POPULATION STRUCTURE, SIZE AT FIRST SEXUAL MATURITY, AND FEEDING ECOLOGY OF CONODON NOBILIS (ACTINOPTERYGII: PERCIFORMES: HAEMULIDAE) FROM THE COASTS OF PERNAMBUCO, NORTH-EASTERN BRAZIL

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Background. Although the information on fish ecology and population dynamic are fundamental for fisheries assessment and the development of sustainable management practices, there is still a gap for bycatch species, mainly in tropical coastal areas. The aim of the presently reported study was to describe the feeding habitats, mean length of maturation, and the population structure of Conodon nobilis (Linnaeus, 1758) caught as bycatch of the shrimp trawl fisheries in the south of Pernambuco, north-eastern Brazil.

Materials and methods. Specimens of C. nobilis were collected monthly from August 2011 through July 2012, using an artisanal shrimp outrigger trawler from the local fleet. The population structure was analysed by sex, length, and seasons. Stomachs and gonads were removed and examined to define the length at first maturity ($L_{50}$) and the feeding habits of C. nobilis in north-eastern Brazil.

Results. A total of 272 specimens were caught. The sex ratio was similar among females and males in the area. The mean size at first maturity ($L_{50}$) was estimated as 14.3 ± 0.65 cm. The diet of the species was mainly based on crustaceans (Penaeidae) and fish, however, it was not observed differences in the diet between juvenile and adults, and climate seasons.

Conclusion. Conodon nobilis was classified as a zoobenthivore species, and showed a higher proportion of individuals caught above the $L_{50}$. The information here provided, combined with other studies in the region, may contribute to the development of improved management strategies to species conservation and exploited marine habitats in northeast Brazil, which is still mostly unknown.

Keywords: bycatch, Haemulidae, barred grunt, $L_{50}$, diet

INTRODUCTION

Bycatch can be defined as the retained catch of non-targeted but commercially valuable species, or species consumed by the crew and local communities, used as bait, or discarded at the port or at sea (Davies et al. 2009, Gilman et al. 2014). Bottom trawling is highly efficient in capturing target species such as shrimp, however, it utilises non-selective gear that is usually associated with high levels of bycatch and (Kelleher 2005). From 2010 to 2014, global discard from bottom trawls was estimated at 4.2 million t, comprising 45.5% of the total annual discard (Pérez Roda et al. 2019). The incidental catch from bottom trawl fishery, combined with the deficiency of fishery management practices, may lead to changes in the marine food web (Rothlisberg and Okey 2007), decline in populations, and increased catch of juveniles and endangered species (Rodrigues-Filho et al. 2015, Silva Júnior et al. 2015, Vieira et al. 2017). However, besides its effects on the aquatic ecosystem, shrimp trawl activity plays an important role in food intake and the source of income of the local communities (Lobo et al. 2010, Tsagarakis et al. 2014, Silva-Júnior et al. 2019).

In the north-eastern part of Brazil, shrimp fishery is predominantly carried out by artisanal boats operating in muddy, shallow coastal waters (Dias Neto 2011). This activity involves more than 100 000 persons, about 1700 motorised and 20 000 non-motorised boats (Santos 2010), and represents approximately 10% of the marine total landed fishery resources in the country (Anonymous 2008). Despite the social importance of this fishery in the

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region, trawl fisheries operating off Pernambuco are not regulated (Santos 2010), resulting in potential risk for the sustainability and maintenance of the fishing activity. The municipality of Sirinhaém has the highest motorised shrimp fishing fleet among the coastal communities of Pernambuco and penaeids are the most exploited crustaceans (Tischer and Santos 2003).

In Pernambuco, the proportion of fish bycatch and shrimp is $0.39 \div 1$ (fish $\div$ shrimp), which includes the barred grunt, *Conodon nobilis* (Linnaeus, 1758), as a frequent catch. Despite being an important food source for local fishers, this species is also an important link in the coastal food web, highlighting the need to understand the role of barred grunt and other species in the ecosystem balance (Garcia et al. 2010, Silva-Júnior et al. 2019). Although some information on the population dynamics (e.g., diet, population structure, and size at sexual maturity) of the barred grunt is available (Lopes and Oliveira-Silva 1998, Vasconcelos Filho et al. 2010, Pombo et al. 2014), this essential information does not exist in the region, thereby hampering initiatives of management and conservation of this species.

