Haemulidae distribution patterns along the Northeastern Brazilian continental shelf and size at first maturity of the most abundant species

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Highlights

► Haemulidae are broadly distributed through Northeast coast of Brazil due to the complex habitat presents in this region. ► *H. plumierii*, *H. aurolineatum* and *H. squamipinna* were considered the most dominant species among the Family. ► The population structure, and size at first maturity were characterized for the most dominant species of Haemulidae (3 spp.) in Northeastern Brazil. ► The southern coasts of Pernambuco and Rio Grande do Norte hold high abundance, richness and concentration of juveniles.

1. INTRODUCTION

The Haemulidae are one of the most abundant fish families along the Brazilian coast (RANGEL et al., 2007; SOUZA et al., 2007). They inhabit various habitats, but mostly use reef environments because of the resources they provide (SOUTER et al., 2000). They play important ecological roles in the reefs by regulating invertebrate abundance and transferring nutrients across habitats (HOLMLUND & HAMMER, 1999; APPELDOORN et al., 2009; ARAÚJO et al., 2018). Species of this family are also considered good quality food fishes and are widely consumed across the globe by coastal residents, especially in tropical regions (MUNRO, 1996; LINDEMAN, 2002). In addition, this family is important to the underwater tourism industry because members of this family are often the most abundant on artificial reefs and shipwrecks (UYARRA et al, 2009; HONÓRIO et al., 2010).

According to the latest Brazilian official statistics, 14,000 metric tons of grunts were landed in the Northeast region between 1997 and 2007, which generated a profit equivalent to $9.3 million (IBAMA/CEPENE, 1997–2008). The average production per year of haemulids during this period doubled from 711 t in 1997 to 1,550 t in 2007. Grunts are usually captured by pole and line, traps, and gill nets. They are also a common bycatch of the shrimp trawling fisheries (LINDEMAN, 2002; EDUARDO et al., 2018a; SILVA-JÚNIOR et al., 2019). In Northeast Brazil, *Haemulon plumierii*, *H. aurolineatum*, and *H. squamipinna* used to be bycatches of the lobster and goatfish fisheries (LESSA et al.,

38 2009). Currently, haemulids and lutjanids are commonly caught by artisanal fisheries as

39 the target species, owing to the decrease in abundance of lobster and goatfish (LESSA et

40 al., 2009; MARQUES & FERREIRA, 2013).

41   Despite their ecological and economic importance, many biological aspects of this

42 family are still unknown or knowledge is restricted in terms of spatial coverage. Available

43 studies do not integrate information about population structure, distribution, abundance,

44 and the habitats occupied by these species. Previous studies in Northeast Brazil have

45 mainly investigated specific aspects of population dynamics, such as the length-weight

46 relationship (EDUARDO et al., 2019), reproduction (SILVA, 2012; SHINOZAKI-

47 MENDES et al., 2013a; SHINOZAKI-MENDES et al., 2013b; EDUARDO et al., 2018a),

48 feeding (DE ALMEIDA, 2005; PEREIRA et al., 2015), age, and growth

49 (VASCONCELOS-FILHO et al., 2018; EDUARDO et al., 2018a). According to the

50 regional and global International Union for Conservation of Nature (IUCN) assessments

51 (ICMBio, 2018), haemulids are not under imminent threat and are classified in the Least

52 Concern category, except *H. plumierii*, whose threats are recognized, however, because

53 there is not enough available information for an evaluation the species is categorized as

54 Data Deficient.

55   The present study investigated the diversity and length at first maturity (L_{50}) of

56 the main haemulid species in Northeast Brazil. Considering that reefs are highly complex

57 environments that provide areas for reproduction, feeding, and shelter for many different

58 species (LINDEMAN, 2002; ALMARY, 2004), this study also evaluated haemulid

59 distribution, abundance, and special patterns related to habitat use in the area. The

60 findings of this study improve the overall knowledge of haemulids and can be used to

61 assist stock assessments, species extinction risk evaluations, and the detection of priority

62 areas for conservation.

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64

65 **2. MATERIALS AND METHODS**

66 *2.1 Study area*

67

68   The study area (Fig. 1) comprised of the Northeast Brazilian continental shelf,

69 between the states of Rio Grande do Norte (RN) and Alagoas (AL) (5°–9°S). With a

70 narrow shelf, this eastern part of the Northeast region, located a few degrees north of the

71   southern branch of the South Equatorial Current nearshore bifurcation (EKAU &
72   KNOPPERS, 1999), is demarcated by river mouths and estuaries (KNOPPERS et al.,
73   1999). The relatively low concentration of nutrients and the consequently low primary
74   production mean that fish are not very abundant in the area. However, diversity is
75   generally high across the region (LESSA et al., 2006), and there are several Marine
76   Protected Areas ('Recife de Coral', 'Costa dos Corais', 'Guadalupe', 'Santa Cruz', and
77   'Barra de Mamanguape') (FERREIRA & MAIDA, 2007; PRATES et al., 2007).
78
79   *2.2 Data collection and sample processing*
80
81   Data were collected during the Acoustics Along Brazilian Coast (ABRACOS)
82   surveys that were performed onboard the R/V ANTEA from August 30 to September 20,
83   2015 (ABRACOS 1; BERTRAND, 2015), and from April 9 to May 9, 2017 (ABRACOS
84   2; BERTRAND, 2017). The expeditions were approved by the Brazilian authorities, such
85   as the Navy and the Ministry of the Environment (Sisbio). A total of 37 stations, were
86   sampled along the continental shelf (5°–9°S) when both expeditions are combined (Fig.
87   1). At each station, a CTD (model: SeaBird911) was used to examine the oceanographic
88   features (temperature, salinity, and oxygen). Biological samples were collected using a
89   bottom trawl (mesh: 40 mm; bag mesh: 25 mm; mouth dimension: 28×10 m). The
90   trawling was carried out at between 15 and 65 m depth. Each haul lasted approximately
91   5 minutes and the speed was 3.2 kt. Net geometry was calculated using the SCANMAR
92   system, which estimated the height, depth, and width of the net. Bobbins were added to
93   the ground rope on the second cruise in order to reduce the impact on the benthic habitat
94   caused by trawling and to avoid damage to the net.

