

**SPATIOTEMPORAL DISTRIBUTION AND POPULATION BIOLOGY ASPECTS  
OF *CETENGRAULIS EDENTULUS* (ACTINOPTERYGII: CLUPEIFORMES:  
ENGRAULIDAE) IN A SOUTH-WESTERN ATLANTIC ESTUARY,  
WITH NOTES ON THE LOCAL CLUPEIFORMES COMMUNITY:  
CONSERVATION IMPLICATIONS**

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Santos S.R., Galvão K.P., Adler G.H., Andrade-Tubino M.F., Vianna M. 2020. Spatiotemporal distribution and population biology aspects of *Cetengraulis edentulus* (Actinopterygii: Clupeiformes: Engraulidae) in a South-western Atlantic estuary, with notes on the local Clupeiformes community: Conservation implications. *Acta Ichthyol. Piscat.* 50 (2): 139–150.

**Background.** Guanabara Bay is a species-rich estuary in the South-western Atlantic and its shores are among the most densely populated urban areas in the world. The biology of clupeiform fishes from Guanabara Bay is currently poorly known. The most extensively exploited species is a small pelagic Atlantic anchoveta or toothless anchovy, *Cetengraulis edentulus* (Cuvier, 1829). The significant knowledge gap concerning the local fish biodiversity hinders the development of the fisheries management tools for this significantly impacted body of water.

**Material and methods.** The population biology of *Cetengraulis edentulus* was analyzed based on samples taken from Guanabara Bay twice a month by an otter-trawl. Five sites were selected, representing the upper, middle, and lower estuary. They were sampled between 2005 and 2007, and a second phase was conducted between 2013 and 2015 at two of the original sites to evaluate the middle and lower estuary. Furthermore, the relative abundance, spatial distribution, and the length–weight relation of the local Clupeiformes were also assessed.

**Results.** A total of 6053 fish individuals collected represented 15 species and three families: *Anchoa januaria*; *Anchoa lyolepis*; *Anchoa marinii*; *Anchoa tricolor*; *Brevoortia aurea*; *Cetengraulis edentulus*; *Chirocentrodon bleekermanus*; *Engraulis anchoita*; *Harengula clupeiola*; *Odontognathus mucronatus*; *Opisthonema oglinum*; *Pellona harroweri*; *Sardinella brasiliensis*. The most abundant was the family Engraulidae (7), followed by Clupeidae (4), and Pristigasteridae (3). While *Cetengraulis edentulus* was predominant during the first phase, a higher presence of *Brevoortia aurea* (Spix et Agassiz, 1829) characterized the second phase. Furthermore, *C. edentulus* was mainly restricted to the upper estuary, with no seasonal pattern. Estimated values for this species comprised growth ( $L_{\infty} = 19.3$  cm,  $k = 0.54$  yr<sup>-1</sup>), mortality ( $Z = 1.62$  yr<sup>-1</sup>,  $M = 1.32$  yr<sup>-1</sup> ( $T = 26.6^{\circ}\text{C}$ ),  $F = 0.3$  yr<sup>-1</sup>,  $E = 0.19$  yr<sup>-1</sup>), longevity (5.6 yr), survival (19.8% yr<sup>-1</sup>) and capture probability ( $L_{25} = 9.95$  cm,  $L_{50} = 10.87$  cm,  $L_{75} = 11.79$  cm).

**Conclusions.** The exploitation rates of *Cetengraulis edentulus* indicate that this species is underfished, although these results may be due to the fishing gear used herein, which may have underestimated fishing mortality rates. A high Clupeiformes richness was verified, corroborating other bay ichthyofauna components. In addition, the occurrence of monospecific peaks identified for other trophic groups was also observed for *C. edentulus*.

**Keywords:** toothless anchovy, Atlantic anchoveta, Guanabara Bay, growth, mortality, exploitation

## INTRODUCTION

Tropical estuarine environments display high ecological relevance for fish communities, comprising juvenile growth areas and breeding adult refuges and feeding grounds, due to high food availability (Potter et al. 2015, Santos et al. 2015, Corrêa and Vianna 2016, Silva Junior et al. 2016). These environments are characterized

by high fish diversity and biomass, but have only a few resident species due to the high physiological stress caused by the constant environmental variations that define this environment (Potter et al. 2015).

Clupeiformes, mainly clupeids and engraulids, are essential fish community components in estuarine ecosystems, constituting a link in the energy transfer to

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higher trophic levels, both directly and indirectly sustaining fishing activities (Pikitch et al. 2012). The engraulid fish, *Cetengraulis edentulus* (Cuvier, 1828), known as toothless anchovy or Atlantic anchoveta, presents a wide geographical distribution, occurring from the Caribbean and Panama to Brazil (Menezes et al. 2003). In Brazil, the species displays a recognizable commercial interest in terms of the production volume (Sampaio Franco et al. 2014), and ecological importance, frequently inhabiting coves, bays, and coastal lagoons (Souza-Conceição and Schwingel 2011).

In Guanabara Bay, *Cetengraulis edentulus* was observed as the dominant commercial fisheries species between 2001–2002, accounting for 69% of total landings (12 427.0 t). It was captured by purse seine and industrially processed for flour and oil (Jablonski et al. 2006) and is currently canned for regional consumption, replacing the Brazilian sardinella, *Sardinella brasiliensis* (Steindachner, 1879). The local population of *C. edentulus* is characterized by significant interannual and seasonal variations in the fishery production, influenced by reproductive and recruitment seasons and environmental conditions, such as eutrophication (Sampaio Franco et al. 2014). The species' reproduction season extends from September through December (Sampaio Franco et al. 2014). The determination of specific parameters, such as growth and mortality, allows for the evaluation of stock fluctuations subjected to fishing pressure, providing relevant information for the management of important commercial populations (Sossoukpe et al. 2013).

The biology of Clupeiformes within the tropical Atlantic Guanabara Bay estuary is currently unknown, despite the fact that the main bay's species, *Cetengraulis edentulus*, is the most locally exploited fish. In order to contribute with the solution of this knowledge gap, the presently reported study aimed to determine the distribution patterns of *C. edentulus* and estimate growth and mortality parameters based on a bottom trawl survey. Furthermore, the study also aimed to determine the Clupeiformes community composition that makes use of the estuary.