The aim of the presently reported study was to describe the feeding habitats, mean length of maturation, and the population structure of *Conodon nobilis* caught as bycatch of the shrimp trawl fisheries in the south of Pernambuco, providing new information that is essential for the development of sustainable management practices.

**MATERIALS AND METHODS**

**Study area.** The study site was the southern coast of Pernambuco, off the city of Sirinhaém, the north-eastern part of Brazil ($08°35′57″ – 08°36′57″S, 034°56′58″ – 035°00′48″W; Fig. 1). This area is located in the Marine Protected Area of Guadalupe (Decree no 19.635).

**Data collection.** Specimens of *Conodon nobilis* were collected monthly (August 2011 through July 2012) by accompanying the local fishers (outrigger trawlers). The fishery operated from 1.5 to 3 nautical miles off the coast, mainly between 10 and 20 m depth, always during the full moon. For each sample (month), three sets of 2 hourly trawls were performed during the daytime, with boat velocity varying between 3 and 7 km h$^{-1}$, using a double
trawl (length: 10 m; horizontal opening: 6.10 m; mesh size body: 30 mm; mesh size codend: 25 mm) as the gear. Once collected, the specimens were immediately placed on ice onboard the vessel and then transported to the laboratory and stored in a freezer (−18°C) until subsequent analysis. The mean monthly rainfall was obtained from the Agência Pernambucana de Águas e Climas (Anonymous 2017). The sample collection was authorized by federal authorities (Ministério do Meio Ambiente and Instituto Chico Mendes de Conservação da Biodiversidade, permit No. 1922971).

Sample processing. Total length (TL, cm) and total weight (TW, g) were recorded for all individuals. Stomachs and gonads were removed for sex and maturation stage determination. The specimens were classified based on the scale proposed by Vazzoler (1996): stages A, immature; B, maturing; C, mature, and D, spawned or resting. Stomachs and gonads were weighed to the nearest 0.01 g. Stomachs were fixed in 10% formaldehyde within 48 h and were then conserved in 70% alcohol. The contents of the individual stomachs were sorted, counted, weighed (g), and identified to the lowest possible taxonomic level.

Data analyses. The population structure was evaluated using the length-frequency distribution considering month and sex. A two-way analysis of variance (ANOVA) was used to determine the differences of mean TL between months and sexes (males, females, and pooled sexes) using transformed data log 10 (x + 1) following the assumptions of normality (Kolmogorov–Smirnov test) and homoscedasticity (Bartlett test). Tukey’s post-hoc test was used to test the differences of TL among months and sexes (Zar 2009). The determined sex ratios were pooled for each month and size class (1 cm), were tested for significant deviations from the expected 1:1 ratio using chi-square (χ²) tests. The significant threshold considered was P < 0.05.

To determine the size at first sexual maturity the percentage of adults by length was calculated and considered as the dependent variable (y) and the TL as the independent variable (x). Individuals with gonads that presented a maturity stage of B, C, or D were classified as adults (Vazzoler 1996). These values were adjusted to a logistic curve by the least-squares approach, to obtain the L50 value, using the King (2007) logistic equation:

\[
P_i = \frac{1}{1 + \exp\left(-r(L_i - L_{50})\right)}
\]

where, \(P_i\) is the proportion of adult individuals for each class, \(r\) is the slope of the curve, \(L_i\) is the upper limit of the TL class, and \(L_{50}\) is the mean length at first maturation. The 95% confidence interval was calculated for the \(L_{50}\) value. Hotelling’s T² test was used to compare the logistic model parameter estimates for males and females (Bernard 1981, Mouine et al. 2012).

