DISTRIBUTION, BIOLOGY, AND POPULATION DYNAMICS OF *ARISTAEOMORPHA FOLIACEA* (RISSO, 1827) (DECAPODA, NATANTIA, ARISTEIDAE) IN THE NORTH-WESTERN IONIAN SEA (MEDITERRANEAN SEA)

BY

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ABSTRACT

The distribution, biology, and population dynamics of *Aristaeomorpha foliacea* (Risso, 1827) have been investigated in the north-western Ionian Sea (middle-eastern Mediterranean). A total of 9,637 specimens, 5,570 females and 4,067 males, was collected during twelve trawl surveys carried out between 350 and 750 m of depth. *Aristaeomorpha foliacea* is found on muddy bottoms with the highest densities generally in the upper 600 m and in a zone where canyons cross the bottoms.

A spatio-temporal distribution correlated to bio-ecological aspects was shown in the population. An increase in males on the fishing bottoms was shown during winter when maturity of this sex begins and shortly after mating occurs in the population. During the winter-spring season the whole population migrates to the upper slope. After the mating peak, in summer, when spawning is at its maximum, the population is again displaced to the deeper grounds.

The ovary maturation period is between May and September and the largest specimens are the first to mate and reach sexual maturity. The size of "maximum reproductive potential" is 37.11 mm carapace length.

Recruitment occurs in spring and the stock is mostly represented by young individuals. Both female and male growth rates fit a Von Bertalanffy function. Both female and male stocks appear to be "mortality-dominated" ($Z/k > 1$). Estimates of the exploitation ratio ($E = F/Z$) are between 0.43 and 0.62 in females and between 0.46 and 0.65 in males.

RÉSUMÉ

La distribution, la biologie et la dynamique de population d'*Aristaeomorpha foliacea* (Risso, 1827) ont été étudiées dans le nord-ouest de la mer Ionienne. 9.637 spécimens, 5.570 femelles et 4.067 mâles, ont été recueillis au total au cours de douze chalutages entre 350 et 750 m de profondeur. *Aristaeomorpha foliacea* est trouvée sur des fonds de vase avec des densités maximales généralement dans les 600 m supérieurs, et dans une zone où les fonds sont traversés par des canyons. La population montrait une distribution spatio-temporelle corrélée avec des aspects bio-écologiques. Un accroissement du nombre des mâles apparaissait sur les fonds de pêche pendant l'hiver, au début de la maturité de ce sexe et peu après l'accouplement dans la population. Pendant la saison hiver-printemps, la population entière migre vers la partie supérieure du plateau. Après le pic de la reproduction, en été, quant la ponte est à son maximum, la population se déplace de nouveau vers de plus grandes profondeurs.

La période de maturation ovarienne est entre mai et septembre et les plus grands individus sont les premiers à se reproduire et à atteindre la maturité sexuelle. La taille du "potentiel reproductif maximum" est de 37,11 mm de longueur de carapace.

Le recrutement survient au printemps et le stock est principalement représenté par des individus jeunes. Le taux de croissance des mâles et des femelles concorde avec la fonction de Von Bertalanffy. Les stocks mâles et femelles apparaissent comme "mortality-dominated" ($Z/k > 1$). Les estimations du rapport d'exploitation ($E = F/Z$) se situent entre 0,43 et 0,62 chez les femelles et entre 0,46 et 0,65 chez les mâles.

INTRODUCTION

The giant red shrimp *Aristaeomorpha foliacea* (Risso, 1827) is a species widespread in the eastern and western Atlantic, Indian Ocean and western Pacific, in the waters of Japan, Australia, New Zealand and in the Mediterranean Sea (Holthuis, 1980).

In this latter basin *Aristaeomorpha foliacea*, together with the blue and red shrimp *Aristeus antennatus* (Risso, 1816), represents the most important biological resource generally distributed at depths between 300 and 700 m over a large portion of the continental slope.

The knowledge of the distribution of these two shrimps in the Mediterranean indicates a longitudinal gradient of their abundance. In fact, in the western basin the blue and red shrimp greatly outnumbers the giant red (Sardà, 1986) while the abundance of this latter species increases eastwards as far as the highest concentration found in the Sicilian Channel (Ragonese, 1993). Slightly beyond this area, in the Ionian Sea, *Aristaeomorpha foliacea* is again less abundant than *Aristeus antennatus* (see Matarrese et al., 1992; Tursi et al., 1993). Of the easternmost side of the Mediterranean no information is available on these shrimps.

