca (Rezende, 2016), sendo composta por peixes, moluscos, equinodermos, crustáceos, cnidários e outros (FAO, 2016). Uma parte considerável dessa fauna é devolvida ao mar já morta. Na pesca camaroeira esta parcela é constituída principalmente por peixes juvenis, o que pode gerar um grande impacto ecológico na comunidade, comprometendo os estoques pesqueiros (Kelleher, 2005). A composição das espécies pode variar de acordo com inúmeros fatores (e.g., área de pesca, profundidade, sazonalidade) (Hart, 2002).

Larimus breviceps Cuvier, 1830 é uma das espécies de bycatch mais abundantes provenientes da pesca do camarão (Lacerda et al., 2014) e está distribuída no Atlântico central e sudeste (da Costa Rica até Santa Catarina no Brasil) (Vianna and Almeida, 2005; Cattani et al., 2011). Esta espécie tem um papel importante na cadeia alimentar, se alimentando de

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componentes do sistema (e.g., peixes pequenos, camarões) ou integrando a dieta de mamíferos e outros peixes (Bittar, 2007; Paitach, 2015; Benedito, 2017). Além disso, *L. breviceps* tem grande importância socioeconômica, servindo de alimento e fonte de renda para a população local, especialmente no estado da Paraíba (Lacerda et al., 2014). Embora algum dos aspectos da sua dinâmica populacional e pesca tenham sido estudados no sul e sudeste do Brasil (Souza e Chaves, 2007; Chaves et al., 2017), informações sobre vários outros aspectos, relacionados com a biologia e ecologia dessa espécie ainda continuam escassas. Como exemplo, apenas alguns estudos conduzidos no nordeste do Brasil incluíram a espécie, focando principalmente em aspectos reprodutivos (Silva-Júnior et al., 2015), vulnerabilidade ao arrasto motorizado de camarão (Silva-Júnior et al., 2013; Bomfim et al., 2019) e papel funcional (Ferreira et al., 2017). Apesar disso, o impacto da pesca de arrasto de praia na espécie, especialmente em sua biologia reprodutiva (e.g., desenvolvimento ovariano e maturação de suas células germinativas), nunca foi reportado.

Estudos sobre a dieta e a atividade alimentar de espécies em seu habitat natural oferecem informações valiosas sobre como as interações dos organismos com o ambiente contribuem para o seu funcionamento e administração de recursos aquáticos (Winemiller et al., 2008; Blaber, 2013). Estudos abordando o comportamento alimentar de *L. breviceps* são restritos ao Sul e ao Sudeste do Brasil (Bessa et al., 2013; Soares e Vazzoler, 2011). Além disso, estes trabalhos são baseados apenas em análise de conteúdo estomacal (ACE), que apesar de apresentar alta resolução taxonômica da dieta, é limitada a um curto período e subestima alguns grupos de presas (e.g., presas digeridas rapidamente são frequentemente não consideradas; Eduardo et al., 2020). Alternativamente, a análise de isótopos estáveis (AIE) oferece informação temporal do material assimilado pelo organismo e pode ajudar a entender a contribuição da presa à composição corporal (Cherel et al., 1993). Portanto, a combinação de ACE e AIE pode prover melhores informações acerca da dinâmica trófica e sobre transporte de energia através de compartimentos tróficos (Eduardo et al., 2020).

A morfologia funcional é outro elemento chave para representar o papel das espécies no ecossistema, caracterizando, por exemplo, como a competição interespecífica leva a diferentes estratégias de vida (Villéger et al., 2008). Todavia, a forma corporal também é utilizada para compreender fatores singulares e multifuncionais relacionados à ecologia comportamental (e.g., alimentação, evasão predatória, ou exibição para coorte) (Loy et al., 2000; Walker, 2010).

As informações aqui apresentadas contribuem para o conhecimento geral da ecologia do *Larimus breviceps* e para o ordenamento de sua pesca, assegurar a sustentabilidade da exploração das espécies e tem os objetivos listados na secção abaixo.

OBJETIVOS

Objetivo geral

Caracterizar a biologia reprodutiva e a ecologia trófica do peixe *Larimus breviceps* (Perciformes: Sciaenidae) no litoral da Paraíba.

Objetivos específicos

2.2.1 Determinar a relação comprimento-peso da espécie para machos, fêmeas e sexos agrupados;

2.2.2 Determinar a proporção sexual da espécie para todos os indivíduos, por época do ano e classe de comprimento;

2.2.3 Determinar aspectos reprodutivos da espécie, como o tamanho de primeira maturidade e época de reprodução;

2.2.4 Descrever macroscopicamente e microscopicamente o processo ovocitário e ovariano de fêmeas;

2.2.5 Caracterizar a composição da dieta através da análise de conteúdo estomacal e isótopos estáveis considerando os períodos do ano e diferenças ontogenéticas;

2.2.6 Descrever aspectos ecomorfológicos para indivíduos juvenis e adultos;

2.2.7 Determinar aspectos alimentares, como amplitude de nicho trófico, estratégia alimentar e variação sazonal;

Esta monografia foi dividida em dois artigos científicos. O artigo 1 teve como objetivo avaliar e caracterizar aspectos reprodutivos do *Larimus breviceps* (e.g., descrições macroscópicas e microscópicas, desenvolvimento ovocitário, tamanho de primeira maturidade). O artigo 2 visa determinar padrões sazonais e ontogenéticos na alimentação do *Larimus breviceps* através de análise do conteúdo estomacal, atributos ecomorfológicos e análise de isótopos estáveis.

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ARTIGO CIENTÍFICO I

Artigo em segunda revisão na Revista
[Regional Studies in Marine Science].

Reproductive biology of the shorthead drum *Larimus breviceps* (Perciformes: Sciaenidae) in northeastern Brazil

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Abstract

The shorthead drum *Larimus breviceps* is one of the main bycatch species of the shrimp fisheries in Brazil. However, studies addressing the biology and fisheries impacts on this species are still scarce. Here we describe the main aspects of the reproductive biology and the female gonadal development of *L. breviceps* on Paraíba, northeast Brazil. A total of 970 individuals (549 females and 421 males) were caught between December 2016 and November 2017 through a beach seine. The total length (TL) varied from 4.2 to 23.0 cm. Females dominated over males (1 female: 0.77 male). The reproductive tract was described by macroscopic and microscopic analysis. The ovaries were composed by oogonia, pre-vitellogenic, vitellogenic, mature and atretic oocytes. Thereafter, the following stages were thus defined for females: immature, initial development, advanced development, mature and regressing. The period of highest reproductive activity occurs between November and March and immature individuals occurs throughout the year. The mean length at first maturity (L_{50}) was 11.1 cm TL. The information provided here contributes to the overall knowledge of this species and may be useful for further development of management practices that ensure sustainability of marine species exploitation.

Keywords

Introduction

Fisheries in tropical coastal ecosystems are commonly known for the great discard of species caught as bycatch, especially in shrimp fisheries (Pauly, 2005). Among gears used for shrimp harvesting, the motorized bottom trawling is one of the most common and destructive in Brazil and elsewhere (Pina and Chaves, 2009). This activity causes high incidental mortality of several species (Thomas et al., 2017) increasing their extinction risk by declining populations, catches of juveniles and leading to several alterations in the ecosystem (e.g., great physical disturbance; Diamond et al., 2000; Arendse et al. 2007; Thomas et al., 2017).

In the state of Paraíba, northeastern Brazil, the ordinance IBAMA nº 833/1990 prohibited the use of the motorized shrimp trawling in the coastal areas (3 nautical miles; Moura et al., 2003). Currently, fisheries are carried out exclusively through beach seine targeting mainly the white (*Penaeus schmitti*), pink (*Penaeus subtilis*), and sea bob shrimps (*Xiphopenaeus kroyeri*) (Santos, 2010). Within this state, the city Lucena is considered the most important for this activity (Moura, 2003). Despite limited to areas nearshore, the beach seining can harvest greater diversity of bycatch species than motorized bottom trawling (Passarone, 2020). Moreover, this activity may cause several impacts (e.g., incidental mortality of juveniles and endangered species) that, given the current state of knowledge, may go mostly unnoticed.

The shorthead drum, *Larimus breviceps* Cuvier, 1830, distributed in the Central and Southwest Atlantic (from Costa Rica to Santa Catarina in Brazil) (Vianna and Almeida, 2005; Cattani et al., 2011), is one of the most abundant bycatch species of the shrimp fisheries in Brazil (Lacerda et al., 2014). This species has an important role in the food chain, either feeding on components of the system (e.g., small fishes, shrimps) or integrating the diet of mammals and other fishes (Bittar, 2007; Paitach, 2015; Beneditto, 2017). Furthermore, *L. breviceps* has high socio-economic importance by serving as food and income source for the local population, especially in Paraíba state (Lacerda et al., 2014). Although some aspects of its population dynamic and fisheries have been studied in the southern and southeastern Brazil (Souza and Chaves, 2007; Chaves et al., 2017), information on many aspects of the biology and ecology of this species are still scarce. As an example, only a few studies conducted in the northeastern Brazil included this species, focusing mainly on reproductive aspects (Silva-Júnior et al., 2015), vulnerability to motorized shrimp trawling (Silva-Júnior et al., 2013; Bomfim et al., 2019), and functional role (Ferreira et al., 2017). However, the impact of beach

seining on this species, especially on its reproductive biology (e.g., ovarian development and maturation of its germ cells) have never been assessed.

The aims of this study were: i) to define, for the first time, a histological classification of the oocyte and maturity stages of *L. breviceps* ovaries to investigate its spawning activity and pattern based upon seasonal variation in the prevalence of the different gonad developmental stages; and ii) to establish mean size at first maturity of shorthead drum populations in the Brazilian northeastern. The new information provided here contributes to the overall knowledge to ensure the sustainability of the species exploitation.