The fullness index (FI) was calculated to evaluate the feeding intensity by season and ontogenetic stages to identify periods or stages that might be more sensible for conservation, given the relevance for the development of the species. This index was based on the equation by Hyslop (1980),

\[
FI = 100 \cdot CW \cdot TW^{-1}
\]

where CW is the stomach contents weight and TW is the total weight of the fish. Three parameters described by Hynes (1950) and Hyslop (1980) were used for the qualitative composition of the diet: the frequency of occurrence (\(F\)), the numerical frequency (\(N\)), and the weight percentage (\(W\)). The importance of each prey item was estimated based on the index of relative importance (%IRI) defined by Pinkas et al. (1971) as

\[
%IRI = 100 \cdot \frac{\sum (\text{IRI})}{\sum (\text{IRI})}
\]

Due to the poor conservation state, some stomachs were not used for diet analysis.

The diet of *C. nobilis* was evaluated considering the stages of development (adult and juvenile) and climatic seasons. Specimens larger than the length at first sexual maturity obtained here were considered as adults. The seasons were determined based on the monthly mean rainfall: dry (September–December; 38.5 mm), dry–rainy transition (January–May; 85.2 mm), and rainy season (June–August; 153.2 mm). The FI difference between the stages of development, climatic season, and the interaction among them was analysed using a parametric two-way ANOVA, following the necessary assumptions and post-hoc test as stated previously.

To assess the degree of similarity in the diet among juveniles and adults, and seasons, multidimensional scaling (MDS) based on a Bray–Curtis similarity matrix was applied for prey abundance (%W), with the stomachs considered as the sampling unit. Wisconsin double standardisation was applied to the raw data of prey abundance to improve the gradient detection ability of the dissimilarity indices (Bray and Curtis 1957). The differences between life stages (juveniles and adults) and seasons (dry, rainy, and dry–rainy) were tested with a two-way PERMANOVA (Anderson 2001). All analyses were performed using the R environment (R Development Core Team 2018), vegan* and rrcov packages (Todorov and Filzmoser 2009).

RESULTS

A total of 272 specimens of *Conodon nobilis* were analysed: 115 (42.2%) were females, 93 (34.1%) were males, and 64 (23.7%) were immatures that could not be sexed (Table 1). Total length (TL) ranged from 6.6 to

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*https://CRAN.R-project.org/package=vegan.*
27.5 cm (females 6.6–25.4 cm, males 7.7–27.5 cm), with individuals larger than 13 cm being dominant (Fig. 2). In general, the sex ratio of females was similar to that of males (1 ± 0.8) ($\chi^2 = 2.32$, df = 2, $P = 0.12$), except for the months of March ($\chi^2 = 2.38$, df = 2, $P < 0.05$), May ($\chi^2 = 2.2$, df = 2, $P < 0.05$), and December ($\chi^2 = 1.8$, df = 2, $P < 0.05$), and for length class 11–12.1 cm ($\chi^2 = 4.26$, df = 2, $P < 0.05$), where females dominated. *Conodon nobilis* was caught throughout the year except in July. The TL of the individuals was significantly different among months ($F_{(10, 52)} = 2.572$; $P < 0.05$). The largest individuals were caught in August, November, and May, whereas the smallest were captured in March (Tukey, $P < 0.05$) (Fig. 3). However, no statistical differences in TL (overall ($F_{(1, 52)} = 0.226$; $P = 0.64$) and monthly ($F_{(10, 52)} = 0.448$; $P > 0.91$)) were found between females ($15.27 ± 3.74$ cm; mean ± SD) and males ($16.1 ± 3.54$ cm).

No significant differences in TL at first maturity ($L_{50}$) for *C. nobilis* were found between sexes (Hotelling’s $T^2$, $T^2 = 3.82$, $P = 0.15$). Therefore, data were pooled and the $L_{50}$ estimated for combined sexes was $14.3 ± 0.65$ cm (Fig. 4). The smallest adult individual had a TL of 9.6 cm, whereas all those with TL above 17.4 cm were adults (Fig. 4). A greater proportion of the catch contained individuals above the $L_{50}$ value (Fig. 2).