## MATERIAL AND METHODS

Guanabara Bay is located in the South-western Atlantic (22°40'–23°00'S and 043°00'–043°18'W), with a surface area over 384 km<sup>2</sup> and maximum stretch of 28 km on the east–west axis and 30 km on the north–south axis. It is one of the largest Brazilian estuaries, with a drainage basin comprising 45 rivers and featuring intense water exchange between the drainage basin and the oceanic waters that flow through its narrow entrance. In addition to natural local rainfall pattern variations concentrated during the summer (December–February), a strong domestic and industrial sewage influence is also noted, as this is one of the largest metropolitan areas in the world (Silva Junior et al. 2016).

Five stations representing the low (station 4), medium (stations 3 and 5), and the upper (stations 1 and 2) estuary were selected for sampling and each area was surveyed

in two different stations (Fig. 1). Trawling was carried out twice a month, between July 2005 and June 2007, by a local fishing fleet bottom trawler 9.5 m in length. The otter trawl net was 7 m long, with a body and the codend mesh size of 18 mm. The local precipitation data were obtained from the Praça Mauá meteorological station (Rio de Janeiro), through the National Institute of Meteorology (INMET\*). This article is part of a series of publications that evaluate several taxonomic groups of this tropical estuary's ichthyofauna, applying the same sampling strategy for five areas throughout the bay (Silva Junior et al. 2013, 2016, Corrêa and Vianna 2016).

Area 1 (Duque de Caxias) (Stations 1.1 and 1.2). This area is severely impacted by pollution from domestic sewage, industrial waste, and garbage dumps, while also suffering from impaired circulation caused by historical land reclamation, which has reduced pollutant removal by coastal waters. It is distinguished by muddy sediments, low salinities (27.0‰–29.5‰), and temperatures between 24.0 and 25.9°C at the bottom (Mayr et al. 1989).

Area 2 (Paqueta Island) (Stations 2.1 and 2.2). This area is characterized by the discharge of the least polluted Guanabara drainage basin rivers, the presence of a large extent of the remaining original mangrove coverage, protected through the establishment of a Federal Conservation Unit (Guapimirim EPA), and the influence of the bay's central channel, a primary source of less polluted waters and the origin of the salt wedge, which favors a less degraded environment than that observed in Area 1. This portion of the estuary is characterized by muddy sediments and bottom salinities and temperatures ranging from 27.0 to 29.5°C and 22.5 to 23.9°C, respectively (Mayr et al. 1989).

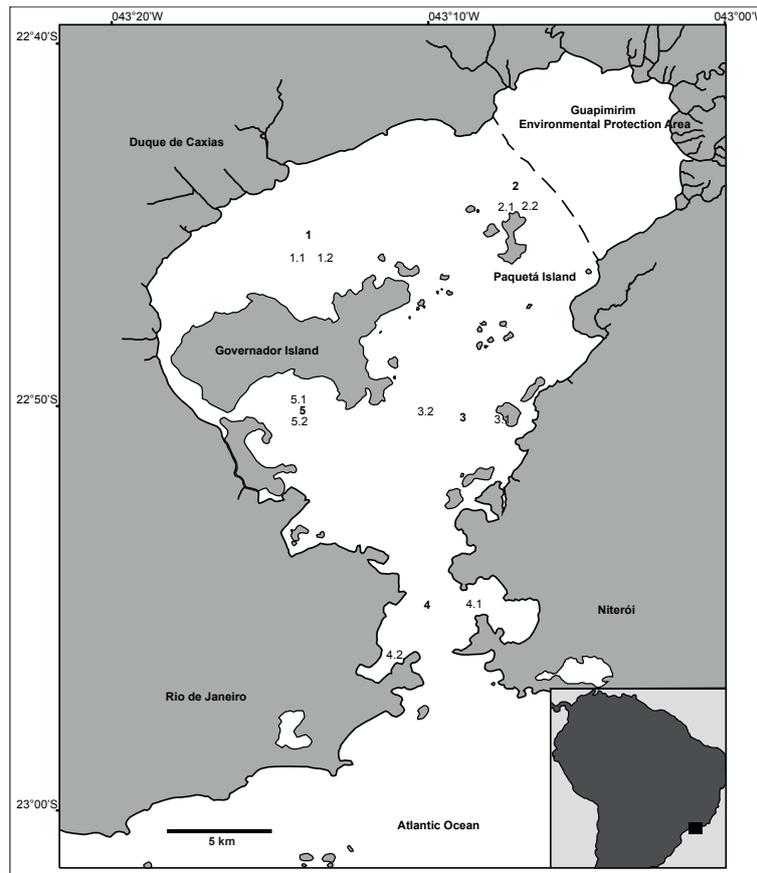
Area 3 (Central channel) (Stations 3.1 and 3.2). The middle estuary, directly influenced by the central channel, presents greater water exchange and better environmental conditions than the upper estuary (Carreira et al. 2004). The substrate is composed of muddy sediments and fine sand, and waters present high salinity, above 30.0‰, and bottom temperatures below 25°C (Mayr et al. 1989).

Area 4 (Botafogo and Jurujuba Inlets) (Stations 4.1 and 4.2). As the most exposed portion of the bay, the lower estuary is strongly influenced by coastal waters and marine conditions. This area is subjected to raw sewage contributions from the cities of Rio de Janeiro and Niterói. Fine or medium sand covers the bottom, while waters present high salinity (>32.0‰) and lower temperatures (<25°C) than the middle and upper estuaries (Mayr et al. 1989).

Area 5 (Governor's Island) (Stations 5.1 and 5.2). This area is subjected to high sewage inputs produced on the island. Despite these conditions, the close proximity to the central channel allows for relatively good water circulation and pollutant dilution (Carreira et al. 2004). Waters in this area are characterized by salinities ranging from 29.5‰ to 32.0‰ and temperatures similar to Area 2. The substrate is composed of muddy sediments (Mayr et al. 1989).

All specimens were identified, measured [cm] for total length ( $L$ ) and weighed [g] to obtain total weight ( $W$ ).