95   The habitats were classified by video (see EDUARDO et al., 2018b) using a
96   subaquatic camera. Then the major substrates were identified: eighteen stations (51%)
97   were classified as sand substrate with rocks, coralline formations and sponges (SWCR),
98   seven as algae (20%), and six as sand (17%) (Fig. 2). Four stations (11%) could not be
99   classified in terms of habitat and were referred to as unknown. The SWCR and algae
100   habitats were found throughout the depth range (10–60 m). However, the sand habitat
101   was only found in samples near to the shore (10–30 m).
102   The average width of the continental shelf is 40 km, and the shelf position
103   classification was based on the sampling point distance from the shore. The classifications

104 were inner-shelf (< 20 km to the shoreline) and outer-shelf (>20 km from the shoreline).

105 The latitudinal gradient was stratified in accordance with EDUARDO et al. (2018b) who

106 investigated the same area. It was stratified by each 1°, as follows: A = [5°–6°]S, B = [6°–

107 7°]S, C = [7°–8°]S, and D = [8°–9°]S.

108   The collected specimens were identified to the lowest taxonomic group while on

109 board the ship. All species belonging to the Haemulidae family were selected and counted

110 in this study. The large samples (>200 specimens) were weighed and 30 individuals were

111 randomly sub-sampled and taken to the laboratory for further analysis. The sub-sampling

112 was conducted only at three stations and, for small samples, all individuals were analyzed.

113 Individuals were preserved in formalin (4%) or frozen. At the laboratory, the most

114 abundant species were sorted for population studies. The fish were measured (standard

115 length, SL, in cm) and weighed (total weight, TW, in g). Then, a ventral-longitudinal

116 incision was performed. The gonads were removed and individuals were sexed and

117 classified as juveniles or adults according to the following macroscopic gonadal

118 development scale for males and females: A: Immature, B: Maturing, C: Mature, and D:

119 Spent (VAZZOLER, 1996).

120

121 *2.3 Data Analysis*

122

123 *2.3.1 Abundance and diversity*

124

125   For each Haemulidae species, the relative abundance index (Catch per Unit of

126 Effort - CPUE) was calculated in terms of biomass (kg km^{-2}) and number (n° km^{-2}) where

127 the trawled area was considered to be the unit of effort. The trawled area was estimated

128 by multiplying the distance covered by the net with the estimated net width obtained

129 through the SCANMAR sensors. An average net mouth opening of 13 m was used for the

130 CPUE calculations. The following formula was used to calculate the CPUE:

131   CPUE = ((n° and kg) / NW * SD) * 1000

132 where: NW = Net Width and SD = Sampled Distance

133

134   After checking for normality using the Shapiro-Wilk test and homoscedasticity

135 using the Breusch-Pagan test, the mean CPUE was calculated separately for number (n°)

136 and biomass (kg), and the mean SLs of individuals were tested for possible differences
137 between shelf positions using a t-test ($\alpha = 0.05$).

138 Species were described by percentage number (%N), biomass (%B), and
139 frequency of occurrence (%FO). Minimum, maximum, and mean sizes were also reported
140 for each species. Dominance was determined according to GARCIA et al. (2006), where
141 species were classified according to %FO and relative abundance (%CPUE) per latitude
142 point (each 1°), shelf position, and habitat type. Species were classified as frequent or
143 rare, and more abundant or less abundant according to their frequency of occurrence and
144 their relative abundance (CPUE), respectively. Based on these classifications, species
145 relative importance indices were determined. They divided the species into four groups:
146 (1) more abundant and frequent, (2) more abundant and rare, (3) less abundant and
147 frequent, and (4) less abundant and rare (according to GARCIA et al., 2006). Species
148 were considered dominant when they were classified into the first, second, and third
149 categories.

150

151 *2.3.2 Spatial and population patterns*

152 The spatial distribution of abundance (based on the CPUE) was plotted for the
153 most frequent species (five spp.). The length at first maturity (L_{50}) (length of the fish
154 when 50% of individuals first achieved gonadal maturity) of the three main species was
155 estimated for pooled sexes and separately. However, as there were no significant
156 statistical differences between males and females, only the pooled sex results were used.
157 The L_{50} was also used to separate juveniles ($<L_{50}$) and adults ($\geq L_{50}$). L50 was calculated
158 using the percentage of adults by length and the values were adjusted according to King's
159 (2007) logistic equation:

160

161 $$P_i = 1 \,/\, 1 + \exp - (a + b * L_{50})$$

162

163 where P_i is the proportion of adults, a is the intercept, b is the slope of the curve, and L_{50}
164 is the mean length at first maturation. The confidence interval was 95%.

165 The maps were constructed using Qgis, version 3.2.2 software (QGIS, 2018), and
166 the "sizeMat" package (TORREJÓN-MAGALLANES, 2016) in R software (version
167 3.6.1) was used for the statistical tests and to calculate the L_{50} values. The length
168 frequency distribution was separately determined for the most abundant species, males,
169 and females, and a t-test was used to identify differences in the mean length between

170 sexes. As oceanographic conditions at sampling stations were rather similar among

171 surveys, no further analyses addressing environmental parameters and spatial and

172 population patterns were performed.

173

174 **3. RESULTS**

175 *3.1 Oceanographic conditions*

176 The oceanographic conditions at sampling stations were rather similar among surveys

177 and regions (Supplementary Material1). Bottom temperatures were higher during the

178 second survey performed in summer but overall ranged from 25.5° C to 29.6 °C

179 (mean: 27.5 °C), while salinity and dissolved oxygen varied from 36.4 to 37.5 (mean:

180 36.9) and 4 mg L−1 to 4.4 ml.L−1 (mean: 4.2 ml.L−1), respectively.

181

182 *3.2 Haemulidae diversity in Northeast Brazil*

183 A total of 2,976 individuals, belonging to five genera and 10 species, were

184 captured. These were *Anisotremus virginicus, Conodon nobilis, Haemulon aurolineatum,*

185 *H. melanurum, H. parra, H. plumierii, H. squamipinna, H. steindachneri, Haemulopsis*

186 *corvinaeformis*, and *Orthopristis ruber*. *Haemulon aurolineatum* and *H. squamipinna*

187 were dominant in terms of numerical percentage (%N), whereas, according to biomass

188 percentage (%B), *H. plumierii*, *H. aurolineatum* and *H. squamipinna* represented the

189 majority of the total weight captured (83.5%). The frequency of occurrence (%FO) results

190 showed that *H. aurolineatum* was the more frequent, followed by *H. plumierii* and *H.*

191 *steindachneri* (Table 1).