Overall, 165 stomachs were analysed and 123 (75%) contained food contents. The values of the fullness index (FI) of the juveniles (2.7) was similar to that of the adults (2.5) ($F_{(1, 162)} = 1.371$; $P = 0.19$). Higher FI values were observed during the dry season ($F_{(2, 162)} = 7.987$; $P < 0.05$)
(Fig. 5). Juveniles and adults presented similar FI values among seasons ($F_{(2, 162)}^1 = 2.808; P = 0.06$). The diet of C. nobilis, which was similar between juveniles and adults, was based on 19 food items, with shrimps (Penaeidae) (%IRI = 79.8) and Actinopterygii (%IRI = 16.2) being the most important components (Table 2).

The diet composition from the MDS ordination displayed a similar pattern for juveniles and adults because they mainly fed on shrimps and ray-finned fishes (Fig. 6). No significant differences between the diets of juveniles and adults (Pseudo-$F_{(1, 121)}^1 = 1.06; P = 0.31$), seasons (Pseudo-$F_{(2, 121)}^1 = 1.61; P = 0.16$), and their interactions (Pseudo-$F_{(2, 121)}^1 = 1.83; P = 0.08$) were observed.

**DISCUSSION**

Fishing activities directly affect demersal fish communities via the removal of species (target and non-target) and habitat modifications (Eduardo et al. 2018a). Trawling activity may promote changes to the seabed, such as sediment resuspension and the injury or death of a wide range of benthic organisms (Ortega et al. 2018). Moreover, untargeted catches lead to adverse effects on population parameters and species composition (Shephard et al. 2010, Hiddink et al. 2011), thus changing the ecological interaction between species, which might affect the sustainability of the fishery. This is the case of Conodon nobilis caught as a bycatch in the shrimp fishery in Brazil.

Size differences between months may be related to the level of exploitation in the area, the ecological characteristics of each region, and the differential selectivity of the fishing gear (Frédoú et al. 2009). Along the southern coast of Pernambuco, the maximum lengths recorded (27.5 cm) for C. nobilis were greater than those recorded for the same species in other areas, e.g., 15 cm in Caraguatatuba Bay, São Paulo (Brazil) (Pombo et al. 2014), 12 cm in Rio Grande do Norte (Brazil) (Garcia et al. 2010), and 26 cm in the Gulf of Salamanca (Colombia) (Garcia et al. 1998). Although the results of the presently reported study may be hampered by the selectivity of the fishing gear, based on the habitat of the species (shallow muddy bottoms) and the $L_{50}$ reported (33.6 cm TL, Cervigón et al. 1992), which is near to the range of individuals caught in the presently reported study (6.6 to 27.5 cm TL, including juveniles and adults), we assumed that our sampling adequately covered the size and behaviour of the species, and the parameters provided here are representative of the C. nobilis population in northeast Brazil.

Females and males presented similar abundance. The sex ratio provides important information regarding the relation between individuals and the environment and the population situation of each species (Conover and Voorhees 1990). It also provides basic information to assess the reproductive potential of the species and to estimate the size of the population stock (Stratoudakis et al. 2006, Cerviño 2014, Farley et al. 2014). This scenario is directly influenced by the reproductive strategy of the species, environmental variations of the ecosystems (Murua et al. 2003, Ospina-Álvarez and Piferrer 2008), and fishing (Robinson et al. 2017).

Conodon nobilis is a benthic carnivorous predator with a short intestine and large stomach that has a great expansion capacity (Garcia et al. 2010). Trawls mainly target demersal organisms (McHugh et al. 2017) and species that forage near the bottom (Pombo et al. 2014), such as C. nobilis, which is directly affected by such trawling activity. The feeding intensity, described as the fullness index (FI), may be greatly influenced by the availability and type of prey, length range of the predator, reproductive season, and daily variation (Pereira et al. 2016, Perelman et al. 2017). In the presently reported study, high FI values were found, indicating an intense use of the environment as a feeding area.
Table 2
Principal prey items characteristics of the *Conodon nobilis* captured between August 2011 to July 2012, off Sirinhaém, State of Pernambuco, north-eastern Brazil

