Morphometric structure and allometry profiles of the giant red shrimp *Aristaeomorpha foliacea* (Risso, 1827) in the eastern Mediterranean

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Abstract

The relative growth of body parts, such as abdomen, uropod, scaphocerite, telson, rostrum, and the third pereiopod of males and females of the giant red shrimp (*Aristaeomorpha foliacea*, Risso, 1827) was studied in samples from the Greek Ionian Sea (eastern Mediterranean) in 1999–2000. These were related to carapace length, sex and size of individuals. A length–weight relationship was also obtained. In general, a negative allometry of swimming appendages (uropod, scaphocerite), abdomen (related to metabolic processes), and length of the third pereiopod (involved in walking ability) was observed in both sexes. Growth of the telson was positively allometric in females and negatively allometric in males. Asynchronous growth of the male rostrum was also noted. Appendages were proportionally longer in juveniles than in adults of both sexes. A strong negative allometry between length–weight for both sexes was shown, and females were heavier than males in all sampled months.

Keywords: Allometry, *Aristaeomorpha foliacea*, Ionian Sea, relative growth

Introduction

The giant red shrimp, *Aristaeomorpha foliacea* (Risso, 1827) (Order: Decapoda, Superfamily: Penaeoidea, Family: Aristeidae), is a widely distributed crustacean known from the eastern and western Atlantic, western Pacific, the Indian Ocean, and the Mediterranean Sea (Holthuis 1980). In the Mediterranean, this species is mainly found in epibathyal and mesobathyal waters, on the edge of submarine trenches and canyons, mostly from 500 to 700 m depth (Fischer et al. 1987). *Aristaeomorpha foliacea* and *Aristeus antennatus* (Risso, 1816), the other species of Aristeidae found in the Mediterranean, are among the most important resources of the deep-water fishery (Bianchini and Ragonese 1994). An unexploited and potentially exploitable stock was recently reported off the Greek coast of the Ionian Sea (west Greece) (Papaconstantinou and Kapiris 2003). The major aspects of the biology of this species in the above area have recently been published (Papaconstantinou and Kapiris 2003). Growth of this species differed significantly between
sexes, and the longevity of females (3–4-year classes) exceeded that of males (2-year classes), indicating a size dimorphism. Further studies by Kapiris et al. (2000) and Kapiris and Thessalou-Legaki (2001a, 2001b, 2001c) from this area included stomach content analysis and biological parameters of this species.

In spite of its great commercial interest, only a few notes dealing with the morphometry of this shrimp have been published. Ragonese et al. (1997) studied the relationship between the total, ocular (from the posterior margin of the orbit to the tip of the telson) and carapace length in populations from the Strait of Sicily. In populations from the Greek Ionian Sea (eastern Mediterranean), Kapiris et al. (2002) compared the allometric growth of male sexual characters of both red shrimp species (*Aristeus antennatus* and *Aristaeomorpha foliacea*). In the current study the relative growth of some appendages of male and female specimens of *A. foliacea* caught in the Greek Ionian Sea from October 1999 to September 2000 are reported for the first time. The differences between sexes and size groups are also discussed. The observed biometric relationships of these appendages were studied, since there are no similar studies available in the literature regarding the growth pattern of this species.

### Material and methods

All specimens were collected during four trawl surveys in the northern Ionian Sea (eastern Mediterranean) in October 1999 and April, July and September 2000, within the framework of the research project “Interreg II”, at a depth range of 300–1171 m (Figure 1).

A commercial trawler was used, equipped with a trawl net of 200 mm stretched mesh size in the cod-end. The random stratified design was used for sampling. The study area was separated into three depth zones: 300–500, 500–700 and 700–900 m. Some stations were selected with depth more than 900 m, in order to establish a general idea about fisheries resources in deeper grounds. In total, 60 stations were sampled. The vessel speed during fishing was maintained at 2.5–2.8 knots. Sampling was restricted to daylight hours and the hauls lasted 1 h each on average. The specimens were mainly caught in the depth zone between 700 and 900 m. A total of 734 females and 715 males was examined.

To avoid bias due to measuring procedures, the same person consistently took the measurements to the nearest 0.1 mm (Figure 2) using calipers.