192 The relative importance index of the 10 species in Northeast Brazil showed that,

193 overall, *H. aurolineatum, H. plumierii*, and *H. squamipinna* were present in most or all

194 areas and were classified as more abundant and frequent (Table 1). The analysis of spatial

195 distribution on the continental shelf showed that most species (nine spp.) occurred in

196 shallow waters on the inner shelf. However, half (five spp.) occurred on the outer shelf.

197 The main species (*H. aurolineatum, H. plumierii*, and *H. squamipinna*) were more

198 abundant and frequent on both shelves. After evaluating the relative importance index by

199 latitude stratum, all species were reported in the 8°–9°S (D) stratum and four were more

200 abundant and frequent. All species were observed in the SWCR; there were five in the

201 sand habitat (*H. aurolineatum, H. plumierii, H. squamipinna, H. steindachneri,* and *O.*

202 *ruber*), and three (*H. plumierii*, *A. virginicus*, and *H. aurolineatum*) in the algae habitat.

203 Only *H. plumierii* had a higher abundance and frequency in all habitats (Table 1).

204

205 *3.3 Population aspects and distribution patterns of Haemulidae*

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207 <u>*3.3.1 Haemulon plumierii*</u>

208

209 *Haemulon plumierii* individuals ranged from 9.2 to 24.2 cm SL ($\overline{X}$ = 16.6 cm; SD

210 ± 3.9) and from 23.1 to 385.7 g TW ($\overline{X}$ = 150.3 g; SD ± 93.7) (Table 1). A total of 105

211 individuals were used to estimate the L_{50}, (13.9 cm SL; CI = 13–14.7) (Fig. 3) and 72.5%

212 of the collected individuals were classified as adults. The most common length class for

213 females and males was 17–19 cm SL (Fig. 3), and males were significantly larger than

214 females (*t-test*, t = –3.56, df = 104.93, *p*-value = 0.00056).

215 *Haemulon plumierii* was widely distributed on the northeast coast and the highest

216 CPUEs (n° and kg) were observed in the southern region of Pernambuco (PE) State (8°–

217 9°) (Fig. 4). There were no significant statistical differences in the mean n° and kg CPUE

218 values (*t-test*, t = 0.76, df = 6.77, *p*-value = 0.47 and t = 0.040, df = 9.11, *p*-value = 0.97,

219 respectively) or the mean lengths of the species found on the inner and outer shelves (*t-

220 test*, t = –2.17, df = 10.99, *p*-value = 0.053). The juveniles were only found on the inner

221 shelf in the southern region of Paraiba (PB) and in the central region of PE. However, the

222 adults were dominant across the whole area (Fig. 4).

223

224 <u>*3.3.2 Haemulon aurolineatum*</u>

225

226 *Haemulon aurolineatum* individuals ranged from 4.5 to 19.5 cm SL ($\overline{X}$ =14.1 cm; SD

227 ± 2.2) and from 1.9 to 120.3 g TW ($\overline{X}$ =72.6 g; SD ± 26.2) (Table 1). A total of 210

228 individuals were used to estimate the L_{50} (11.7 cm SL; CI = 11.1–12.2), and 69.4% of the

229 specimens were adults ($SL > L_{50}$) (Fig. 3). The 13–15 cm and 15–17 SL cm length classes

230 were the most common for females and males, respectively (Fig. 3). Males were slightly

231 larger than females (*t-test*, t = –2.45, df = 264.24, *p*-value = 0.015).

232 *Haemulon aurolineatum* occurred throughout the study area (RN to PE), with

233 higher CPUE values (n° and kg) reported in RN and in the southern part of PE (Fig. 5).

234 There were no significant differences in the mean n° and kg CPUEs between the inner

235 and outer shelves (*t-test,* t = –0.17, df = 9.34, *p*-value = 0.87 and t = 0.067, df = 10.70, *p*-

236   value = 0.95, respectively). Individuals were larger on the outer shelf than on the inner

237   shelf (*t-test*, t = –3.17, df = 13.88, *p*-value = 0.007). There was a higher proportion of

238   adults than juveniles, except on the inner shelf south of RN and in PE where juveniles

239   were most abundant (Fig. 5).

240

241   *3.3.3 Haemulon squamipinna*

242

243   *Haemulon squamipinna* individuals ranged from 9.2 to 16.3 cm SL ($\overline{X}$ = 12.9 cm;

244   SD ± 1.7) and from 18.3 to 110.9 g TW ($\overline{X}$ = 60.5 g; SD ± 21.5). A total of 58 individuals

245   were used to estimate the L_{50} (10.1 cm SL; CI = 8.6–11), and 92% of the individuals were

246   adults (SL > L_{50}) (Fig. 3). The 13–15 cm length class was the most common for both

247   females and males (Fig. 3). The mean length of females and males was similar (*t-test*, t =

248   0.60, df = 105.40, *p*-value = 0.55).

249   *Haemulon squamipinna* was found in PB and PE, with the highest CPUE (n° and

250   kg) values reported on the south coast of PE (Fig. 6). The differences between the CPUE

251   (n° and kg) values for the inner and outer shelves (*t-test*, t = –1.08, df = 3.00, *p*-value =

252   0.36 and t = –1.13, df = 3.00, *p*-value = 0.34, respectively) and mean length (*t-test*, p = t

253   = –1.21, df = 4.26, *p*-value = 0.28) were not significantly different. Overall, there was a

254   higher proportion of adults than juveniles, particularly on the inner shelf of the coast along

255   PE (Fig. 6).

256

257   *3.3.4 Haemulon steindachneri*

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259   *Haemulon steindachneri* individuals ranged from 10.7 to 18.0 cm SL ($\overline{X}$ = 14.2

260   cm; SD ± 1.8) and from 33.4 to 135.9 g TW ($\overline{X}$ = 78.1 g; SD ± 24.5). This species was

261   observed on the inner shelf from RN to PE, and southern RN and southern PE had the

262   highest CPUE (n° and kg) values (Fig. 7).

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264   *3.3.5 Orthopristis ruber*

265

266   *Orthopristis ruber* individuals ranged from 11.1 to 17.8 cm SL ($\overline{X}$ = 14.7 cm; SD

267   ± 1.3) and from 37.4 to 133.2 g TW ($\overline{X}$ = 83.2 g; SD ± 21.4). This species was observed

268   on the inner shelf from RN to PE, and southern PB had the highest CPUE (n° and kg)

269   values (Fig. 8).