| Prey item | Overall | Juveniles (<14.3 cm) | Adults (≥14.3 cm) |
|-----------|---------|----------------------|-------------------|
|           | %F₀   | %N     | %P   | %IRI | %F₀   | %N     | %P   | %IRI | %F₀   | %N     | %P   | %IRI |
| ACTINOPTERYGI |        |         |      |      |        |         |      |      |        |         |      |      |
| Clupeiformes | 1.42  | 0.68   | 0.50 | 0.02 | 0.79  | 0.55   | 0.68 | 0.01 | 2.70  | 1.28   | 0.28 | 0.06 |
| Engraulidae | 0.71  | 0.23   | 0.99 | 0.01 | 0.79  | 0.27   | 1.79 | 0.02 | —     | —      | —    | —    |
| Polynemidae | 0.71  | 0.23   | 0.29 | <0.01| 0.79  | 0.27   | 0.53 | 0.01 | —     | —      | —    | —    |
| Anchoa spp. | 1.42  | 0.45   | 2.38 | 0.05 | 0.79  | 0.27   | 3.28 | 0.04 | 2.70  | 1.28   | 1.28 | 0.09 |
| Chirocentrodon bleekerianus | 2.13 | 0.68 | 6.79 | 0.18 | — | — | — | 8.11 | 3.85 | 15.08 | 2.04 |
| Odontognathus mucronatus | 0.71 | 0.23 | 1.21 | 0.01 | — | — | — | 2.70 | 1.28 | 2.68 | 0.14 |
| Paralonchurus brasiliensis | 3.55 | 1.36 | 1.66 | 0.12 | 2.38 | 0.82 | 0.61 | 0.04 | 5.41 | 3.85 | 2.93 | 0.49 |
| Stelifer spp. | 0.71 | 0.23 | 0.49 | 0.01 | — | — | — | 2.70 | 1.28 | 1.10 | 0.09 |
| Symphurus spp. | 4.96 | 2.26 | 0.68 | 0.16 | 4.76 | 2.20 | 1.10 | 0.20 | 2.70 | 2.56 | 0.17 | 0.10 |
| Actinopterygii not identified | 58.16 | 9.28 | 15.61 | 16.23 | 54.76 | 9.07 | 18.42 | 19.01 | 35.14 | 10.26 | 12.17 | 10.49 |
| Brachyura | 0.71  | —      | 0.07 | <0.01| 0.79  | —      | 0.12 | 0.00 | —     | —      | —    | —    |
| Penaeidae | 56.03 | 73.08 | 53.95 | 79.82 | 47.62 | 74.18 | 52.21 | 76.03 | 51.35 | 67.95 | 56.07 | 84.80 |
| Palaemonidae | 0.71 | 0.45 | 1.48 | 0.02 | 0.79 | 0.55 | 2.69 | 0.03 | — | — | — | — |
| Xiphopenaeus kroyeri | 4.96 | 7.69 | 6.86 | 0.81 | 4.76 | 9.07 | 9.45 | 1.11 | 2.70 | 1.28 | 3.71 | 0.18 |
| Isopoda | 1.42  | 0.45   | 0.04 | 0.01 | 1.59  | 0.55   | 0.08 | 0.01 | —     | —      | —    | —    |
| ML Squid | 0.71  | 0.45   | 0.42 | 0.01 | 0.79  | 0.55   | 0.77 | 0.01 | —     | —      | —    | —    |
| CRUST |        |         |      |      |        |         |      |      |        |         |      |      |
| Penaeidae | 39.01 | 5.72   | 2.50 | 34.13 | 7.98  | 3.44   | 32.43 | — | 2.97 | 1.28 |
| Platyhelminthes | 0.71 | 0.23 | 0.65 | 0.01 | — | — | — | 2.70 | 1.28 | 1.45 | 0.10 |

CRUST = Crustacea, ML = Mollusca, OT = other; %F₀ = frequency of occurrence, N = number of fish examined, %N = numerical frequency, %IRI = percentage index of relative importance.