Material and Methods

Specimens of *L. breviceps* were collected monthly from the bycatch of an artisanal shrimp fishery in Lucena, north coast of Paraíba state (6°53'50"S, 34°51'01"W), from December 2016 to November 2017, except in May (Fig. 1).
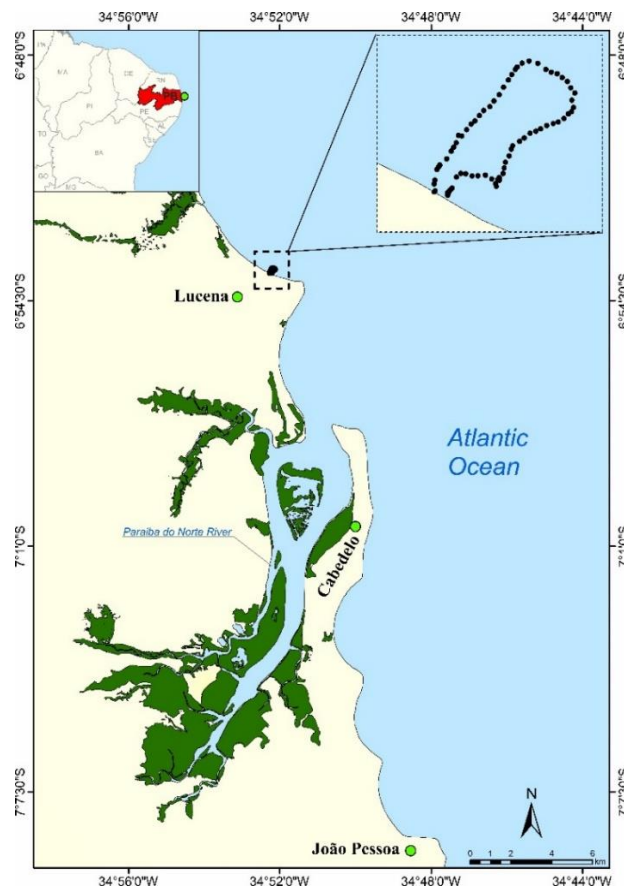
Figure 1. Study area on the north coast of Paraíba State, northeastern Brazil. Black dots represent a real example of the fishing operation.

Two hauls were performed monthly using a beach seine (see Passarone et al., 2019 for description) deployed from 500 meters off (depth of 6 meters to the surf zone) and towed toward the coast, using a non-motorized craft, employed by the local fishers. Fish collected were kept on ice, then transported to the laboratory. Rainfall data, based on the local mean precipitation for the last 10 years (http://www.aesa.pb.gov.br), were used for further analysis.

Total length (TL – cm) and the total weight (TW – g) were recorded, and, since data did not follow the necessary assumptions for the parametric test, the nonparametric Kruskal-Wallis was used to test for months and sexes differences. The Dunn's post-hoc test was used to determine significant differences between months (Zar, 2009). The sex-ratios (males individuals / females individuals), determined in total sample, by month and by size classes (1.0 cm), were statistically tested for significant differences from the expected 1:1 ratio with a χ^2 test ($p<0.05$) (Dagnelie, 1975). The length-weight relationship (LWR) was considered isometric when b=3, negative allometric when b<3, and positive allometric when b>3 (Froese, 2006). The allometry coefficients were further tested for significant deviations from b=3 by Student's t-test. A maximum likelihood ratio test was used in comparison of LWR between sexes.

The gonads were removed and weighed for sex and maturation stage determination. Microscopic analysis was carried out in 250 ovaries to confirm the macroscopic characterization and to describe gonad development stages. Samples were taken from the median portion of the ovary, fixed in 10% buffered formaldehyde for 24 hours, then cleaved, fixed again for another 24 hours, and transferred to 70% alcohol for conservation. The ovary fragments were dehydrated, cleared in xylol, embedded in paraffin at 45ºC, cut in slices of 5 μm and stained with hematoxylin/eosin-phloxine. Maturational stages were identified through ovary sections photographed using an optical microscope LEICA DM500 (LEICA, Wetzlar, Germany).

The ovaries were classified macroscopically and microscopically in different reproductive phases (Brown-Peterson et al., 2011) according to the most advanced oocyte stage present (West, 1990). Were measured, fifty oocytes per category using the software Image Tool© version 2.0 for Windows. The mean and the standard deviation of oocyte

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diameter of the different germ cells of each specimen were obtained. Oocyte diameters were taken in the cross-section of the ovary.

For the mean length at first maturity (L_{50}; length at which 50% of the individuals attain gonadal maturity for the first time), the percentage of adults (microscopic stages II, III, IV, and V) by length was calculated. These values were adjusted by the least-squares method to a logistic curve, which is given according to King (2007): $P_i=1/(1+e^{-r(L_i-L50)})$, where P_i is the proportion of adult individuals for each class i, L_i is the length at each class i, L_{50} is the length that corresponds to 0.5 proportion (50%) of adults in the population and r is the logistic curve slope. L_{50} and a confidence interval of 95% was obtained for females.

The spawning season was evaluated through the monthly relative frequency of the gonadal maturation stages and by calculating the Gonadosomatic Index (GSI) for females: GSI=GW/EW*100, where GW is the gonad weight and EW is the eviscerated weight of the specimen. To test for significant differences in GSI between months, the Kruskal-Wallis test was performed (Sokal and Rohlf, 1987). Immature specimens were excluded from the GSI analysis. The Spearman's rank correlation (r) was used to measure the strength of associations between the GSI values and rainfall.

The software R 3.4.4 was utilized to perform all statistical analyses (R Core Team, 2018). The package *sizeMat* ("Size at Morphometric and Gonad Maturity in R"; Torrejón-Magallanes, 2016) was used for the estimation of L_{50} values.

Results

A total of 970 specimens of *L. breviceps* were collected: 549 females (56%) and 421 males (44%) ranging from 4.2 to 23 cm TL (females 4.3–23 cm; males 4.2–22.8 cm, TL), and the total weight from 0.7 to 167.7 g (females 0.8–158.1 g; males 0.7–167.7 g, TW). The mean TL of females [11.3 ± 2.9 cm (mean±SD)] and that of males (10.5 ± 2.6 cm) were statistically different ($p<0.05$) (Fig. 2). The largest individuals were caught in October (13.9 ± 1.3 cm of TL), while the smallest in April (8.9 ± 1.6 cm of TL) (Fig. 2). Females were statistically larger than males only in March and April ($p<0.05$) (Fig. 2). Overall, there was a predominance of females over males (1: 0.77; χ^2, $p<0.05$). The same pattern was observed in the length class 13–14 and in the months February, March, July, and October (χ^2, $p<0.05$) (Fig. 2).
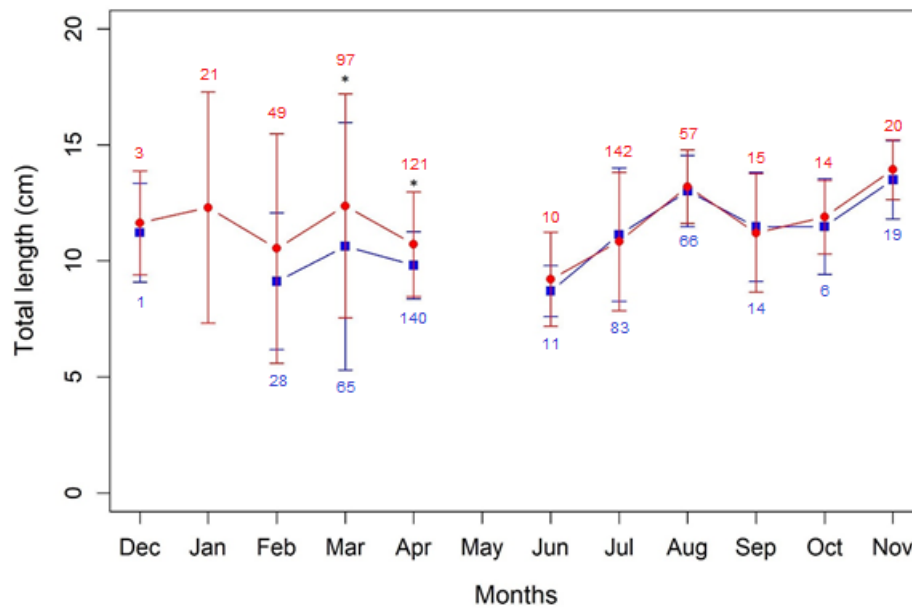
Figure 2. Monthly average (±, standard deviation) of the total length (TL, cm) of females (red) and males (blue), of *Larimus breviceps* captured from December 2016 to November 2017 off the coast of Paraíba state, northeastern Brazil. (*, significant length differences between females and males; p<0.05; red, female; blue, male).

The LWR for females and males did not differ significantly (p<0.05) presenting a positive allometric growth in all cases (b>3; p<0.05) (Tab. 1).

Table 1. Descriptive statistics and TL–TW relation parameters of *Larimus breviceps* captured from December 2016 to November 2017 off the coast of Paraíba state, Northeastern Brazil [TL, total length (cm); TW, total weight (g); SD, standard deviation; min, minimum; max, maximum; SL, standard length (cm)].

	Females	**Males**	**Pooled sexes**
Length characteristics			
TL, mean ± SD	11.31±2.94	10.46±2.62	10.97±2.88
TL min–TL max	4.3–23	4.2–22.8	4.2–23
Weight characteristics			
TW, mean ± SD	18.94±17.3	14.58±15.17	17.03±16.54
TWmin–TWmax	0.77–158.1	0.68–167.67	0.68–167.67
Relations			
TL-TW equation	$TW=0.00596TL^{3.22}$	$TW=0.00584TL^{3.23}$	$TW=0.00588TL^{3.23}$
Coefficient of determination (r^2)	0.96	0.96	0.96
t–test (coefficient b=3)	$p<0.05$	$p<0.05$	$p<0.05$

Growth type	Positive allometry (3.22)	Positive allometry (3.23)	Positive allometry (3.23)

The oocyte development was classified in 8 phases (Fig. 3), as follows:

Oogonia (OO)

The oogonia is the most primitive stage of germinative cells, presenting diameter varying from 17.1 to 30.3 µm. Its core is wide and located in the center of the cell surrounded by a thin layer of cytoplasm and containing a single and large nucleolus located in the center of the core, which tends to migrate to the periphery as the cell develops (Fig. 3A).

Previtellogenic oocyte or perinucleolar (PVTO)

In this stage a considerable increase in cellular volume occurs, regarding the previous stage, with a mean diameter 63.8±3.3 µm. The cytoplasm is larger than the core, presenting peripheric nucleolus in cells core as it develops. These cells reveal strong basophilia and they are found in all ovary development stages (Fig. 3B).

Cortical alveoli oocyte (CA)

The cortical alveoli formation is the main indicator of the beginning of oocyte maturational development. This stage is characterized by the appearance of the oil droplets, which are small spherical vesicles, initially around the core, spreading over the cytoplasm. The cortical alveoli grow in number and size as the oocyte develops. The lipid vacuoles begin to accumulate in the cytoplasm (mean diameter 170.8±19.8 µm) (Fig. 3C).

Vitellogenic oocytes (VTG$_1$, VTG$_2$, and VTG$_3$)

This stage endures since the appearance of yolk vesicles in cytoplasm until its fusion through the final maturation. The vitellogenic stage is subdivided into 3 subphases, considering the accumulation of nutrients in the oocyte cytoplasm: *primary vitellogenic oocytes* (VTG$_1$), the oil droplets occupy the areas around the core (mean diameter 264.6±10.4 µm); *secondary vitellogenic oocytes* (VTG$_2$), the oil droplets occupy a greater area in the cytoplasm regarding the previous stage and the yolk granules accumulate in the cytoplasm (mean diameter 360.3±10.9 µm); *tertiary vitellogenic oocyte* (VTG$_3$), the oil droplets are

larger than the previous stages and yolk granules spread all over the cytoplasm (mean diameter 412.9±8.9 µm) (Fig. 3D).