270

4. DISCUSSION

This study provides new and integrative information about the diversity, distribution, and population biology of the main haemulids along the northeast coast of Brazil. It contributes to our knowledge on spatial patterns of abundance and habitat use by these species across an Ecologically or Biologically Significant Marine Area (CBD, 2014).

In this study, 10 species of Haemulidae were collected. They comprised of five genera that were dominated by the genus *Haemulon*. LESSA and NÓBREGA (2000) reported 12 species in the same area, of which nine were present in our study (except *A. surinamensis, H. chrysargyreum*, and *H. macrostomum*). However, the *H. squamipinna* collected in this study was not recorded by LESSA and NÓBREGA (2000). A total of 13 Haemulidae species are currently reported to inhabit the Northeast Brazil region when both studies are taken into account. The Northeast region has a greater species richness than other regions due to the high diversity of complex habitats, which means that there are several genera of this family in the region. Furthermore, the Northeast Brazilian coast has a greater species richness than the central coast (four species, COSTA et al., 2007), and all of the central coast species have been observed in the Northeast region (*A. surinamensis, A. virginicus, H. aurolineatum*, and *H. plumierii*). Similar results have been recorded for the southeast Brazilian coast, with 11 species (MENEZES, 2011), of which, seven have been observed in the northeast (*A. virginicus, C. nobilis, H. aurolineatum, H. parra, H. plumierii, H. steindachneri*, and *O. ruber*).

The area is also species rich compared to other Atlantic coral regions. The coast of Costa Rica contains seven species (FOURRIÉRE et al., 2017) and the Méxican Atlantic coast contains nine species (GALVÁN-VILLA et al., 2016). Furthermore, in the Indian Ocean region around Western Australia, 10 species and two genera (*Diagramma* and *Plectorhinchus*) have been reported (HARRY, 2001). In the Pacific region, the Japanese coast contained a similar number of species (12 spp.) to the northeast coasts of Brazil, although there were only four genera (*Diagramma, Parapristipoma, Plectorhinchus,* and *Pomadasys* (currently, *Haemulopsis*) (MOTOMURA & HARAZAKI, 2017). Other studies have also reported the high diversity of haemulids in areas with coral reefs (WHITE, 1994; REAKA-KUDLA, 1997; JAIXON-HARM et al., 2012; HONDA et al., 2013), and that they were dominated by the genus *Haemulon* (BROTTO ET AL., 2007;

303 MADRID ET AL., 1997).

304   Northeast Brazil was dominated by *H. aurolineatum*, *H. plumierii*, *H.*
305 *squamipinna*, which confirmed other studies on the region (ROCHA et al., 1998; IVO et
306 al., 2010; OLAVO et al., 2011). Species richness was higher on the inner shelf, especially
307 between 8°S and 9°S where coral habitats predominate. Pernambuco (PE) and Rio Grande
308 do Norte (RN) are considered to be "hotspots" for haemulids due to the high abundances
309 of *H. aurolineatum* (PE and RN), *H. plumierii* (PE), *H. squamipinna* (PE), and *H.*
310 *steindachneri* (PE and RN). Pernambuco has been previously classified as a biodiversity
311 "hotspot" for demersal fishes (EDUARDO et al., 2018b; SOARES, 2019). These areas
312 have several Marine Protected Areas – APA Costa dos Corais and APA Recifes de Coral
313 (FERREIRA & MAIDA, 2006), patchy reefs, and various artificial reefs (mainly in PE)
314 that provide habitats for fishes and other local fauna (DOS SANTOS et al., 2010).
315 Furthermore, complex sandstone reef formations ("Parrachos") favor the settlement of
316 corals and thus influence the diversity and abundance of fish assemblages (CAMPOS et
317 al., 2010, LOPES et al., 2014), especially in RN where there are a great number of these
318 formations.

319   In this study, L_{50} values were determined for *H. plumierii* and *H. aurolineatum*.
320 This study also recorded the first L_{50} values for *H. squamipinna* in the world. The L_{50} *H.*
321 *plumierii* length (15.1 cm FL) was slightly lower than those observed by SHINOZAKI-
322 MENDES et al. (2013[a]). The L_{50} registered for *H. aurolineatum* (15.3 cm TL) was similar
323 to the value reported by LESSA et al. (2004). The differences may be due to
324 environmental conditions and anthropogenic factors, such as fishing, which may lead to
325 the earlier maturation of a stock (OLSEN et al., 2004; LOURENÇO et al., 2015; FROESE
326 et al. 2016), or to methodological differences, for example, the use of different equipment
327 or maturity scales.

328   The L_{50} was also used in this study to evaluate the spatial distribution of juvenile
329 and adult haemulids. Although the adults dominated most species and areas, the inner
330 shelf of the PE coast, RN (*H. aurolineatum*), and southern PB (*H. plumierii* and *H.*
331 *aurolineatum*) had a high proportion of older juveniles. According to LINDEMAN
332 (2000), the reef environment is an area in which juveniles near maturation and adults of
333 most haemulid species live and spawn. Haemulids inhabit mangrove areas and seagrass
334 beds during the post-larval and early juvenile phases, and then migrate to the reefs once
335 they reach maturity (MUNRO, 1983; LINDERMAN et al., 2000; DE LA MORINIERE
336 et al., 2002; 2003).

337   Some species of the family Haemulidae, such as *Conodon nobilis* (LIRA et al.,

338   2019), *Haemulopsis corvinaeformis* (EDUARDO et al., 2018), and *Orthopristis ruber*

339   (COSTA et al., 2018), are frequently captured as shrimp trawling bycatch. They are

340   caught near the shore and are mostly individuals that are below the size of first maturity

341   (PASSARONE et al., 2019). Species of the genus *Haemulon* are not widely affected by

342   trawling because they inhabit coral reef areas that cannot be normally reached by the

343   trawling gear. However, species of this genus are often captured in traps (MARQUES &

344   FERREIRA, 2010). *Haemulon plumierii* is particularly prone to capture across Rio

345   Grande do Norte and Ceará in Northeast Brazil (LESSA et al., 2004; IVO et al., 2010),

346   and *H. aurolineatum* and *H. squamipinna* are often caught along the coast of Pernambuco

347   (LESSA et al., 2004; MARQUES & FERREIRA, 2010). Haemulids used to be bycatch

348   of the lobster fishery. However, a sequential depletion of target stocks occurred in the

349   trap fishing areas of Northern Brazil, starting with the most valuable resource, the spiny

350   lobster (*Panulirus* spp.). Other stocks were then successively targeted, such as goatfishes

351   (*Pseudopeneus maculatus*), parrotfishes (*Scarus* spp.), snappers (*Lutjanus* spp.), and

352   finally grunts (*Haemulon* spp.) (OLIVEIRA et al., 2015). RIBEIRO (2006) reported that

353   the decrease in the abundance of the trap fishing target species meant that the fishing of

354   other reef species had greatly increased. Haemulidae catches doubled over 10 years

355   according to the Brazilian official statistics (IBAMA/CEPENE, 1997–2008). However,

356   currently, there are no data (statistics and status of the stock) available. This has hampered

357   actions in terms of fishery management and conservation, which could be a concern

358   because this group may experience the same outcome as the previous ones.