Fig. 6. MDS plot of the feed composition of *Conodon nobilis* off Sirinhaém, State of Pernambuco, north-eastern Brazil; abbreviations, Clup = Clupeiformes, Engra = Engraulidae, Stel = Stelifer spp., Poly = Polynemidae, Anch = Anchoa spp., C.bleek = Chirocentrodon bleekerianus, O.mucr = Odontognathus mucronatus, P.bras = Paralonchurus brasiliensis, Symp = Symphurus spp., Tel = ray-finned fishes not identified, Bra = Brachyura, Pen = Penaeidae, X.kroy = Xiphopenaeus kroyeri, Isop = Isopoda, Squid = squid
Previous studies on the feeding habits of this species (Lopes and Oliveira-Silva 1998, Vasconcelos Filho et al. 2010) in Itamaracá Island, northeast part of Brazil and Caraguatatuba Bight, south-eastern Brazil (Pombo et al. 2014) have shown that their main prey items are crustaceans. Similar results were observed in the presently reported study, with *C. nobilis* classified as a zoobenthivore, feeding on crustaceans, mainly shrimps of the family Penaeidae. The occurrence of aquatic plants, detritus, and Platyhelminthes detected in the stomachs of carnivorous species are probably ingested accidentally (Feitosa et al. 2002). The availability and consequently the aggregation of prey can strongly influence the species feeding habitat patterns (Lawton and Pratchett 2012, Jacobson et al. 2018), causing them to feed on prey that has the highest availability.

The presently reported study provides, to the best of our knowledge, the first estimation of the mean length at first maturity ($L_{50}$) for *C. nobilis*. The size at first sexual maturity is fundamental information in fishery science for the management of single species assessment, and is frequently used as a reference for evaluating the catch of juveniles in fisheries worldwide (Wolff et al. 2015, Lappalainen et al. 2016, Lucena Frédou et al. 2016, Tirado-Ibarra et al. 2018). In general, the trawling bycatch is mainly composed of small individuals, usually juveniles (Silva Júnior et al. 2015). However, for *C. nobilis*, a higher proportion of individuals above the $L_{50}$ value were found, thus the majority of the harvested individuals might have been able to reproduce and contribute to population renewal (Eduardo et al. 2018b). This represents a good indicator of the sustainability of the stock. However, considering that *C. nobilis* is a bycatch species, fishery performance indicators (Anderson et al. 2015) are considered quite promising in evaluating multispecies fisheries, such as shrimp trawling. The monitoring over time of basic indicators of target and non-target species, which considers population parameters such as size, weight, and maturity, are also important tools to evaluate the sustainability of a fishery (Wells et al. 2008, Jarić et al. 2016, Plazas-Gómez et al. 2018) as well as for the application of different management strategies such as area and time closures and Bycatch Reduce Devices (BRD) (Arellano-Torres et al. 2006, McHugh et al. 2017, Pérez Roda et al. 2019).

The shrimp fishery off the coast of Pernambuco, which has a multispecies capture, is under no fishing regulations or landing control, which goes against the Code of Conduct for Responsible Fisheries (CCRF) (Anonymous 1995). The CCRF recommends that the entire catch should be managed in an ecologically sustainable manner; thus, a regulation for this area should be established considering the main species involved (target and bycatch). Previous studies in the region have shown that the bulk of the catch of the shrimp fishery in Pernambuco shares the same feeding ground and season of reproduction (e.g., between October and March) (Lopes et al. 2014, 2017, Silva et al. 2015, 2016, 2018, Silva Júnior et al. 2015, Eduardo et al. 2018b, Peixoto et al. 2018) and a closed season could be established during the austral summer. In addition, the application of BRD (e.g., fisheye, grid and square mesh) used to exclude fish and other small bycatch from the trawl (Broadhurst 2000, Eayrs 2007, Larsen et al. 2017) might be a good conservation tool. Some initiatives that are limited by the lack of information occur in this region, such as the experimental use of bycatch reduction technologies (Anonymous 2018) and Marine Protected Areas (e.g., APA Guadalupe), which still has no management plan. The results of the presently reported study combined with other available information in the area will contribute to the development of improved management policies, considering the ecosystem approach to fisheries for improving species conservation and exploited marine habitats in Pernambuco, which is still mostly unknown.

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