Mature or oocyte undergoing germinal vesicle breakdown (GVBD)

In this stage occurs the germinal vesicle migration and breakdown and the yolk granules begin to fuse. It is observed great accumulation of yolk granules in the cytoplasm, provoking a significant increase in its volume, with a mean diameter 512.3±6.3 µm (Fig. 3E).

Atretic oocyte (OA)

The atretic oocyte is the degeneration of oocyte follicles. This may occur in all ovary development stages, although these cells are observed in higher frequency in the regressing stage. They present an undefined format due to the rupture of the membrane during the process of resorption (Fig. 3F).

Post ovulatory follicle (POF)

This oocyte residual occurs only in the final maturational stages. It confirms that a successful spawn took place, and that no oocyte absorption was held by the fish (Fig. 3G).
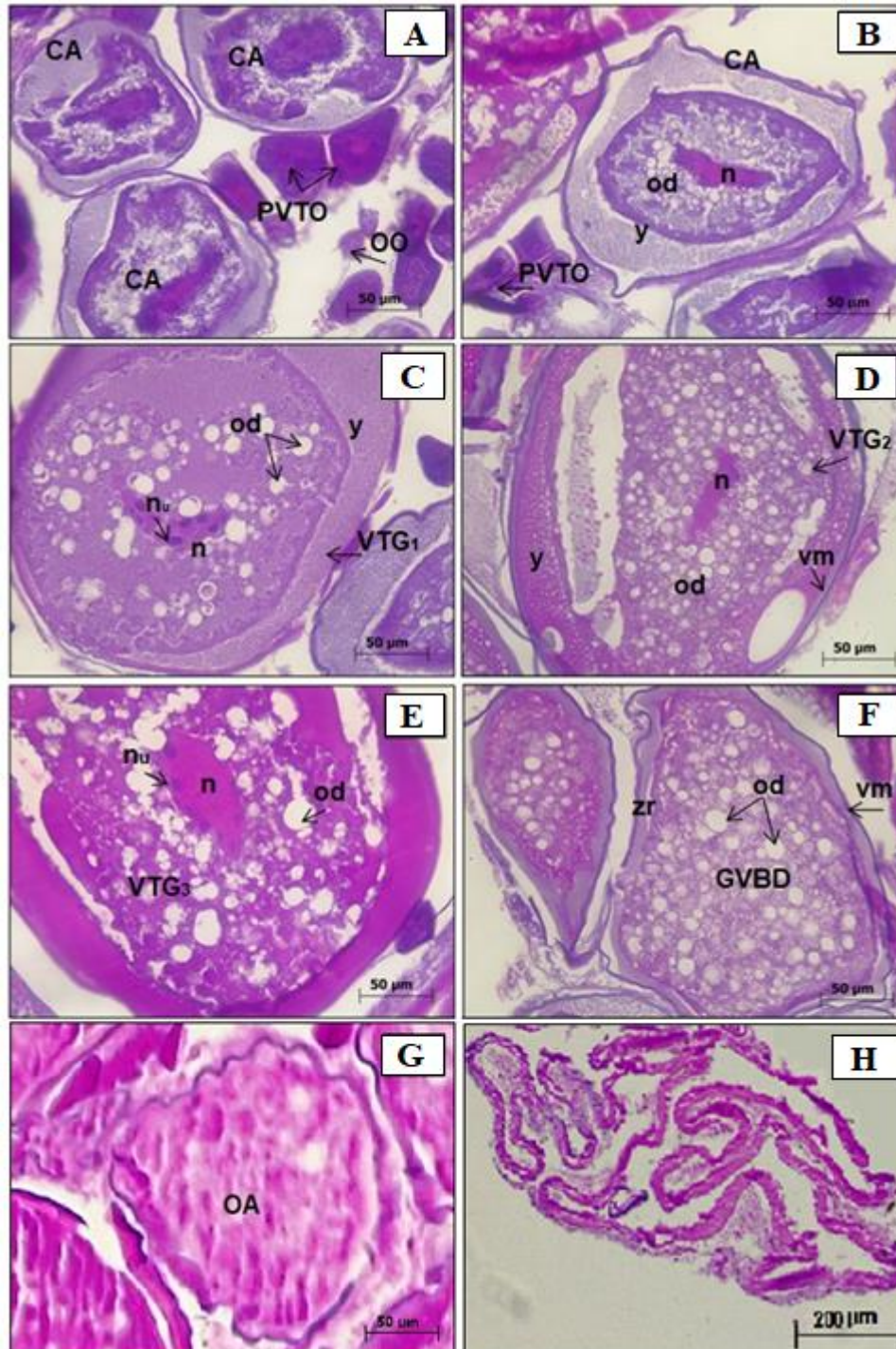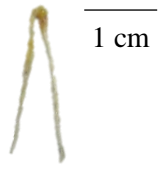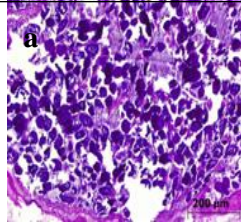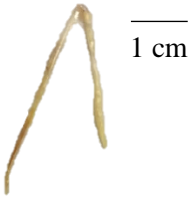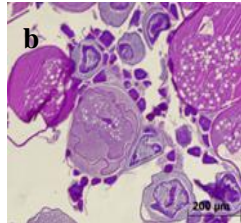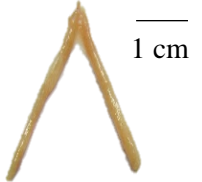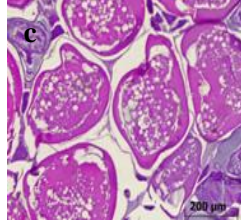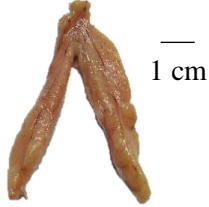
Figure 3. Stages of oocyte development in the *Larimus breviceps* captured from December 2016 to November 2017 off the coast of Paraíba state, northeastern Brazil. A) oogonia (OO) in primitive stage and previtellogenic oocyte stage (PVTO); B) oocytes in cortical alveolar (CA) stage; C) oocyte in primary vitellogenic stage (VTG$_1$); D) oocyte in secondary vitellogenic stage (VTG$_2$); E) oocyte in tertiary vitellogenic stage (VTG$_3$); F) oocyte undergoing germinal vesicle breakdown (GVBD); G) oocyte in atresia (OA); H) Post

ovulatory follicle. n, nucleus; n_u, nucleolus; ca, cortical alveoli; y, yolk granules; od, oil droplets; vm, vitelline membrane; zr, zona radiata.

Larimus breviceps is a gonochoristic species with no identifiable sexual dimorphism in body shape or color. According to the macroscopic and microscopic analyses of 250 ovaries examined, it was observed asynchrony in oocytes development, and the females were classified in five maturation stages: immature, initial development, advanced development, spawning capable or mature and regressing (Tab. 2). From the total of ovaries analyzed, 46.4% were immatures, 26% in initial development, 6.4% in advanced development, 11% were mature, and 10% regressing.

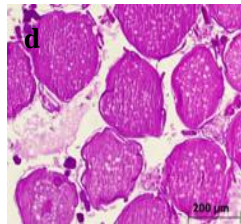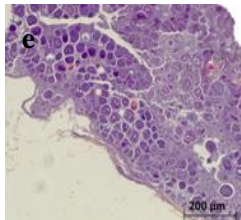Table 2. Macroscopic and microscopic photos and description of ovarian development stages of *Larimus breviceps* captured from December 2016 to November 2017 off the coast of Paraíba state, northeastern Brazil.

Stages	Ovaries	Microscopic sections	Macroscopic and microscopic characteristics
I *Immature*			The ovaries are rudimentary, thin and characterized by a transparent hue, without apparent oocytes and vascularization (0.01±0.004 g). The mean gonadosomatic index (GSI) was 0.15. This stage only presented oogonia and previtellogenic oocytes. Besides that, the connective tissue found between the follicles are scarce and the ovarian wall is thin. There is no evidence of lipid droplets in oocytes.
II *Initial development*			The ovaries presented a yellow-transparent hue, no apparent oocyte and vascularization (0.03±0.009 g). The mean GSI was 0.2. Microscopically, was observed the emergence of cortical alveolar (CA), that characterizes the beginning of the reproductive development, and thereafter the primary vitellogenic oocytes (VTG_1), the greater development oocyte of this stage.
III *Advanced development*			The ovaries in this stage are characterized by a yellow hue, oocytes and vascularization may be apparent (0.04±0.02 g). The mean GSI was 0.22. The presence of secundary vitellogenic oocytes (VTG_2) and a few CA and VTG_1 were observed.
IV *Spawning capable or Mature*			The ovaries in this stage are turgid and large, with intense orange hue and high vascularization. The oocytes are large, abundant and visible all over the ovary (0.8±0.9 g). The mean GSI was 0.47. Microscopically is possible to observe the presence of tertiary vitellogenic oocytes (VTG_3) and oocytes undergoing germinal vesicle breakdown (GVBD). Besides that, the post ovulatory follicles (POF's) are also present, indicating animals in actively spawning.
V *Regressing*			The ovaries are flaccid with thick ovarian wall. Although blood vessels are present, the ovaries are less vascularized, regarding the previously stage (0.11±0.14 g). The mean GSI was 0.19. Microscopically was observed GVBD, POF's and atretic oocytes.