\* Anonymous 2018. BDMEP – Banco de Dados Meteorológicos para Ensino e Pesquisa. [Meteorological Database for Teaching and Research.] Instituto Nacional de Meteorologia (INMET), Ministério da Agricultura, Pecuária e Abastecimento, Brazil. [Accessed in June 2018.] <http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep>



**Fig. 1.** Guanabara Bay estuary in the South-western Atlantic, with the trawl areas of the presently reported study; area numbers are bold; station numbers in regular font (upper estuary: **1** = Duque de Caixas, **2** = Paquetá Island; Medium estuary: **3** = Central channel, **5** = Governor’s Island; Lower estuary: **4** = Botafogo and Jurujuba Inlets)

Despite a good representation of the main Clupeiformes species, captures of other small pelagic fish species were limited concerning the evaluation of all population biology aspects. The composition and the population structure of *Cetengraulis edentulus* were verified based on individual distribution by length classes, grouping sex for seasonal comparisons. The relative abundance was calculated by Capture per Unit of Effort, as the number of individuals ( $CPUE_n, n \cdot h^{-1}$ ) and per weight ( $CPUE_w, kg \cdot h^{-1}$ ), and organized bimonthly to avoid short term variation influences at the sampling moment (weather, local tide regime, marine traffic). Spatial and seasonal comparisons were performed for CPUEs to estimate the degree of linear association between abundance and precipitation, through Pearson’s correlation coefficient, after a normality test (Shapiro–Wilk test). The methodology, although partially precluding the capture of pelagic species, follows the same method used for other ichthyofauna components, to allow for comparisons between different fish community components (Andrade et al. 2015, Santos et al. 2015).

**Temporal composition variation.** Due to the dynamic nature of estuaries, especially in the context of a bay amidst a highly urbanized region, this study also compared the medium and low estuarine areas in Guanabara Bay during a second period, from July 2013 to June 2015, to verify potential differences in the Clupeiformes community.

Stations 3.2 from area 3 and both stations (5.1 and 5.2) in area 5 sampled during the first campaign were selected for the second stage, representing the low and middle estuaries, respectively. Samples comprised of monthly surveys composed of three consecutive trawls in both areas, by the same vessel, and using the same fishing gear as during the first period. The Kruskal–Wallis test was applied to compare all samples to identify the presence of significant differences, followed by the Mann–Whitney pairwise test to determine which stations are responsible for the observed differences.

**Length–weight relation (LWR).** The LWR was calculated by applying equation

$$W_i = aL_i^b$$

where  $W_i$  is the total weight,  $L_i$  is the total length,  $a$  is the intercept, and  $b$  is the slope (of the regression). The least-squares method was applied to the logarithmized length and weight values of individuals belonging to each species, using equation

$$\log W_i = \log a + b \log L_i$$

where  $W_i$  is the total weight and  $L_i$  is the total length. The type of growth was based on the estimated value for  $b$  (Ricker 1975).

**Growth.** The asymptotic length  $L_\infty$  was obtained by the ELEFAN I routine (Pauly and David 1981) that analyzes size class frequency distribution by the FAO-ICLARM Stock Assessment Tools (FiSAT II) software. The ELEFAN I routine estimates growth parameters as a function of the von Bertalanffy equation (1938) and the study considered the non-seasonal equation

$$L_t = L_\infty [1 - e^{-k(t-t_0)}]$$

The  $L_\infty$  and the growth rate  $k$  estimates were based on the highest measure of relative fit  $R_n$ , as a function of the species biology. The growth performance index ( $\Phi'$ ) was calculated according to Pauly and Munro (1984) and also indicated the adequacy of the parameters ( $\Phi' = \log k + 2 \log L_\infty$ ).

**Mortality.** The natural mortality ( $M$ ) was estimated by the equation defined by Pauly (1980). A conversion of the linearized length curve was applied to estimate  $Z$  (Pauly 1983) using the FiSAT II software. Age was calculated by the inverse von Bertalanffy equation:

$$t = (-1 \cdot K^{-1}) \ln (1 - L_t \cdot L_\infty^{-1})$$

The mean ages used as independent values on the abscissa axis ( $x$ ) correspond to the midpoint of each size class  $[(L_1 + L_2) \cdot 2^{-1}]$ , calculated by the inverse von Bertalanffy equation

$$(t_{[(L_1 + L_2) \cdot 2^{-1}]} = (-1 \cdot k^{-1}) \ln [1 - ((L_1 + L_2) \cdot 2^{-1}) \cdot L_\infty^{-1}])$$

The catch curve considers only the declining segment of the regression, which is the fraction fully exploited by fishing. The fishing mortality ( $F$ ) is the difference between the total and natural mortality ( $F = Z - M$ ) (Sparre and Venema 1998).

**Exploitation, longevity, and survival.** The exploitation rate ( $E$ ) is a preliminary stock valuation estimated under optimal exploitation when  $E = 0.5$  ( $E = F \cdot Z^{-1}$ ) (Pauly 1983). The capture probability was estimated by trawl selectivity from the ascending segment of the catch curve. The mean size of the first catch ( $L_c$ ) was generated by the cumulative catch probability method as a function of

the mean length.  $L_c$  was determined from the resulting curve, corresponding to the cumulative probability of 50%. The capture probabilities using the FiSAT II routine were estimated by projecting the numbers that would be expected if there were no selectivity ( $N'$ ), using

$$N'_{i-1} = N'_i \cdot \exp^{(Z\Delta t)}$$

where  $Z$  is  $(Z_i + Z_{i+1}) \cdot 2^{-1}$ ;

$$Z_i = M + F_i; F_{i-1} = F_i - X_i; X = F \cdot (\text{number of classes below } P_1 + 1)^{-1}$$

where:  $P_1$  is the first size group, with capture probability equal to 1.0, in which the lower limit is an estimate of  $L^1$ . The capture probabilities by length were computed by the  $N'_i \cdot N'_{i-1}$  ratio. Longevity ( $t_{\max}$ , year) was estimated based on Taylor (1958) ( $t_{\max} = 3 \cdot k^{-1}$ ). The survival rate ( $S$ ) followed the equation defined by Ricker (1975).

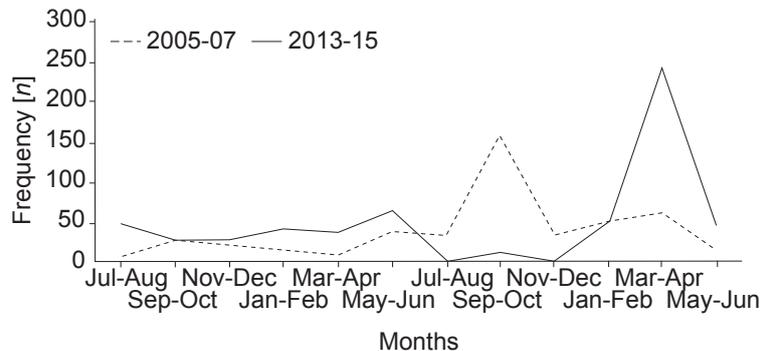
## RESULTS

**Population parameters of *Cetengraulis edentulus*.** A total of 3954 *Cetengraulis edentulus* individuals were measured during the first two years of the study, 1625 during the first year and 2329 during the second, with a total biomass of 61 121.1 g (Fig. 2). The total weight varied between 0.3 and 46.3 g ( $15.5 \pm 8.3$  g), and the total length between 4.0 and 16.7 cm ( $11.8 \pm 2.1$  cm) (Fig. 3). Assuming the first sexual maturity size to be 11.8 cm, as described by Souza-Conceição et al. (2005), the ratio between juveniles and adults was of  $1.0 \div 1.0$  for both sampling years. The CPUE, both in the number of individuals and in weight (Table 1), was concentrated in areas characterized by a muddy bottom (93%), followed by stations without a predominant type of sediment (4.3%), very fine sand (2.4%), and fine sand (0.3%).