359   Increasing knowledge about the biology of key reef species and their respective

360   relationships with their habitats is essential for identifying priority areas for conservation

361   and, thus, the optimal implementation of marine spatial planning. Additionally, this new

362   information may be crucial to protecting threatened species, especially those living in reef

363   environments that are under several increasing pressures (ARTHINGTON et al., 2016;

364   BAX et al., 2016).

365

366   **5. CONCLUSIONS**

367   For management measures and conservation of haemulids, special attention

368   should be focused on the inner shelf of the southern coast of Pernambuco and Rio Grande

369   do Norte, as these areas are species rich, have high species abundances, and high juvenile

370   biomass. If management plans are to have a broader conservation impact, the

management actions should address all parts of the shelves between 8°−9° and 5°–6°S. Despite implementation of conservation measures and increased efforts to conserve these ecosystems and species, they are still insufficient to mitigate or reverse the increasing anthropogenic impacts in this important area. The findings of this study suggest that no-take areas in already existing Marine Protected Areas should be created or expanded in order to enhance biodiversity and protect stocks within their boundaries.

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Figure Captions

Figure 1- Study site with bathymetry data and sample points along the continental shelf of Northeast Brazil RN = 5°- 6°S, PE = 6º – 7°S, PB = 7° – 8°S and AL = 8° - 9°S, surveyed on the expeditions of 2015 and 2017 of the project ABRACOS.

Figure 2- Habitat types classification by underwater video footage (Adapted from EDUARDO, 2018b) along the Northeast coast of Brazil.

Figure 3 – Size at first maturity, standard deviation and coefficients (A and B; $p < 0,05$) (a1, a2 and a3); and length frequency of females and males of Haemulidae on the Northeast coast of Brazil (red line indicates the estimated length at first maturity) (b1, b2 and b3). (a1, b1) *H. plumierii;* (a2, b2) *H. aurolineatum* and (a3, b3) *H. squamipinna.*

Figure 4 – CPUE of *H. plumierii* a) in number of individuals b) in biomass (kg) and (c) the ratio of adults and juveniles in the shelf (inner and outer) along the northeast coast of Brazil. The dashed line, in Figure 4c indicates the separation between the inner and outer shelves.