The mean length at first maturity (L_{50}) was estimated as 11.1 cm TL (CI±2) for 549 females. The smallest adult individual presented 7.8 cm TL, whereas all those with TL above 13.8 cm were adults (Fig. 4). A total of 50.1% of the individuals captured presented TL lower than the L_{50}.
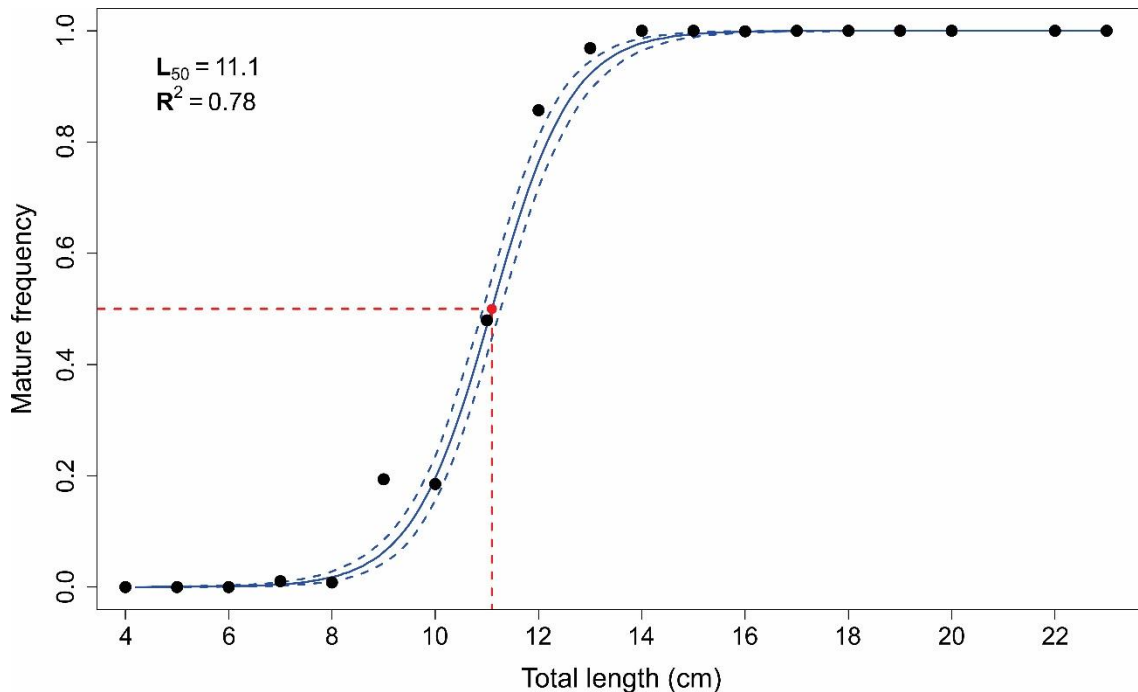
Figure 4. Mean length at first maturity for females of *Larimus breviceps* captured from December 2016 to November 2017 off the coast of Paraíba state, northeastern Brazil.

Was found a higher frequency of immature females in April (83.5%), initial development in July (60%), advanced development in December (66.6%), spawning capable in February (60%) and regressing in October (27%). Immature individuals were present throughout the year and mature females were only present from November to April. This period of the year also presents the gonadosomatic indexes (GSI) peaks: December and February. After February, the GSI starts to decrease, being relatively constant from April to October ($p < 0.05$) (Fig. 5). The Spearman's rank correlation presented a non-significant relationship between rainfall with GSI values and percentage of mature females (stage IV) ($p > 0.05$).
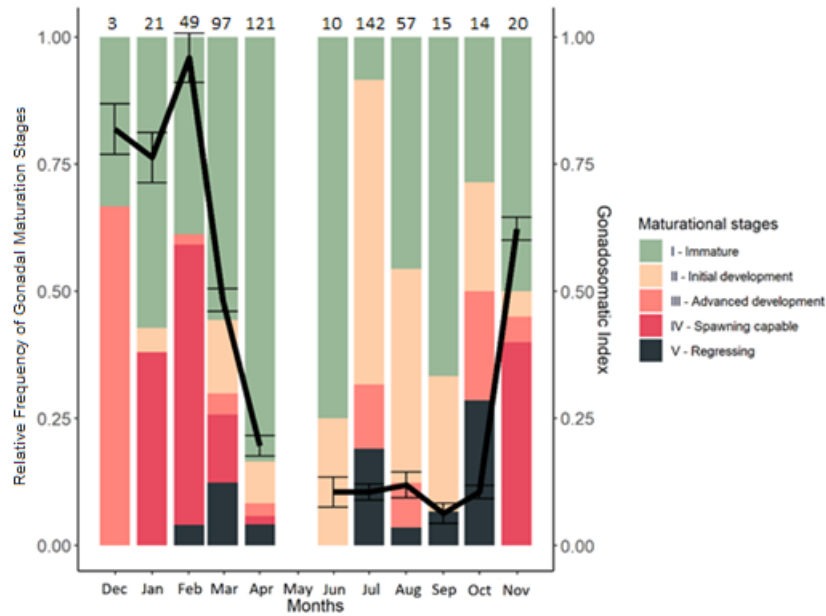
Figure 5. Female monthly gonadosomatic index (±, standard deviation) and maturational stages proportion of *Larimus breviceps* captured from December 2016 to November 2017 off the coast of Paraíba state, northeastern Brazil (black line: GSI; on the top of the columns appears the monthly size of the sample).

Discussion

Larimus breviceps is one of the most abundant species in number captured as bycatch in the shrimp fisheries in Brazil (Lacerda et al., 2014), being accidentally caught in at least 8 states (Braga, 2000; Tischer and Santos, 2003; Souza et al., 2008; Oliveira-Silva et al., 2008; Freitas et al., 2011b; Silva et al., 2012; Bomfim et al., 2019; Passarone et al., 2019) and 5 other countries (Smith et al., 2008; Willems et al., 2015; Plazas-Goméz et al., 2018). This species alone may represent around a quarter of the total catch. For instance, in Santa Catarina state, south Brazil, *L. breviceps* may represent approximately 28% of the incidental catches (Freitas et al., 2011b); whereas in the study area it represents up to 10% of the total catch (Passarone et al., 2019). Here we brought new information on the oocytary development and reproductive biology of this species. This data improves the biological knowledge of an important bycatch species and may thus contribute to sustainable management and conservation practices.

Nektonic animals possess the ability to maintain themselves on food-rich surroundings and to select optimal habitat types for different phases in their life histories (Barnes and

Hughes, 1982). Harden-Jones (1968) envisaged fish migration between three areas according to its life cycle stage: spawning area; nursery area and adult stock. Nursery areas are habitats that provide optimal conditions, in terms of food and shelter, for the growth of juveniles. Although *L. breviceps* may reach 32.5 cm TL (Aparecido et al., 2019), such large adults were not encompassed in this study. Additionally, in the present study, individuals ranging from 4.2 to 23 cm TL were captured, half of them being immature. Hence, juveniles of *L. breviceps* are relevant within this fishery, also occurring throughout the year, corroborating Silva-Júnior et al. (2015) in Pernambuco state. In Cabedelo, adjacent beach, with the same fishing activity and similar fishing gear, but restricted to the surf zone, individuals from 3.15 to 11 cm TL were captured, with 100% of immature individuals (Ferreira et al., 2017). *Larimus breviceps* is classified as a marine migrant species (Bessa et al., 2013; Passarone et al., 2019), and uses the estuary as a spawning area and for larvae recruitment (Costa et al., 2012). The ontogenetic variation between studies characterizes the surf zone not only as a nursery area but also as a transition zone between the estuary and the adult stock. This pattern was also observed for other fishes in northeastern Brazil and other Sciaenidae in different parts of the world (Robert et al., 2007; Zhang et al., 2019).

Juveniles of *L. breviceps* were also observed in motorized bottom trawls of the adjacent states such as Pernambuco (6 to 23.2 cm) (Silva-Júnior et al., 2015) and Rio Grande do Norte (3 to 18 cm) (Bomfim et al., 2019), adjacent states, with 80% and 76% of immature individuals, respectively. The high catches of juveniles by motorized bottom trawls is also highlighted in other locations (Branco and Verani, 2006; Silva-Júnior et al., 2013). To protect, not only the juveniles of bycatch species, but likely the entire local biodiversity, no-taken zones or closed fishing seasons and the insertion of bycatch reduction devices in the fishing gears could be created to mitigate the fishing impact (Wigley and Gabriel, 1991; FAO, 2016).

Considering the Length-Weight relationship (LWR), in the present study, *L. breviceps* presented positive allometry (b=3.2; p<0.05), within the limits indicated by Froese (2006) (2.5 to 3.5), evidencing greater increment in weight than in length. This pattern was also observed for *L. breviceps* in other localities, as in Paraíba (b=3.06; Ferreira et al., 2017), Santa Catarina (b=3.2; Freitas et al., 2011a) and Southeastern Brazil (b=3.1; Vianna et al., 2004). This allometry seems to be standard not only for the species, but also for the genus. Flores-Ortega et al. (2017) reported positive allometry for *L. acclivis* (b=3.38) and *L. effulgens* (b=3.08) in

Mexico coast. Growth may vary according to food availability or populational and environmental conditions (Froese, 2006).

The sex ratio provides key information about the reproductive potential of the individuals and their relation to the environment, being relevant to estimate the population stock size (Stratoudakis et al., 2006). The total sex ratio found was 1 F: 0.78 M, differing significantly from 1:1 (p<0.05). Mature females predominated in February and March (reproduction season). This may have happened to increase the reproductive success of the population, since the reproductive potential depends on the abundance of females (Coelho et al., 1987). In shrimp motorized fishery operating at approximately 20m depth in Pernambuco, a predominance of males was observed (Silva-Júnior et al., 2015) while in British Guiana, equal proportion of sexes was observed (McConnell, 1966). These divergences may be caused by ecosystem differences, areas of trawling, and the increase of fishing pressure in one of the sexes, given possible differential growth rates (Rijnsdorp et al., 2010).

The knowledge about oocyte and ovary development patterns are inexistent not only for *L. breviceps*, but for the genus *Larimus*. Therefore, the comparisons were made to family level. Macroscopically, there are several differences between stages nomenclatures and their respective descriptions among Sciaenidae species. For example, Farmer et al. (2008) described 8 macroscopic stages for *Argyrosomus japonicus* and, for our studied species, we noticed differences in color and body cavity occupation in most stages. Despite the microscopic descriptions follow the same feature (e.g., differences in nomenclature), all Scianidae species studied are group-synchronous or asynchronous batch spawners (Hutchings *et al.*, 2006; Yamaguchi et al., 2006; Dadzie et al., 2007). *L. breviceps* has a long reproductive period presenting advantages that can maximize reproductive success, due to higher reproduction opportunities, ensuring adequate environmental conditions to the offspring, allowing the development and survival of juveniles (Yamahira, 2004). Therefore, the offspring widely varies with age, resulting in different life histories, as well as different vulnerability to the minimum size of capture (Lowerre-Barbieri et al., 2011). Additionally, oocyte stages between undergoing germinal vesicle break down (GVBD) and atresia were not encompassed in this study (e.g., germinal vesicle migration and hydrate oocytes) and a low frequency of GVBD was observed, therefore, the species oocyte maturation and spawn may occur rapidly.

The gonadosomatic index (GSI) and the proportion of the maturational phases are critical tools to determinate the spawning season of a species, which can be used to determine conservation action plans and rearing in captivity (Mian et al., 2017). In this study, we observed that *L. breviceps* reproduce throughout the year, peaking in austral summer. This pattern was also observed in Pernambuco (Silva-Júnior et al., 2015) and Santa Catarina (Souza and Chaves, 2007). The energy allocation for reproduction over a wide period defines behavioral strategies to maximize reproductive success and guarantee the offspring survival in different environmental conditions (Winemiller, 2005). This strategy results from a large investment by the parents to produce a high number of offspring at each reproductive cycle (Pianka, 1970).