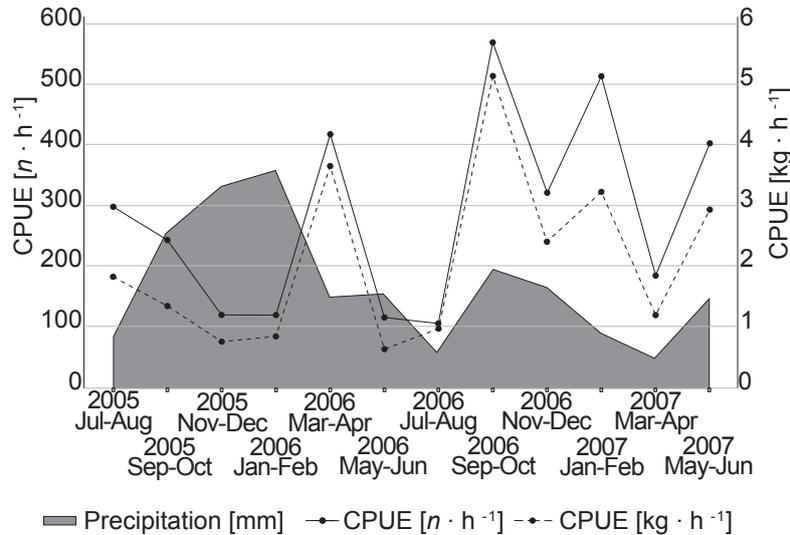
WR was determined by equation

$$W_t = 0.0025L_t^{3.475} (R^2 = 0.970)$$

The allometry coefficient ranged from 3.044 (during November–December 2005) to 4.045 (during May–June 2006). Growth estimates were calculated as  $L_\infty = 19.30$  cm,



**Fig. 2.** Total bimonthly catch of Clupeiformes at Guanabara Bay (22°S), South-western Atlantic, during the two sampling periods (2005–2007, 2013–2015)



**Fig. 3.** Relative abundance (CPUE) of *Cetengraulis edentulus* at Guanabara Bay (22°S), South-western Atlantic, in number of individuals [ $n \cdot h^{-1}$ ] (solid line) and biomass [ $kg \cdot h^{-1}$ ] (dashed line), plotted alongside bimonthly precipitation [mm] (gray area) between July 2005 and June 2007

**Table 1**

Descriptive statistics of Clupeiformes in a tropical estuary at Guanabara Bay, in the South-western Atlantic, presenting the total number of individuals captured and estimated length–weight relation (LWR) parameters

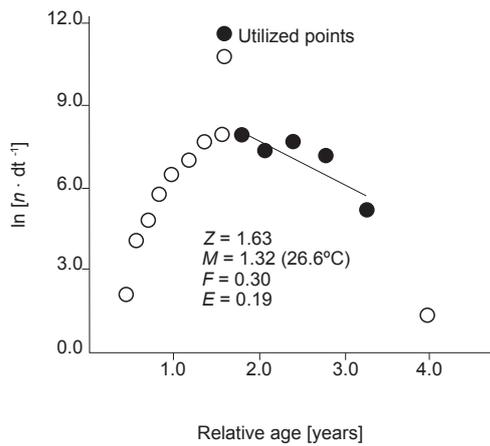
Species	n	Length [cm]			Weight [g]		LWR parameters				
		Min	Mean	Max	Min	Max	a	b	CI 95%	R <sup>2</sup>	S
<i>Brevoortia aurea</i>	654	4.3	10.2	31.7	0.4	283.2	0.0073	3.073	3.049–3.097	0.999	
<i>Harengula clupeiola</i>	245	5.5	9.4	19.0	1.1	91.3	0.0050	3.320	3.242–3.399	0.966	
<i>Opisthonema oglinum</i>	6	7.5	9.9	13.5	3.7	21.6	—	—	—	—	>45
<i>Sardinella brasiliensis</i>	33	6.4	14.3	18.0	2.5	50.8	—	—	—	—	
<i>Chirocentrodon bleekermanus</i>	329	5.2	8.5	14.9	1.0	31.0	0.0028	3.316	3.169–3.463	0.857	
<i>Odontognathus mucronatus</i>	5	6.5	7.3	8.2	1.3	3.0	—	—	—	—	>45
<i>Pellona harroweri</i>	45	3.1	8.0	12.0	0.6	15.7	0.0132	2.817	2.632–3.001	0.957	
<i>Anchoa filifera</i>	1	8.3		8.3	3.5	3.5	—	—	—	—	>45
<i>Anchoa januaria</i>	63	4.2	7.3	8.7	0.4	4.6	0.0013	3.799	3.549–4.047	0.939	
<i>Anchoa lyolepis</i>	113	3.4	6.5	12.2	0.1	14.0	0.0011	3.836	3.624–4.048	0.921	
<i>Anchoa marinii</i>	8	4.5	5.8	6.6	0.5	1.9	—	—	—	—	>45
<i>Anchoa tricolor</i>	101	4.2	9.1	12.1	0.5	13.4	0.0082	2.829	2.614–3.058	0.878	
<i>Cetengraulis edentulus</i>	3988	4.2	11.9	16.7	0.4	46.3	0.0025	3.475	3.456–3.494	0.970	
<i>Engraulis anchoita</i>	2	4.80	8.65	12.5	0.6	16.3	—	—	—	—	>45

a = intercept, b = slope, CI = confidence of interval of b, R<sup>2</sup> = coefficient of determination, S = sample size.