Figure 5 - CPUE of *H. aurolineatum* a) in number of individuals b) in biomass (kg) and (c) the ratio of adults and juveniles on the shelf (inner and outer) along the northeast coast of Brazil. The dashed line in Figure 5c indicates the separation between the inner and outer shelves.
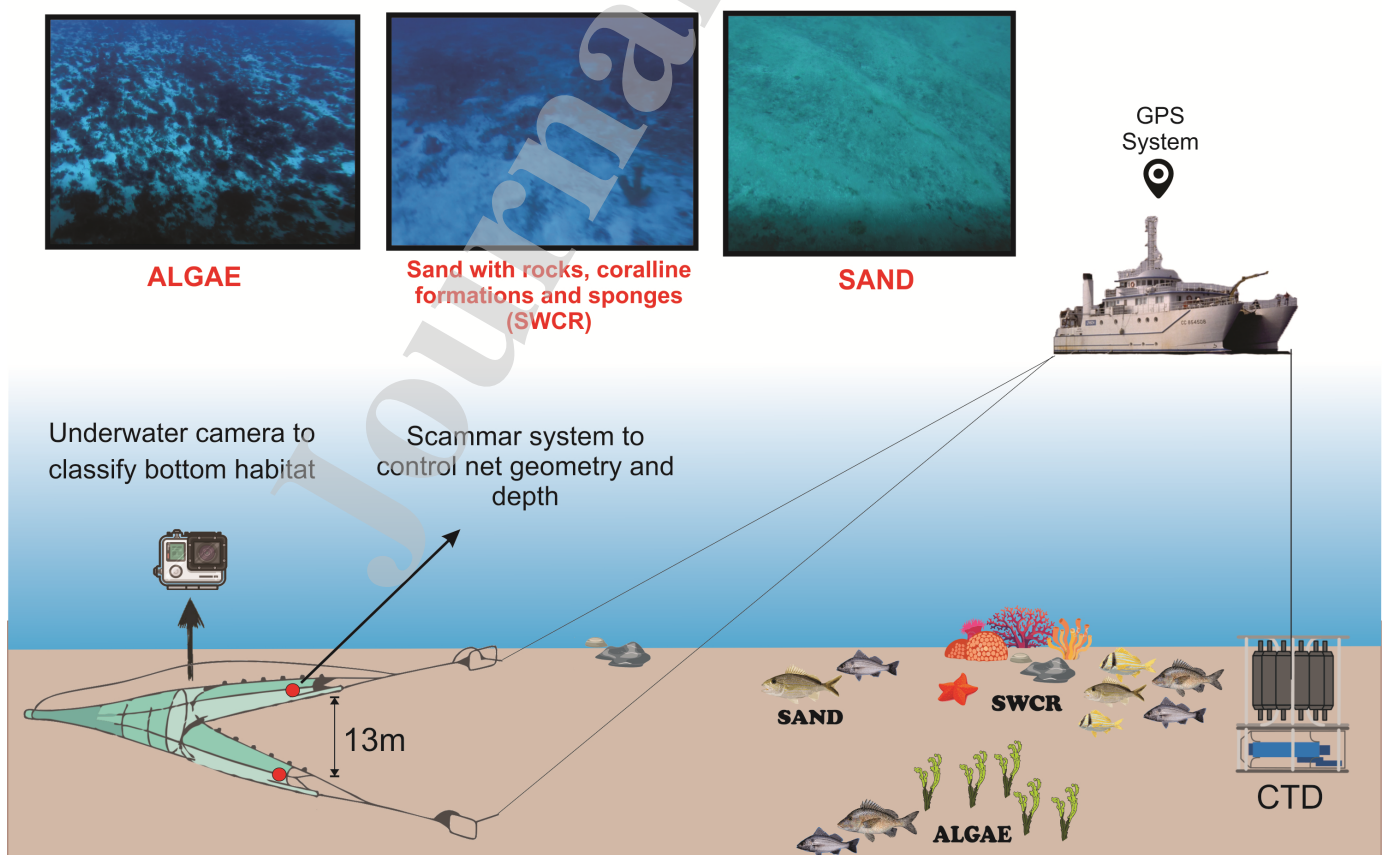
Figure 6 - CPUE of *H. squamipinna* a) in number of individuals b) in biomass (kg) and (c) the ratio of adults and juveniles in the shelf (inner and outer) along the northeast coast of Brazil. The dashed line in figure 6c indicates the separation between the inner and outer shelves.