In temperate waters, where there is a notorious seasonal variation, it is common for the species to have a single spawning season and a reproductive period well marked (Vazzoler, 1996). Despite that, most teleosts in middle latitudes, where the variation of temperature is low have skipped spawning, reproducing all year around (Cortés and Aron, 2011). Therefore, pluviometry has a decisive role in reproductive cycles (Souza and Chaves, 2007; Chellappa et al., 2010). However, in our case, no relationship between rainfall and spawning was observed. Thus, other factors may trigger and promote the spawning, such as differentiation in, temperature, daylight, turbidity, depth of water and food availability (Jasmine and Molina, 2016).

The mean length at the first maturity (L_{50}) is a key parameter for the development of a sustainable fisheries management. For instance, based on this information it is possible to set a minimum size of catch and thus properly dimension fishing gears (Vieira and Haimovici, 1997; Fonteles-Filho, 2011). In the present study, the L_{50} of *L. breviceps* was 11.1 cm TL. Maturation in early ages is typical in Sciaenidae and in short-lived fishes in general, which tend toward r-strategist life histories (Shlossman and Chitteden, 1981). Silva-Júnior et al. (2015) reported larger values in Pernambuco (13.5 cm TL). These differences may be explained by methodological differences, such as areas or maturity scales. In our case, we performed a microscopical analysis to validate the macroscopic stages.

In the study area, fishing is a relevant socioeconomic activity, representing a source of food and income for a large part of the population (Lacerda et al., 2014). The shorthead drum, as a marine migrant species, plays an important role by connecting different areas, using the estuary for breeding, the surf zone for protection and growth, and deeper marine areas for the

adult stock, revealing high ecosystemic connectivity that supports the importance of ecosystem conservation (Costa et al., 2012; Bessa et al., 2013). In this study, based on macroscopic and microscopic ovarian analysis, five maturational stages were defined. Despite the ecologic importance of *Larimus breviceps*, the lack of studies (e.g., reproduction, diet, age, growth, mortality) and legislations prevent a complete assessment of the ecology and hamper the development of management practices that ensure the sustainability of the species exploitation. However, given the multi-specific nature of this fishery, the shorthead drum must be considered in an ecosystem approach for management, considering other main bycatch and target shrimp species.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Lucas Vinícius Santos: Writing - original draft, Investigation, Microscopic analysis, Formal analysis and Review. **Cecília Fernanda Farias Craveiro**: Microscopic analysis and Editing. **Andrey Paulo Cavalcanti Soares:** Formal analysis and Editing. **Leandro Nolé Eduardo**: Editing. **Rafaela Passarone**: Editing. **Emanuell Felipe Beserra da Silva**: Project administration and Editing. **Flávia Lucena-Frédou**: Project administration, Conceptualization, Supervision and Editing.

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ARTIGO CIENTÍFICO II

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Trophic ecology and ecomorphology of *Larimus breviceps* (Perciformes: Sciaenidae) in northeastern Brazil

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Abstract

The shorthead drum, *Larimus breviceps* Cuvier, 1830, is one of the most abundant species of the bycatch in the shrimp fisheries in Brazil and has an important role in the subsistence of local communities. Besides that, studies addressing the trophic ecology in the Brazilian northeastern coast on this species are still scarce. In this study, we present further information on the trophic ecology of the *L. breviceps*, on Paraíba, northeast Brazil, including dietary analyses and several morphometric measurements. The specimens were captured from February to November 2017 by the local artisanal shrimp fisheries. A total of 46 individuals (27 juveniles and 19 adults) were subsampled for ecomorphological analysis. Significant differences in the ecological attributes between ontogeny were only found for peduncle flatness index (PFI) and body flatness index (BFI). A total of 479 stomachs of *L. breviceps* were analyzed. The total length (TL) varied between 6.3 and 19.2 cm. Nine feeding categories were defined for *L. breviceps*. Sergestidae was characterized as the main prey (IAi=83%). The diet composition from the nMDS ordination displayed a different pattern for juveniles and adults. A total of 40 individuals (dry season = 20; rainy season = 20) were selected for stable isotope analysis. Mean values of $\delta^{13}C$ and $\delta^{15}N$ were different by size in the dry season. We observed a trophic level between the third and fourth position for the shorthead drum, classifying the species as a carnivore predator. This information improves the general knowledge and ecological data on bycatch species, as well as may give support to management initiatives aiming conservation.

Keywords

diet; ecomorphological attributes; feeding strategy; seasonal variation; stable isotope.

Introduction

Marine coastal regions include key ecological systems for several species, which can be affected by fishing activities (e.g., fishery resources overexploitation, substrate destruction) (Santos et al., 2008). In Brazil, these ecosystems are exploited by artisanal fisheries, characterized by the multiple uses of gear and great diversity of target and bycatch species (Pauly, 2005). One of the most common modalities of this activity is the shrimp trawling, carried out by motorized and beach trawling (Neiva, 1988; Marrul-Filho, 2003).

In the state of Paraiba, Northeastern Brazil, the ordinance IBAMA nº 833/1990 prohibited the motorized trawling in the main fishing areas. Currently, fisheries are carried out exclusively through beach trawling, targeting mainly the white (*Penaeus schmitti*), pink (*Penaeus subtilis*), and seabob (*Xiphopenaeus kroyeri*) shrimps. Despite limited to areas nearshore, this trawling modality has high bycatch biomass catches (Passarone et al., 2019), provoking incidental mortality of many species (Hall et al., 1999) and contributing to the ecological unbalance of the ecosystem. Among the components of the bycatch, sciaenid are the most abundant fish caught by motorized bottom trawling fleet in the coastal waters of Northeastern Brazil (Santana and Severi, 2009; Silva-Júnior et al., 2019).

The shorthead drum, *Larimus breviceps* Cuvier, 1830, is a Sciaenidae widely distributed in the southwest Atlantic (from Costa Rica to Santa Catarina) and one of the most abundant species of the bycatch in the shrimp fisheries in Brazil, included the beach trawling (Vianna and Almeida, 2005; Cattani et al., 2011; Passarone et al., 2019). Even though it has a low commercial value, smaller specimens are utilized as fish bait, while larger ones are usually commercialized, serving as an income source for the local artisanal fishermen (Chao, 1978; Lacerda et al., 2014), therefore, this species may play an important role in the subsistence of local communities (Silva-Júnior, 2019).

Studies about diet and feeding activity of species in their natural habitats provide valuable information on how the interactions of the organisms with the environment contribute to their functioning and management of the water resources (Winemiller et al., 2008; Blaber, 2013). Although its ecological and socio-economic importance, studies addressing the feeding behavior of *L. breviceps* are restricted to the South and Southeast of Brazil (Bessa et al., 2013; Soares and Vazzoler, 2001). Moreover, these studies are based solely on stomach content analysis (SCA), which, although it may present high taxonomic resolution of the diet, is limited to a short period; and it is subject to underestimation of some prey groups (e.g., quickly digested preys are often not considered; Eduardo et al., 2020). Alternatively, the stable isotope analysis (SIA) provides temporal information of the material assimilated by the organisms and may help to understand the prey contribution to body composition (Cherel et al., 1993). Therefore, the combination of SCA and SIA is efficient to describe the trophodynamic and energy flow across trophic compartments (Eduardo et al., 2020).

The functional morphology is another key element to represent the roles of species in the ecosystems. For instance, it characterizes how interspecific competition among ecologically equivalent species drives different life strategies (Villéger et al., 2008). Moreover, body shape is also used to comprehend the single and multifunctional factors related to behavioral ecology (e.g., feeding, predator evasion, or courtship display) (Loy et al., 2000; Walker, 2010).

The present study provides novel information on the trophodynamics and ecomorphological aspects of *Larimus breviceps*, including gut content analyses, stable isotope data, and several morphometric measurements in a poorly studied region where *L. breviceps* is frequently caught as non-target species. This information contributes to the understanding of *L. breviceps* ecology and the development of future management and conservation practices, considering an ecosystem viewpoint.

Material and methods

Sampling procedures

The study site is the Lucena beach, Paraíba state (6° 53′50" S; 34° 51′01" W) (Fig 1), the region with the most productive shrimp fisheries in Paraíba state (Moura, 2003). Specimens were captured by the local artisanal shrimp fisheries from February to November 2017.
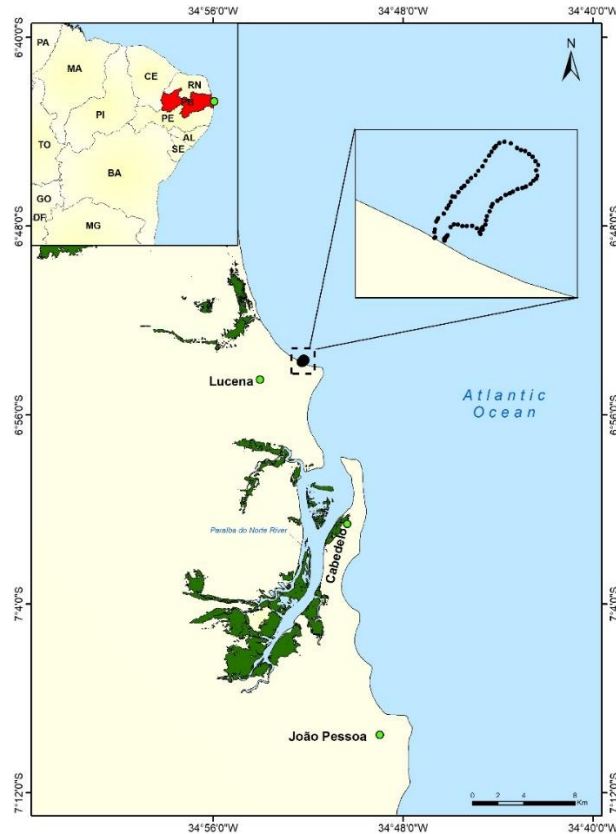
Figure 1. Study area on the coast of the state of Paraíba, Northeastern Brazil. Black dots represent an example of a transect of the fishing activity.

Two trawls, carried out by a small and non-motorized craft, were hold monthly for 50 minutes from a depth of 6 meters deep to the surf zone using a beach seine (horizontal x vertical dimensions: 120×6 m, body mesh: 2 cm, cod-end mesh: 1.5 cm). Once collected, the specimens were put on ice and then transported to the laboratory. The Standard Length (SL-cm) and Total Weight (TW-g) were obtained. The individuals were dissected, the stomachs were removed and weighed (g). The fullness degree (FD) of the stomachs was classified by the scale: 1 = empty, 2 = partially empty, 3 = partially full, and 4 = full (Viana et al., 2010). Thereafter, the contents of the individual stomachs were identified to the lowest taxonomic level possible, counted, weighted (g), and sorted according to their state of digestion defined by Vaske-Júnior and Castello (1998) methodology: 1- fresh prey; 2- partially digested prey; 3- digested, but identifiable prey; 4-digested, but not identifiable.