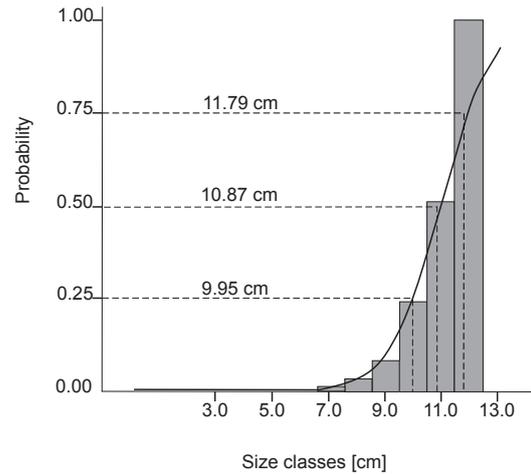
$k = 0.54 \cdot yr^{-1}$ ,  $R_n(10^{-3}) = 0.225$  and  $\Phi' = 2.30$ . Finally, mortality (Z, M, and F), exploitation (E), survival (S), catch probabilities ( $L_{25}$ ,  $L_{50}$ , and  $L_{75}$ ), and longevity ( $t_{max}$ ) estimates for *Cetengraulis edentulus* were of  $Z = 1.62 yr^{-1}$ ,  $M = 1.32 yr^{-1}$  ( $T = 26.6^\circ C$ ),  $F = 0.30 yr^{-1}$ ,  $E = 0.19 yr^{-1}$ ,  $S = 19.8\% yr^{-1}$ ,  $L_{25} = 9.95$  cm,  $L_{50} = 10.87$  cm,  $L_{75} = 11.79$  cm, and  $t_{max} = 5.6$  yr (Figs. 4 and 5).

**Clupeiformes community in Guanabara Bay.** During the first sampling period, between 2005 and 2007, the Clupeiformes a total of 5007 specimens were captured, represented by three families and 13 species. The Clupeidae were represented by *Brevoortia aurea* (Spix et Agassiz, 1829), *Harengula clupeiola* (Cuvier, 1829), *Opisthonema oglinum* (Lesueur, 1818), and *Sardinella*

*brasiliensis* (Steindachner, 1879), while Pristigasteridae were formed by *Chirocentrodon bleekermanus* (Poey, 1867), *Pellona harroweri* (Fowler, 1917), and *Odontognathus mucronatus* Lacepède, 1800. The family represented by the majority of species, Engraulidae, comprised *Anchoa januaria* (Steindachner, 1879), *Anchoa lyolepis* (Evermann et Marsh, 1900), *Anchoa marinii* Hildebrand, 1943, *Anchoa tricolor* (Spix et Agassiz, 1829), *Engraulis anchoita* Hubbs et Marini, 1935, and *Cetengraulis edentulus* (Cuvier, 1829). Half of the species were frequent during the entire sampling period, and only four presented a wide distribution, while the others were restricted and concentrated in the upper estuary. Only *C. edentulus* was captured in considerable



**Fig. 4.** Capture curve by length for *Cetengraulis edentulus* from Guanabara Bay (22°S), South-western Atlantic, and mortality  $Z$ ,  $M$ ,  $F$ , and exploitation rate  $E$  estimates



**Fig. 5.** *Cetengraulis edentulus* capturability at Guanabara Bay (22°S), South-western Atlantic, for  $L_{25}$ ,  $L_{50}$ , and  $L_{75}$  length classes

numbers for the population aspect analyses (Tables 1 and 2). The spatial distribution of Clupeiformes was highly uneven throughout the estuary, with 93.4% of a total of 3954 individuals caught between 2005 and 2007 being captured in the upper estuary, 5.64% in the middle portion, and 0.94% in the lower estuary. Stations 3 and 5 were examined during two periods, to identify patterns between the low and medium estuaries (Fig. 2, Table 3). The sampling during the first period (2005–2007) yielded 461 individuals representing 11 Clupeiformes species, while the second period (2013–2015) was characterized by a similar richness, with 11 species but presenting slightly different composition, and capture of a higher number of individuals (585). Despite being similar in the number of species, composition differed with the capture of *Anchoa filifera* (Fowler, 1915) and the absence of *O. mucronatus* and *O. oglinum* during the second period. Nonetheless, no significant difference was indicated by the Kruskal–

Wallis test between both periods. No significant difference among the sampled areas was observed when considering all five areas, although the Kruskal–Wallis results were close to significance ( $P = 0.051$ ). The Mann–Whitney pairwise test was performed to verify which areas crossed this threshold, and some areas were significantly different from others but not during all sampling years. The most critical distinctions were observed between the lower (area 4) and the upper (area 1) estuary ( $P = 0.015$ ).

Due to statistical limitations, the LWR and allometry analyses were performed only for species presenting a total catch greater than 45 individuals. Thus, *Anchoa marinii*, *Engraulis anchoita*, *Sardinella brasiliensis*, *Odontognathus mucronatus*, and *Opisthonema oglinum* were excluded. The regressions were highly significant for all species ( $P < 0.01$ ). The coefficient of determination ranged from 0.86 for *Chirocentrodon bleekermanus* to 0.99 for *Brevoortia aurea*. The parameter  $a$  ranged from 0.0011 for *A. lyolepis*

**Table 2**

The total number of Clupeiformes captured in five areas throughout Guanabara Bay (22°S), in the South-western Atlantic, between 2005 and 2007 per species

Species	Sampling area (first year)					Sampling area (second year)					Total
	1	2	3	4	5	1	2	3	4	5	
<i>Anchoa januaria</i>	8	0	1	0	0	45	2	2	0	4	62
<i>Anchoa lyolepis</i>	0	0	0	0	0	67	4	2	4	3	80
<i>Anchoa marinii</i>	5	0	0	0	0	3	0	0	0	0	8
<i>Anchoa tricolor</i>	22	3	10	6	7	11	0	3	3	3	68
<i>Brevoortia aurea</i>	1	4	1	2	0	251	3	2	0	75	339
<i>Cetengraulis edentulus</i>	1475	69	31	6	44	1928	222	65	5	109	3954
<i>Chirocentrodon bleekermanus</i>	0	0	39	0	0	0	0	135	0	0	174
<i>Engraulis anchoita</i>	1	0	0	0	0	0	0	0	1	0	2
<i>Harengula clupeiola</i>	25	7	28	1	6	125	39	12	0	0	243
<i>Odontognathus mucronatus</i>	0	0	1	0	0	0	0	4	0	0	5
<i>Opisthonema oglinum</i>	2	0	0	0	0	1	1	0	0	1	5
<i>Pellona harroweri</i>	0	0	0	0	0	22	0	13	0	0	35
<i>Sardinella brasiliensis</i>	4	0	3	0	0	0	1	3	18	3	32
Total	1543	83	114	15	57	2453	272	241	31	198	5007