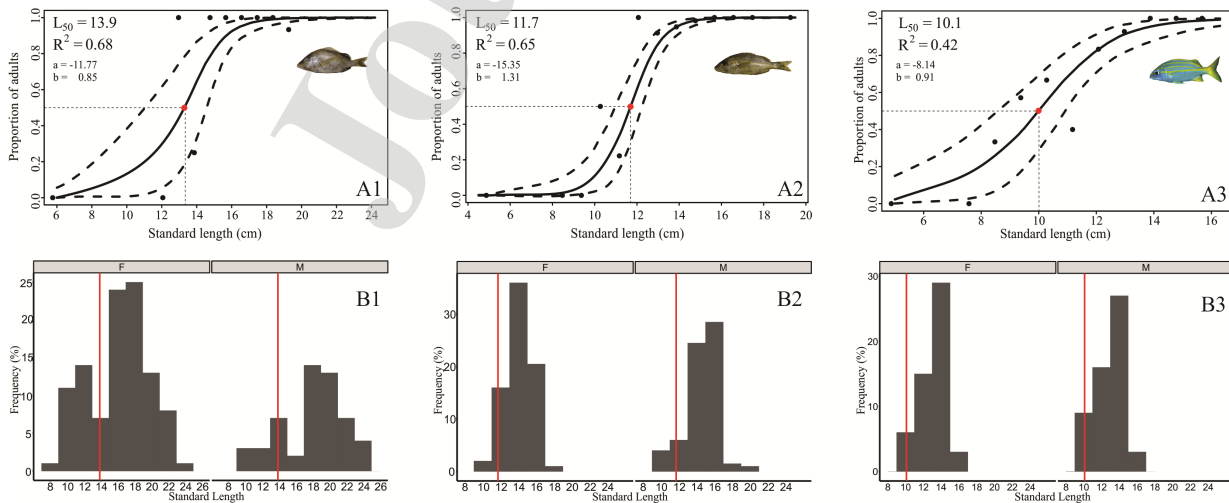
Figure 7 - CPUE of *H. steindachneri* in the number of individuals(a) and in biomass (kg) (b) on the northeast coast of Brazil.
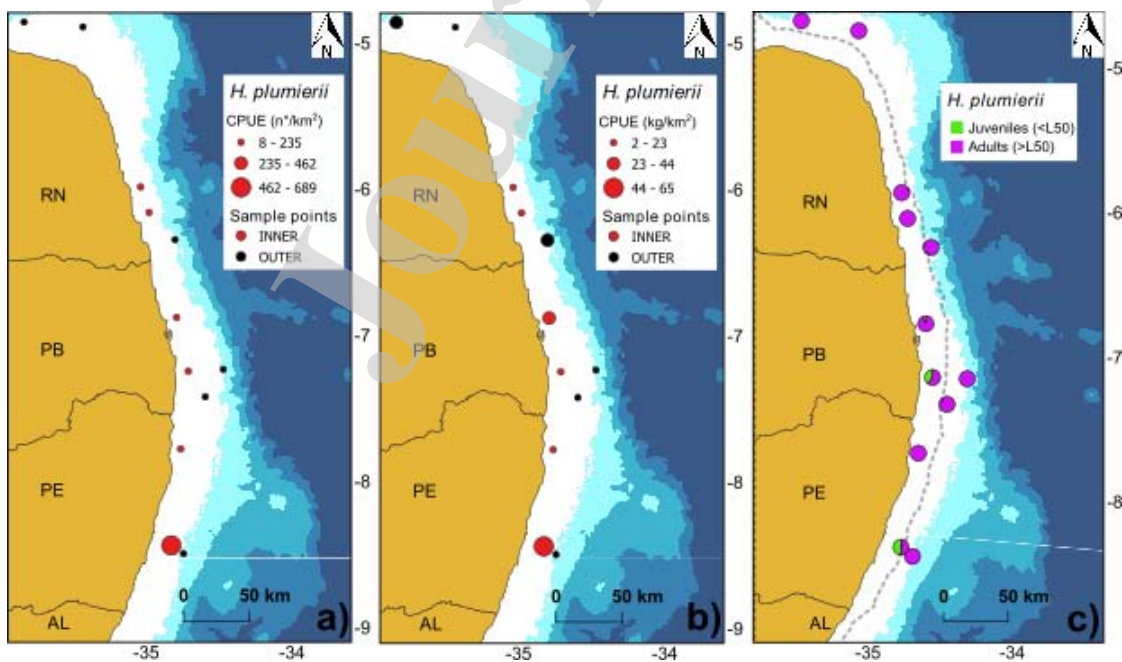
Figure 8 - CPUE of *O. ruber* in number of individuals(a) and in biomass (kg) (b) on the northeast coast of Brazil.
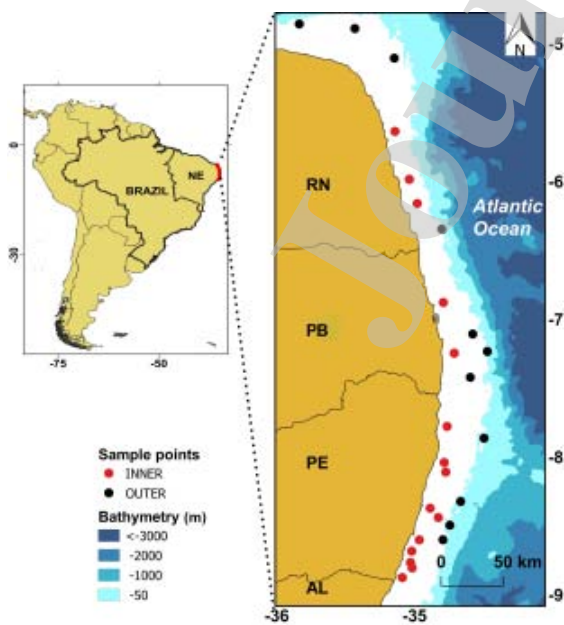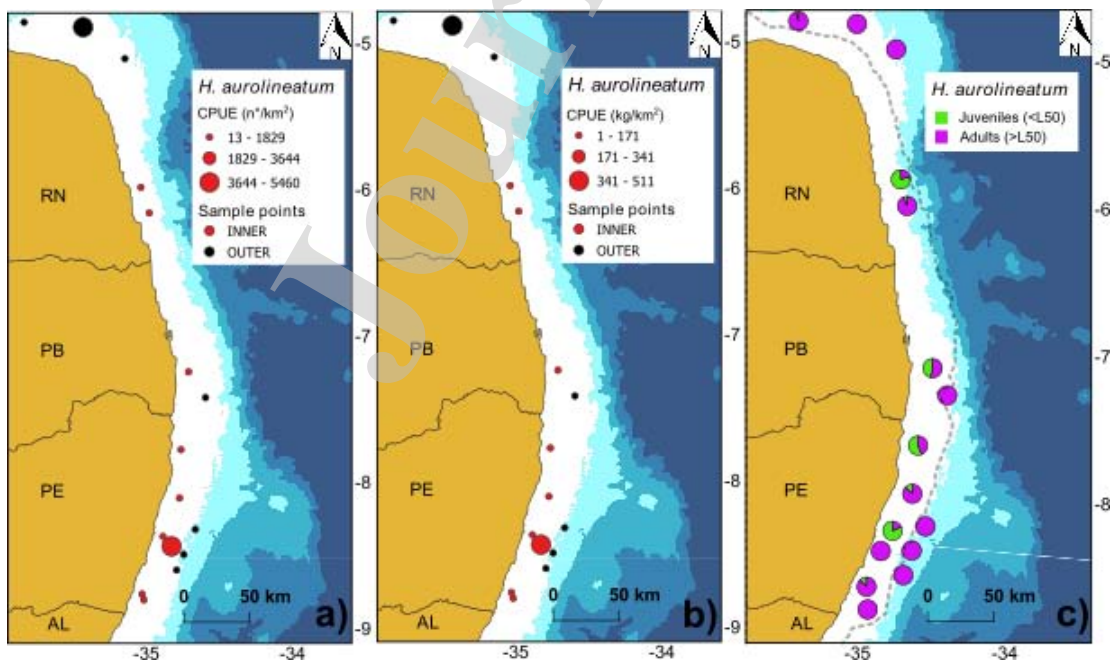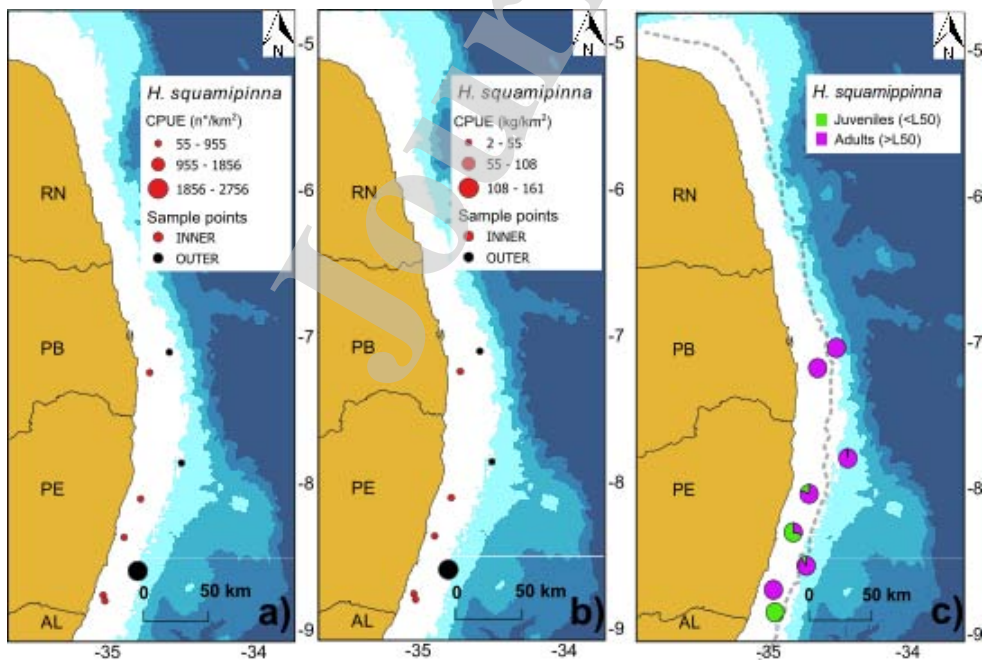
Habitat classification