Trophic ecomorphology

A total of 46 specimens were subsampled for ecomorphological analysis with thirteen linear measurements taken from the left side of the individuals with a 0.01 mm

precision pachymeter. The following measurements were taken: standard length (SL), body height (BH), body width (BW), caudal peduncle height (PH), caudal peduncle width (PW), caudal peduncle length (PL), head height (HH), head width (HW), head length (HL), eye height (EH), mouth width (MW), mouth height (MH), length of the upper jaw (A) and length of the lower jaw (B) (Fig. 2). The size of the mouth opening was estimated by Shirota (1970), using the formula $D = \sqrt{2}MH$, where D = size of the mouth opening and MH is the measure of the length of the upper jaw, based on the recommendations contained in Shirota (1978). Subsequently, 10 ecomorphological attributes were estimated (Tab. 1) (Gatz, 1979; Watson & Balon, 1984; Winemiller, 1991).
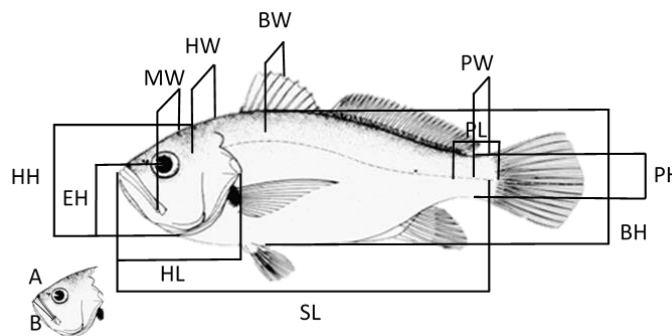

Figure 2. Morphometric measurements used for *Larimus breviceps* Cuvier, 1830 of the coast of Paraíba state, northeastern Brazil.

Table 1. Ecomorphological attributes according to Gatz (1979), Watson and Balon (1984), and Winemiller (1991) (HW, Head Width; BW, Body Width; HH, Head Height; HL, Head Length; MW, Mouth Width; MH, Mouth Height; CPW, Caudal Peduncle Width; CPL, Caudal Peduncle Length; CPH, Caudal Peduncle Height; BH, Body Height; EH, Eye Height).

	Ecomorphological attributes	Attribute estimation
Prey size	Relative Head Width (RHW)	RHW = HW / BW
	Relative Head Height (RHH)	RHH = HH / BH
	Relative Head Length (RHL)	RHL = HL / SL
	Relative Mouth Width (RMW)	RMW = MW / SL
	Relative Mouth Height (RMH)	RMH = MH / SL
Predator behavior	Relative Peduncle Width (RPW)	RPW = PW / BW
	Relative Peduncle Heigth (RPH)	RPH = PH / BH
	Relative Peduncle Length (RPL)	RPL = PL / SL
	Peduncle Flatness Index (PFI)	PFI = PH / PW
	Body Flatness Index (BFI)	BFI = BH / BW
	Vertical Eye Position (VEP)	VEP = EH / HH

Diet composition

To verify possible ontogenetic changes, individuals were classified as juveniles and adults according to the length at first gonadal maturity reported in the literature (L_{50}; 11.1 cm TL; Santos et al., subm). Additionally, to identify seasonal diet changes, two climatic seasons were considered: dry (September, October, November, and February) and rainy (March, April, July, and August). Climatic seasons were defined based on the monthly mean precipitation index for the region in the last 10 years (aesa.pb.gov.br).

The Fullness Index (FI), the percentage ratio of the weight of stomach contents to the total weight of the fish, was used to characterize feeding intensity (Moreno and Castro, 1995). Since data did not follow the necessary assumptions for the parametric test, the non-parametric Kruskal-Wallis was used to test the FI differences between seasons.

Diet and importance of each prey item were described by the occurrence frequency (%O), numerical frequency (%N), and weight percentage (%W) (Baker et al., 2014). The Alimentary index (*IAi*) (Kawakami and Vazzoler, 1980, adapted by Oliveira et al., 2004) was calculated by the following formula: $\text{IAi} = \frac{(\%O \times \%W)}{(\sum_{i=1}^{n}(\%O \times \%W) \times 100)}$. To facilitate the interpretation and comparisons between food categories, the *IAi* was standardized and presented in percentage (%*IAi*). In addition, based on the *IAi*, it was determined the feeding category classification by Kawakami and Vazzoler (1980), in which the preys were classified as: principal (*IAi* > 50%), secondary (25% ≤ *IAi* ≥ 50%), and accessory (*IAi* < 25%).

Niche breadth varies from 0 (species that feed on only one item) to 1 (species that feed on the same proportion of all evaluated items) and was estimated by Levins standardized index (Levins, 1968): $B_J = \frac{1}{n-1}(\frac{1}{\sum p_{ij}^2} - 1)$, where B_j is the Levin's standardized index for predator *j*, $p_i{}^2{}_j$ is the proportion in weight of prey *i* in the diet of predator *j* and *n* is the number of prey categories.

The feeding strategy of the species for ontogenetic and season factors was assessed from the method proposed by Costello (1990) and modified by Amundsen et al. (1996). In this method, the prey-specific abundance (P_i) and the occurrence frequency (%O) of each item were arranged in a two-dimensional graph. The P_i of each item is the number of items *i* divided by the total number of items present in individuals where the item *i* was observed.

The distribution of points on the graph in this method indicates the importance and the occurrence of each item for the diet of the species.

To assess the degree of similarity in the diet, the multivariate technique of non-metric multidimensional scaling (nMDS) based on the Bray-Curtis similarity matrix was performed, with stomachs being considered as the sampling units. Ontogenetic and seasonal differences were tested with a two-way PERMANOVA (Anderson, 2001).

Stable isotope analysis

A total of 40 individuals (dry season = 20; rainy season = 20) were selected for stable isotope analysis. White muscular tissue was extracted from the fish and cleaned with distilled water to remove exogenous material (e.g., remaining scales, bones, or sediment particles). Samples were set to dry in an oven at 60ºC for 48 h and grounded into a fine powder with a mortar and pestle. After drying, the samples were analyzed for carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios through a mass spectrometer (Thermo Delta V+) coupled to an element analyzer (Thermo Flash 2000, interface Thermo ConFio IV) in the Platform Spectrometry Ocean (PSO, IUEM), France.

Results of stable isotope analysis for $\delta^{13}C$ and $\delta^{15}N$ are derived from the relation of the isotopic value from the sample and a known standard: $\delta^{13}C$ or $\delta^{15}N = [(R_{sample}/R_{standard}) - 1] \times 10^3$; in which R corresponds to the ratio between $^{13}C/^{12}C$ or $^{15}N/^{14}N$. Since the mean values of $\delta^{13}C$ and $\delta^{15}N$ follow the necessary assumptions for the parametric test, the Student's t-test was used to test differences between seasons, and the ANOVA test was used to test the ontogeny within seasons.

The trophic position of the shorthead drum was assessed using the formula proposed by Post (2002): $TP_{SIA} = \lfloor(\delta^{15}N_{consumer} - \delta^{15}N_{baseline})/TDF\rfloor + TP_{baseline}$, in which $\delta^{15}N_{consumer}$ and $\delta^{15}N_{baseline}$ are the $\delta^{15}N$ values of the target consumer and the baseline. TDF is the trophic discrimination factor and $TP_{baseline}$ is the trophic position of the baseline. As particulate organic matter may be influenced by the co-occurrence of detritus (Montoya et al. 2002) and microzooplankton in the water column (Post, 2002), the mean $\delta^{15}N$ of zooplankton was used as a reference Figueiredo et al. (2020). For further information on Zooplankton community sampling, refer to Figueiredo et al. (2020).

The software R 3.4.4 was utilized to perform all statistical analyses (R Core Team, 2018). The vegan package (Oksanen et al. 2019) was used for the multivariate analyses.

Results

Trophic ecomorphology

Of the 46 specimens examined, 27 were juveniles and 19 adults. Standard length ranged from 5.9–9.1 cm [7.6±0.6 cm (mean ± SD)] for juveniles and from 9.9–15 cm (12.5±2.4 cm) for adults. The total weight varied from 3.0 to 11.49 g (8.0±1.7 g) for juveniles and from 6.2 to 80.1 g (49±27 g) for adults.

Significant differences of the ecological attributes considering the ontogeny were only found for peduncle flatness index (PFI) and body flatness index (BFI) (Tab. 2).

Table 2. Ecomorphological attributes parameters of *L. breviceps* captured from December 2016 to November 2017, off the Paraíba state coast, northeastern Brazil (sd, standard deviation).

Ecomorphological attributes	Acronyms	Juveniles	Adults	*p-value*
Relative Head Width	RHW	1.3±0.1	1.0±0.09	p > 0.05
Relative Head Height	RHH	0.8±0.06	0.9±0.05	p > 0.05
Relative Head Length	RHL	0.3±0.01	0.3±0.006	p > 0.05
Relative Mouth Width	RMW	0.08±0.006	0.09±0.02	p > 0.05
Relative Mouth Height	RMH	0.03±0.001	0.06±0.02	p > 0.05
Relative Peduncle Width	RPW	0.2±0.03	0.2±0.06	p > 0.05
Relative Peduncle Length	RPL	0.2±0.008	0.1±0.02	p > 0.05
Relative Peduncle Height	RPH	0.3±003	0.3±0.02	p > 0.05
Peduncle Flatness Index	PFI	3.9±1.2	3.2±0.7	**p < 0.05**
Body Flatness Index	BFI	3.1±0.3	2.4±0.3	**p < 0.05**
Vertical Eye Position	VEP	0.6±0.04	0.6±0.07	p > 0.05

Diet composition

A total of 479 stomachs of *L. breviceps* were analyzed subdivided in juveniles in the dry season (J_d; n= 11) and rainy season (J_r; n= 199) and adults in the dry season (A_d; n= 46) and rainy season (A_r; n= 223). The total lengths (cm) varied between 6.3 and 19.2 [12.09±2.05 (mean ± SD)] and the total weight (g) between 1.23 and 85.6 (21.53±13.49). Stomachs with only digested organic matter (D.O.M.; n= 36) were removed of the quantitative analysis. Most of the stomachs (n= 403) presented one (53.3%) or two (39.5%) food items, whereas only a small percentage of stomachs contained three (5.4%), four (1.6%),

or five items (0.2%). The fullness index varied from 1.06 to 3.51, with higher values in the rainy season (Kruskal-Wallis test: $\chi^2 = 323.96$, p<0.05).