**Table 3**

The total number of Clupeiformes captured in the middle (5- Governor's Island) and lower estuary (3.2- Central channel), throughout Guanabara Bay (22°S), in the South-western Atlantic, during two periods (2005–2007 and 2013–2015), per species

Species	2005		2007		2013		2015		TOTAL
	3.2	5	3.2	5	3.2	5	3.2	5	
<i>Anchoa filifera</i>	0	0	0	0	1	0	0	0	1
<i>Anchoa januaria</i>	1	0	0	4	1	0	0	0	6
<i>Anchoa lyolepis</i>	0	0	0	3	4	13	2	14	36
<i>Anchoa marinii</i>	0	0	0	0	0	0	0	0	0
<i>Anchoa tricolor</i>	5	7	0	3	32	1	0	0	48
<i>Brevoortia aurea</i>	0	0	1	75	23	5	7	280	391
<i>Cetengraulis edentulus</i>	11	44	15	109	0	22	9	3	213
<i>Chirocentrodon bleekermanus</i>	39	0	117	0	107	18	30	0	311
<i>Engraulis anchoita</i>	0	0	0	0	0	0	0	0	0
<i>Harengula clupeiola</i>	0	6	0	0	1	0	1	0	8
<i>Odontognathus mucronatus</i>	1	0	4	0	0	0	0	0	5
<i>Opisthonema oglinum</i>	0	0	0	1	0	0	0	0	1
<i>Pellona harroweri</i>	0	0	12	0	9	0	1	0	22
<i>Sardinella brasiliensis</i>	0	0	0	3	0	1	0	0	4
TOTAL	57	57	149	198	178	60	50	297	1046

to 0.0132 for *P. harroweri*, while the parameter  $b$  ranged from 2.829 for *Anchoa tricolor* to 3.836 for *A. lyolepis*. The type of growth given by  $b$  indicated positive allometry for all species except *Pellona harroweri* and *A. tricolor*.

## DISCUSSION

**Population parameters of *Cetengraulis edentulus*.** The observed length variations of *Cetengraulis edentulus* coincided with those observed for other Brazilian estuaries. Silva et al. (2003) recorded specimens between 7.0 and 20.0 cm at Sepetiba Bay (22°S), while Souza-Conceição et al. (2005), at Saco dos Limões (27°S), recorded individuals between 7.0 and 18.0 cm, with modes at 9.0 and 15.0 cm. Mazzetti (unpublished\*) reported a significant abundance of adults and eggs at Guanabara Bay, suggesting that the species completes its entire life cycle inside the estuary. According to Castro et al. (2005), *C. edentulus* larvae displayed high abundance in the region, indicating that it can be considered a resident estuarine species, as also suggested by Souza-Conceição et al. (2005). The mean size obtained in this study was lower than that verified by Sampaio Franco et al. (2014) for the same estuary (14.7 cm  $L_t$ ) in a study based on a purse seine fleet, which is more appropriate for the capture of small pelagic species. The LWR parameters coincided with the values reported by Joyeux et al. (2009) for the coast of Pará (01°S) and Paraná (25°S), and by Giarrizzo et al. (2006) for Pará (01°S), as well as for parameter  $b$  described by Frota et al. (2004) for the coastal zone between latitudes 13°S and 23°S, but with no clear latitudinal gradient. A high value of the coefficient  $b$  was noted due to the higher number of adult specimens in the samplings in the presently

reported study, suggesting that Guanabara Bay is used as a feeding area. The same was observed at Sepetiba Bay by Silva et al. (2003). The reproductive period and high fecundity reported for Guanabara Bay has also previously indicated the use of this estuary as a breeding area (Kraus and Bonecker 1994, Castro et al. 2005). The high representation of *C. edentulus* in the samples obtained during the first stage (2005–2007) coincided with larvae data for the same period, indicating that the species is the main Clupeiformes in the estuary (Castro et al. 2005). As for the aforementioned estuaries, the observed size range indicates that the species inhabits the estuary during all life stages. This would make *C. edentulus* the most relevant estuarine resident species, both in biomass and fishery production, and the main link between the lower and upper parts of the trophic web.

The species preferred shallower areas, located in the upper estuary with mean salinity values and a muddy bottom, thus corroborating Whitehead et al. (1988), who indicated the occurrence of this species in low salinity areas and even in freshwater environments. The study carried out by Sergipense and Sazima (1995), at Sepetiba Bay, reported the occurrence of this species in shallow areas and turbid waters. The same species was also studied by Silva et al. (2003) and considered to be a seasonal inhabitant of muddy bay bottoms, which would serve as feeding areas. Mazzetti (unpublished\*) also attributes the occurrence of *Cetengraulis edentulus* at Guanabara Bay to the same environmental conditions. Muddy bottoms have also been reported as presenting ecological importance for this species at Itacorubi mangrove (27°S), (Cleazar et al. 1998). According to Able (2005), an estuary occupation

\* Mazzetti M.V. 1983. Contribuição à biologia de alguns Engraulidae (Pisces-Clupeoidei) encontrados na Baía de Guanabara (RJ, Brasil) e áreas adjacentes. [Contribution to the biology of some Engraulidae (Pisces-Clupeoidei) found in Guanabara Bay (RJ, Brazil) and adjacent areas.] Dissertação de mestrado. Rio de Janeiro, UFRJ/Museu Nacional. [In Portuguese.]

strategy aims to minimize predation risks, which are reduced in shallower areas.

The use of size class distributions as a subsidy to estimate growth and mortality parameters is a widely applied method, due to low costs (Sossoukpe et al. 2013). The largest *Cetengraulis edentulus* individual was sampled by Osório Duabily and Báez Hidalgo (2002b) (20.2 cm) in the Caribbean, presenting a much higher length than that observed in the presently reported study. Souza-Conceição and Schwingel (2011) captured the largest individual at Saco dos Limões (27°S), at 16.4 cm, similar to the values observed at Guanabara Bay. The sizeable individual length amplitudes observed herein are an indication that these species use the bay as a growth area. Fish population growth studies indicate length determination as a function of age (Sparre and Venema 1998). Age structure analyses allow for the evaluation of stock alterations under fishing exploration. Therefore, growth studies are essential for fish resource evaluations, since they allow to identify the population structure alterations over time, strongly correlated to fishing intensity pressures. The ELEFAN I method applied herein is one of the most suitable techniques for working with tropical fish species and has been widely applied to fish population parameter studies (Sossoukpe et al. 2013).

