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Harry Boos
Instituto Chico Mendes de Conservação da Biodiversidade

Allan Scalco
Instituto Chico Mendes de Conservação da Biodiversidade

Paula Beatriz Araujo
Universidade Federal do Rio Grande do Sul

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Biological and ecological traits of *Bathynomus giganteus* and *Bathynomus miyarei* (Crustacea: Isopoda): Contribution to the conservation of deep-sea in southern Brazil

Harry Boos[1,2] Allan Cesar Silva Scalco[1] and Paula Beatriz Araujo[2]

[1]Centro Nacional de Pesquisa e Conservação da Biodiversidade Marinha do Sudeste e Sul - CEPSUL/ICMBio, Itajaí, SC, Brazil.

[2]Programa de Pós-Graduação em Biologia Animal, Universidade Federal do Rio Grande do Sul - UFRGS, Porto Alegre, RS, Brazil.

*Corresponding author: harry.boos-junior@icmbio.gov.br

Abstract

1. The study aimed to comprehend the biological and distributional aspects of deep-sea giant isopods *Bathynomus giganteus* and *Bathynomus miyarei* to access their extinction risk.
2. *Bathynomus giganteus* (663 specimens) and *B. miyarei (*649 specimens) were collected during five research cruises involving 265 hours of sampling effort, 32

fishing operations of circular pots, baited traps, between 400 and 1,000 m deep, between 26° and 29°S adjacent to the Brazilian coast.

3. A trend for larger, sexually mature animals in shallower regions was observed for both species, and depth was the most important environmental variable influencing the animals'distribution.
4. *Bathynomus. giganteus* were collected between 600 m and 1000 m depth, while the highest densities of *B. miyarei* was at shallower depths, between 400 m and 600 m.
5. The sex ratio was equal for both *B. giganteus* and *B. miyarei* for different seasons, latitudes and bathymetry.
6. The sexual maturity of *B. giganteus* was estimated at 340-345 mm total length for males and between 280-290 mm for females. *Bathynomus miyarei* males' sexual maturity was estimated at 225-230 mm size class.
7. *Bathynomus giganteus* showed reproductive activity throughout the year.
8. The longevity of *B. giganteus* was estimated at 6 years for males and 7.7 years for females. The longevity of *B. miyarei* was estimated at 9 years for males and 6 years for females.
9. Extinction risk assessment for *B. giganteus*, which has a greater latitudinal and bathymetric distribution, was evaluated as Least Concern (LC). However, *B. miyarei* was evaluated in the Data Deficient (DD) category

KEYWORDS: Deep-sea; giant isopods; marine conservation; bycatch; growth; IUCN Red List.

1. INTRODUCTION

Of the 412 known species of the family Cirolanidae Dana, 1852, the most remarkable is *Bathynomus giganteus* A. Milne Edwards, 1879, representing the largest species of isopods (Poore & Bruce, 2012) and found predominantly between 365 and 730 m deep (Holthuis & Mikulka, 1972). Currently, its distribution is considered restricted to the Atlantic Ocean and extends from 31°N, adjacent to the State of Georgia, USA (Lowry & Dempsey, 2006), to 30°S, off the coast of Rio Grande do Sul, Brazil (Soto & Mincarone, 2001). Along the Brazilian coast (Soto & Mincarone, 2001), *Bathynomus miyarei* has been collected from Amapá (4ºN) (Cintra, Ramos Porto, Silva & Viana, 1998) to Rio Grande do Sul (30ºS), between 230 and 800 m deep (Magalhães & Young, 2003).

Although *Bathynomus* spp. is not a target species for fishing (Poore & Bruce, 2012), it is not free from fishing activity impacts. *Bathynomus* species are captured as bycatch by fisheries in deep waters such as the monkfish, *Lophius gastrophysus* Miranda Ribeiro, 1915 from gillnet fishery in southern Brazil. During 2001, on 14 industrial fishing cruises, 55,475 individuals of *Bathynomus* spp. were captured as bycatch (the incidental capture of non-target species) (Perez & Wahrlich, 2005), and hence it is fundamental to evaluate *Bathynomus* spp. conservation status according to Guidelines for Using the IUCN Red List Categories and Criteria (Mace et al., 2008). Both the evaluation of the extinction risk and the adoption of conservation measures that involve fishing activity will be possible from better knowledge of the species' biological and ecological parameters affected by fisheries. This information is scarce or non-existent for *B. giganteus* and *B. miyarei,* and is essential for the correct application of the extinction risk assessment method (IUCN, 2017). However, it is not enough to know the taxonomy, distribution and biology of the species; it is also necessary to know and adequately measure the threats faced by the species.

This study has four objectives: (a) to compare the seasonal, bathymetric and latitudinal distribution of *B. giganteus* and *B. miyarei* in the continental slope of the Western South Atlantic; (b) to analyse the sex ratio, reproductive period and first sexual maturity; (c) to estimate the growth curves, longevity and mortality of *B. giganteus* and *B. miyarei* and (d) to evaluate the risk of extinction for both species.

2. MATERIALS AND METHODS

2.1 Study area

The collection stations were evenly distributed along the continental slope between 400 and 1,000 m deep, between 26° and 29°S, adjacent to the Brazilian coast (Figure 1). This region is under the influence of the Subtropical Convergence (38ºS ± 2º) formed by the convergence of the Brazil Current and the Malvinas (Falklands) Current (Olson, Podestá, Evans, & Brown, 1988), which leads to an increase in the primary productivity (Rossi-Wongtschowsky et al., 2006; Castello, Haimovici, Odebrecht, & Vooren, 2012). The temperature at depths between 200 and 750 m varies from 6 to 20 °C due to the influence of the South Atlantic Central Water (SACW) (Amaral, Lana, Fernandes, & Coimbra, 2004). At greater depths, up to 950 m, the primary influence is from the Antarctic Intermediate Water (AAIW), with a temperature between 3 and 6°C (Almeida, 2001). An essential source of carbon of continental origin, particularly under the influence of the El Niño/Southern Oscillation (ENSO), is the plumes of “Rio da Prata” (Piola, Matano, Palma, Möller Jr. & Campos, 2005). This plume occupies the coastal strip towards the north (Piola, Möller Jr. Guerrero, & Campos, 2008) up to the area sampled in the present study during the winter (Figure 1).

2. 2 Sampling

Five research cruises were carried out between 2009 (winter, spring) and 2010 (summer, autumn, winter) aboard the R/V Soloncy Moura, involving 32 deployments of circular pots, Japanese model (Slack-Smith, 2001), with pot lines containing four units. Skipjack tuna, *Katsuwonus pelamis* (Linnaeus, 1758) were used as bait, comprising about 265 hours of sample effort. The sampling sites were grouped into five latitudinal sectors: North (26°14'-26°18'S), North-Central (26°50'-26°51'S), Central (27°15'-27°46'S), South-Central (28°31'-28°45'S), South (29°03'-29°05'S) (Figure 1).

The sampling procedure was authorized by the environmental agency (SISBIO / ICMBio n° 16886-2).

2.3 Identification, biometry and sexing

The species were identified according to Magalhães & Young (2003), and total length (Lt) was measured with a 1 mm precision ichthyometer from the end of the clypeus to the median tooth of the pleotelson (Figure 2A).

Specimens without the 7th pair of pereiopods were identified as manca, a stage lacking the posterior pair of pereopods in isopods, and juveniles were those individuals possessing the 7th pair of pereiopods, but without genital papilla or oostegites. Sex was identified by the presence (males) or absence (females) of the genital papilla located on the ventral face of the seventh pereomer (Loyola e Silva, 1999) (Figure 2B). Males were considered immature when they presented the genital papilla only and mature when the male appendages were present in the endopodites of the second pleopods (Tso & Mok, 1991; Loyola e Silva, 1999; Briones-Fourzan & Lozano-Alvarez, 1991; Barradas-Ortiz, Briones-Fourzan, & Lozano-Alvarez, 2003; Magalhães & Young 2003). Females were considered mature when they had functional oostegites or immature when they presented rudimentary oostegites (Tso & Mok, 1991; Briones-Fourzan & Lozano-Alvarez, 1991; Barradas-Ortiz et al., 2003). Based on these criteria, individuals were grouped into six categories: manca, juvenile, immature males, mature males, immature females and mature females.

Part of the animals sampled were anesthetized in ice and later fixed and preserved in 95% ethanol. Vouchers were deposited in the Biological Collection of CEPSUL (CEPSUL nº, 131, 132, 133, 135, 202) and in the collection of the Department of Zoology of the Federal University of Rio Grande do Sul (UFRGS nº 6371).

2.4 Data analysis

The X^2 test compared Catches Per Unit of Effort (CPUEs) for six categories of *B. giganteus* and *B. miyarei*. Analysis of variance (ANOVA *one way*, with Tukey test) compared the CPUEs of each latitudinal sector and season for each category of *B. giganteus*. *B. miyarei* exhibited unequal variances, and the Kruskal-Wallis test was applied. Comparisons were paired between groups using the Dunnett test for differences between the categories. A comparison of the CPUEs for *B. giganteus* and *B. miyarei* between different depths was performed using the Kruskal-Wallis test and the Dunn test (Ayres, Ayres Júnior, Ayres, & Santos, 2007).

The relationship between the distribution of the animals and the environmental variables (season, latitude and bathymetry) was verified by the Unweighted Pair-Group Method using arithmetic averages (UPGMA) and Principal Component Analysis (PCA) (Legendre & Legendre, 1998; Valentin, 2000; Borcard, Gillet, & Legendre, 2011). Each variable's importance for the ordering was analysed from the *circle of equilibrium contribution* (Borcard et al., 2011).

Linear regressions and Pearson's correlation coefficient were used to analyse the relationship between total length (Lt) and capture depth.

Differences in sex ratio for each season, latitudinal gradient and depth were verified by the X^2 test.

The reproductive period was inferred from the capture of females with functional oostegites (Barradas-Ortiz et al., 2003). The mean size of the first sexual maturity was estimated from the length class where 50% of females had functional oostegites and males had complete appendages (Santos, 1978; Vazzoler, 1981).

The software "R Statistics" (R Development Core Team, 2014; Oksanen et al., 2015), Statistica 7.1 software (StatSoft, Inc., 2005) and BioEstat 5.0 (Ayres et al., 2007) were used for the analyzes. The significance level of 0.05 was used.

The growth of males and females was described from the distribution of absolute length (Lt) frequencies in histograms (Santos, 1978) with classes of 20 mm, defined from the value obtained by the Sturges formula (Sturges, 1926). Mancas and juveniles, where sex cannot be identified, were grouped and included for males and females for cohort identification. The length data were analyzed by FiSAT (FAO-ICLARM *Stock Assessment Tools*) (Gayanilo, Sparre, & Pauly, 1996) using the Bhattacharya method to identify principal seasonal cohorts in each sex. The normal components were confirmed by the *normally separation* routine (NORMSEP) (Pauly & Caddy, 1985). Growth was described by the von Bertalanffy model (VBGF): $Lti = L\infty [1-e-k (t-t0)]$, where: Lti = total length at age t; $L\infty$ = maximum theoretical length that the species can reach (asymptotic length); k = growth coefficient; t0 = theoretical age at birth. The growth performance index (ϕ ') was calculated according to: $\phi' = \log k + 2\log L\infty$. All these parameters were estimated using the ELEFAN I method (*Electronic Lengths-Frequency Analysis*) (Pauly & David, 1981) inserted in the computational package FiSAT II (FAO-ICLARM *Stock Assessment Tools*) (Gayanilo et al., 1996; Gayanilo & Pauly, 1997; Gayanilo, Sparre, & Pauly, 2005). The asymptotic total length ($L\infty$) was estimated from the largest individual captured (Lmax,), Being: $L\infty$ = Lmax

/ 0.95 (Pauly, 1983a). Longevity, defined as the time the individual takes to reach 95% of the asymptotic length, was estimated based on the formula proposed by Taylor (1958): tmax = t0 + 2,996 / k.

The total mortality rate was estimated using the linearized converted catch curve method starting from the distribution of the full length-frequency data and the growth curve parameters (Pauly, 1983b; 1984a; 1984b).

The extinction risk assessment of *B. giganteus* and *B. miyarei* used the method developed by the International Union for Conservation of Nature (IUCN, 2017). The method estimates the risk of extinction of a species in the near future, taking into account current knowledge about the biology, distribution, population trends as well as actual and future threats (Mace et al., 2008). Generation length is the time interval, to assess the risk of extinction of each species, in the past or future. For this, information on sexual maturity and mortality is used (IUCN, 2017). The threats impacting the species, we considered the bycatch in the industrial fishery by gillnet directed to the monkfish in the south of Brazil.

3. RESULTS

3.1 Seasonal, latitudinal and bathymetric abundance

In total, 663 *B. giganteus* were captured; 147 mancas, 108 juveniles, 212 males (187 immature and 25 mature) and 196 females (131 immature and 65 mature). For *B. miyarei* 649 individuals were captured, comprising 22 mancas, 81 juveniles, 207 males (196 immature and 11 mature) and 339 females, all immature.

The CPUEs recorded for each category were unequal for both *B. giganteus* (X^2 = 16.942, df = 5, p = 0.0046), and *B. miyarei* (X^2 = 93.109, df = 4, p <0.0001).

There was a difference between CPUEs recorded seasonally for *B. giganteus* ($F_{4,25}$ = 3.9230; p = 0.0132), but only observed between winter / 09 and winter / 10 (p < 0.05). For *B. miyarei*, no difference was observed between CPUEs recorded at each station (H = 4.999; df = 3; p = 0.1733) (Table 1).

Males and females of *B. giganteus* showed a relatively even distribution for all categories, all seasons of the year, except in the autumn, when the mancas were more abundant and mature females less abundant. *B. myarei* catches were irregular, with no mature females in all samples and no specimens collected in winter /10 (Table 1).

There was no significant difference between the age groups for *B. giganteus* ($F_{4,25}$ = 1.2807, p = 0.3037) and for *B. miyarei* (H = 7.0768; df = 4; p = 0. 1319) in relation to CPUEs registered in the latitudinal sectors (Table 1). On the other hand, a difference was observed between the catches at different depths for the two species. The difference was between the lowest bathymetric range (401-500m) and between 601 and 900 m depth (p <0.05) for *B. giganteus* (H = 15.7106; df = 5, p = 0.0077). In relation to *B. miyarei* the difference was found in CPUEs (H = 9.3267; df = 3, p = 0.0252) between 501-600m and 701-800m deep (p <0.05) (Table 1). There was a relationship between specimen size and depth for both *B. giganteus* (F = 55.59, p <0.001) and *B. miyarei* (F = 130.40, p <0.0001), with larger animals at shallower depths.

Grouping analysis for *B. giganteus* revealed two main groups (distance = 86.8), one formed by mature males and mature females and another by the other categories (manca, juvenile, immature males and immature females). These were divided into two other groups (distance = 75.9), one with mancas and immature males and the other with juveniles and immature females. For *B. miyarei*, immature females (distance = 178.5) were separated from the other categories, where immature males (distance = 158.2) were distinguished from mancas, mature males and juveniles (Figure 3).

Principal component analysis (PCA) for *B. giganteus* abundance indicated that mancas, immature females and immature males were distributed similarly. The two principal axes explained 74,93% of the total variation. The analysis of *B. miyarei* indicated that 87.04% of the total variation was due to components 1 and 2. The variables that contributed mostly to axis 1 and 2 in the two species were depth and seasons (Figure 4).

3.2 Sex ratio, reproductive period and sexual maturity

The proportion between males and females was equal for both *B. giganteus* and *B. miyarei* for different seasons, latitudes and depths ($p > 0.005$).

B. giganteus males were more abundant in autumn ($X^2 = 6.125$, df = 1, $p = 0.0133$), in the northern sector ($X^2 = 13.885$, df = 1, $p = 0.0002$) and between 701- 800 m deep ($X^2 = 15.61$, df = 1, $p < 0.0001$). Females were more numerous during winter /09 ($X^2 = 6.259$, df = 1, $p = 0.0124$), in the southern sector ($X^2 = 16.901$, df = 1, $p < 0.0001$) and between 501-600 m deep ($X^2 = 19.512$, df = 1, $p < 0.0001$). In relation to *B. miyarei*, males were more abundant in winter /09 ($X^2 = 6.968$, df = 1, $p = 0.0098$) and spring ($X^2 = 31.508$, df = 1, $p < 0.0001$), in the South-central ($X^2 = 18.284$; df = 1; $p < 0.0001$) and South ($X^2 = 35.842$, df = 1, $p < 0.0001$), and in depths between 501 and 600 m ($X^2 = 27.939$; df = 1; $p < 0.0001$) (Table 2).

Females with functional oostegites, mancas and juveniles of *B. giganteus* were present in all samples collected, indicating the existence of ovigerous females throughout the year.

B. giganteus sexual maturity was estimated to be 340-345 mm length, whereas females' sexual maturity was estimated between 280-290 mm.

For males of *B. miyarei*, the first sexual maturity was estimated for 225-230 mm length. As mature females were not sampled, it was not possible to estimate the size of sexual maturity for females.

3.3 Growth, longevity and mortality

The total size range of *B. giganteus* individuals was 50 mm (mancas) to 405 mm (mature male). The length of *B. miyarei* ranged from 31 mm (mancas) to 265 mm (mature male). The mean length of *B. giganteus* was higher than for *B. miyarei* for all age groups (Table 3).

Four hundred sixty-seven (467) males and 451 females were used to estimate *B. giganteus* growth. The asymptotic size ($L\infty$) of males (426 mm) was higher than that of females (417 mm), and the same trend was seen for "k" values (0.49 and 0.39, respectively). Male longevity (tmax) was estimated at 6 years, lower than that of females (7.5 years) (Figure 5, Table 4).

For the estimation of the *B. miyarei* growth curve, 310 males and 442 females were considered. The asymptotic size ($L\infty$) for males (279 mm) was higher than for females (204 mm), whereas the growth coefficient (k) was higher in females (0.49) than males (0.33). The longevity (tmax) was estimated at 9 years for males and 6 years for females (Figures 6, Table 4).

B. giganteus growth performance indexes (ϕ) were slightly higher than those of *B. miyarei*; however, they were similar between sexes of each species (Table 4). From the equation describing the growth of *B. giganteus* females, it was possible to estimate that sexual maturity occurs, on average, around the second year of life. Considering the smallest (170 mm) and the largest mature female (392 mm) sampled, we can estimate that sexual maturity occurs between 1.2 years (460 days) and 3 years (1062 days). For males, this estimate was close to 2 years, ranging from 1.5 years (518 days) to 2.5 years (894 days), when considering the smallest (235 mm) and the largest (405 mm) mature male sampled. For *B. miyarei* the age at which males reach sexual maturity was estimated to be approximately 3 years.

The mortality rate was estimated at 0.62/year for males and 1.14/year for *B. giganteus* females (Table 4).

3.4 Assessment of risk of extinction

The generation length was estimated to be 4.5 years for *B. giganteus*. In the case of *B. miyarei*, the generation time was calculated in 5.25 years.

Our results indicated the existence of a bathymetric stratification between *B. giganteus* and *B. miyarei*. From this observation, it is possible to estimate that 85% of the 55,475 individuals were captured as bycatch (reported by Perez & Wahrlich, 2005), i.e. approximately 47,000 individuals were *B. miyarei*.

After 2001, the gillnets fishery for monkfish decreased, even though between 2000 and 2012, 5,474,882 kg of this species were landed (UNIVALI/CTTMar, 2001; 2002; 2003; 2004; 2006; 2007a; 2007b; 2008; 2009; 2010; 2011; 2013a; 2013b). Between 2000 and 2015, a period that corresponds to three generation length according to IUCN (2017), more than 200,000 *B. miyarei* were killed only by monkfish gillnets fisheries in the south of Brazil.

The absence of fisheries monitoring looking at *B. miyarei* as bycatch prevents the estimation of the population decrease, so it is not possible to accurately assess its extinction risk, assigning the species to the status of Data Deficient (DD). However, the latitudinal and bathymetric distribution is larger for *B. giganteus*, reducing the impact of fishing activity on this species, categorizing it as a Least Concern (LC), in terms of extinction risk.

4. DISCUSSION

B. miyarei record at depths greater than 900 m extends the earlier known bathymetric range between 230 and 800 m depth for this species (Magalhães & Young, 2003). The largest catch of *B. giganteus* reported here between 601 and 700 m confirms previous research (Holthuis & Mikulka, 1972; Briones-Fourzán & Lozano-Alvarez, 1991; Soto & Mincarone, Barradas-Ortiz et al., 2003). The relationship between individuals'size and depth confers *a priori* a vertical ontogenetic stratification, especially for *B. giganteus*, with larger animals at shallower depths. For *B. miyarei*, however, the studied bathymetric range (400-1000 m) did not allow adequate sampling of the population.

The massive abundance of *B. giganteus* mancas between 701 and 800 m is in line with observations in the Gulf of Mexico (Briones-Fourzán & Lozano-Alvarez, 1991). In turn, juveniles, were captured in the range of 900-1000 m, as seen when analysing the separation between mature and immature/mancas/juveniles. For *B. miyarei*, the animals were recorded between 400 and 600 m, except for two mancas and a juvenile found between 901 and 1000 m. This information is essential for identifying and managing vulnerable marine ecosystems in deep waters (FAO, 2009).

The equal proportion between males and females for different seasons, latitudes and depths are similar to that observed in the Gulf of Mexico for *B. giganteus* (Briones-Fourzán & Lozano-Alvarez 1991). As no ovigerous females were collected, it was not possible to indicate the reproductive period directly. However, *B. giganteus* females with functional oostegites and mancas and juveniles in the samples collected indicate the presence of ovigerous females throughout the year. In eastern Taiwan, no seasonality was observed in the reproductive activity of *B. doederleini* (Soong & Mok, 1994). However, the larger CPUE for *B. giganteus* mancas and juveniles during spring may be related to higher reproductive activity in the previous autumn and winter. In the Gulf of Mexico, most mancas were similarly collected in the spring (Briones-Fourzán & Lozano-Alvarez, 1991; Barradas-Ortiz et al., 2003).

There are only two records of *Bathynomus* spp ovigerous females: one captured in the Bay of Bengal, Myanmar (Lloyd, 1908) and one in the Gulf of Mexico (Schmitt, 1931 apud Holthuis & Mikulka, 1972). The absence of captured ovigerous females suggests a behavior of seclusion in pits dug in the substrate, as well as the interruption of the foraging during the incubation of eggs, consequently decreasing the capture of ovigerous females with baited traps (Briones- Fourzán & Lozano-Alvarez, 1991). Survival over long periods with no foraging is possible because of the females' ability to store organic reserves in hepatopancreas (Tso & Mok, 1991), intestinal gland and adipocytes (Biesiot, Wang, Perry, & Trigg, 1999).

Good mobility, ability to ingest large amounts of food in a short time and storage of organic reserves (Biesiot et al., 1999) for long periods are advantageous for giant animals like *B. giganteus* (Lowry & Dempsey, 2006). Thus, the sinking of large carcasses, both by natural deaths and through bycatch from industrial fishing should favor the presence of ovigerous females throughout the year (Kelleher, 2005).

The size at sexual maturity of males and females of *B. giganteus* are similar to those observed in the population of the Gulf of Mexico (Briones-Fourzán & Lozano-Alvarez, 1991). Moreover, similar to that observed by Briones-Fourzán & Lozano-Alvarez (1991), no intermediate stages were found in oostegites growth, suggesting that oostegites become functional after a single parturial molt (Subramoniam, 2017).

B. giganteus was larger than *B. miyarei* in all categories, corroborating Soto & Mincarone (2001). The regular sizes sampled for *B. giganteus* were between 220 and 280 mm, with males larger than females (McClain et al., 2015). We saw a similar trend here for

B. miyarei, for both the calculated means and the estimated maximum length values for both sexes. Although morphologically very similar, both species are different concerning the maximum and the mean size for each sex. However, it is essential to recognise that the absence of mature females of *B. miyarei* during sampling may have underestimated the growth curve, with a similar effect on estimates of asymptotic size and longevity. Nevertheless, it provides a reasonable approximation to the parameters cited.

Although a 500 mm specimen of *B. giganteus* was reported in Brazil (Lowry & Dempsey, 2006), the data was uncertain and the specimens are unknown in any collection. Thus, the largest confirmed record for the species is a 421 mm male sampled in southern Brazil (Soto & Mincarone, 2001).

Differential growth between males and females is expected, insofar as growth and reproduction are antagonistic (Hartnoll, 1982). Slower growth of females may also be due to reduced feeding during egg incubation (Hartnoll, 2006), which seems to be the case for *B. giganteus* females (Briones-Fourzán & Lozano-Alvarez, 1991).

The influence of seasonal changes was not considered for the growth rates calculated for *B. giganteus* and *B. miyarei* (Chang, Sun, Chen, & Yeh, 2012). However, the values are in line with the expected pattern for species that inhabit deep waters, with lower growth rates than species of shallower depths (Company & Sardà, 2000). The slow growth, high longevity and periods of low mobility of ovigerous females, inferred for *B. giganteus* and *B. miyarei*, result from low metabolic rate, a well-known characteristic in other giant animals living in places with few or intermittent feeding resources (Vermeij, 2016). Species with these characteristics, when targeted or collected as bycatch of fisheries, tend to suffer a rapid and marked decline in population biomass (Rogers, Clark, Hall-Spencer, & Gjerde, 2008; Clark et al., 2016), which can lead to extinction risk.

Although captured *Bathynomus* spp. can be returned alive to the sea, the post-release mortality may vary between 50 and 100%, depending on the animal's reflexes before release and the time they are exposed (Talwar, Brooks, & Dean Grubbs, 2016). In this way, most of the *Bathynomus* spp. captured, even if released alive, are likely to die. The stress the animals are subjected through bycatch from the industrial fishery is very high, the inappropriate handling (animals are thrown or kicked away from the species of interest) and the time on board (under the sun) are stressful. Therefore, although the two species studied were not considered to be under threat of extinction, the category of Data Deficient (DD) attributed to *B. miyarei* indicates that more information is needed and recognizes that the species could be impacted and under threat.

In addition to the mortality caused by industrial fishing in deep waters, the accumulation of plastic debris has already been observed in these areas (Van Cauwenberghe, Vanreusel, Mees, & Janssen, 2013; Woodall et al., 2014; Taylor, Gwinnett, Robinson, & Woodall, 2016), including its presence in the stomach of *B. giganteus* collected in the Gulf of Mexico (Briones-Fourzán & Lozano-Alvarez, 1991). These events damage the animals by contamination as well as by filling the stomach with nondigestible items. Moreover, contamination can affect growth and reproduction. Animals that dig holes, such as *Bathynomus* spp. are even more exposed to plastic fragments that aggregate in the holes (Murray & Cowie, 2011).

On the other hand, thanks to their size, unique morphology and distribution in large oceans areas, species of the genus *Bathynomus* have aroused sympathy in young and adults, mainly in Asia. Nowadays, it is possible to buy replicas made of plastic or plush on the internet. For this reason, these species could be potentially known as flagship species. Charismatic groups of animals (e.g., sea turtles and panda) have been a successful conservation strategy in recent decades when used to sensitize society to the need for conservation not only of the species but also on the environment in which they live.

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Table 1. Capture per unit effort (CPUE for individuals numbers caught every 6 hours of fishing operation with 4 fish pots per main line); (g) *Bathynomus giganteus*; (m) *Bathynomus miyarei* divided by sex and age for each season, latitudinal sector and bathymetric gradient.

Variables	Manca		Juvenile		Immature male		Mature male		Immature female		Mature female	
	g	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*
Winter'09	0.57	2.08	0.38	9.09	1.32	24.23	0.00	1.32	2.27	34.45	1.51	0.00
Spring	4.64	0.45	4.79	3.00	5.09	4.49	0.75	0.00	4.04	13.78	3.15	0.00
Summer	2.63	0.58	3.29	0.80	4.68	1.68	0.66	0.29	3.14	3.14	0.95	0.00
Autumn	4.63	0.00	0.69	0.17	1.72	1.29	0.26	0.00	0.69	1.89	0.09	0.00
Winter'10	3.46	0.00	3.16	0.00	9.32	0.00	1.20	0.00	6.16	0.00	3.31	0.00
North	6.41	0.00	1.18	0.00	5.65	0.00	0.34	0.08	2.53	0.08	0.25	0.00
North-central	5.72	0.00	3.68	1.09	7.22	2.18	0.82	0.14	5.99	1.63	1.63	0.00
Central	1.10	0.00	1.97	0.71	3.31	7.96	0.39	0.47	2.29	9.46	0.47	0.00
South-central	1.29	0.92	6.10	2.22	1.85	2.96	0.55	0.00	1.48	9.43	0.92	0.00
South	1.2	2.55	1.35	7.80	2.25	9.45	1.05	0.45	3.00	23.24	5.85	0.00
401-500	0.30	0.44	0.00	0.89	0.15	2.80	0.07	0.30	0.15	4.65	0.52	0.00
501-600	0.77	1.08	0.85	4.88	1.16	12.24	0.46	0.54	1.70	21.39	3.02	0.00
601-700	6.10	0.00	0.00	0.00	15.02	0.00	0.94	0.00	11.74	0.00	3.76	0.00
701-800	9.27	0.00	5.25	0.41	10.50	0.00	1.07	0.00	6.07	0.00	0.66	0.00
801-900	3.88	0.00	2.91	0.00	4.85	0.00	1.94	0.00	2.91	0.00	1.94	0.00
901-1000	1.40	0.94	14.03	0.47	2.34	0.00	0.47	0.00	2.34	0.00	0.47	0.00

Table 2. *Bathynomus giganeus* and *Bathynomus miyarei* - Sex ratio (males / females) for each season, latitudinal sector and bathymetric gradient. No males or females of *B. miyarei* collected at different seasons and depths are indicated with a dash (-). Two mancas and one juvenile were collected between 901-1000.

	B. giganteus				***B. miyarei***			
Variables	**males**	**females**	**sr**	***P***	**males**	**females**	**sr**	***P***
Winter'09	7	20	0.3	0.0209*	135	182	0.7	0.0098*
Spring	39	48	0.8	0.3911	30	92	0.3	<0.0001*
Summer	73	56	1.3	0.1589	27	43	0.6	0.0730
Autumn	23	9	2.6	0.0216*	15	22	0.7	0.3239
Winter'10	70	63	1.2	0.6029	0	0	-	-
North	71	33	2.1	0.0003*	1	1	1	0.0261[a]
North-central	59	56	1.0	0.8521	17	12	1.4	0.4576
Central	47	35	1.3	0.2245	107	120	0.9	0.4258
South-central	13	13	1	1	16	51	0.3	<0.0001*
South	22	59	0.4	<0.0001*	66	155	0.4	<0.0001*
401-500	3	9	0.4	0.1489	42	63	0.7	0.0510
501-600	21	61	0.3	<0.0001*	165	276	0.6	<0.0001*
601-700	34	33	1	1	0	0	-	-
701-800	141	82	1.7	0.0001*	0	0	-	-
801-900	7	5	1.4	0.7728	0	0	-	-
901-1000	6	6	1	1	0	0	-	-

sr. sex ratio. [a] = chi-square test with Yates correction. * = significant.

Table 3. Average total length, minimum, maximum and standard deviation for different stages of males and females (g) *Bathynomus giganteus* and (m) *Bathynomus miyarei*.

Total length	Manca		Juvenile		Immature male		Mature male		Immature female		Mature female	
	g	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m**
N	147	22	108	81	187	196	25	11	131	339	65	-
Mean (mm)	69.9	45.5	83.3	55.4	180.8	136.2	329.5	231.4	165.5	112.1	277.1	-
SD	14.0	4.5	16.6	5.1	61.9	40.8	45.1	17.6	49.7	33.8	28.9	-
min (mm)	50	31	54	48	68.0	64	235	203	76	62	170	-
max (mm)	133	55	130	74	300.0	239	405	265	272	194	392	-

N. number; SD. Standard deviation; * No mature females of *B. miyarei* were caught.

Table 4. Parameters of the growth curve (**L∞. k**). and growth performance index (ϕ '). total mortality (Z) and longevity of *B. giganteus* and *B. miyarei*.

	Sex	L∞ (mm)	k	ϕ'	Z ($year^{-1}$)	Longevity (year)
B. giganteus	Males	426	-0.49	4.949	0.62	6
	Females	417	-0.39	4.831	1.14	7.5
B. miyarei	Males	279	-0.33	4.410	-	9
	Females	204	-0.49	4.309	-	6

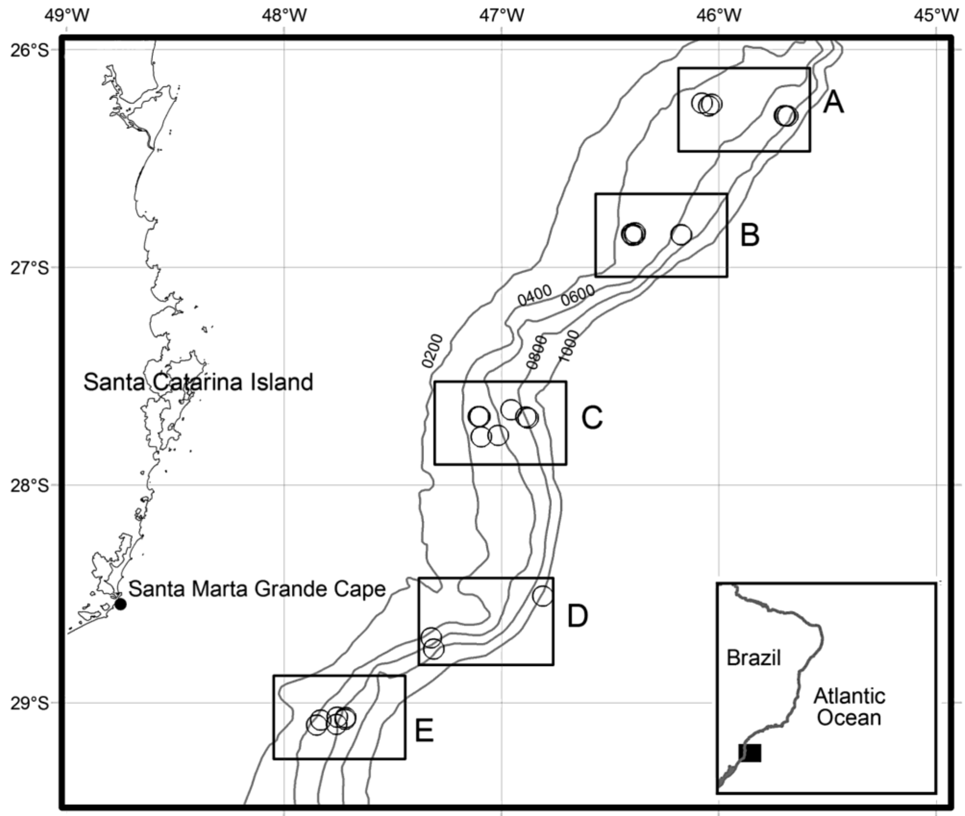

Figure 1. Sampling area conducted aboard the R/V Soloncy Moura. Circles indicate the sampling stations and rectangles indicate the latitudinal sectors: A: north (26°14'-26°18'S), B: North-central (26°50'-26°51'S), C: central (27°15'-27°46'S), D: South-central (28°31'-28°45'S) and E: south (29°03'-29°05'S).

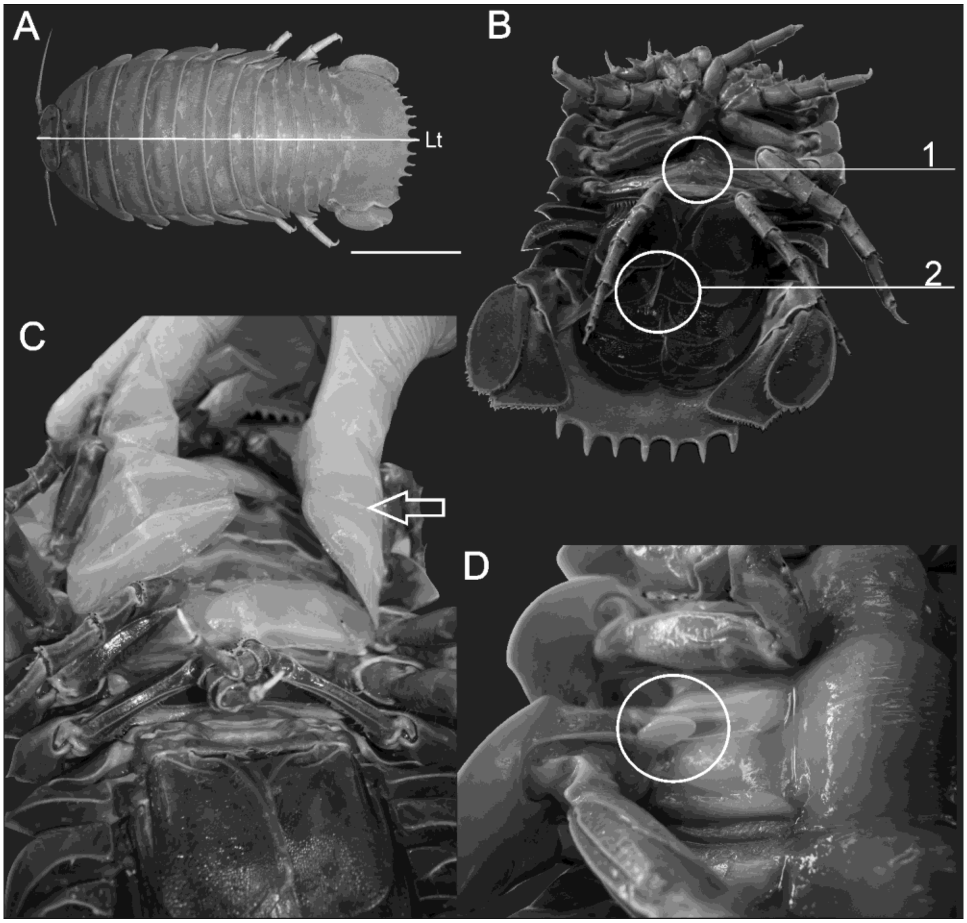

Figure 2. *Bathynomus giganteus* A, Milne Edwards, 1879, A - Total length (Lt); B - Male indicating (circles) the genital papilla (1) and the male appendix (2); C - Female indicating functional oostegites; D - Female indicating rudimentary oostegites; Scale bar (A), 10 cm) (Photos: ICMBio / CEPSUL Collection).

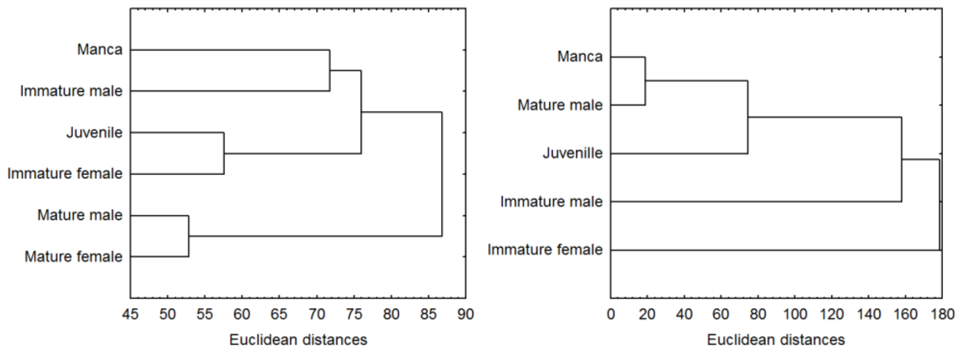

Figure 3. Grouping analysis (unweighted pair group method with arithmetic averages - UPGMA) for mancas, juveniles, immature males, mature males, immature females and mature females in the latitudinal gradients, bathymetric and seasonal, A - *Bathynomus giganteus*, B - *Bathynomus miyarei*.