The measurements were defined as follows (Sarda ‘ and Demestre 1989; Sarda ‘ et al. 1995): carapace length (CL), from the posterior margin of the orbit to the posterior margin of the carapace, parallel to the axis of the body; abdominal length (ABD), from the anterior margin of the first abdominal segment to the posterior margin of the last abdominal segment; pereiopod (P), the total length of the third pereiopod (ischium, carpus, merus, propodus) excluding the basis; rostral length (R), from the distal tip to the eye orbit; scaphocerite length (S), from the margin of the commissure of the articulation to the end of the spine on the inner ridge; telson (T), the terminal somite of abdomen; uropodal exopodite (U), from the margin of the commissure of the articulation to the end of the terminal spine on the dorsal ridge.

In order to determine any possible relationship between juveniles (CL<16 mm) and adults (CL>16 mm), we compared the ratios between the above measurements and the carapace length (CL/ABD, CL/R, CL/U, CL/S, CL/T, CL/P). These proportions were estimated per individual and the mean values of juveniles and adults were compared.
Additionally, the total wet body weight (W) of 655 males and 698 females was recorded (to 0.01 g) with the aid of an analytical balance. All measurements were related to carapace length, which was considered to be the independent variable. The relationship between all measurements versus CL was investigated for each season and sex separately using the multiplicative model $Y = aX^b$, where $Y$ and $X$ are the morphological dimensions and $a$ and $b$ the regression constants. The relationships obtained were log-transformed to the form $\log Y = \log a + b \log X$. The log transformation is preferred in order to satisfy better the assumptions of regression analysis (Sokal and Rohlf 1981). This allows one to derive a single value from the analysis for the scaling relationship between the two morphometric parameters. Carapace length–wet weight relationships were calculated for each sampling period and sex separately, and also for the pooled data by using the equation: $W = aCL^b$ ($W$ in g and $CL$ in mm). The pattern

Figure 1. Map of the sampling area and the depth range of the sampling stations of *Aristaeomorpha foliacea* (Risso, 1827) in the Greek Ionian Sea.
of allometry for each parameter was established by testing the slope \((b)\) of the obtained regression equations against isometry \((b=1)\) applying the Student’s \(t\)-test. The comparison between the parameters of the regressions between sexes, sizes and sampling period was carried out by ANCOVA (Zar 1984). The Kruskall–Wallis test (Zar 1984) was used to identify possible differences in time. For both sexes analysis of variance (ANOVA) was used for testing the significance of temporal differences of mean length of appendages. Normality of appendage length was determined by means of the Kolmogorov–Smirnov test (Sokal and Rohlf 1981) for comparing the mean sizes of different size groups of shrimps. The Mann–Whitney test was applied as a non-parametric test to compare independent samples (Sokal and Rohlf 1981).

**Results**

The majority of specimens of this species were caught mainly in the depth zone 500–700 m, in all the seasons. Only a few individuals were caught in the shallower (300–500 m, July 2000) and in the deeper depth zone (700–900 m, September 2000). *Aristaeomorpha foliacea* was found in the whole study area, although it was more abundant in some areas (west and south of Corfu Island, south of Zakynthos Island; Figure 1).

Mean sizes and standard deviations of all female appendages were larger than males throughout the sampling period (Mann–Whitney and Kolmogorov tests, \(P=0.0\)). All mean values of measurements of females were higher in July 2000 and lower in October 1999. Males showed their highest values in October 1999 and September 2000. The measured characteristics proved to be statistically significant between several seasons in both sexes (ANOVA, Kruskall–Wallis, \(P<0.01\)). The lowest values for all the measured parameters were found in April 2000 for both sexes (Table I).

The pooled equation parameters representing the relative growth of each parameter in relation to carapace length, after log transformation, of both sexes are given in Table II. In the same table the correlation coefficient \((r)\) and the type of allometry are included as well as a comparison of the slopes of the regression lines. In females, higher correlation

![Figure 2. Morphometric measurements taken on *Aristaeomorpha foliacea* (Risso, 1827). CL, carapace length; T, telson; U, uropodal exopodite; S, scaphocerite; P, third pereiopod; R, rostrum; ABD, abdomen.](image_url)
coefficients \((r)\) were observed. On the other hand, the slopes \((b)\) were more isometric than in males, indicating significant sexual dimorphism. For all the variables, with the exception of the rostrum of males, regressions were statistically significant (ANCOVA, \(P<0.05\)). The main morphometric relationships established for males and females are illustrated in Figures 3, 4.

The measurements of both sexes show a unique continuous regression line, except for the rostrum of males, since juveniles and adults did not show any abrupt change in their morphology. Thus, the regression parameters (Table II) have been estimated taking into consideration all the monthly measurements.

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### Table I. Mean values (lengths in mm, weight in g) and standard deviation (SD) of *Aristaeomorpha foliacea* (Risso, 1827) measurements of both sexes in the study area and at different sampling months.

| Measure | Sex | October 1999 | April 1999 | July 2000 | September 2000 |
|---------|-----|-------------|------------|-----------|----------------|
| ABD     | M   | 59.6 (13.4) | 57.4 (7.0) | 86 (16.4) | 86.9 (10.9)    |
|         | F   | 61.5 (22.9) | 59.1 (18.3)| 64 (12.5) | 63.8 (12.3)    |
| CL      | M   | 32.7 (8.2)  | 29.8 (5.4) | 31 (4.97) | 31.5 (4.0)     |
|         | F   | 39.3 (15.6) | 33.5 (14.9)| 44 (10.8) | 42.6 (11.1)    |
| P       | M   | 50.5 (6.7)  | 48.4 (6.8) | 50 (8.0)  | 51.5 (6.4)     |
|         | F   | 60.3 (16.6)| 58.1 (16.4)| 69.2 (15.2)| 68 (14.1)      |
| R       | M   | 14.07 (7.7)| 11 (4.8)   | 13.7 (8.2)| 13 (7.3)       |
|         | F   | 33.8 (6.3)  | 32.8 (9.3) | 36.8 (7.1)| 36.6 (7.7)     |
| S       | M   | 15.9 (1.87)| 15 (1.9)   | 15.8 (1.78)| 15.4 (1.6)     |
|         | F   | 17.4 (4.0) | 16.7 (5.0) | 18.8 (3.4)| 18.5 (3.4)     |
| T       | M   | 16.8 (1.65) | 16.4 (2.74)| 17.2 (2.44)| 17 (2.12)      |
|         | F   | 19.9 (5.2) | 18.6 (6.7) | 21.6 (4.1)| 21.4 (4.4)     |
| U       | M   | 17.5 (1.93)| 16.5 (2.75)| 17.8 (2.8)| 16.7 (2.0)     |
|         | F   | 19.1 (4.5) | 18.2 (6.2)| 20.8 (4.4)| 19.7 (3.9)     |
| W       | M   | 14.5 (4.03)| 11.8 (5.14)| 14.4 (4.99)| 11.9 (4.34)    |
|         | F   | 26.7 (1.7) | 22.2 (2.0)| 30.2 (1.6)| 27.7 (1.6)     |

\(n\), number of measurements; ABD, abdominal length; CL, carapace length; P, pereiopod length; R, rostral length; S, scaphocerite length; T, telson length; U, uropodal exopodite; W, weight; F, females; M, males.

### Table II. Allometry of the measured appendages in *Aristaeomorpha foliacea* (Risso, 1827) in the Greek Ionian Sea.

| Measure/CL | Sex | \(n\) | \(a\) | \(b\) | \(r\) | \(t\)-test | Allometry | Figure |
|------------|-----|-------|-------|-------|-------|-----------|-----------|--------|
| ABD        | M   | 441   | 1.43  | 0.48  | 0.91  | -43.66    | Negative  | 4a     |
|            | F   | 599   | 1.34  | 0.60  | 0.94  | -44.58    | Negative  | 3a     |
| P          | M   | 345   | 1.29  | 0.65  | 0.72  | -10.32    | Negative  | 4d     |
|            | F   | 432   | 1.25  | 0.74  | 0.92  | -18.46    | Negative  | 3d     |
| R          | M   | 196   | 1.25  | 0.46  | 0.92  | -39.67    | Negative  | 3e     |
|            | F   | 549   | 0.99  | 0.45  | 0.67  | -21.08    | Negative  | 4b     |
| S          | M   | 678   | 0.82  | 0.88  | 0.97  | -13.73    | Negative  | 3b     |
|            | F   | 420   | 0.97  | 0.55  | 0.84  | -20.03    | Negative  | 4c     |
| T          | M   | 517   | 0.79  | 1.03  | 0.96  | 3.33      | Positive  | 3c     |
|            | F   | 507   | 1.02  | 0.45  | 0.62  | -16.54    | Negative  | 4f     |
| U          | M   | 632   | 0.82  | 0.93  | 0.95  | -37.25    | Negative  | 3f     |

\(CL\), carapace length; \(n\), number of measurements; \(a\), \(y\)-intercept; \(b\), slope; \(r\), correlation coefficient; \(t\)-test, Student’s \(t\)-test statistic; ABD, abdominal length; P, pereiopod length; R, rostral length; S, scaphocerite length; T, telson length; U, uropodal exopodite; W, weight; F, females; M, males. Data represented by these regressions parameters are shown as presented in Figures 3, 4. In all cases \(P<0.05\).
Few diversifications between the two sexes were observed. In the study area, the length of the telson of females was positively allometric, while all the other measurements indicated a significant negative allometry ($b<1$) in both sexes. A non-significant relationship was observed between the rostrum and the carapace length of males.

The juveniles caught differed significantly ($P<0.01$) from adults in all ratios of the measured appendages. Almost all the CL/appendage ratios were proportionally longer in
juveniles of both sexes (Table III). Only the weight of the larger individuals, as was expected, was higher than that of the juveniles.

Monthly carapace length–wet weight relationships for each sex are summarized in Table IV. All the data suggest that wet weight increased with negative allometry, the coefficient \( b \) varied between 2.236 and 2.873 \((b<3)\). Coefficients of correlation had values ranging from 0.79 to 0.99, indicating a high relationship between the carapace length and the wet weight of the shrimps. All the correlation coefficients, with the exception of those for males in October 1999, were high and significant \((P<0.01)\). Differences in slopes and intercepts

Figure 4. Relationship between carapace length and other measurements (mm) (logarithmic plots) of males of Aristaeomorpha foliacea (Risso, 1827) (data pooled for all the sampling periods).
between the CL–W regressions of the two sexes were tested using analysis of covariance (ANCOVA). Both differed significantly between the two sexes ($F=75.87$, $r=0.98$, $P=0.01$ for $a$; $F=9.01$, $r=0.90$, $P<0.01$ for $b$). Females, for the same length, were heavier than males in all the cases. The females sampled in October 1999 and the males caught in April 2000 weighed significantly less than those collected in the other months. On the other hand, heavier females and males were caught in April 2000 and July 2000, respectively.

**Discussion**

Biometric studies of deep-water shrimps are few and sporadic. The higher stability of the deep-sea environment tends to lead to marine organisms living there to adapt to a functional equilibrium of their appendages (Bas and Sardà 1998). Although, the deep-water aristeid shrimp species have been studied quantitatively and qualitatively in many
regions, data on morphometric relationships are few and scarce. For example, Guéguen (1997) studied the morphometry of two deep-water shrimp species in French Guiana (Solenocera acuminata (Pérez Farfante and Bullis, 1973) and Plesiopenaeus edwardsianus (Johnson, 1867)). Sardà et al. (1995) related different body parts of Aristeus antennatus to carapace length. Bas and Sardà (1998) analysed possible morphometric variations in the relationship between various measurements of the same species using a 30-year time series of data. Finally, Sardà and Cartes (1997) described the morphology of the juveniles of A. antennatus in the Catalan Sea. Unfortunately, only the parameters of the length–weight relationship are known for Aristaeomorpha foliacea. Since there are no other morphometric relationships available in the literature for the studied species, only data from the companion species Aristaeus antennatus will be used for comparison.

A clear sexual dimorphism in size was found for Aristaeomorpha foliacea, with females reaching larger dimensions than males during the whole study period. All the observed morphological variations between the sexes could be attributed to the marked differences in growth pattern of the males (much lower maximum size, lower growth rate) compared to females (Sardà et al. 1995).

Regarding relative growth in our samples, only a slight variation in morphometric relationships was found between the sexes. A proportional reduction of almost all the swimming appendages (scaphocerite, uropodal exopodite) was observed in both sexes. In contrast, the other appendage involved in swimming (telson) showed a proportional increase in females and a proportional reduction in males, but with a very high slope, indicating that this appendage grows almost isometrically. The higher slopes \( b \) of the regression lines for all swimming appendages in females indicate their greater swimming ability than males. The reduction of the swimming ability of both sexes of the red shrimp Aristaeus antennatus with increasing size has also reported by Sardà et al. (1995).

Similarly, a proportional reduction (negative allometry) in the length of the abdomen (directly related to overall metabolic process, primarily reproduction, rapid locomotion and the muscular mass responsible for the impulse; Sardà et al. 1995) was observed. The reduction in the ability for rapid locomotion with increasing size is in agreement with the above reduction in swimming ability. The same growth pattern of the abdomen has been established by Sardà et al. (1995) for the companion species, A. antennatus, in the Catalan Sea.

A proportional reduction in third pereiopod length (directly related to walking ability and cropping behaviour when rooting for food in the substratum (Sardà et al. 1995) was found in both sexes. This growth pattern was not expected, since as swimming ability decreases (more clearly in males), walking ability should be increased. On the other hand, a clear positive allometry of the third pereiopod of the sympatric species, A. antennatus, was ascertained (Sardà et al. 1995). It is worth noting that the latter species has a closer contact with the bottom and its diet consists of prey items which live deeper in the substratum (Cartes and Sardà 1989), although the diet of Aristaeomorpha foliacea is based more on pelagic resources or prey items with good swimming ability than on organisms closely associated with the bottom (Cartes 1995).

The relative growth of the rostrum in males did not present statistically significant results indicating an asynchronous growth. Rostral variability is commonly found in aristeid shrimps and is related to sex, sexual maturity and size (Sardà and Demestre 1989). The rostral shortening in A. foliacea occurred in males during the end of autumn (Kapiris, unpublished data), while in Aristaeus antennatus it occurred during the end of winter in the Greek Ionian Sea (Kapiris and Thessalou-Legaki 2001a). According to Sardà and
Demestre (1989) a number of factors within the life cycle of crustaceans may play a role in this rostral shortening, such as asynchronous growth, the extended spawning season, the prolonged period of recruitment and the duration of the larval growth stages in the pelagic habitat.

The relatively longer appendages in juveniles (telson, scaphocerite and uropods) indicated that they may be considered as more efficient swimmers than the adults. On the other hand, the quite similar proportion of CL/P (carapace length/pereiopod) between juveniles and adults indicated that the smaller individuals (CL<16 mm) of Aristaeomorpha foliacea have a similar ability to walk or root the substratum as the larger ones. Sardà and Cartes (1997) stated that some of the appendages (pereiopods, telson, uropods) of the juveniles of Aristaeus antennatus were proportionally longer than in adults.

The parameters of the carapace length body weight relationship were within the range of those recorded for Aristaeomorpha foliacea caught in the South Ionian Sea (Anonymous 1999, 2001, 2003). The weight relations showed a similar pattern between males and females. In agreement with the literature from other Mediterranean areas, a strong negative allometry exists between carapace length body weight in both sexes (Righini and Abella 1994; Spedicato et al. 1994; Ragonese et al. 1997). This observed statistically significant negative allometry was more pronounced in males than females. The higher value of the slope (b) and the lower value of the intercept (a) in females is obvious, due to their larger carapace length and is very common between the decapods (Dall et al. 1990).

Summarizing, this is a first attempt to study the relative growth of some appendages of the red shrimp A. foliacea in the north Ionian Sea. The growth of A. foliacea is continuous, since the exoskeleton is more flexible and moulting is frequent and continuous (Dall et al. 1990). Additionally, all the reproductive processes, namely sexual maturity, mating and spawning, occur over a large size-age range (Ragonese et al. 1997). These characteristics could explain the harmony, which has been statistically observed in both sexes, despite some differentiations.

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