The fact that bottom trawlers capture high numbers of individuals of this pelagic species can be related to the findings reported by Sergipense et al. (1999), who examined *Cetengraulis edentulus* feeding habits and found that dietary items include several benthic organisms, which would facilitate its capture while feeding. This may be the deciding factor that allowed for a much larger *C. edentulus* catch when compared to other Clupeiform species in the presently reported study, while not disregarding the problems with the sampling method. Osório Duabily and Báez Hidalgo (2002b) estimated growth parameters for this species, obtaining a similar  $L_{\infty}$  (19.2 cm) to that obtained in the presently reported study, but with a higher  $k$  ( $0.744 \text{ yr}^{-1}$ ) value, while Souza-Conceição and Schwingel (2011) reported  $L_{\infty}$  (15.7 cm) and  $k$  ( $1.05 \text{ yr}^{-1}$ ). The values obtained for the species in this study are within the range found in the literature.

Variations in the stock abundance depend on biomass gain through growth and recruitment and loss through mortality. Individuals are subjected to different mortality causes and intensities throughout their life cycle. The larger the size, the lower the susceptibility to predation and the higher the chances of obtaining food in the face of resource competition (Sparre and Venema 1998), leading to higher survival rates ( $S$ ). However, even though vulnerability to predation is lower in adults, the aging factor must be considered. Therefore, the highest  $M$  rates occur during the larval and juvenile phases. Temperature also exerts an essential role on  $M$ , since metabolic processes accelerate with increasing environmental temperatures. Pauly (1980) developed an equation to estimate  $M$  which, although simple, is useful in obtaining information, especially for fish schools (Sparre and Venema 1998). Conversely

to  $M$ , the larger the individuals, the higher the chance of being caught by fishing activities.

In short-lived, fast-growing species, such as Clupeiformes, it is plausible to assume  $F$  and  $M$  as constants. For *Cetengraulis edentulus*,  $Z$  and  $F$  rates were low. While Sergipense et al. (1999) and Krumme et al. (2008) reported that *C. edentulus* displays benthic dietary habits, predominantly ingesting diatoms, representing the only engraulid with a relevant contribution to bottom trawls at Sepetiba Bay (Araújo Silva et al. 2003), this fishing gear is not the best suited to survey this species. In fact,  $F$  may have been underestimated, since the fishing gear applied herein is not the most suitable for pelagic fish. While the mortality estimates should not be considered the most accurate for use in management, the estimates reported herein demonstrated that a 50% probability of being captured was below the values reported by Souza-Conceição and Schwingel (2011) for maturity lengths (11.2 cm of males and 11.8 cm of females), indicating that immature individuals were being caught by the local commercial fleet. Osório Duabily and Báez Hidalgo (2002a) demonstrated that *C. edentulus* on the Island of Salamanca was being overexploited ( $E = 0.65 \text{ yr}^{-1}$ ), reporting much higher  $Z$  and  $F$  values than those in the presently reported study. As  $F$  is the most influential over  $Z$ , it was reflected in  $E$  for Salamanca. For Guanabara Bay, the low  $F$  estimate deserves further investigation. Although not of significant commercial value, it is known that *C. edentulus* has been suffering from intensive fishing in recent years. In the case of Brazil, the strategy was aimed at compensating losses from the decline of the Brazilian sardinella fisheries (Araújo Silva et al. 2003). The low  $E$  estimate observed herein was caused by the low  $F$  value. Therefore, further studies should be carried out regarding this species mortality and exploitation using specific pelagic fishing gear to confirm the results presented herein.

The growth coefficient may be physiologically interpreted since it tends to vary directly with factors that cause stress and increase oxygen consumption. For this reason, the longevity of any species is inversely correlated to the rate of body activity promoted by metabolism, growth, and reproduction. High temperatures and plentiful food supplies accelerate growth and physiological aging, while low temperatures and low food supplies reduce growth rates and extend life expectancy (Pauly 1980). Osório Duabily and Báez Hidalgo (2002b) and Souza-Conceição and Schwingel (2011) demonstrated that *Cetengraulis edentulus* has a short life cycle. While the  $k$  values for other engraulids (Carvalho et al. 2018) may be higher than the one reported herein, this value corroborates the expected for a small pelagic species.

**Clupeiformes community of Guanabara Bay.** The diversity observed in the presently reported study followed expectations for the evaluated group, based on the known distribution of Clupeiformes species (Menezes et al. 2003). Engraulidae richness identified at Sepetiba Bay (Araújo et al. 2008), a nearby estuary, was similar to that detected for Guanabara Bay, except for the capture

of *Lycengraulis grossidens* (Spix et Agassiz, 1829) in the former. The presence of this species can be related to the use of more restricted capture methods at low depths, such as beach seines, which does not exclude its presence at Guanabara Bay. Although the catch method is not particularly useful for the sampling of small pelagic species, the results indicate that richness was not affected by the methodology, while allowing correlations between small pelagic groups and other trophic network components (Silva Junior et al. 2016).

The proximity between sampling stations 3.2, 5.1 and 5.2 did not reflect environmental similarities and opened the possibility of exploring how environments located so close to one another may vary. The prevailing conditions within Guanabara Bay are mostly low depths, but with a deep channel connected to an oceanic canyon (Fistarol et al. 2015). This feature explains the intense water exchange between the estuary and the sea, which dramatically attenuates the anthropogenic impacts to which this estuary is subjected to (Fistarol et al. 2015). The intense water exchange also implies in the prevalence of marine conditions throughout most of the bay. Henriques et al. (2017), when analyzing correlations between the fish community in several estuaries and prevailing environmental conditions, identified that, in general, estuaries in colder regions with larger areas and presenting greater connectivity to marine ecosystems tended to present a more significant proportion of marine fish in relation to freshwater species, as well as a more ostensive presence of larger species and greater participation of macrocarnivores and planktivores. In this context, Guanabara Bay, despite being a tropical estuary, presents several temperate estuary characteristics, especially concerning the abundant representation of Clupeiformes, both in richness and biomass (Sampaio Franco et al. 2014, Silva Junior et al. 2016). The deterioration of the local environmental quality (Fistarol et al. 2015, Silva Junior et al. 2016) and the intense and historical fishing pressure on macrocarnivore species in the region are responsible for the small number of species belonging to this fish fauna component. The analysis showed no significant differences between the sampled areas, based on a Kruskal–Wallis test ( $P = 0.051$ ), but the Mann–Whitney pairwise test demonstrated that significant differences were observed between stations, albeit presenting a limited and discontinuous pattern.