The feeding spectrum of *L. breviceps* totalized nine feeding categories: Actinopterygii (not identified due to the advanced state of digestion), Crawfish, Gastropoda, Hemiramphidae, *Isopisthus parvipinnis*, Isopoda, *Larimus breviceps*, Sergestidae, and *Xiphopenaeus kroyeri*. Regarding the occurrence (%O), numerical frequency (%N), and weight percentage (%W), Sergestidae dominated (74.8%, 47.1% and 68.4%, respectively), followed by *Isopisthus parvipinnis* (37.1%, 23.4% and 23.9%) and Actinopterygii (25.9%, 16.3% and 4.5%). The other items showed %O, %N, and %W lower than 3%. Sergestidae predominated in all categories regardless season and ontogeny and was characterized as the main prey (IAi= 83%; Tab. 4). The diet composition from the nMDS ordination displayed a different pattern for juveniles and adults (PERMANOVA: A_d, R= 2.7; p<0.05), which was similar with the %O, %N and %W.

The largest niche breadth was observed for J_d and A_r (Bi= 0.32 and 0.23, respectively) and narrower niche widths for J_r and A_d (Bi= 0.17 and 0.07, respectively). According to the modified Costello diagram, Sergestidae shrimps were preferentially consumed by all categories. Actinopterygii had a high contribution to the diet of J_d and A_r performed high diversity of bottom-related preys (Fig. 3; Tab. 3).

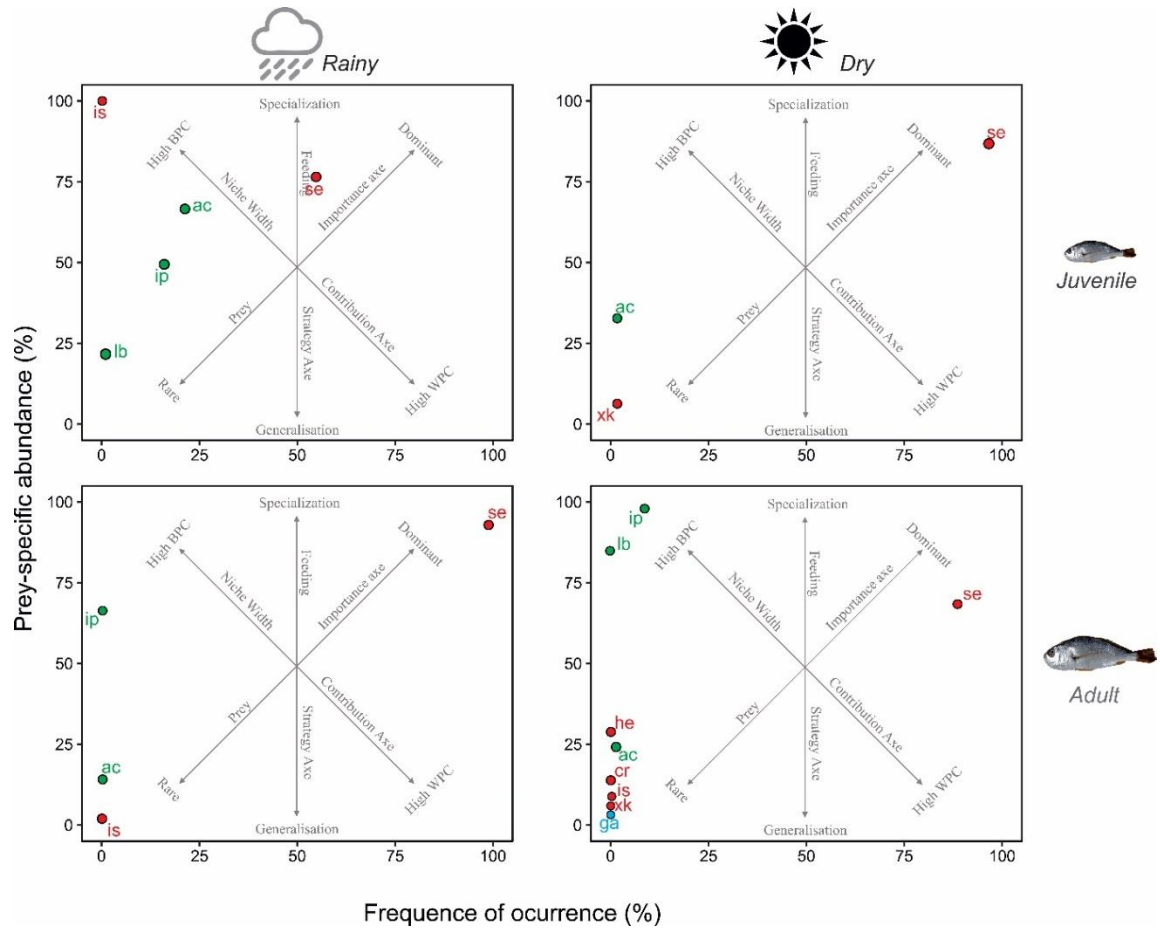Figure 3. Feeding strategy among ontogeny and season of *Larimus breviceps* captured from February 2016 to November 2017 off the Paraíba state coast, northeastern Brazil (Coloured points represent Crustacea (red), Teleostei (green) and Mollusca (blue); ga, Gastropod; ip, *Isopisthus parvipinnis*; is, Isopod; se, Sergestidae; xk, *Xiphopenaeus kroyeri*; lb, *Larimus breviceps*; ac, Actinopterygii; he, Hemiramphidae; cr, Crawfish).

Table 3. Occurrence (%O) and numerical (%N) frequencies, weight percentage (%W), food importance (%IAi) and food preference classification (C) of juveniles and adults by season of *Larimus breviceps* captured from February 2016 to November 2017 off the Paraíba state coast, northeastern Brazil (P, Principal; A, Accessory).

| Prey | Dry season | | | | | | | | | | Rainy season | | | | | | | | | |
| | Juveniles (n = 11) | | | | | Adults (n =46) | | | | | Juveniles (n = 199) | | | | | Adults (n = 223) | | | | |
	%O	%N	%W	%IAi	C	%O	%N	%W	%IAi	C	%O	%N	%W	%IAi	C	%O	%N	%W	%IAi	C
Crustacea																				
Crawfish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.90	0.06	0.12	<0.01	A
Isopoda	-	-	-	-	-	2.17	0.13	0.12	<0.01	A	0.17	0.17	<0.01	<0.01	A	4.48	0.31	0.32	0.02	A
Sergestidae	81.82	96.61	86.95	98.36	P	95.65	98.93	92.19	99.60	P	37.69	54.81	51.0	65.29	P	86.10	88.63	64.17	76.99	P
Xiphopenaeus kroyeri	9.09	1.69	1.30	1.48	A	-	-	-	-	-	-	-	-	-	-	0.45	0.03	0.06	<0.01	A
Mollusca																				
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.45	0.03	0.01	<0.01	A
Teleostei																				
Non-identified Teleostei	9.09	1.69	11.75	0.16	A	4.35	0.27	1.01	0.05	A	37.19	21.31	18.98	23.98	A	14.80	1.43	3.49	0.72	A
Hemiramphidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.90	0.09	0.17	<0.01	A
Isopisthus parvipinnis	-	-	-	-	-	4.35	0.27	5.95	0.29	A	18.59	15.98	16.97	10.72	A	53.81	8.69	29.69	22.26	A
Larimus breviceps	-	-	-	-	-	-	-	-	-	-	1.51	1.03	0.27	0.01	A	0.90	0.06	0.28	<0.01	A
D.O.M.	-	-	-	-	-	6.52	0.40	0.73	-	-	6.70	6.70	12.78	-	-	9.42	0.65	1.69	-	-

Stable isotope analysis

The values for $\delta^{13}C$ and $\delta^{15}N$ varied between -16.09 and -14.88‰ and between 14.04 and 15.12‰, respectively. The mean of $\delta^{15}N$ for *L. breviceps* was higher in the rainy season than dry (*t*-test: t= -9.2785, df= 32.609, p<0.05), while the $\delta^{13}C$ between seasons was similar (Fig. 4).

Figure 4. Stable isotopes plot by season of *Larimus breviceps* captured from February 2016 to November 2017 off the Paraíba state coast, northeastern Brazil.

