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# Deep-sea Mediterranean biology: the case of *Aristaeomorpha foliacea* (Risso, 1827) (Crustacea: Decapoda: Aristeidae)*

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SUMMARY: Data on the distribution, abundance and biological parameters of the giant red shrimp *Aristaeomorpha foliacea* were collected during a research survey in deep waters (600-4000 m) of the Mediterranean Sea at three locations: the Balearic Sea, the western Ionian and the eastern Ionian in early summer 2001. The shrimp was mainly found in the shallower zone (< 1000 m) of the eastern Ionian Sea. Few specimens were caught in the deeper waters of this region, with 1100 m being the lower limit of its distribution. This is the maximum depth reported for the species in the Mediterranean. At the other two locations, the species was scarcely caught and only in the shallowest zone (< 1000 m). In the area and depth zone of high abundance, 5 modal groups for females and 3 for males were distinguished using the Bhattacharya method. The recruitment seems to take place at the shallowest stations (600 m). More than 50% of adult females were in advanced maturity stages. The striking abundance differences of the species between the western and eastern locations may be explained by the different exploitation level of the deep waters (almost null in the eastern Ionian Sea and extensive more westwards). However, the distribution and biological characteristics of *A. foliacea* indicate a higher vulnerability to over-fishing comparing to the other commercial co-occurring deep-water shrimp *Aristeus antennatus*.

*Key words*: *Aristaeomorpha foliacea*, distribution, biology, deep waters, Mediterranean.

RESUMEN: BIOLOGÍA DEL MEDITERRÁNEO PROFUNDO: EL CASO DE *ARISTAEOMORPHA FOLIACEA* (RISSO, 1827) (CRUSTACEA: DECAPODA: ARISTEIDAE). – Se obtuvieron datos sobre distribución, abundancia y parámetros biológicos de la gamba gigante *Aristaeomorpha foliacea* durante una campaña de investigación en aguas profundas (600-4000 m) en tres localidades a lo largo del Mediterráneo: región Balear, Iónico occidental y Iónico oriental, que tuvo lugar en verano de 2004. Esta gamba fue encontrada mayoritariamente en la zona menos profunda (< 1000m) del Iónico oriental. En aguas más profundas de esta región (1100 m) se encontraron menos ejemplares, pero determinó el límite inferior de su distribución. Esta es la máxima profundidad registrada en el Mediterráneo para esta especie. En las otras dos localidades, esta especie fue escasa y solo se encontró en la zona menos profunda (< 1000 m). En el área y en la profundidad de máxima abundancia, se observaron 5 grupos modales de hembras y 3 de machos mediante el método de Battacharya. El reclutamiento parece que tiene lugar en aguas menos profundas (600 m). Más del 50% de las hembras adultas se encontraron en avanzado estado de madurez gonadal. Esta curiosa diferencia entre la parte más occidental y las localidades más orientales puede explicarse por el diferente nivel de explotación en las aguas profundas (casi nulo en el Iónico oriental e intensivo más al oeste). Sin embargo, la distribución y características biológicas de *A. foliacea* indican una vulnerabilidad alta a la sobre-explotación pesquera si la comparamos con otras especies de gambas comerciales profundas como *Aristeus antennatus*.

*Palabras clave*: *Aristaeomorpha foliacea*, distribución, biología, aguas profundas, Mediterráneo.

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## INTRODUCTION

The giant red shrimp *Aristaeomorpha foliacea* (Risso, 1827) is a species of wide geographical distribution in the world. It occurs in the Mediterranean Sea and the eastern Atlantic, the western Atlantic, the Indian Ocean and the western Pacific from Japan to Australia, New Zealand and the Fiji Islands (Pérez Farfante and Kensley, 1997).

In the Mediterranean, the species is of great economic interest and, together with *Aristeus antennatus* (Risso, 1816), it is the main target species of the slope trawl fisheries down to 800-1000 m (Demestre, 1994; Ragonese *et al*., 1994a,b; Sardà and Cartes, 1994; Matarrese *et al*., 1997; Cau *et al*., 2002). The exploitation of red shrimps has not yet been developed in the eastern Mediterranean, where the commercial trawl fishing is traditionally exercised no deeper than 400-500 m (Politou *et al*., 1998).

The economic importance of the giant red shrimp in the Mediterranean enhanced the scientific interest of the study and evaluation of its stocks. Most scientific information on *A. foliacea* comes from the central Mediterranean, where the species is relatively abundant and exploited by the commercial fishery (e.g. Ragonese *et al*., 1994b; D'Onghia *et al*., 1998a). It concerns its biology (e.g. D'Onghia *et al*., 1994; Leonardi and Ardizzone, 1994; Vacchi *et al*., 1994; Righini and Abella, 1994; Pipitone and Andaloro, 1994; Mori *et al*., 1994; Levi and Vacchi, 1988; Tunesi, 1987; Mura *et al*., 1992, 1997; Gristina *et al*., 1992), ecology (e.g. Cau and Deiana, 1982; Spedicato *et al*., 1994, 1998; Mura *et al*., 1997; Ragonese *et al*., 1994a; Bianchini, 1999; Cau *et al*., 1994) and fisheries (e.g. Ragonese, 1995; Murenu *et al*., 1994; Matarrese *et al*., 1994, 1995; Cau *et al*., 1985, 1994). However, this information comes mostly from surveys not exceeding 800 m depth. In the eastern Mediterranean (Greek waters), knowledge of the species was only recently obtained in the framework of trawl survey projects carried out in deep waters. Some information on its distribution (Kallianiotis *et al*., 2000; Kapiris *et al*., 2001), morphometry (Kapiris *et al*., 2002) and biology (Kapiris *et al*., 1999; Kapiris and Thessalou-Legaki, 2001; Kapiris *et al*., 2001; Papaconstantinou and Kapiris, 2003) appeared in the literature. Furthermore, a comparative study of the species distribution and biology in the Mediterranean for depths down to 800 m was recently published (Cau *et al*., 2002).

According to the present state of knowledge the species depth distribution ranges between 123 and 1047 m, with a maximum abundance from 400 to 800 m in most areas. However in most cases waters deeper than 800 m were not investigated. Its geographical distribution, although patchy, presents a longitudinal gradient in the Mediterranean, showing higher abundance in the central-eastern part. However, aspects such as maximum depth distribution, stock identification, factors affecting its distribution and larval ecology are still unknown or poorly known.

The present work aims to contribute to the knowledge of the species distribution, abundance and biology using data obtained in the framework of the DESEAS project, which was carried out in deep waters (down to 4000 m) at three locations along the Mediterranean (Balearic Sea, western and eastern Ionian Sea). More specifically, it aims to: a) determine the maximum depth distribution of *A. foliacea* and compare its abundance levels among the areas investigated, b) discuss biological aspects and compare areas, and c) investigate the relationship between environmental parameters (such as temperature, salinity and fishing pressure) and biological features in order to explain the distribution pattern of *A. foliacea* in relation to that of *A. antennatus* in the different studied areas.

## MATERIAL AND METHODS

Sampling was performed during daytime in early summer 2001 (6 June to 6 July) by means of the R/V *García del Cid* (CSIC, Spain) of 40 m length with a 1500 HP engine. The sampling gear used was an otter trawl Maireta System, which was adapted and designed to trawl at great depths (Sardà *et al*., 1998). Three areas (the Balearic Sea and the western and eastern Ionian Sea) of the Mediterranean were chosen to carry out trawl sampling (Fig. 1). The sampling depth ranged from 600 to 4000 m, and three strata were considered: < 1000 m, 1000-1500 m and > 1500 m. Exact haul position can be obtained from Sardà *et al*. (2004). At least two hauls were performed per depth stratum in each area. The tow duration ranged between 1 and 3 hours. The geographical position of the trawl was recorded using a differential GPS, and the trawl geometry and performance were observed using a SCANMAR remote sensor system. Temperature and salinity measurements were also taken by means of a CTD.

After each haul, catches were identified to species level, and species abundance in number and weight was recorded. For the target species, other

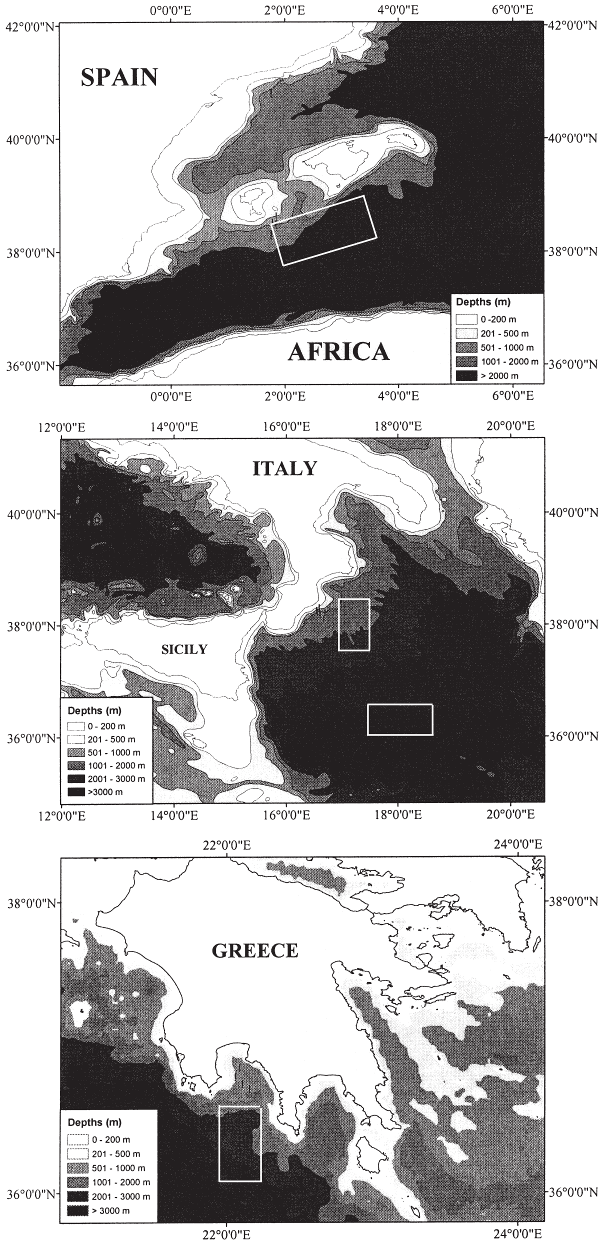


FIG. 1. – Map of sampling areas.

biological data were also taken on board: size (CL in mm), sex, presence of spermatophore on the thelycum and gonad maturity stage of females. The maturity scale used for *Aristaeomorpha foliacea* was that proposed by Levi and Vacchi (1988) for this species. The moulting activity was also considered and the specimens in moulting process or with soft body were recorded.

The modal components of the size frequency distributions of males and females were distinguished by means of the Bhattacharya method. The means of the identified age groups were used to calculate the von Bertalanffy growth parameters. A non-linear least squares procedure was used, in which the estimates of $CL_\infty$, K and $t_0$ were determined to minimise the sum of deviations between the observations and the estimated growth curve (LFSA program, Sparre, 1987). The growth performance index φ' (Pauly and Munro, 1984) was also estimated. In order to distinguish between small and large specimens, the size threshold of 29 mm CL was used, which corresponds to the smallest female with ripe gonads caught. This threshold was considered for both sexes, since all specimens (both males and females) under this size belong to the first age group, and all the rest are older (see results).

## RESULTS

### Abundance and biomass distribution

The species was scarcely found in the two westernmost locations (Balearic Sea and W. Ionian Sea), where very few specimens were fished in the shallowest stations exclusively (600-650 m) (Table 1).

TABLE 1. – *Aristaeomorpha foliacea* abundance and biomass per haul by studied area.

| Study area | Haul duration (h) | Depth (m) | Abundance index (N km$^{-2}$) | Biomass index (kg km$^{-2}$) | Mean weight (g) |
|---|---|---|---|---|---|
| Balearic A | | | | | |
| | 1.16 | 650 | 26 | 0.76 | 29.00 |
| | 1.06 | 800 | 0.0 | 0.0 | 0.00 |
| | 1.40 | 1000 | 0.0 | 0.0 | 0.00 |
| | 1.30 | 1200 | 0.0 | 0.0 | 0.00 |
| | 1.13 | 1500 | 0.0 | 0.0 | 0.00 |
| | 2.28 | 2500 | 0.0 | 0.0 | 0.00 |
| | 2.30 | 2800 | 0.0 | 0.0 | 0.00 |
| W. Ionian B | 1.11 | 600 | 13 | 1.00 | 76.00 |
| | 0.95 | 800 | 0.0 | 0.0 | 0.00 |
| | 1.48 | 1000 | 0.0 | 0.0 | 0.00 |
| | 0.33 | 1200 | 0.0 | 0.0 | 0.00 |
| | 2.00 | 1500 | 0.0 | 0.0 | 0.00 |
| | 1.08 | 1500 | 0.0 | 0.0 | 0.00 |
| | 1.45 | 1700 | 0.0 | 0.0 | 0.00 |
| | 1.16 | 2000 | 0.0 | 0.0 | 0.00 |
| E. Ionian C | 1.00 | 600 | 5009 | 95.35 | 19.04 |
| | 1.30 | 600 | 4593 | 74.06 | 16.12 |
| | 1.05 | 800 | 852 | 35.77 | 41.97 |
| | 1.15 | 800 | 420 | 14.33 | 34.12 |
| | 1.15 | 1100 | 53 | 1.72 | 32.50 |
| | 1.00 | 1300 | 0.0 | 0.0 | 0.00 |
| | 1.30 | 1700 | 0.0 | 0.0 | 0.00 |
| | 2.15 | 2200 | 0.0 | 0.0 | 0.00 |
| | 1.30 | 2600 | 0.0 | 0.0 | 0.00 |
| Abyssal W. Ionian | | | | | |
| | 3.00 | 3000 | 0.0 | 0.0 | 0.00 |
| | 2.00 | 4000 | 0.0 | 0.0 | 0.00 |

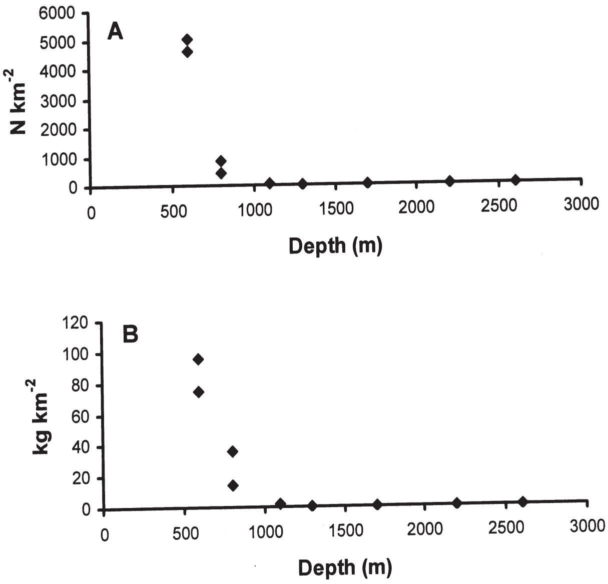


FIG. 2. – Abundance (A) and biomass (B) indices with depth for *Aristaeomorpha foliacea* in the E. Ionian Sea.

In the eastern Ionian Sea, its abundance and biomass was high at the shallower stations (600 m) and decreased with depth (Table 1, Fig. 2). The maximum abundance and biomass indices obtained were about 5000 N km$^{-2}$ and 95 kg km$^{-2}$ respectively in 600 m depth. The minimum of these indices was observed at 1100 m (53 N km$^{-2}$ and 1,7 kg km$^{-2}$), and this depth represented the lowest limit of the species distribution. The low mean weights observed at the shallow stations (600 m) of the eastern Ionian Sea can be attributed to the presence of small specimens (CL < 29 mm for both sexes), which were not found at any other station (Fig. 3).

### Size frequency distribution

Of the two specimens caught in the Balearic Sea, one was a female measuring 49.6 mm CL and the other was a male of 38.3 mm CL. The female caught in the western Ionian Sea had a carapace length of 66 mm.

In the shallower zone (< 1000 m) of the eastern Ionian Sea (Fig. 3), male CL ranged between 19.9 and 51.3 mm (median: 33.9 mm) and that of females between 16.2 and 61.7 mm (median: 42.9 mm) for the depth of 600 m. At the depth of 800 m, the carapace length of males ranged between 32 and 39 mm (median: 36 mm) and that of females between 36 and 61 mm (median: 53 mm).

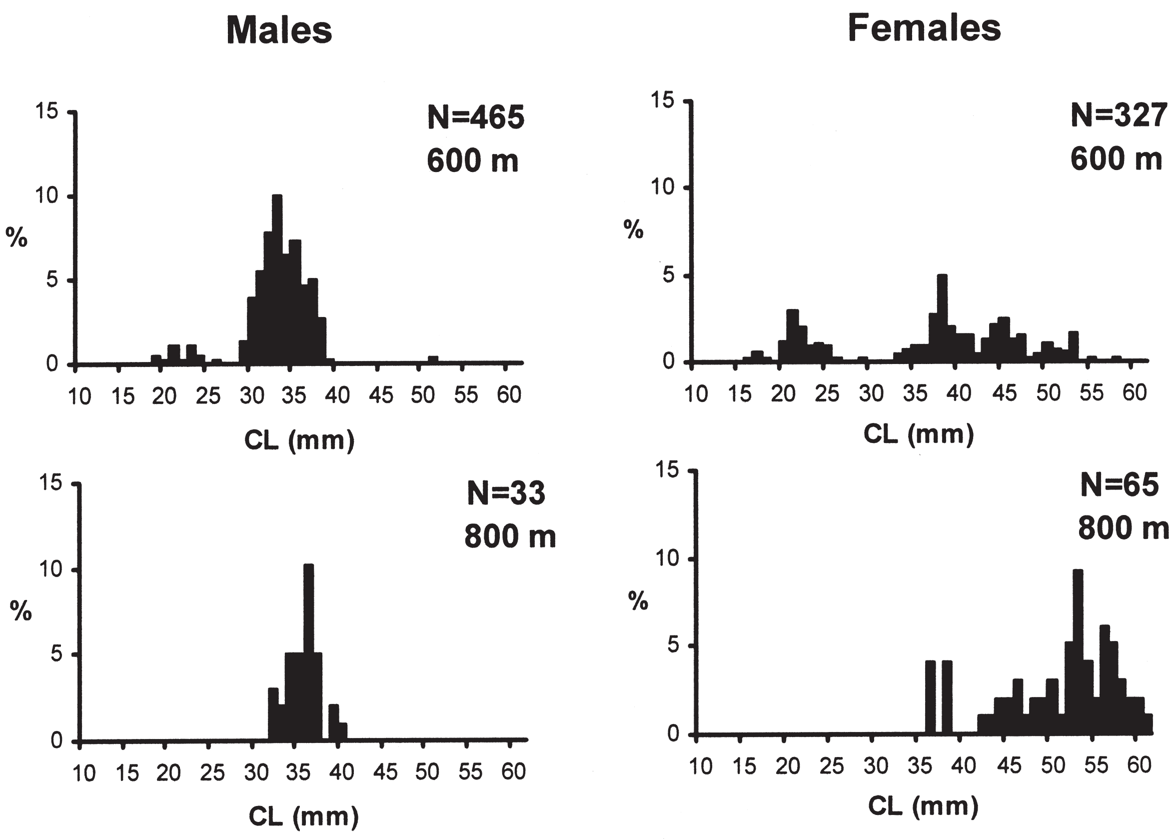


FIG. 3. – Size frequency distribution of *Aristaeomorpha foliacea* in the E. Ionian Sea (< 1000 m).

There was always a statistically significant difference between the size distributions (Kolmogorov-Smirnov test, $P < 0.05$) and the medians of the two sexes (Mann-Whitney test, $P < 0.05$), with females being larger than males. Additionally, for each sex separately there was a statistically significant difference between the size distributions (Kolmogorov-Smirnov test, $P < 0.05$) and between the medians for the two depths examined (Mann-Whitney test, $P < 0.05$), with size increasing with depth according to the following equations:

Males: $CL = 26.55 + 0.0115 * depth$; $r = 0.95$; $r^2 = 0.89$; $N = 4$; $P < 0.05$ (ANOVA)
Females: $CL = 8.89643 + 0.0501071 * depth$; $r = 0.94$; $r^2 = 0.88$; $N = 5$; $P < 0.05$ (ANOVA)

A considerable number of small specimens (about 15%) of both sexes (19-26 mm in males and 16-29 mm in females) was found at the shallower stations (600 m) only. Taking into account that the spawning of the giant red shrimp takes place in summer, mainly from June to August (Kapiris and Thessalou-Legaki, 2001), the age of these young individuals is estimated at about 12 months.

In the 1000-1500 m zone of the eastern Ionian Sea only three large males (37.4, 38.3 and 41.2 mm CL) and one large female (62.6 mm CL) were found.

## Age composition and growth

The modal components of males and females separately were distinguished for the shallower zone (< 1000 m) of the eastern Ionian Sea. Five well-separated modes were identified in the case of females, whereas males were composed of three modal groups (Table 2). Although the small sample in the 1000-1500 m zone did not permit an analysis of the age structure, according to the above results the females of this depth stratum should belong to group V and the males to group III.

TABLE 2. – Age composition of *Aristaeomorpha foliacea* in the E. Ionian Sea (< 1000 m).

| Group | Mean CL (mm) | Standard deviation | Separation index |
|---|---|---|---|
| Females | | | |
| I | 22.2 | 1.70 | |
| II | 37.9 | 0.74 | 12.86 |
| III | 44.8 | 1.61 | 5.85 |
| IV | 51.5 | 1.49 | 4.30 |
| V | 57.5 | 0.98 | 4.86 |
| Males | | | |
| I | 21.0 | 0.55 | |
| II | 32.6 | 1.83 | 9.74 |
| III | 36.4 | 1.21 | 2.50 |

TABLE 3. – Von Bertalanffy growth parameters for *Aristaeomorpha foliacea* in the E. Ionian Sea (< 1000 m).

| Parameters | Females | Males |
|---|---|---|
| $CL_\infty$ (mm) | 66.6 | 47.0 |
| K ($y^{-1}$) | 0.37 | 0.45 |
| $t_0$ (y) | -0.11 | -0.42 |
| φ' | 3.215 | 2.997 |

The estimated growth parameters for the shallower zone of the eastern Ionian Sea are given in Table 3. Females attained a higher maximum CL with a faster growth rate than males.

## Sex ratio

TABLE 4. – Sex ratio estimated for *Aristaeomorpha foliacea* in the E. Ionian Sea (< 1000 m). (* = statistically significant difference for $P < 0.05$, ν = degrees of freedom); M, males; F, females.

| | N of males | N of females | Sex ratio (M:F) | $x^2$ |
|---|---|---|---|---|
| All | 386 | 295 | 1.31 | 48.28* (ν=4) |
| Small | 17 | 52 | 0.33 | 10.49* (ν=2) |
| Large | 369 | 243 | 1.52 | 72.42* (ν=4) |

The overall sex ratio of the giant red shrimp in the < 1000 m zone of the eastern Ionian Sea was significantly in favour of males (Table 4). If the small (< 29 mm CL) and large (> 29 mm CL) specimens are considered separately, the sex ratio was significantly in favour of females in the first case and significantly in favour of males in the second case.

## Reproduction

In the shallower zone of the eastern Ionian Sea, the great majority of females (92.6%) were carrying spermatophores in their thelycum, proving that mating had occurred earlier. The smallest mated female measured 26.9 mm CL. Almost all large females (96.7%) and the total of those with mature gonads (ovary maturity stage > III) were carrying spermatophores in their thelycum. The majority of the small specimens (93.6%) were not carrying these structures. However, the presence of spermatophore in some of them (6.4%) shows that mating can take place between a mature male and an immature female.

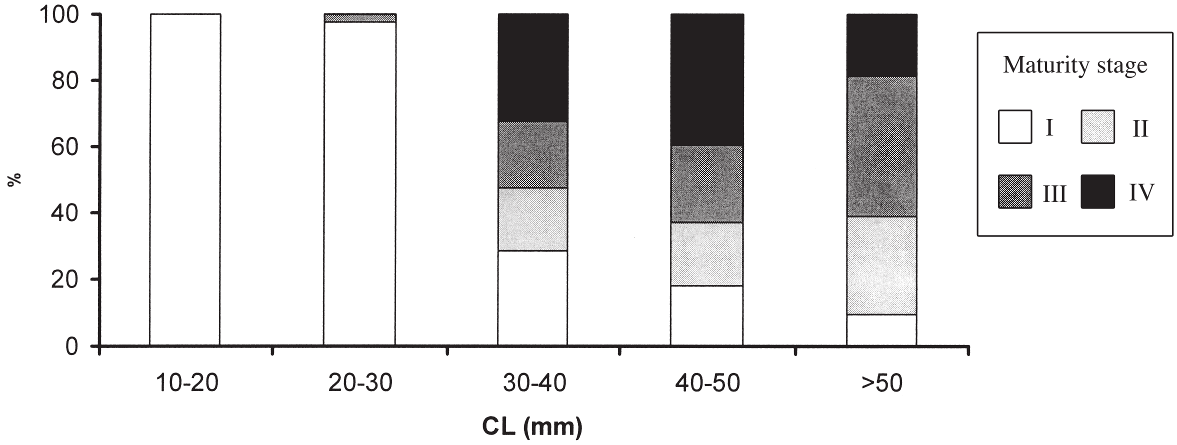


FIG. 4. – Ovary maturity stages per female size of *Aristaeomorpha foliacea* in the E. Ionian Sea (< 1000 m).

In the same zone, all the stages of ovary maturity were present. As expected, the smaller females were of maturity stage I, and the smallest female with mature gonads measured 29.8 mm CL (Fig. 4). These observations indicate that the females of the species start their reproduction activity in the second year of their life (Table 2). The highest percentage (34%) of the larger females was in the advanced maturation stage (IV), and 22% of them were in mature condition (stage III). The rest of the adults were of lower ovary maturity stages.

The female found in the 1000-1500 m zone of the eastern Ionian Sea was in the advanced maturation stage (IV) without spermatophore.

The female caught in the Balearic Seat (stratum < 1000 m) was in the advanced maturation stage (IV) without spermatophore, whereas the female caught in the western Ionian Sea (stratum < 1000 m) was in maturity stage I carrying a spermatophore in the thelycum.

**Moulting**

Moulting activity was limited in both sexes during the study period.

Only 3.2% of males in the eastern Ionian Sea had a soft body and 0.4% of males were in moulting process. All were large. Among females, 5.2% from the same area had a soft body and 3.1% were moulting. Almost all the small ones were moulting (8.1% of small females) and only a few individuals had a soft body (1.1% of small females). Among the large ones, most of them (6.2% of large females) had a soft body and the rest (1.8% of large females) were moulting. It must be noted that all the moulting large females had immature gonads (ovary stage I).

DISCUSSION

Despite the limited sampling period and the low number of specimens in the samples, mainly in the westernmost areas, some interesting conclusions can be drawn from the present work. The depth of 1100 m representing the lower limit of the distribution of the giant red shrimp is the deepest reported in the Mediterranean Sea (Table 5). However, in the depth range investigated (600-4000 m), the main bathymetric zone of the species distribution was found to be between 600 and 800 m. This range is within the depth limits reported in previous works (Table 5), though the minimum depth distribution of the species was observed in shallower waters that were not investigated in the present project. Although the species was always found on the slope, a minimum of 123 m was reported for its occurrence during the night, when it is supposed that it swims in the water column (Matarrese *et al.*, 1995).

The difference in the giant red shrimp abundance between the studied areas was expected to some extent. An increasing abundance gradient from the western to the eastern Mediterranean is confirmed by several previous works for the species. In the Spanish Mediterranean waters, the Gulf of Lions and the Ligurian Sea, *A. foliacea* is scarce or absent and a dominance of *Aristeus antennatus* is observed (Abelló *et al.*, 1988; Cartes and Sardà, 1992; Cartes *et al.*, 1994; Campillo, 1994; Orsi Relini and Relini, 1994; Cau *et al.*, 2002). The abundance of *A. foliacea* increases gradually eastwards, from the Tyrrhenian Sea to the Straits of Sicily and the waters around Greece, where it becomes more abundant than *Aristeus antennatus* (Murenu *et al.*, 1994; Ragonese *et al.,* 1994a,b; D'Onghia *et al.*, 1998a;

TABLE 5. – Bathymetric distribution of *Aristaeomorpha foliacea* in different Mediterranean areas.

| Geographic region | Depth range investigated (m) | Distribution depth range (m) | Max density depth range (m) | Reference |
|---|---|---|---|---|
| Catalan Sea | 3-871 | 273-748 | scarce | Abelló *et al*., 1988 |
| Catalan Sea | 141-730 | 245-515 | 430-515 | Cartes *et al*., 1994 |
| Sardinia | | 400-800 | 150-740, 550-600* | Murenu *et al*., 1994 |
| Sicily | | 393-817 | 450-750 | Ragonese, 1989 |
| N. Tyrrhenian | 12-615 | 468-496 | | Righini and Auteri, 1989 |
| S. Tyrrhenian | 100-750 | 200-750 | 500-750 | Spedicato *et al*., 1994 |
| W. Ionian | 350-750 | 350-750 | 400-550 | Matarrese *et al*., 1997 |
| W. Ionian | 350-750 | 350-715 | 500-600 | D' Onghia *et al*., 1988 |
| W. Ionian | 123-165 | 123-165 | 123-165* | Matarrese *et al*., 1995 |
| E. Ionian | 302-1171 | 388-1047 | 500-700 | Anon., 2001 |
| E. Ionian | 250-800 | 364-768 | 500-600 | Papaconstantinou and Kapiris, 2003 |
| Mediterranean | 10-800 | 200-800 | 500-800 | Cau *et al*., 2002 |
| Mediterranean | 600-4000 | 600-1100 | 600-800 | Present study |

* = surveys during night

TABLE 6. – Biological parameters estimated for *Aristaeomorpha foliacea* in different Mediterranean areas.

| Geograph. region | Sex | Size range (CL mm) | $CL_\infty$ (mm) | K | Age groups | Sex ratio (M:F) | Min. mature (CL mm) |
|---|---|---|---|---|---|---|---|
| Algeria[1] | Females | 24-67 | 65-73 | 0.45-0.56 | 6 | | |
| | Males | 23-45 | 44-45 | 0.66 | 5 | | |
| Sicilian Channel[2] | Females | | 65.5 | 0.67 | 2-3 | | |
| | Males | | 41.5 | 0.96 | | | |
| S. Tyrrhenian[3] | Females | | 71 | 0.47 | | 1:1 | 38 |
| C. Tyrrhenian[4] | Females | | 73 | 0.62 | 3 | 1.06:1 | 35 |
| | Males | | | | 2 | | |
| W. Ionian Sea[5] | Females | 10-65 | 70 | 0.45 | | | 33 |
| W. Ionian Sea[6] | Females | 9-65 | 66 | 0.45 | 4 | slightly in favor of females | 33 |
| | Males | 9-45 | 50 | 0.42 | | | |
| E. Ionian Sea[7] | Females | 10-70 | 72.5 | 0.43 | | slightly in favor of females | 27 |
| | Males | 12-59 | 60 | 0.4 | | | |
| E. Ionian Sea[8] | Females | 16-62 | 64 | 0.46 | 3 | slightly in favor of males | |
| | Males | 20-40 | 47 | 0.56 | 2 | | |
| Mediterranean[9] | Females | 10-74 | 62.1-72 | 0.39-0.67 | | 1:1.6 (W and C Medit.) 1.17:1 (Aegean Sea) | |
| E. Ionian[10] | Females | 16 -62 | 66.6 | 0.37 | 5 | 1.31:1 | 29 |
| | Males | 19-51 | 47.0 | 0.45 | 3 | | |

1, Yahiaoui, 1994; 2, Ragonese *et al*., 1994b; 3, Spedicato *et al*., 1994; 4, Leonardi and Ardizzone, 1994; 5, Matarrese *et al*., 1997; 6, D' Onghia *et al*., 1998; 7, Anon, 2001; 8, Papaconstantinou and Kapiris, 2003; 9, Cau *et al*., 2002; 10, present study.

Cau *et al*., 2002; Politou *et al*., 2003). In the western Ionian Sea, *A. foliacea* was found in low concentrations with a dominance of *Aristeus antennatus* (Matarrese *et al*., 1994; D'Onghia *et al*., 1998a). In our case, the scarcity of the giant red shrimp around the Balearic Islands is in agreement with the above. Its almost absence in the samples of the western Ionian may be due to the low number of hauls carried out and to the species aggregate distribution (Matarrese *et al*., 1994) in combination with its low abundance in the area. Moreover, in the western Ionian Sea, the species is mostly distributed at depths shallower than the strata investigated during the DESEAS project. On the other hand, the abundance of the species in the eastern Ionian Sea was high and exceeded the maximum abundance obtained for the other deep-sea shrimp, *A. antennatus,* in the three areas investigated (Table 8). Such high abundance indices for *A. foliacea* were also reported for the 500-800 m zone of the eastern Ionian Sea in previous works from the area (D'Onghia *et al.*, 2003; Papaconstantinou and Kapiris, 2003; Politou *et al.,* 2003).

The biological parameters estimated for *A. foliacea* in the area where it was abundant (stratum < 1000 m, eastern Ionian Sea) were compared with those obtained in previous works for the Mediterranean (Table 6). Its size distribution was within the size range reported in the literature, with females attaining larger CL than males. A tendency of larger individuals to be found in the eastern Ionian Sea can be observed, if all the works are considered. The age groups identified and the growth parameters estimated for females and males in the present paper did not show remarkable differences from other works. Although sex ratio was in equilibrium or slightly in favour of females in most areas (Table 6), the dominance of males observed in our case was also found previously in the waters around Greece and in the central Tyrrhenian Sea. No explanation has been given until now for this phenomenon and more investigation is needed in order to understand this sex repartition. Concerning the reproduction of the giant red shrimp, according to our results, this is about to start or has started in the eastern Ionian Sea (high percentage of mature females), and there is indication that this is also true for the Balearic Islands (female in spawning condition). On the other hand, a maturation of females in a smaller size eastwards than westwards can be deduced by comparison with the literature. In the eastern Ionian Sea, the smallest mature female measured 29 mm CL, a size comparable to that previously found in this region and lower than those reported from the westernmost regions.

Different hypotheses have been put forward to explain the distribution pattern of the giant red shrimp in the Mediterranean. Different hydrological conditions (i.e. temperature and salinity) between the westernmost and the easternmost areas have been reported to affect the species distribution (Orsi Relini and Relini, 1985; Relini and Orsi Relini, 1987; Murenu *et al*., 1994). *A. foliacea* is considered to be linked to warmer and more saline water masses than the other deep sea shrimp *A. antennatus* (Ghidalia and Bourgeois, 1961). According to the literature (Hopkins, 1985; Theocharis *et al*., 1993) and to our data (Table 7), the water temperature is considerably higher in the eastern Ionian than in the westernmost areas, and there is also an increase in salinity from the west to the east. Furthermore, the eastern Mediterranean deep water transient (Klein *et al*., 1999) may play a role, through the food chain, in the increased abundance of *A. foliacea* in the eastern Ionian Sea. According to Klein *et al*. (1999), this event is associated with a significant upward nutrient transport, which is most pronounced in the eastern Ionian Sea, and may result in greater biological productivity, although this area was considered highly oligotrophic (Stergiou *et al*., 1997).

TABLE 7. – Profiles of temperature and salinity of the three studied areas.

| Parameter | Depth (m) | T (°C) | S ‰ |
|---|---|---|---|
| Balearic | 600 | 12.8 | 38.80 |
| | 800 | 12.8 | 38.78 |
| | 1000 | 13.7 | 38.77 |
| | 1500 | 13.8 | 38.77 |
| | 2000 | 13.9 | 38.78 |
| Western Ionian | 600 | 13.3 | 38.79 |
| | 800 | 13.7 | 38.78 |
| | 1000 | 13.7 | 38.76 |
| | 1500 | 13.7 | 38.77 |
| | 2000 | 13.7 | 38.78 |
| Eastern Ionian | 600 | 14.2 | 38.82 |
| | 800 | 13.8 | 38.82 |
| | 1000 | 13.8 | 38.82 |
| | 1500 | 13.9 | 38.82 |
| | 2000 | 14.0 | 38.83 |
| | 2500 | 14.1 | 38.83 |

Another major factor, which may explain the distribution pattern of *A. foliacea*, is the vulnerability of the giant red shrimp to over-fishing in combination with the different fishing pressure exercised on the deep waters of the westernmost and eastern areas (Orsi Relini and Relini, 1985; Relini and Orsi Relini, 1987; Matarrese *et al*., 1997; D'Onghia *et al*., 2003). As mentioned above (see introduction), the deep waters of the western and central Mediterranean are extensively exploited down to a depth of 800-1000 m, whereas they are almost unexploited in the eastern Mediterranean (waters around Greece), since commercial fishing is exercised in waters shallower than 500 m. Evidence for overexploitation of the species is given for some areas of the central Mediterranean (middle-southern Tyrrhenian Sea: Spedicato *et al*., 1998, western Ionian Sea: Tursi *et al*., 1998). In other regions the disappearance of the stock, which was previously exploited, has been reported (Gulf of Lions: Campillo, 1994; Gulf of Genoa: Orsi Relini and Relini, 1985; Relini and Orsi Relini, 1987), though it has not been possible to estimate the effect of the fishing pressure. Even though our results do not give direct evidence to support the hypothesis of overfishing, a comparison of the data obtained for *A. foliacea* with those obtained for *A. antennatus* indicates a higher vulnerability of the former species to fishing pressure (Table 8). *A. foliacea* was present in shallower waters than *A. antennatus,* and its main distribution was found in the zone exploited by the fisheries ( < 1000 m). In contrast to *A. antennatus,* the giant red shrimp was scarce or absent in waters deeper than 800 m, and consequently a part of unexploited stock, which could serve as reserve for the exploited part, was not available. Also, its relatively stenobathic distribution shows a lower resilience of this species to changes in environmental conditions. The recruitment of *A. foliacea* was observed at the shallower stations (600 m), making juveniles highly available

TABLE 8. – Comparison of parameters obtained for *Aristaeomorpha foliacea* (present work) and *Aristeus antennatus* (Sardà *et al*., 2001) during DESEAS.

| Parameter | *Aristaeomorpha foliacea* | *Aristeus antennatus* |
|---|---|---|
| Max. depth distribution (m) | 1100 | 3300 |
| Main depth distribution (m) | 600-800 | 600-1500 |
| Biomass index (kg km$^{-2}$) | Balearic: 0.76<br>W. Ionian: 1.00<br>E. Ionian: 14.33-95.35 | Balearic: 2.87-17.76<br>W. Ionian: 0.15-16.80<br>E. Ionian: 0.19-28.12 |
| Recruitment depth (m) | 600 | 1500 |
| Min. female CL (mm) bearing spermatophore (age group) | 26.9 (Greek waters)<br>(1+) | 24.4 (Greek waters)<br>(0+) |
| Min. female CL (mm) with mature gonads (age group) | 29.8 (Greek waters)<br>(1+) | 24 (Greek waters)<br>(0+) |

to fishing. On the other hand, the recruitment of *A. antennatus* was taking place in the unexploited zone and mainly at 1500 m depth. Additionally, *A. foliacea* showed a later maturation, with the smallest mature females being larger and older compared to *A. antennatus*. Consequently, the former species has a lower probability of reproduction before being caught in the nets.

Matarrese *et al*. (1997) came to similar conclusions regarding the vulnerability and resilience to fisheries of *A. foliacea* and *A. antennatus* in the western Ionian Sea, and they also underlined the important role of the high reproductive potential of the latter species in the recovery of the stock. Furthermore, in a recent work of size structure comparison for some deep-sea species between the eastern and the western Ionian Sea (Mytilineou *et al*., 2001), highly significant differences were found between the populations of *A. foliacea* in the exploited (western Ionian) and unexploited (eastern Ionian) waters. More specifically, large specimens were more abundant and the mean size was higher in the unexploited area. No significant differences were shown for *A. antennatus*.

Following the above observations, *A. foliacea* seems to be particularly sensitive to fisheries and special management measures are needed for its exploitation. The stocks of the species were found to be highly abundant in the easternmost Mediterranean area studied (waters around Greece), which is still almost unexploited in the deep waters. Though more research is needed in order to propose effective management measures before starting the exploitation of the resource, the implemented official closure of trawl fishery in the Greek waters every summer, coinciding with the reproduction period of the giant red shrimp, would be beneficial for the species stocks in the area. Also, an increase of the trawl cod-end mesh size from 20 mm (side), imposed by the EU regulation, to 28 mm (Ragonese and Bianchini, 1996) or more (Ragonese *et al*., 2002; D'Onghia *et al*., 1998b) for the deep waters, could reduce the participation of juveniles in the catch and enhance the stock sustainability.

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