This study pointed to the existence of an abundance peak for each evaluated period, each was associated with a single species. Potential peaks were also observed for other local fish fauna species, such as *Chilomycterus spinosus* (Linnaeus, 1758), in May–June 2007 (Andrade et al. 2015, Santos et al. 2015) and *Genidens genidens* (Cuvier, 1829) throughout 2005 (Silva Junior et al. 2013, 2016). Although the fishing gear applied herein is not the most suitable for pelagic capture, this non-selective method allowed for the verification of a diverse set of species, where specific peaks were observed, including the small pelagics *Cetengraulis edentulus* and *Brevoortia aurea*, the zoobenthivore *C. spinosus*, and the opportunist

*G. genidens*. The observation becomes more consistent when observing that all these studies came from the same sample, which excludes methodological differences.

Silva Junior et al. (2016) demonstrated the vast range of environmental conditions found in Guanabara Bay, as well as its diverse fish fauna (130 species) with regard to all other Brazilian estuaries. Also, environmental conditions are affected by the excessive use of the bay by various anthropogenic activities, including fishing, port traffic and transport (Prestrelo and Vianna 2016). These interventions have become even more significant in recent years. Between the first (2005–2007) and the second (2013–2015) study periods, the bay underwent interventions to facilitate navigation along the estuary, as well as dredging operations for over 5 million m<sup>3</sup>. It is also important to note that the second period was marked by an unusually severe Clupeiformes die-out event in October–December/2014 (Fistarol et al. 2015). Thus, these alterations were expected to be reflected in biomass and local fish composition results. The fact that species presenting distinct trophic positions were dominant in these peak events may signal that their occurrence is both a function of intrinsic population characteristics and reproductive potential and recruitment success, including ecological and environmental factors, food availability, disturbance degree, and substrate changes. In this sense, the combination of these factors may allow for a given species to enjoy favorable conditions that ensure population increases observed in one peak, while other species, even under the same conditions, may not have been favored.

Estuary dynamics and the high verified richness can explain why the peak events are not constant for the same species, as well as for different species, and that the same trophic level can be dominant during two distinct periods, as in the case of *Cetengraulis edentulus* and *Brevoortia aurea*. These results may also be a consequence of redundancy within the functional group since all species were present during both periods but presenting the aforementioned changes in abundance. In a comparative study carried out between two tropical estuaries, Dolbeth et al. (2016) observed that the estuary most disturbed by human activity presented higher biomass and redundancy, dominated by fewer species when compared to a more preserved estuary. This may also be the reason behind the fact that other taxonomic groups display the same pattern at Guanabara Bay (Andrade et al. 2015, Silva Junior et al. 2016). Furthermore, richness and abundance in subtropical estuaries have been reported as being higher in higher salinity areas and in wetter months (Pichler et al. 2017), reflected in the Guanabara Bay fish community of (Silva Junior et al. 2016). The differences in Clupeiformes abundance common to both evaluated periods may be a consequence of salinity and rainfall variations, with the latter period being notably drier.

The analyzed periods allowed for the identification of abundance differences within the clupeiform fauna between the middle and low Guanabara Bay estuaries (Table 3). The most explicit difference was the decreased

participation of *Cetengraulis edentulus* in the number of caught individuals, with a more significant presence of *Brevoortia aurea* and *Chirocentrodon bleekermanus* (Table 3). In addition, a greater *Anchoa* participation in the most recent period, from 2013 to 2015, was also observed. Peaks above normal Clupeiformes fluctuations were credited to the expressive capture of a single species. As mentioned previously, a peak was observed for *C. edentulus* in September–October 2006. During the second period, *B. aurea* was responsible for the peak noted in March and April 2015 (Fig. 2 and Table 3).

*Cetengraulis edentulus*, the primary fishing resource of the assessed estuary (Sampaio Franco et al. 2014), alongside other small pelagic species, represented this group, which plays a vital role concerning energy transfer to higher trophic web levels. The need to preserve this crucial functional group was exposed by Pikitch et al. (2012), since the state of these stocks can severely affect their predator populations, many of which are also commercially exploited. It is of the utmost importance to insert the biomass necessary to maintain predator populations within the acceptable limits of small pelagic fish species exploitation. Although a debate on the scale at which small pelagic biomass fluctuations interfere in other trophic web components is noted (Pikitch et al. 2012, 2018), the need to monitor the fishery and population alterations of each Clupeiformes species is essential as a criterion for the evaluation of the environmental quality of the assessed estuary (Pikitch et al. 2018). Differences were observed between the identified LWR and allometry parameters when compared to literature information. Data obtained for lagoons close to the studied estuary (Franco et al. 2014) coincided with parameters calculated for Guanabara Bay (Table 1), with similar values for *Anchoa januaria* and *A. tricolor*, *Harengula clupeiola* and *Brevoortia aurea*.

This study demonstrated that the high richness verified in other studies for local ichthyofauna components was also reflected in Clupeiformes. The occurrence of monospecific peaks identified for other trophic groups was also observed in small pelagics, as demonstrated for *Cetengraulis edentulus* and *Brevoortia aurea*. The observed richness was also accompanied by an expressive Clupeiformes biomass, corroborated by the importance of *C. edentulus* regarding catch volume by local commercial fisheries. Both facts were noted in an estuary inserted in one of the largest metropolitan areas of the world, displaying a high degree of anthropogenic impacts. In addition to providing comparable parameters for other studies on the species, the *C. edentulus* population analysis indicates that this species completes its life cycle in the estuary. Furthermore, the considerable presence of small pelagics, a crucial link to higher trophic levels, both regarding richness and biomass, indicates that, if a substantial effort is spent on improving the hypertrophic conditions of the bay, a considerable potential in reconstituting depleted populations is identified, particularly regarding macrocarnivores, known to have been part of the local fauna and still present in nearby estuaries.

## ACKNOWLEDGMENTS

The authors would like to thank all who were involved in this study, especially BioTecPesca colleagues, for their assistance in sample collection and the biometric analyses. The authors also thank the editor and reviewers for offering helpful comments that improved the article. This study was part of the “Environmental Assessment of Guanabara Bay” program, coordinated and funded by the CENPES-PETROBRAS, supported by the Long Term Ecological Program – CNPq (403809/2012-6) and FAPERJ (E-26/110.114/2013).

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Received: 4 July 2018

Accepted: 12 February 2020

Published electronically: 1 June 2020