A1: $L_{50} = 13.9$, $R^2 = 0.68$, $a = -11.77$, $b = 0.85$

A2: $L_{50} = 11.7$, $R^2 = 0.65$, $a = -15.35$, $b = 1.31$

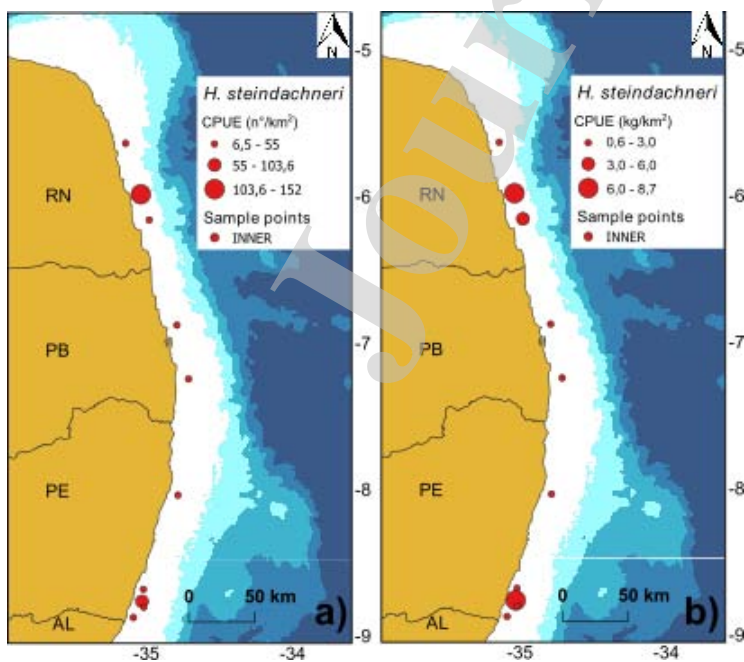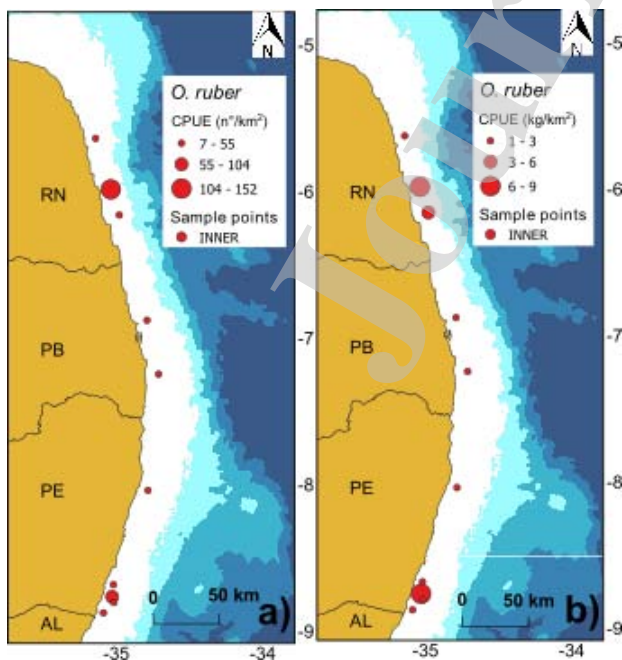A3: $L_{50} = 10.1$, $R^2 = 0.42$, $a = -8.14$, $b = 0.91$

Table 1 – Species of the Haemulidae family sampled in the ABRAÇOS 1st (2015) and 2nd (2017) surveys, habitat type (Sand with Coral and Rocks – SWCR, Sand, Algae), depth range, total number of individuals (N), percentage in number N(%), biomass B(%) frequency of occurrence (FO%), minimum, medium and maximum standard length. Relative Importance Index for shelf position (Inner and Outer), latitude stratum (A (5°- 6°), B (6°-7°), C (7°-8°), D (8°- 9°)) and habitat type: more abundant and frequent (1), more abundant and rare (2), less abundant and frequent (3) and less abundant and rare (4).

Species	N	Habitat	Depth (m) (Min-Max)	N%	B%	FO%	Length Min-Max ($\overline{X}$) (SL - cm)	Shelf Position Inner	Shelf Position Outer	Latitude A	Latitude B	Latitude C	Latitude D	Habitat SWCR	Habitat Sand	Habitat Algae	Overall
Anisotremus virginicus (Linnaeus, 1758)	6	Algae, SWCR	32 - 56	0.2	2.2	10.8	13.8-20.7 (18.5)	4	4				3	4		3	4
Conodon nobilis (Linnaeus, 1758)	1	SWCR	15	0.03	0.06	2.7	12.2-12.2 (12.2)	4					4	4			4
Haemulon aurolineatum (Cuvier, 1830)	1956	Algae, Sand, SWCR	17 - 61	66.1	35.4	43.2	4.5-19.5 (14.0)	1		1	1	1	1	1	1	3	1
Haemulon melanurum (Linnaeus, 1758)	6	SWCR	56 - 57	0.2	2.3	5.4	19.1-24.5 (21.5)		4			4	4	4			4
Haemulon parra (Desmarest, 1823)	1	SWCR	30	0.03	0.46	2.7	22.5-22.5 (22.5)	4					4	4			4
Haemulon plumierii (Lacépède, 1801)	202	Algae, Sand, SWCR	17 - 61	6.7	37.6	35.1	9.2-24.2 (16.6)	1	1	1	1	1	1	1	1	1	1
Haemulon squamipinna Rocha & Rosa, 1999	685	Sand, SWCR	17 - 65	22.7	10.5	21.6	9.2-16.3 (12.9)	1	1	1	2	2	1	1	2		1
Haemulon steindachneri (Jordan & Gilbert, 1882)	69	Sand, SWCR	15 - 43	2.29	5.7	27	10.7-18.0 (14.2)	1	1	1	1	2	1	1	1		3
Haemulopsis corvinaeformis (Steindachner, 1868)	10	SWCR	15 - 32	0.27	5.1	8.1	10.6-15.0 (13.1)	2				4	4	2	1		4
Orthopristis ruber (Cuvier, 1830)	40	Sand, SWCR	15 - 32	1.39	0.65	16.2	11.1-17.8 (14.7)	3				2	3	4	3		4

Highlights

- Haemulidae are broadly distributed through Northeast coast of Brazil due to the complex habitat presents in this region.

- *H. plumierii, H. aurolineatum* and *H. squamipinna* were considered the most dominant species among the Family.

- The population structure, and size at first maturity were characterized for the most dominant species of Haemulidae (3 spp.) in Northeastern Brazil.

- The southern coasts of Pernambuco and Rio Grande do Norte hold high abundance, richness and concentration of juveniles.

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To: **Editor of Regional Studies in Marine Science**

Dear Editor,

We are pleased to submit the revision of the research article entitled: "HAEMULIDAE DISTRIBUTION PATTERNS ALONG THE NORTHEASTERN BRAZILIAN CONTINENTAL SHELF AND SIZE AT FIRST MATURITY OF THE MOST ABUNDANT SPECIES" by Catarina Cardoso de Melo, Andrey P. Cavalcanti Soares, Latifa Pelage, Leandro Nole Eduardo, Thierry Frédou, Alex Souza Lira, Beatrice Padovani Ferreira, Arnaud Bertrand, and Flávia Lucena Frédou.

The authors have no conflict of interest and all have participated in the manuscript preparation and revision. See below a contribution's list of each author:
AB and FLF conceptualize and coordinated the research project. CCM performed analyses and wrote the manuscript with contributions of AB, ASL, APCS, LNE, LP, FLF, BPF and TF. Some authors participated of the at-sea surveys and contributed substantially on biological analyses. All the authors participated in the reviews of the language and referee's considerations.

Thank you for your consideration.
Sincerely.

Catarina Cardoso de Melo

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: