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***Research Article***

# Reproductive cycle and population structure of the deep-water shrimp *Aristeus antillensis* A. Milne Edwards & Bouvier, 1909 (Decapoda: Aristeidae) on southeast Brazilian continental slope

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**ABSTRACT.** The “alistado shrimp” (*Aristeus antillensis*) is one of the targets of the trawling fleet operating since 2002 along the continental slope of the Brazilian Economic Exclusive Zone between 700 and 800 m depth. Catches of the species occur mainly in two small fishing grounds located on the east coast of Espírito Santo State (19-22°S). This paper aimed to obtain the first biological data for this species along the Brazilian coast. A total of 13,797 individuals were sampled aboard fishing vessels by observers on almost all fishing hauls, corresponding to 10 to 20% of the total catch recorded in the period. Males and females are sexually mature at 25.4 and 40.2 mm carapace length, respectively, based on an analysis of the proportions of individuals with fused petasma (males) and spermatophores in the thelycum (females). The proportion of impregnated females was higher than 80% year round, suggesting a continuous reproductive cycle, although preliminary information on gonadal development points to possible seasonal reproduction. In general, mature females, which attain larger sizes than males, dominate the catches (M:F = 0.12:1). However, populational groups including males and juveniles of both sexes occupy the fishing grounds in different periods of the year, probably reflecting migratory movements whose directions and driving forces are not completely understood yet. A depth-stratified population structure by sex and size is hypothesized.

**Keywords:** deep-water resource, sexual maturity, reproductive cycle, population structure, Aristeidae, Brazil.

# Ciclo reproductivo y estructura poblacional del camarón de aguas profundas *Aristeus antillensis* A. Milne Edwards & Bouvier, 1909 (Decapoda: Aristeidae) en el talud continental del sureste de Brasil

**RESUMEN.** La gamba de aguas profundas *Aristeus antillensis* es uno de los recursos explotados por la flota de arrastre, que está operando desde el año 2002 en el talud continental de la Zona Económica Exclusiva de Brasil, entre 700 y 800 m de profundidad. Las capturas de esta especie se realizan básicamente en dos pequeños fondos de pesca que se encuentran en la costa este de la región de Espírito Santo (19-22°S). Este trabajo tiene por objetivo obtener los primeros antecedentes biológicos de esta especie en la costa brasileña. Un total de 13.797 camarones fueran muestreados en los buques pesqueros por observadores en casi todos los lances de pesca, que correspondieron entre 10 y 20% de las capturas totales en el período. Machos y hembras están sexualmente maduros a 25,4 y 40,2 mm respectivamente (longitud de carapazón), según el análisis de las proporciones de individuos con petasma unido (machos) y telicum con espermatóforo (hembras). La proporción de hembras con espermatóforo fue superior a 80% en todo el año, sugiriendo un ciclo reproductivo continuo. Sin embargo, informaciones preliminares sobre el desarrollo gonadal indican una posible estacionalidad en la reproducción. Generalmente, hembras adultas, que alcanzan tallas mayores que los machos, dominaron las capturas (M:F = 0,12:1). Sin embargo, grupos poblacionales, incluyendo machos e inmaduros de ambos sexos, ocupan los fondos de pesca en diferentes períodos del año, probablemente como reflejo de los movimientos migratorios, cuyas direcciones y fuerzas aún no son totalmente comprendidos. Se discute una posible estructura poblacional estratificada de sexos y tallas por el gradiente batimétrico.

**Palabras clave:** recurso de profundidad, madurez sexual, ciclo reproductivo, estructura poblacional, Aristeidae, Brasil.

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## INTRODUCTION

Deep-water shrimps from the family Aristeidae represent an important and valuable fishery resource in many parts of the world (Crosnier & Tauter, 1968; Rainer, 1992; Guéguen, 1998; Kao *et al.*, 1999; Ragonese *et al.*, 2002; Tudela *et al.*, 2003; Can & Aktas, 2005).

On the Brazilian coast, the exploitation of aristeid shrimps started in 2002 as part of a governmental program launched to expand industrial fisheries to previously unexploited slope fishing grounds where valuable benthic and demersal resources concentrate. The history and dynamics of this fishery, which experienced a "boom and bust" developmental cycle, have been extensively reviewed by Pezzuto *et al.* (2006) and Dalagnollo *et al.* (2009).

Since the beginning of the fishery, *Aristaeopsis edwardsiana* ("carabineiro" or scarlet shrimp), *Aristaeomorpha foliacea* ("moruno" or giant red shrimp), and *Aristaeus antillensis* ("alistado") have been the targets of bottom stern-trawlers along almost all the Brazilian Economic Exclusive Zone (EEZ), but operations have concentrated mainly between 18°S and 34°S and from 700 to 800 m (Pezzuto *et al.*, 2006; Dallagnolo *et al.*, 2009). *A. antillensis* is the least abundant species in the catches, representing nearly 5% of the total deep-water shrimp landings recorded between November 2002 and May 2007. In part, this reflects the fact that most of the exploitable biomass of the species is largely concentrated in only two small fishing grounds (total area = 588.3 km$^2$) located on the eastern coast of the Espírito Santo State (19-22°S) (Dallagnolo, 2008; Dallagnolo *et al.*, 2009). Scientific surveys conducted in this area revealed otherwise, that *A. antillensis* exhibits a wider bathymetric distribution ranging between 200 and 1,144 m, with density peaks at 750 m deep (Pezzuto *et al.*, 2006; Serejo *et al.*, 2007).

In general, aristeid shrimps are believed to be more vulnerable to overexploitation than coastal penaeids due to: a) their higher economic value; b) K-strategist life history, with lower growth rates and longer life spans; c) complex distribution patterns, with migratory movements across bathymetric gradients; and d) aggregated reproductive behavior, inducing the seasonal formation of highly vulnerable biomass concentrations in the fishing grounds (Ragonese & Bianchini, 1996; Sardá *et al.*, 2003a, 2003b; Tudela *et al.*, 2003; Pezzuto *et al.*, 2006; Dallagnolo *et al.*, 2007; Pezzuto & Dias, 2007). Biological information about *A. antillensis* is very scarce. As far as we know, the only specific studies available to date were carried out by Guéguen (2000, 2001), who described the bathymetric distribution, morphometry, overall sex-ratio, and size-frequency distribution of the species on the continental slope of French Guiana, where *A. antillensis* is also a minor component of a seasonal industrial fishery for *A. edwardsiana*. However, despite not knowing the growth rates, longevity, and other biological characteristics of *A. antillensis*, high prices in the international market, low biomass levels, and a distribution concentrated in a few, small, easily accessible fishing areas in southeastern Brazil make the species highly susceptible to severe depletions in the near future.

A management plan for the aristeid fishery is now being discussed and implemented in Brazil. This is mostly concerned with the sustainability of *A. edwardsiana*, the main target of the fishery. A total allowable catch (TAC) of 60,000 kg has been set for the three species together but, in order to protect *A. antillensis* from depletion, fishing operations north of 21°S must be stopped when its annual catches reach 4,350 kg, the estimated Maximum Sustainable Yield (MSY) for the species (Dallagnolo, 2008; Perez *et al.*, 2009).

As biological reference points based on size/sex-structure and reproduction are not available for the three species, this work aimed to provide the first results on the population structure and reproductive biology of *A. antillensis* in Brazilian waters in order to support additional recommendations for the sustainable exploitation of this new deep-water resource.

## MATERIALS AND METHODS

### Study site

Commercial catches of aristeid shrimps occur in four fishing grounds (N1 to N4) over the continental slope of the Espírito Santo State (Fig. 1). However, *A. antil-*

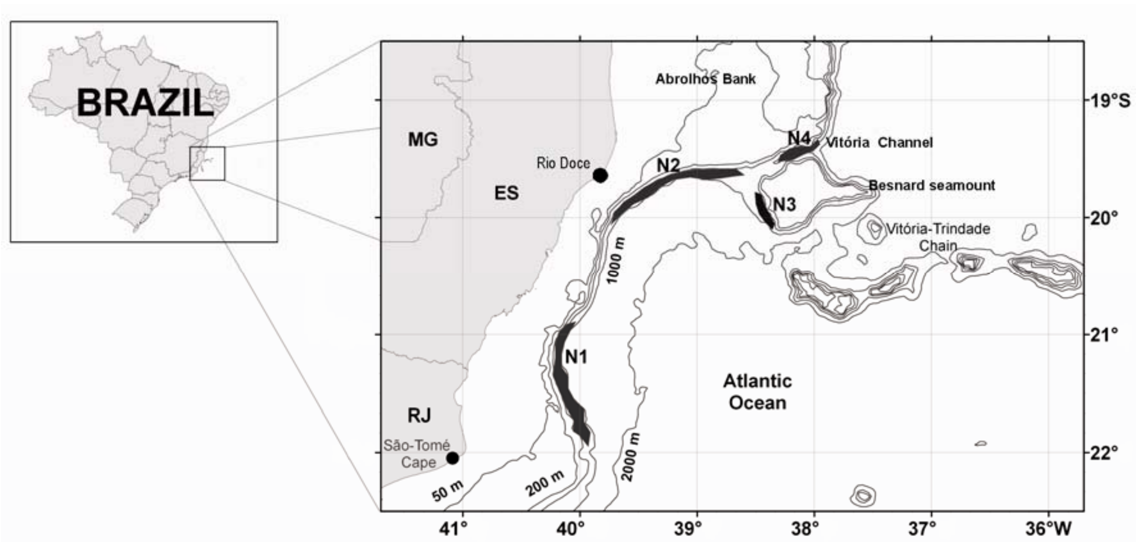

**Figure 1.** Main fishing grounds of *Aristeus antillensis* (N2 and N4) in southeastern Brazil. ES, MG, and RJ refer to Espírito Santo, Minas Gerais, and Rio de Janeiro states.

**Figura 1.** Principales fondos de pesca del *Aristeus antillensis* (N2 y N4) en el sueste de Brasil. ES, MG y RJ se refieren a los estados de Espirito Santo, Minas Gerais y Rio de Janeiro.

*lensis* is mostly found in only two of them: N2 and N4. These are located in an area with very distinct morphological and oceanographic characteristics on the Brazilian coast. They are situated close to or inside the Vitória Channel, a deep strait that separates the continental slope adjacent to the Abrolhos Bank from the scarp of the Besnard seamount, one of the main features of the Vitória-Trindade chain (20 to 21°S) (Fig. 1). In this area, the continental slope is very steep and narrow (18 km), exhibiting several small subparallel canyons extending from the shelf to nearly 800 m depth. Both canyons and the slope are supposed to receive a terrigenous influence from the discharge of the Rio Doce (França, 1979). Three water masses have been found to occupy the upper 1,500 m of the water column over the *A. antillensis* fishing grounds: a) Tropical Water (TW; T > 20°C; S > 36.2) occupies the surface layers (0 ~ 200 m) flowing towards the southwest; b) South Atlantic Central Water (SACW; T = 6-20°C; S = 34.6-36) is found below the TW up to 700 m depth, and c) Antarctic Intermediate Water (AIW; T = 3-4°C; S = 34.2-34.6) flows to the north between 700 and 1,500 m (Costa *et al.*, 2005; Castro *et al.*, 2006; Haimovici *et al.*, 2007). The euphotic zone is dominated by oligotrophic warm tropical waters having low productivity and primary productivity that is not uniform either spatially or temporally. Lower and higher values are found, respectively, in the summer and winter months, whereas intermediate ones occur in the autumn and spring. Major estuaries such as Rio Doce, which opens to the sea in front of the N4 fishing ground, exert a positive influence on the inner shelf, creating areas of higher primary production. In addition, both the Abrolhos bank and Vitória-Trindade chain act as important topographic barriers to the Brazil Current, which carries the TW along the eastern coast of Brazil towards the south, producing a very complex hydrographic structure including vortices, upwellings, and vertical mixing processes (Valentin *et al.*, 2007). One of these features, the "Vitória vortex", forms south of the Abrolhos bank, enriching the euphotic zone with comparatively nutrient-rich SACW waters (Ciotti *et al.*, 2007; Rezende *et al.*, 2007; Valentin *et al.*, 2007).

### Sampling and processing

Fishing and biological data used in this work were collected by observers aboard all commercial vessels that operated off the Espírito Santo State (18°20'-22°S, 360 to 890 m depth) between October 2003 and November 2008 (Fig. 1). Details about the fleet and gears can be found in Dallagnolo (2008) and Dallagnolo *et al.* (2009). For each trawl, the geographic coordinates, date, time, and depth (m) were recorded at deployment and retrieval, and trawl speed (nm $h^{-1}$), trawl duration (h), head rope length (m), mesh size at cod-end (mm), and catch composition (kg) were also registered. A total of 13,797 individuals were sampled from almost all the fishing hauls, corresponding to 10% to 20% of the total catch recorded in the period.

Only individuals caught between 650 and 800 m depth were considered in this study, as nearly 80% of the hauls with positive catches of the species occurred between these limits. As significant differences in size-sex structure with depth have been found for other Aristeids, including the congeneric species *A. antennatus* in the Mediterranean (Sardà & Cartes, 1993; Sardà *et al.*, 2003b, 2004; Tudela *et al.*, 2003), this procedure intended to eliminate possible noise caused by samples eventually taken in other depth strata where population characteristics could differ from those found in the main fishing grounds.

Sex was identified macroscopically in all shrimps by the presence of petasma in males and thelycum in females. Carapace length (CL) was measured with sliding calipers (precision 1 mm) from the orbit to the dorsal mid-point of the posterior margin of the carapace. Numbers in the samples were raised to the total catch of each haul by multiplying them by the quotient between total catch and sample weights recorded by the observers.

Size at maturity and the reproductive cycle were studied in an additional sample of 2,419 individuals examined aboard between July 2005 and November 2008 during the same trips. As most of these shrimps pertained to the medium and large size classes (*i.e.* males > 27 mm, females > 40 mm CL), this sample was added, respectively, to the 148 and 254 small males and females caught in northeastern Brazil by the same vessels in the same period and depths. Males were classified according to the following criteria: a) terminal ampullae empty (immature) or filled with sperm (mature), and b) petasma with their lobes fused (mature) or separated (immature). Females were examined only to identify the presence or absence of spermatophores plugged in their telicum (Sardá & Demestre, 1989; Belcari *et al.*, 2003); macroscopic examinations of the gonads were not possible aboard due to logistical constraints. As we could not assess whether inseminated females were, in fact, physiologically mature, our estimates of size at maturity for *A. antillensis* refer only to the median size at which females are able to copulate and retain spermatophores in their telycum.

### Data analysis

Size at maturity ($CL_{50\%}$) was estimated by examining the proportion of females (n = 2,351) carrying a spermatophore and males (n = 469) with fused petasma by size class. Because nearly 100% of the males in the smallest size class sampled (24 mm CL) showed their ampullae filled with sperm (*i.e.* were physiologically mature), no attempt was done to calculate size at maturity ($CL_{50\%}$) based on this criteria, as very biased estimates could result from modeling proportions in size classes not represented in the samples.

A non-linear minimum squares estimation procedure was used to fit a generalized logistic model (Restrepo & Watson, 1991) to the data as follows:

$$P_{CL} = \frac{\beta}{1 + e^{(\alpha_1 - \alpha_2 CL)}} \qquad (1)$$

where $P_{CL}$ is the proportion of individuals in each size class, and $\alpha 1$, $\alpha 2$, and $\beta$ are parameters. In this model, $\beta$ is a more general parameter that allows for the asymptotic proportion of the model to be lower or equal to 1. Therefore, a penalty function for $\beta \leq 1$ was included in the parameter estimation procedure. Size at maturity was given by the equation:

$$CL_{50\%} = \frac{\alpha_1}{\alpha_2} \qquad (2)$$

The reproductive cycle was studied by analyzing the monthly variation in the proportion of spermatophore-bearing females and males with terminal ampullae filled with sperm masses. Only potentially mature individuals (*i.e.* with CL larger than $CL_{50\%}$) were considered for this analysis.

Temporal changes in the population structure of the alistado shrimp were investigated by examining size frequency distributions, sex ratio (M:F), and the proportion of immature (individuals smaller than $CL_{50\%}$) and mature individuals in the catches monitored between October 2003 and March 2007. Data were analyzed both globally (*i.e.* considering this whole sampling period) as well as grouped by month.

For the sake of simplicity, seasons were defined here as summer (January to March), autumn (April to June), winter (July to September) and spring (October to December).

## RESULTS

### Size at maturity

After exhibiting some fluctuation in the smaller size classes, the proportion of spermatophore-bearing females showed a sharp increase in individuals larger than 39 mm (CL) and stabilized around 0.9 between 48 and 56 mm (CL). Only individuals larger than 62 mm were all inseminated (Fig. 2a). No males smaller than 24 mm were sampled along the study period but nearly 32% of the individuals in this size class had fused petasma. This proportion increased steadily up to the 28-mm size class and oscillated around 0.9 up to the two largest size classes, where all shrimps had fused petasma (Fig. 2b). The logistic model fitted to the data indicated mean sizes at maturity of 40.2 (females) and 25.4 mm (males) (Table 1).

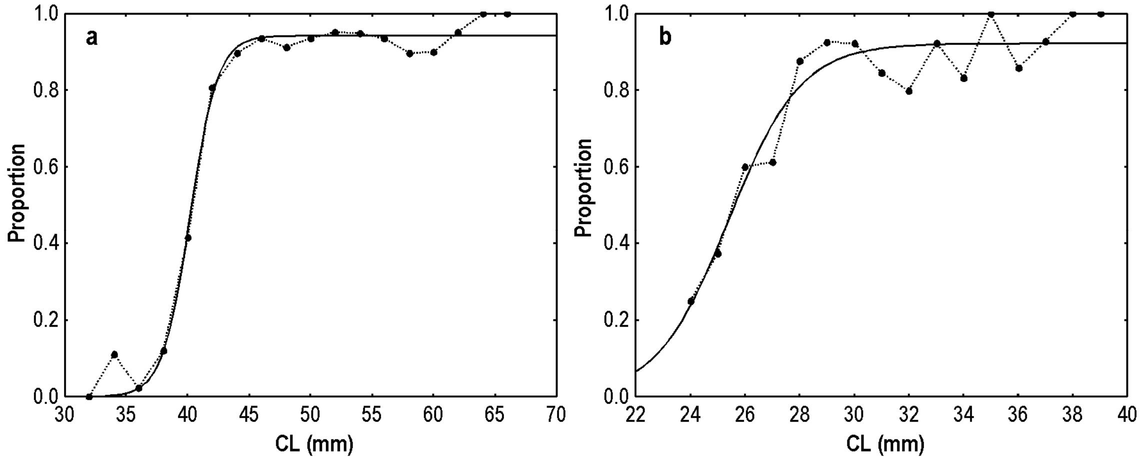

**Figure 2.** *Aristeus antillensis*. Logistic model (solid line) fitted to the proportions (dashed line) of a) spermatophore-bearing females and b) males with fused petasma by size class, sampled in fishing grounds N2 and N4 (southeastern Brazil) between 2005 and 2008. CL: carapace length. N males = 469; N females = 2,351.

**Figura 2.** *Aristeus antillensis.* Modelos logísticos (línea continua) establecidos para las proporciones (línea descontinua) de a) hembras cargando espermatóforo y b) machos con petasma unido en grupo de tallas, muestreados en los fondos de pesca N2 y N4 (sudeste de Brasil) entre 2005 y 2008. CL: longitud del carapazón. N machos = 469; N hembras = 2.351.

**Table 1.** *Aristeus antillensis*. Parameters (α1, α2, β) of the logistic curves (± CI 95%) fitted to the proportion of males with fused petasma and spermatophore-bearing females by size class and the corresponding sizes-at-maturity ($CL_{50\%}$).

**Tabla 1.** *Aristeus antillensis.* Parámetros (α1, α2 y β) de las curvas logísticas (± CI 95%) ajustados para las proporciones de machos con petasma unido y hembras cargando espermatóforos por clase de talla, y las correspondientes tallas de primera madurez ($CL_{50\%}$).

| Parameter | Males | | Females | |
|---|---|---|---|---|
| | Mean | CI (95%) | Mean | CI (95%) |
| β | 0.922 | 0.870 - 0.974 | 0.942 | 0.917 - 0.968 |
| α1 | 19.264 | 10.830 - 27.699 | 35.881 | 26.078 - 45.684 |
| α2 | 0.758 | 0.427 - 1.089 | 0.892 | 0.648 - 1.137 |
| $CL_{50\%}$ (mm) | 25.4 | - | 40.2 | - |

## Reproductive cycle

The percentage of spermatophore-bearing females larger than the $CL_{50\%}$ was higher than 80% during the entire year except in December when no data were available (Fig. 3a). Sexually mature males were much scarcer than females. Therefore, the analysis of the reproductive cycle was restricted to five months (late autumn to early austral spring). Proportions of males whose terminal ampullae contained sperm were very high from June to October, ranging between 87% (June) and 100% (October) (Fig. 3b).

## Population structure

Catches of *A. antillensis* in the N2 and N4 fishing grounds were dominated by females and immature individuals of both sexes (Table 2). Females were significantly larger than males and represented nearly 90% of the individuals sampled along the study period. The global size-frequency distribution of males was polymodal and asymmetrical for larger sizes, with the main mode peaking at 30 mm. The female distribution was nearly bimodal, with the highest frequencies occurring between the 44 and 50-mm size classes (Fig. 4).

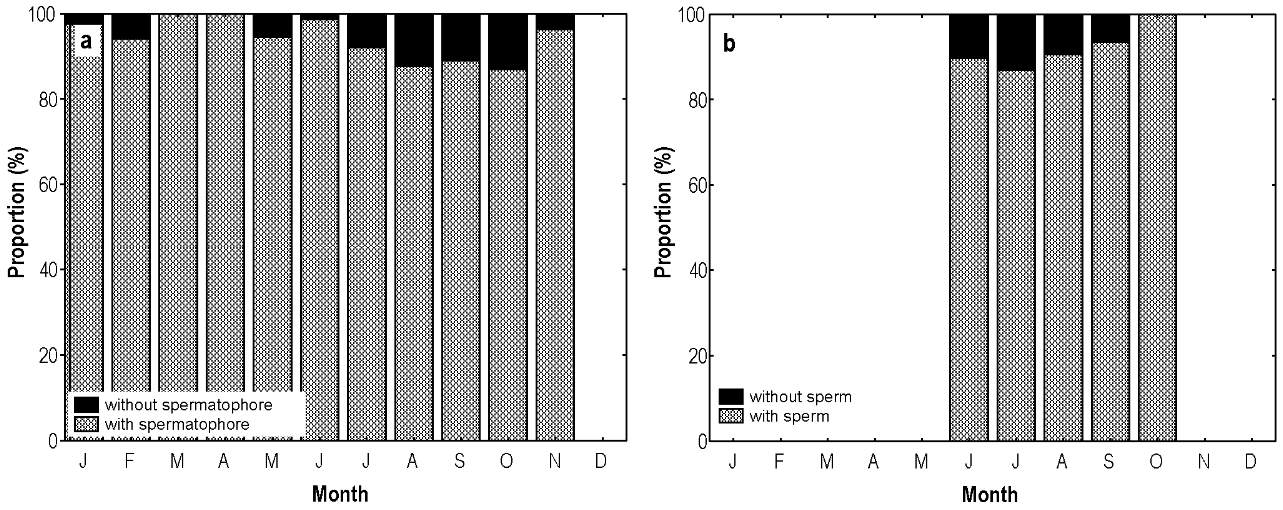

**Figure 3.** *Aristeus antillensis*. Monthly proportion of females with spermatophores (a) and males with sperm in their terminal ampullae (b) sampled in fishing grounds N2 and N4 (southeastern Brazil) between 2005 and 2008.

**Figura 3.** *Aristeus antillensis.* Proporción mensual de hembras portando espermatóforo (a) y machos con ampollas seminales llenas (b) muestreados en los fondos de pesca N2 y N4 (sudeste de Brasil) entre 2005 y 2008.

**Table 2.** *Aristeus antillensis.* Number of shrimps sampled and caught (estimated), sex-ratio (M:F), numbers and percentages of sexually immature males and females in fishing grounds N2 and N4 during the study period.

**Tabla 2.** *Aristeus antillensis.* Número de camarones muestreados y capturados (estimados), proporción sexual (M:F), número y porcentajes de machos y hembras en los fondos de pesca N2 y N4 durante el período de estudio.

| | Males | Females | M:F | Total |
|---|---|---|---|---|
| Number sampled | 1,582 | 12,215 | - | 13,797 |
| Number caught (estimated) | 10,662 | 89,751 | 0.12:1 | 100,413 |
| Immature (estimated) | 3,026 | 22,749 | - | 25,775 |
| Immature (%) | 28% | 25% | - | - |

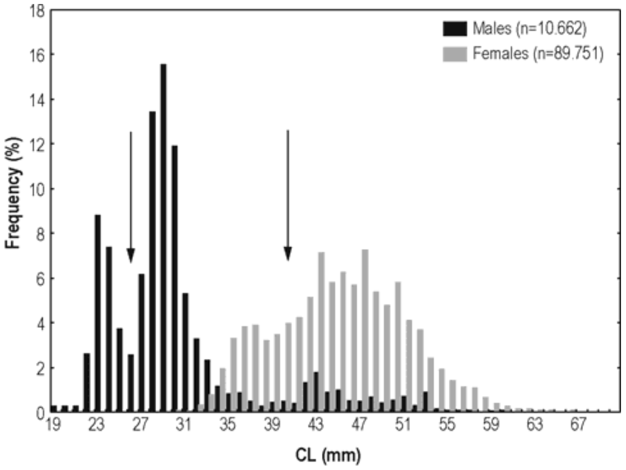

**Figure 4.** *Aristeus antillensis*. Global size-frequency distribution of males and females caught in fishing grounds N2 and N4 (southeastern Brazil) between 2003 and 2007. Arrows indicate the $CL_{50\%}$ of males (left) and females (right).

**Figura 4.** *Aristeus antillensis.* Distribución global de las frecuencias de talla de machos y hembras capturados en los fondos de pesca N2 y N4 (sudeste de Brasil) entre 2003 y 2007. Las flechas indican el $CL_{50\%}$ de machos (izquierda) y hembras (derecha).

Monthly changes were observed in either the sex-ratio or in the percentage of immature individuals. Females always dominated the catches, but the proportion of males increased from June to October (Fig. 5). During most of the year, immature individuals of both sexes contributed with less than 15% of the catches. However, their occurrence increased sharply from late spring to mid-summer, especially for immature males, whose contribution exceeded 70% in February (Fig. 5).

Examining monthly changes in size-frequency distributions by sex revealed that the fishing grounds are occupied by different populational groups along the year (Fig. 6). As previously shown in Figure 5, immature individuals (males and females smaller than 25.4 and 40.2 mm CL, respectively) were present in large numbers from December to February in conjunction with intermediate-sized mature males and females (~29 mm and ~45 mm CL, respectively). From April to June, males and immature females practically disappeared and the fishing grounds were occupied mostly by large-sized females measuring between 43 and 50 mm. Mature males (27-31 mm CL) appeared in large numbers in the winter (July to September) and gradually reduced their occurrence in October and November, when mostly large-sized females remained in the area.

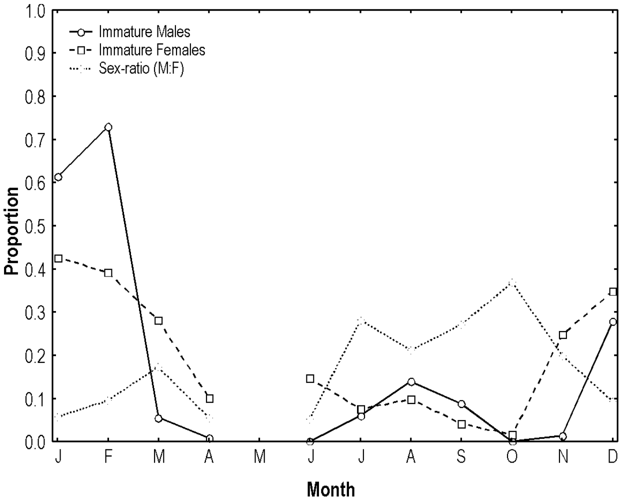

**Figure 5.** *Aristeus antillensis*. Monthly variation in the sex-ratio (M:F) and in the proportion of immature individuals of both sexes caught in fishing grounds N2 and N4 (southeastern Brazil) between 2003 and 2007.

**Figura 5.** *Aristeus antillensis.* Variación mensual en la proporción sexual (M:F) y en las proporciones de inmaduros de los dos sexos capturados en los fondos de pesca N2 y N4 (sudeste de Brasil) entre 2003 y 2007.

## DISCUSSION

The present work represents the first contribution to the knowledge of the reproductive biology and population structure of the deep-sea shrimp *Aristeus antillensis* in Brazil, complementing the taxonomic (Tavares & Serejo, 2007), distributional (Araújo-Silva, 2002a, 2002b; Costa *et al.*, 2005; Serejo *et al.*, 2007), technological, and fishing (Asano Filho & Holanda, 2005; Pezzuto *et al.*, 2006; Dallagnolo, 2008; Dallagnolo *et al.*, 2009) data available on the species in Brazilian waters.

Following the general rule verified for other aristeid species, *A. antillensis* exhibits strong sexual dimorphism, with females being significantly larger than males. Commercial catches have been shown to be dominated by females as well.

In spite of the widespread latitudinal distribution of the slope trawling fleet operations along the region (Dallagnolo *et al.*, 2009), catches of the species have been obtained mostly in the two fishing grounds selected for this study, producing nearly 73% of the species landings monitored by Dallagnolo (2008) between November 2002 and May 2007. Moreover, the species distribution was found to not be homogeneous along the bathymetric gradient; rather, the best catch rates and yields were concentrated in a very small depth range, declining steadily in areas deeper than 800 m (Pezzuto *et al.*, 2006; Serejo *et al.*, 2007; Dallagnolo *et al.*, 2009). Although making only a small contribution to the total deep-sea shrimp landings in Brazil, the concentration of the catches in such small areas suggests a striking dependence of *A. antillensis* on some locally prevailing environmental conditions that are not yet totally understood.

The dominance of mature females in the commercial catches raises the hypothesis that the otter trawls used in the fishery could be selective, retaining fewer small-sized males and juveniles. This explanation was also proposed by Guéguen (2001) in French Guiana, where females of the same species accounted for 99% of the catches obtained on four research cruises (depth range = 200 to 900 m). However, the temporal changes in the size-frequency distributions by sex reveal that males and juveniles were caught in large numbers in Brazil during some periods of the year. Therefore, without rejecting the possible contribution of the net cod-end selectivity to the catch-size composition, it is probable that, in fact, males and juveniles are not totally available during part of the year. In this case, part of the stock should move seasonally to and from the fishing grounds. Where they can be found the rest of the time is a question that needs to be investigated.

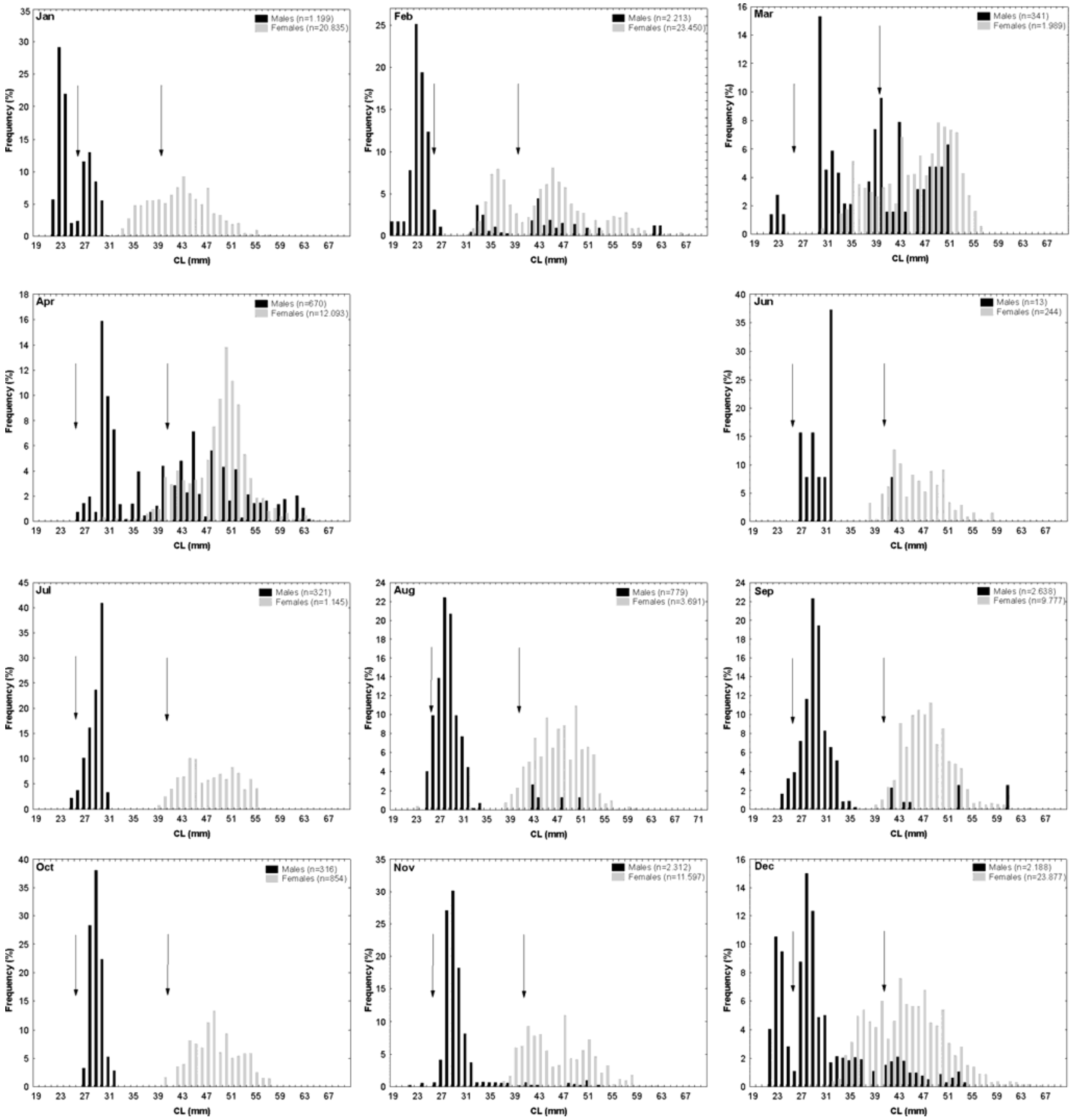

**Figure 6.** *Aristeus antillensis*. Monthly size-frequency distributions of males and females caught in fishing grounds N2 and N4 (southeastern Brazil) between 2003 and 2007. Arrows indicate $CL_{50\%}$ of males (left) and females (right).

**Figura 6.** *Aristeus antillensis.* Distribución mensual de frecuencias de tallas de machos y hembras capturados en los fondos de pesca N2 y N4 (sudeste de Brasil) entre 2003 y 2007. Las flechas indican el $CL_{50\%}$ de machos (izquierda) y hembras (derecha).

Migratory movements of the congeneric *A. antennatus* have been largely observed in the Mediterranean, especially in the vicinity of submarine canyons (Sarda *et al.*, 1997, 2003a, 2003b, 2004; Tudela *et al.*, 2003). The species shows a well described segregation with depth: mature females concentrate in shallower slope areas (500-900 m) and juveniles are largely dispersed along deeper grounds (*i.e.* > 1,000 m). Supposedly, this pattern contributes to resource optimization, concentrating reproductive potential and recruitment in different areas (Sardà & Cartes, 1993; Sardà *et al.*, 2003a, 2003b). Apart from ontogenetic movements, seasonal migrations of this species have been attributed to the need to develop reproductive aggregations and/or exploit distinct energetic and trophic conditions. More recently, the role of climate and extreme bottom currents in the interannual displacement of the stock to the lower slope have also been demonstrated (Company *et al.*, 2008).

In southeastern Brazil, *A. antillensis* is known to inhabit slope grounds up to 1,144 m depth (Serejo *et al.*, 2007) but, unfortunately, no information on its population structure is available outside of the fishing grounds examined in the present study. Analyzing the distribution, abundance, and zonation of crustaceans collected during two research cruises conducted in the shelf break and slope of the study area (maximum depth 2,178 m), Serejo *et al.* (2007) identified three main assemblages dispersed along different bathymetric ranges (< 500 m; 500 to 900 m; > 900 m). In spite of being found in deeper areas, *A. antillensis* was one of the main components of the intermediate group (500-900 m), which also included the giant isopods *Bathynomus giganteus* and *B. miyarei*, the aristeids *Aristaeomorpha foliacea* and *Aristaeopsis edwardsiana*, the sergestid *Sergia prehensilis*, and the carideans *Plesionika* spp., *Glyphocrangron alispina*, and *Janicella spinicauda* (Serejo *et al.*, 2007). Studied concomitantly in the same area, cephalopods and bony demersal fishes also showed quite similar trends, as medium and lower slope assemblages of these megafaunal groups were found to be separated by depths situated roughly between 750 and 900 m (Costa *et al.*, 2007; Haimovici *et al.*, 2007). Taking into account the correspondence between the distributional patterns of the fish assemblages and the local water masses, Costa *et al.* (2007) suggested that the 4°C isotherm (corresponding to the upper limit of AIW) could determine the transition between the bathyal and abyssal fauna in the study area.

Based on these findings, it is possible to hypothesize that, as observed for *A. antennatus* in the Mediterranean waters, males and juveniles of the species also inhabit deeper areas in southeastern Brazil, below the limit between SACW and the colder AIW. Childress *et al.* (1990) has demonstrated experimentally that metabolic rates of decapod crustaceans decline with increasing depth of occurrence as a response to the concurrent decline in temperature. In the Mediterranean, such segregation has been attributed mostly to a food-resource optimization strategy since temperature remains constant around 13°C along the slope (Sardà & Cartes, 1993), whereas, in Brazil, water temperature could play a more significant role: the distribution of smaller-sized individuals (males and juveniles) in the colder areas dominated by AIW could partially compensate the higher expected size-specific metabolic demand.

A wind-induced subsurface intrusion of SACW over the shelf bottoms is known to occur seasonally in south and southeastern Brazil in the austral summer. This water mass, whose upper levels are otherwise restricted to the shelf break, invades the inner shelf and enriches coastal waters with nutrients (Castro *et al.*, 2006). It is not clear whether the seasonal movement of SACW exerts some influence at its base, also bringing part of the AIW to the upper levels of the slope. However, if this occurs, then the appearance of large numbers of males and juveniles in the catches – as observed from December to February – could support the hypothesis that they inhabit deeper waters, appearing in the fishing grounds during seasonal movements of the water masses.

Whether *A. antillensis* shows a continuous or seasonal reproductive cycle is a question that needs to be investigated. Sexually mature males and large-sized females were observed simultaneously in the fishing grounds during austral winter when the sex-ratio (M:F) also increased, indicating that reproduction could occur mostly between July and September. However, as the proportion of impregnated females remained very high year round, a continuous reproductive cycle is also suspected. A definitive answer to this question depends on obtaining temporal series of macro- and microscopic gonadal development data. Although this was not possible for this study, an exploratory analysis was conducted based on a small subsample of 58 large-sized females (*i.e.* $CL > CL_{50\%}$) of *A. antillensis* caught in January, April, May, June, July, October, and December. Animals were selected aboard by the observers, frozen, and brought to the laboratory for processing. Gonads were examined macroscopically and classified in four stages (I undeveloped; II developing; III mature; IV spawning), taking into consideration the progressive increase in size and change in color verified along their development. From preliminary observations, the color scale used by Orsi-Relini & Relini (1998) and Kapiris & Thessalou-Legaki (2009) for *A. antennatus* (white, pink, light violet, dark violet) seemed to fit *A. antillensis* as well. All individuals sampled in the present study exhibited ovaries in stages I and II and 75% of them were impregnated, suggesting that, despite carrying spermatophores during the entire year, spawning could take place in a more limited spatial-temporal scale. Spermatophore-bearing females with immature gonads have also been observed in other aristeids, indicating that copula and gonadal development could take place in different periods of the year (Papaconstantinou & Kapiris, 2003; Politou *et al.*, 2004; Kapiris & Thessalou-Legaki, 2009). In addition, based on the presence of spermatophores and mature ovaries in females of a virginal stock of *A. antennatus*, Kapiris & Thessalou-Legaki (2009) estimated sizes at maturity of 26.3 and 29.4 mm, respectively, indicating that gonadal maturity follows insemination in this species.

Fishing for *A. antillensis* in southeastern Brazil relies mainly on large-sized individuals that seem to be mature. However, the spatially restricted distribution of the species, the significant contribution of juveniles in the summer catches, and the uncertainty about the actual size at sexual maturity of females cannot be disregarded for management purposes. Migratory movements from and to the fishing grounds seem to be the rule for the species, but neither the migratory directions nor the driving factors are completely understood. The existence of unavailable portions of the stock in deeper areas has been regarded as one of the main reasons for the sustainability of the *A. antennatus* fishery in Mediterranean waters (Sardà *et al.*, 2003b). Since more definitive data are not available on size at sexual maturity of females, the reproductive cycle, and the distribution of the stock in different areas and depths, a precautionary approach should be developed for the management of the *A. antillensis* fishery in southeastern Brazil.

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## REFERENCES

Araújo-Silva, K.C., A.P.M. Muniz, M. Ramos-Porto, G.F.S. Viana & I.H.A. Cintra. 2002a. Camarões da superfamília Penaeoidea Rafinesque, 1815, capturados durante pescarias experimentais para o Programa REVIZEE/Norte (Crustacea: Decapoda). Bol. Téc. Cient. CEPNOR, Belém, 2(1): 9-40.

Araújo-Silva, K.C., M. Ramos-Porto, I.H.A. Cintra, A.P.M. Muniz & M.C.N. Silva. 2002b. Crustáceos capturados durante o Programa REVIZEE na costa norte brasileira. Bol. Téc. Cient. CEPNOR, Belém, 2(1): 97-108.

Asano Filho, M. & F.C.A.F. Holanda. 2005. Descrição dos métodos de captura dos camarões de profundidade na costa norte do Brasil, durante o Projeto Proarrasto. Bol. Téc. Cient. CEPNOR, Belém, 5(1): 141-154.

Belcari, P., C. Viva, M. Mori, & S. de Ranieri. 2003. Fishery and biology of *Aristaeomorpha foliacea* (Risso, 1827) (Crustacea: Decapoda) in the northern Tyrrhenian Sea (western Mediterranean). J. Northw. Atl. Fish. Sci., 31: 195-204.

Can, M.F. & M. Aktas. 2005. A preliminary study on population structure and abundance of *Aristaeomorpha foliacea* (Risso, 1827) (Decapoda, Natantia) in the deep water of the northeastern Mediterranean. Crustaceana, 78(8): 941-946.

Castro, B.M., J.A. Lorenzzetti, I.C.A. Silveira & L.B. Miranda. 2006. 1. Estrutura termohalina e circulação na região entre o Cabo de São Tomé (RJ) e o Chuí (RS). In: C.L.D.B. Rossi-Wongtschowski & L.S.P Madureira (ed.). O ambiente oceanográfico da plataforma continental e do talude na região sudeste-sul do Brasil. EDUSP, São Paulo, pp. 11-120.

Childress, J.J., D.L. Cowles, J.A. Favuzzi & T.J. Mickel. 1990. Metabolic rates of benthic deep-sea decapods crustaceans decline with increasing depth primarily due to the decline in temperature. Deep-Sea Res., 37(6): 929-949.

Ciotti, A.M., E. Gonzalez-Rodriguez, L. Andrade, R. Paranhos & W.F. Carvalho. 2007. Clorofila *a*, medidas bio-ópticas e produtividade primária. In: J.L. Valentin (ed.). Características hidrobiológicas da região central da Zona Econômica Exclusiva brasileira (Salvador, BA, ao Cabo de São Tomé, RJ). Série Documentos REVIZEE/SCORE-Central, Ministério do Meio Ambiente, Brasília, pp. 61-72.

Company, J.B., P. Puig, F. Sarda, A. Palanques, M. Latasa & R. Scharek. 2008. Climate influence on deep sea populations. Plos ONE, 3(1): e1431.

Costa, P.A.S., A.S. Martins, G. Olavo, M. Haimovici & A.C. Braga. 2005. Pesca exploratória com arrasto de fundo no talude continental da região central da costa brasileira entre Salvador-BA e o Cabo de São Tomé-RJ. In: P.A.S. Costa, A.S. Martins & G. Olavo (eds.). Pesca e potenciais de exploração de recursos vivos na região central da Zona Exonômica Exclusiva brasileira. Museu Nacional, Rio de Janeiro. Série Livros. Documentos REVIZEE/SCORE-Central, pp. 145-165.

Costa, P.A.S., A.C. Braga, M.R.S. Melo, G.W. Nunan, A.S. Martins & G. Olavo. 2007. Assembléias de teleósteos demersais no talude da costa central brasileira. In: P.A.S. Costa, G. Olavo & A.S. Martins (eds.). Biodiversidade da fauna marinha profunda na costa central brasileira. Museu Nacional, Rio de Janeiro. Série Livros. Documentos REVIZEE/SCORE-Central, pp. 87-107.

Crosnier, A. & J.J. Tauter. 1968. La pêche dês crevettiers espagnols au large du Congo et de l'Angola. Pêche Marit., 539-541.

Dallagnolo, R. 2008. A pesca dos camarões-de-profundidade (Aristeidae) na região sudeste e sul do Brasil. MSc Thesis. Universidade do Vale do Itajaí, Itajaí, 197 pp.

Dallagnolo, R., J.A.A. Perez, P.R. Pezzuto & R. Wahrlich. 2009. The deep-sea shrimp fishery off Brazil (Decapoda: Aristeidae): development and present status. Lat. Am. J. Aquat. Res., 327-345.

Dallagnolo, R., J.A.A. Perez, P.R. Pezzuto & R. Wahrlich. 2007. Análise da pescaria de camarões-de-profundidade (Decapoda: Aristeidae) no talude das regiões Sudeste e Sul do Brasil. Relatório Técnico apresentado à 5ª Sessão Ordinária do Subcomitê Científico do Comitê Consultivo Permanente de Gestão de Recursos Demersais de Profundidade (CPG/Demersais)/SEAP/PR–Itajaí, SC, 11 – 13/06/2007. DOC 19 SCC CPG 052007 P5.

França, A.M.C. 1979. Geomorfologia da margem continental leste brasileira e da bacia oceânica adjacente. In: H.A.F. Chaves (ed.). Geomorfologia da margem continental brasileira e das áreas oceânicas adjacentes. Projeto REMAC 8. Relatório Final, pp. 89-128.

Guéguen, F. 1998. Biologie de la crevette profonde *Plesiopenaeus edwardsianus* en Guyane Française. C.R. Acad. Sci. Paris, 321: 757-770.

Guéguen, F. 2000. Distribution et abondance des crustacés décapodes du talus continental (200-900 m) de Guyane Française. Crustaceana, 73(6): 685-703.

Guéguen, F. 2001. Notes sur la biologie de la crevette de profondeur *Aristeus antillensis* em Guyane française. C.R. Acad. Sci. Paris. Sci. Vie, 324: 689-700.

Haimovici, M., P.A.S. Costa, R.A. Santos, A.S. Martins & G. Olavo. 2007. Composição de espécies, distribuição e abundância de cefalópodes do talude da região central do Brasil. In: P.A.S. Costa, G. Olavo & A.S. Martins (eds.). Biodiversidade da fauna marinha profunda na costa central brasileira. Museu Nacional, Rio de Janeiro. Série Livros. Documentos REVIZEE/SCORE-Central, pp. 109-132.

Kapiris, K. & M. Thessalou-Legaki. 2009. Comparative reproduction aspects of the deep-water shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus* (Decapoda: Aristeidae) in the Greek Ionian Sea (eastern Mediterranean). Int. J. Zool., 2009: 9 pp.

Kao, H.C., T.Y. Chan & H.P. Yu. 1999. Ovary development of the deep-water srimp (*Aristaeomorpha foliacea*) (Risso, 1826) (Crustacea: Decapoda: Aristeidae) from Taiwan. Zool. Stud., 38(4): 373-378.

Orsi-Relini, L. & G. Relini. 1998. Seventeen instars of adult life in female *Aristeus antennatus* (Crustacea: Decapoda: Aristeidae). A new interpretation of life span and growth. J. Nat Hist., 32: 1719-1734.

Papaconstantinou, C. & K. Kapiris. 2003. The biology of the giant red shrimp (*Aristaeomorpha foliacea*) at an unexploited fishing ground in the Greek Ionian Sea. Fish. Res., 62: 37-51.

Perez, J.A.A., P.R. Pezzuto, R. Wahrlich & A.L.S. Soares. 2009a. Deep-water fisheries in Brazil: history, status and perspectives. Lat. Am. J. Aquat. Res., 37(3): 513-541.

Pezzuto, P.R. & M.C. Dias. 2007. Estrutura populacional e reprodução dos camarões-de-profundidade (Aristeidae) no talude do Sudeste e Sul do Brasil. Relatório Técnico apresentado à 5ª Sessão Ordinária do Subcomitê Científico do Comitê Consultivo Permanente de Gestão dos Recursos Demersais de Profundidade (CPG/Demersais)/SEAP/PR–Itajaí, SC, 11-13/06/2007. DOC 21 SCC CPG 052007 P5.

Pezzuto, P.R., J.A.A. Perez & R. Wahrlich. 2006. Deep-sea shrimps (Decapoda: Aristeidae): new targets of the deep-water trawling fishery in Brazil. Braz. J. Ocean., 54(2-3): 123-134.

Politou, C.Y., K. Kapiris, P. Maiorano, F. Capezzuto & J. Dokos. 2004. Deep-sea Mediterranean biology: the case of *Aristaeomorpha foliacea* (Risso, 1827) (Crustacea: Decapoda: Aristeidae). Sci. Mar., 68(3): 129-139.

Ragonese, S. & M.L. Bianchini. 1996. Growth, mortality and yeld-per-recruit of the deep-water shrimp *Aristeus antennatus*, (Crustacea: Aristeidae) of the Strait of Sicily (Mediterranean Sea). Fish. Res., 50(2): 258-274.

Ragonese, S., M.L. Bianchini & L.D. Stefano. 2002. Trawl cod-end selectivity for deepwater red shrimp (*Aristaeomorpha foliacea*, Risso 1827) in the Strait of Sicily (Mediterranean Sea). Fish. Res., 57(2): 131-144.

Rainer, S.F. 1992. Diet of prawns from the continental slope of North-Western Australia. Bull. Mar. Sci., 50(2): 258-274.

Restrepo, V.R. & R.A. Watson. 1991. An approach to modeling crustacean egg-bearing fractions as a function of size and season. Can. J. Fish. Aquat. Sci., 48(8): 1431-1436.

Rezende, C.E., L. Andrade, M.S. Suzuki, B.C.M.T. Faro, A.S.M. Gonzáles & R. Paranhos. 2007. Hidroquímica. In: J.L. Valentin (ed.). Características hidrobiológicas da região central da Zona Econômica Exclusiva brasileira (Salvador, BA, ao Cabo de São Tomé, RJ). Série Documentos REVIZEE/SCORE-Central, Ministério do Meio Ambiente, Brasília, pp. 31-60.

Sardà, F. & J.E. Cartes. 1993. Relationship between size and depth in decapod crutacean populations on the deep slope in the western Mediterranean. Deep-Sea Res., 40(11-12): 2389-2400.

Sardà, F., J.B. Company & A. Castellón. 2003a. Intraspecific aggregation structure of a shoal of a western Mediterranenn (Catallan coast) deep-sea shrimp, *Aristeus antennatus* (Risso, 1816), during the reproductive period. J. Shellfish Res., 22(2): 569-579.

Sardà, F., J.B. Company, & F. Maynou. 2003b. Deep-sea shrimp *Aristeus antennatus* (RISSO, 1816) in the Catalan Sea, a review and perspectives. J. Northw. Atl. Fish. Sci., 31: 127-136.

Sardà, F. & M. Demestre. 1989. Shortening of the rostrum and rostral variability in *Aristeus antennatus* (Risso, 1816) (Decapoda: Aristeidae). J. Crust. Biol., 9(4): 570-577.

Sardà, F., G. D'Onghia, C.Y. Politou, J.B. Company, P. Maiorano, & K. Kapiris. 2004. Deep-sea distribution, biological and ecological aspects of *Aristeus antennatus* (Risso, 1816) in the western and central Mediterranean Sea. Sci. Mar., 68(3): 117-127.

Sardà, F., F. Maynou & L. Talló. 1997. Seasonal and spatial mobility patterns of rose shrimp *Aristeus antennatus* in the western Mediterranean: results of a long-term study. Mar. Ecol. Prog. Ser., 159: 133-141.

Serejo, C.S., P.S. Young, C.I. Cardoso, C. Tavares, C. Rodrigues & T.C. Almeida. 2007. Abundância, diversidade e zonação dos crustáceos no talude da costa central do Brasil (11º-22ºS) coletados pelo Programa REVIZEE/Score Central: prospecção pesqueira. In: P.A.S. Costa, G. Olavo & A.S. Martins (eds.). Biodiversidade da fauna marinha profunda na costa central brasileira. Museu Nacional, Rio de Janeiro. Série Livros. Documentos REVIZEE/SCORE-Central, pp. 133-162.

Tavares, C.R. & C.S. Serejo. 2007. Taxonomy of Aristeidae (Dendrobranchiata: Penaeoidea) from the central coast of Brazil, collected by the REVIZEE program, between 19º and 22ºS. Zootaxa, 1585: 1-44.

Tudela, S., F. Sardà, F. Maynou & M. Demestre. 2003. Influence of submarine canyons on the distribution of the deep-water shrimp, *Aristeus antennatus* (Risso, 1816) in the NW Mediterranean. Crustaceana, 76(2): 217-225.

Valentin, J.L., R. Paranhos, B.C.M.T. Faro & A.S.M. Gonzalez. 2007. Massas d'Água. In: J.L.Valentin, (ed.). Características hidrobiológicas da região central da Zona Econômica Exclusiva brasileira (Salvador, BA, ao Cabo de São Tomé, RJ). Série Documentos REVIZEE/SCORE-Central, Ministério do Meio Ambiente, Brasília, pp. 21-29.

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