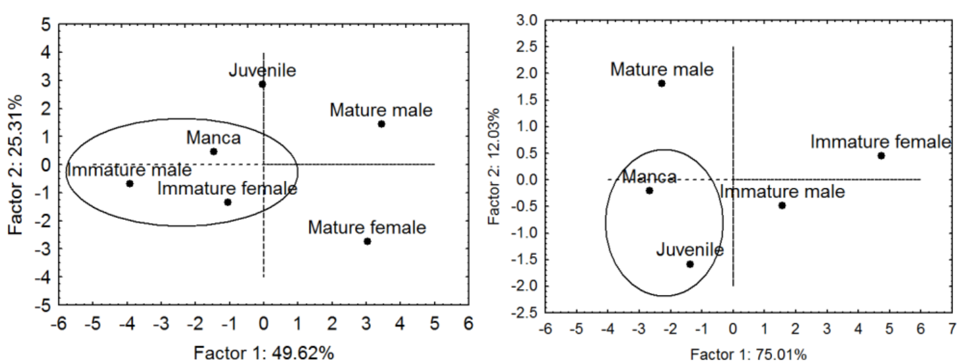

Figure 4. Principal Component Analysis (PCA) for mancas abundance data, juveniles, immature males, mature males and immature females in the latitudinal gradients, bathymetric and seasonal, A - *Bathynomus giganteus*, B - *Bathynomus miyarei.*

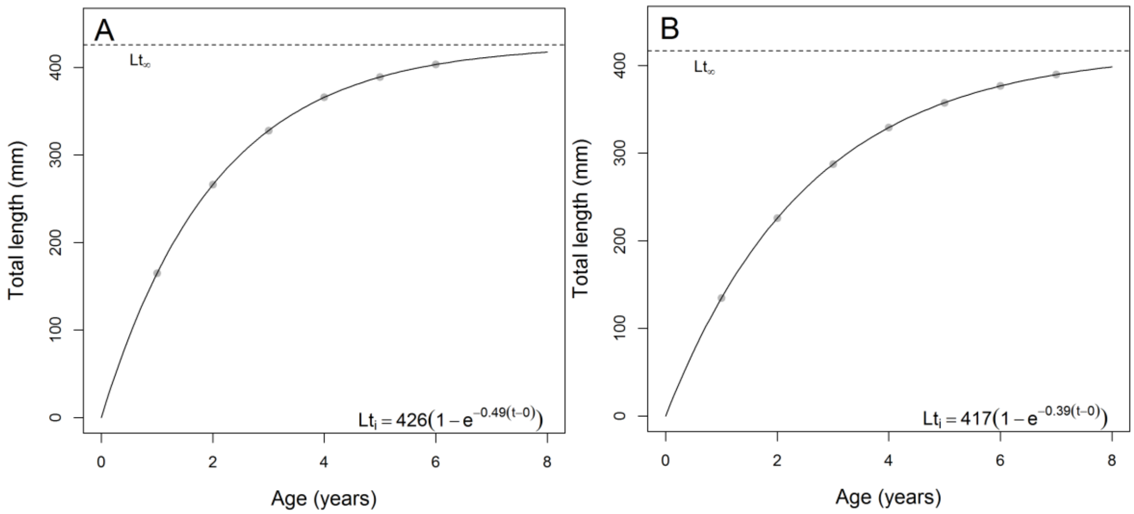

Figure 5. *Bathynomus giganteus* - Curves and equations describing the growth of (A) males and (B) females.

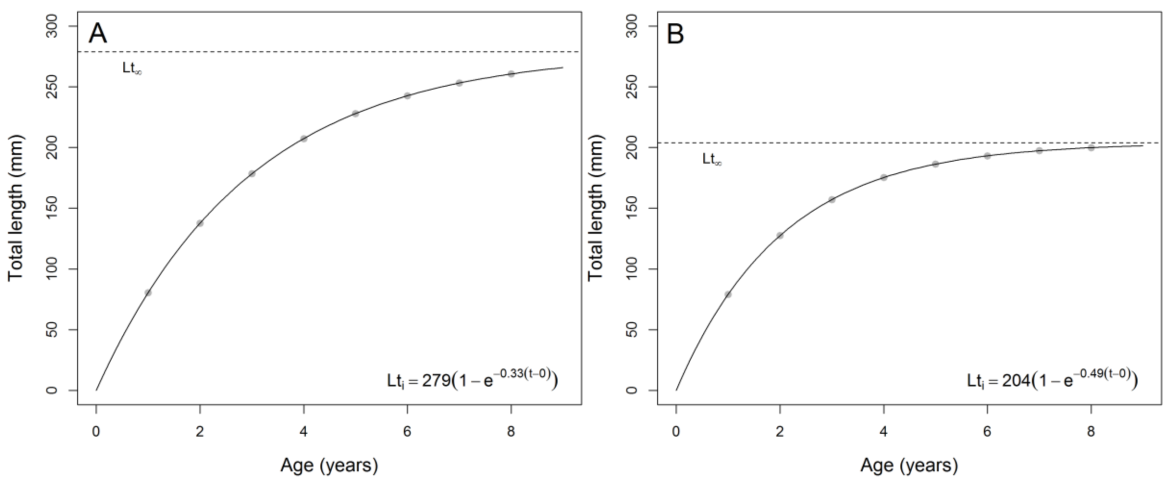

Figure 6. *Bathynomus miyarei* - Curves and equations describing the growth of (A) males and (B) females.