Significant differences in $\delta^{13}C$ and $\delta^{15}N$ values by size was observed in the dry season (ANOVA: $\delta^{13}C$, F= 17.01, p<0.05; $\delta^{15}N$, F= 10.64, p<0.05). No significant differences were found in $\delta^{13}C$ and $\delta^{15}N$ values when considering ontogeny in the rainy season (ANOVA: $\delta^{13}C$, F= 1.69, p>0.05; $\delta^{15}N$, F= 1.20, p>0.05) (Fig. 5).
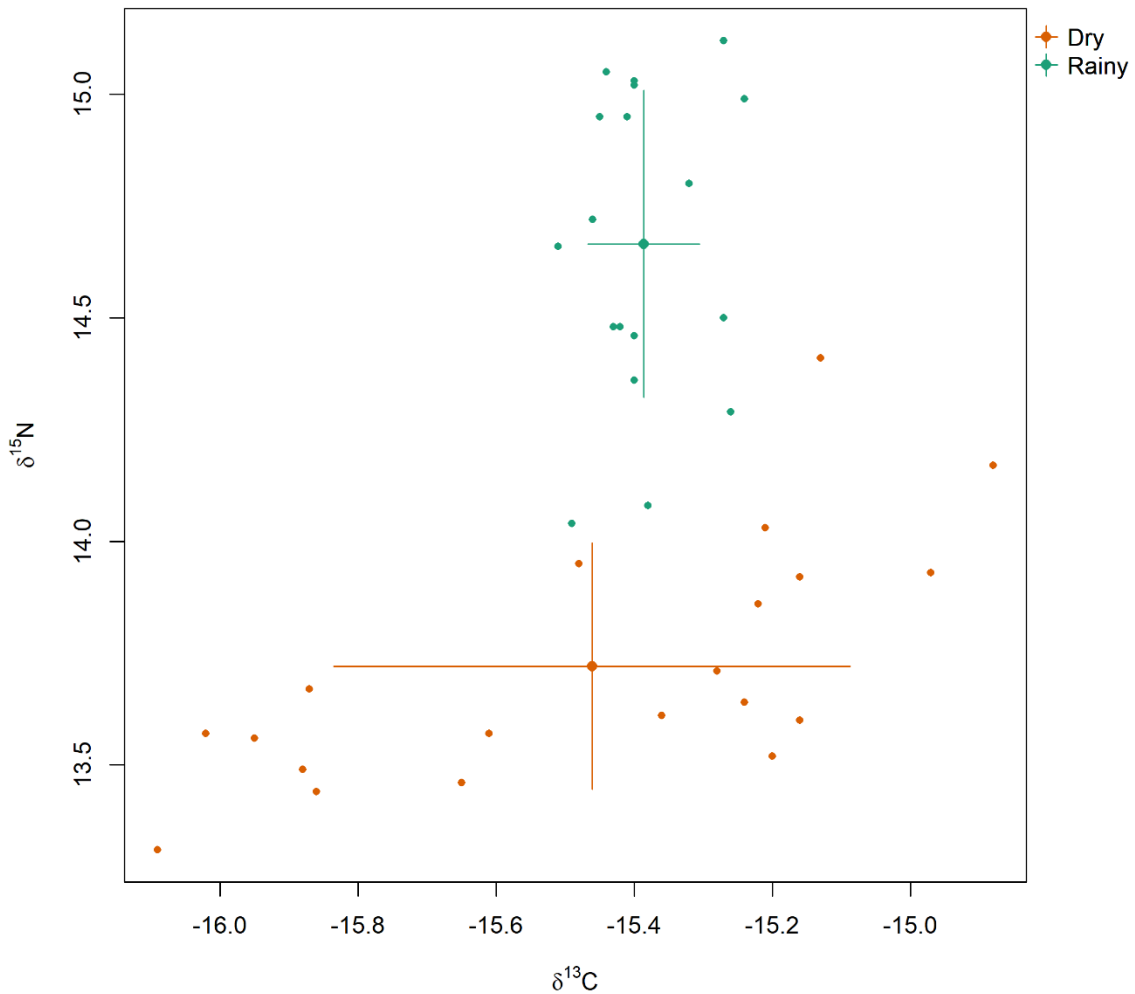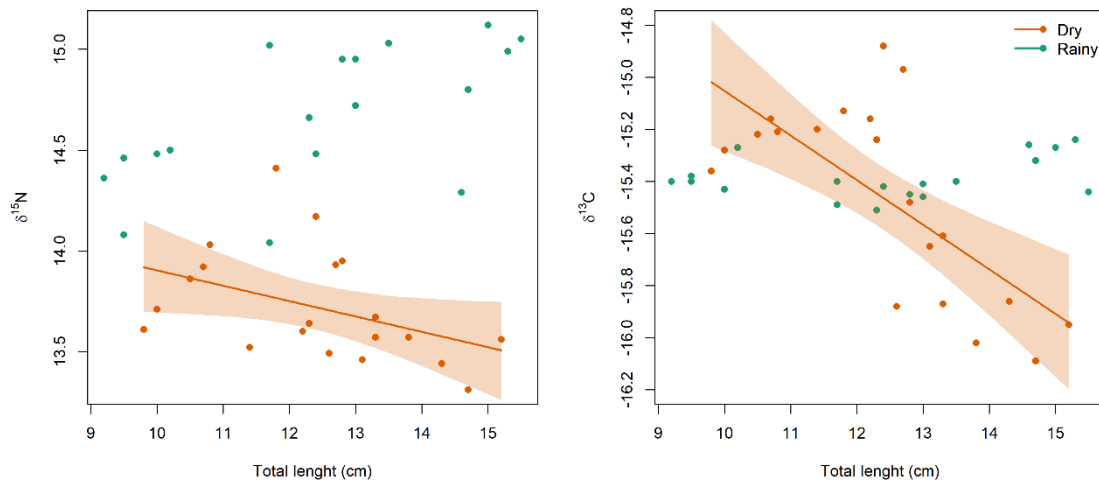
Figure 5. Stable isotopes plot by total length of *Larimus breviceps* captured from February 2016 to November 2017 off the Paraíba state coast, northeastern Brazil.

Overall, we found a trophic level between the third and fourth position for the shorthead drum, classifying the species as a carnivore predator.

Discussion

Larimus breviceps is one of the most abundant bycatch species of the shrimp trawling fisheries (Lacerda et al., 2014), being caught in at least 8 Brazilian states and 5 other countries (e.g., Plaza-Gómez et al., 2018; Passarone et al., 2019). Here we combine, for the first time, gut content analysis, stable isotope data, and several morphometric measurements to provide novel insights on the trophodynamics and ecomorphological aspects of *L. breviceps.*

Even though most of the ecological attributes did not show significant differences between juveniles and adults, the body flatness index (BFI) and the caudal peduncle flatness index (PFI) presented differences between the categories. These indexes indicate the fish speed in the water: the higher are the indexes, the lower is the fish speed (Gatz, 1979). Therefore, species with high relative values of BFI and PFI, ingest slow or sessile prey that are usually related to the bottom. The BFI and PFI values for juveniles (3.1; 3.9) were higher than the ones found for adults (2.4; 3.2) of *Larimus breviceps* in Paraíba. This may indicate that juveniles are slower swimmers than adults. Moreover, these values may also be related to the consumption of small (<1.5 cm) pelagic Sergestid species, which are relatively slow and easier to capture (Stickney and Torres, 1989; Ross, 1989). Indeed, the prevalence of

crustaceans in the diet of Sciaenidae species is widely reported (Palmeira and Monteiro-Neto, 2010; Niang et al., 2010).

In the present study, most of the individuals contained food in their digestive tract, regardless of ontogeny or season. This may be related with our sampling strategy, as *L. breviceps* has higher feeding intensity at night (circadian-like pattern) (Soares and Vazzoler, 2001) and most of our trawls were held at dawn. Overall, *L. breviceps* mainly fed on pelagic crustaceans, which were the most common (%O=74.8%) and abundant (%N=47.1%) item. Besides, benthic items were also observed in the species diet (e.g., Crawfish, Gastropoda, Isopoda, *Xiphopenaeus kroyeri*). Moreover, the species feeding strategy suggests that *L. breviceps* is an opportunistic pelagic-demersal species and it has a carnivorous feeding habit, specialized in carcinophagia. This pattern has also been observed for others Sciaenidae (Ross, 1989; Feitosa et a., 2002; Gómez-Canchong et al., 2004; Bessa et a., 2013). We observed differences in the diet among seasons and ontogeny. Adults in the dry season showed differences in the diet in relation to the other categories. These differences are likely related to migration pattern to reproduce (Santos et al., subm). Therefore, while juveniles inhabit the surf zone for protection, feeding mainly on Sergestidae shrimps and Actinopterygii, adults migrate to estuary for spawning in the dry season, mostly feeding on Sergestidae and few additional benthonic preys. The fullness index (FI) showed differences between seasons, in which the reproductive period, which coincided with the dry season, had the lowest values. The low FI values and the search for slower preys may be related to the allocation of energy for reproduction (Rijnsdorp, 1990), wasting less energy on capturing preys.

In the dry season (reproductive period) adults had the lowest trophic niche breadth and feed on preys with lower δ^{13}C values than the ones found for preys of juveniles. Therefore, *L. breviceps* adults remain in the estuary long enough to have their δ^{13}C signatures shifted from an originally enriched signature (obtained during their juvenile stage within the surf zone) to a more depleted signature. This pattern is also found for other species (Garcia et al., 2007). In addition, in the dry season, larger individuals seem to feed on prey with lower values of δ^{15}N. This may happen because adults feed on higher diversity of preys than juveniles in the dry season due to their reproductive migration and juveniles remaining in the study area feeding mainly on, besides Sergestidae, high δ^{15}N level species.

Although sediments and scales were reported in the diet of *L. breviceps* here and elsewhere (Lopes and Oliveira-Silva, 1999; Moraes et al., 2004), the consumption of these

items were considered as accidental, as *L. breviceps* does not present lepidophageal behavior and usually forage where these items are easily found (Lopes and Oliveira-Silva, 1999). The species also presented cannibalism. This behavior was previously reported for *L. breviceps* (Moraes et al., 2001) and other Scianidae (e.g., *Macrodon ancylodon* and *L. fasciatus*; Vazzoler et al., 1999; Ross, 1989).

The trophic position estimated through the SIA showed that *L. breviceps* is ranked between the third and fourth trophic level. These results are endorsed by previous studies based on stable isotope analysis for *L. breviceps* (Gomes et al., 2018) and for other species of the family Sciaenidae (Lira et al., 2018) from trophic-dynamic model. These studies were conducted through similar habitats of the present study (e.g., coastal areas with the impact of trawling fisheries).

Shrimp fisheries cause several impacts on the ecosystem that, given the current state of knowledge, may go mostly unnoticed (Whitfield and Elliott 2002; Mclusky and Elliott 2004). As an example, *Larimus breviceps* are amongst the main bycatch species within the shrimp fisheries in Brazil and its ecology is still poorly understood. Impacts on the population of this species may directly affect nutrition of the local inhabitants, artisanal fisheries, and several organisms that are related to this species. In this study, we present further information on the trophic ecology of the *L. breviceps*, including dietary analyses, stable isotope data, and several morphometric measurements. This information improves the general knowledge and ecological data on bycatch species, as well as may give support to management initiatives, potentially associated to trophic models, or may be considered into the design of Bycatch Reduction Devices (BRD), taking into account the current paradigm of the Ecosystemic Approach to Fishery (EAF).

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CONCLUSÃO GERAL

Na praia de Lucena, litoral da Paraíba-BR, a pesca é socioeconomicamente relevante, representando fonte de alimento e sustento para grande parte da população. Apesar disso, esta atividade causa vários impactos no ecossistema que, dado o atual estado do conhecimento, pode passar despercebido por cientistas e biólogos conservacionistas, principalmente considerando espécies que fazem parte da fauna acompanhante. Como exemplo, o *Larimus breviceps* é uma das principais espécies capturadas pela pesca do camarão no Brasil e sua ecologia ainda é pouco conhecida. O Boca-mole, como uma espécie marinha migrante, tem um papel importante na conexão de diferentes áreas, usando o estuário para reprodução, a zona de arrebentação para proteção e crescimento, e áreas marinhas mais profundas como estoque adulto, revelando alta conectividade ecossistêmica. No presente estudo foram definidos padrões de desenvolvimento ovocitário e ovariano, que ajudam na correta identificação dos estágios maturacionais da espécie e determinação do período reprodutivo para futuras práticas de manejo. Assim como encontramos variações sazonais e ontogenéticas na dieta do *L. breviceps*, determinando padrões alimentares pelos adultos no período seco que corroboram o deslocamento reprodutivo estoque adulto-estuário encontrado pelo presente estudo. Impactos na população da espécie podem afetar a população local, pescadores artesanais e vários organismos que estão troficamente relacionados com o *L. breviceps*. Além disso, os dados morfométricos aqui apresentados podem ser utilizados para dispositivos redutores de bycatch. Apesar da importância ecológica da espécie, a falta de estudos (e.g., reprodução, dieta, idade, crescimento, mortalidade) e legislações impedem um acesso completo da ecologia e dificulta o desenvolvimento de práticas administrativas que asseguram a sustentabilidade da exploração das espécies. As informações apresentadas contribuem para o conhecimento geral e dados ecológicos de espécies de bycatch, assim como dá suporte a iniciativas administrativas visando a conservação. No entanto, dada a natureza multiespecífica da pesca, o Boca-mole deve ser considerado numa visão ecossistêmica para o manejo, considerando outras espécies principais de bycatch e espécies-alvo.