Although a large amount of information has been collected in the last two decades, contributing to the knowledge of the biology of both species, their spatio-temporal patterns are still not well understood.

Aspects of the life cycle and population dynamics also remain open questions for both species. Larvae and postlarvae distribution are still almost completely unknown; recruitment and growth patterns change over relatively short scales and uncertainty exists in the definition of life span. The main problems of the use of length-frequency data in population dynamics studies of shrimps are the representativeness of the samples and the degree of overlapping between the different size components. In areas with canyons length-based methods, such as modal progression analysis, lead to misinterpretation of data and apparent "negative" growth can be explained as an effect of the size dependent migration into zones unsuitable for trawling (Sardà et al., 1994). Moreover, changes in recruitment pattern may have a marked influence on the estimate of population parameters.

In the north-western Ionian Sea, despite both *Aristaeomorpha foliacea* and *Aristeus antennatus* representing the target species of deep-water bottom trawling, the information on their bio-ecology is rather limited (Matarrese et al., 1992; Tursi et al., 1993; D'Onghia et al., 1994; Matarrese et al., 1994; Matarrese et al., 1995). This information is based on data collected at long time intervals between surveys (six months) and always during the same seasons (spring and autumn), so that aspects of population biology and dynamics of deep water shrimps were not completely covered.

Recently, research targeted on the distribution and population biology of these shrimp species in the north-western Ionian Sea has been funded by the European Commission. The aim of this paper is to provide a contribution to the knowledge on distribution, reproductive biology and population dynamics of *Aristaeomorpha foliacea* in this basin of middle-eastern Mediterranean Sea.

MATERIALS AND METHODS

The whole study area covers a surface of about 1,000 square miles (3,400 km^2) between Cape S. Maria of Leuca (Lecce, Italy) and Cape Spartivento (Reggio Calabria, Italy) and depths from 350 to 750 m (fig. 1).

Twelve trawl surveys were carried out, at two month intervals, on the whole area between August 1993 and July 1995. A commercial 75 tons gross tonnage vessel, with 360 Hp engine, was chartered. It was equipped with a nylon otter-trawl net with 40 mm stretched mesh (20 mm side) in the cod-end. The horizontal and vertical net openings were measured for each depth by means of the SCANMAR sonar system (Fiorentini et al., 1994). They depended on various factors (depth, warp length, towing speed, etc.) and ranged from 21.71 to 25.09 m and from 0.8 to 0.73 m, respectively. The vessel speed, measured by using GPS, was maintained at 2.5–2.8 knots.

For each survey the hauls were randomly sampled within the study area (Fogarty, 1985). An average total of 17 hauls was carried out during each survey. The number of individuals for each haul carried in three investigated zones during the twelve surveys are reported in table I. The depth range surveyed was between 350 and 750 m. Fishing was restricted to day-light hours and the hauls lasted two hours each on average.

TABLE I

Number of individuals *Aristaeomorpha foliacea* (Risso, 1827) caught in each haul in three areas in the north-western Ionian Sea

	Northern area									Central area									Southern area						
Hauls	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7
Survey	N of individuals																								
August '93	12	219	0	24	10	10				80	29	0	0	0	25	0	0	1	3	16	160	119	395	0	
November '93	11	0	6							0	8	173	0	20	0	0			793	95	3	13			
January '94	3	0	182							0	1	2	1	46	13	0	0		104	561	40	246			
March '94	18	34	100	5	0	119				76	96	0	5	25	1	0	3		0	0	0	0			
May '94	22	0	4	1	7	0	1	1	2	30	0	0	7						7	0	2	0	49		
July '94	0	0	65	2		23				1	7		0	0	1				0	16	0	1	7	120	0
Aug.-Sept. '94	0	112	7	3	1					0	36	7	0	0	0				0	3	8	72	0	26	0
Oct.-Nov. '94	0	364	14	26						0	274	1	0	520					0	364	14	26			
January '95	136	90	0	0	29	6				0	150	0	0	26	3	1	16	2	17	6	200	15	500		
March '95	219	17	0	188	0					2	0	0	0	2	2	6			46	28	0	20	0	0	
May '95	0	176	0	7	271	70	31			18	71	14	98						5	23	0	72		54	95
July '95	0	0	4	20	25	55	60			60	0	0	4	0	16				80	0	0	666	0	17	

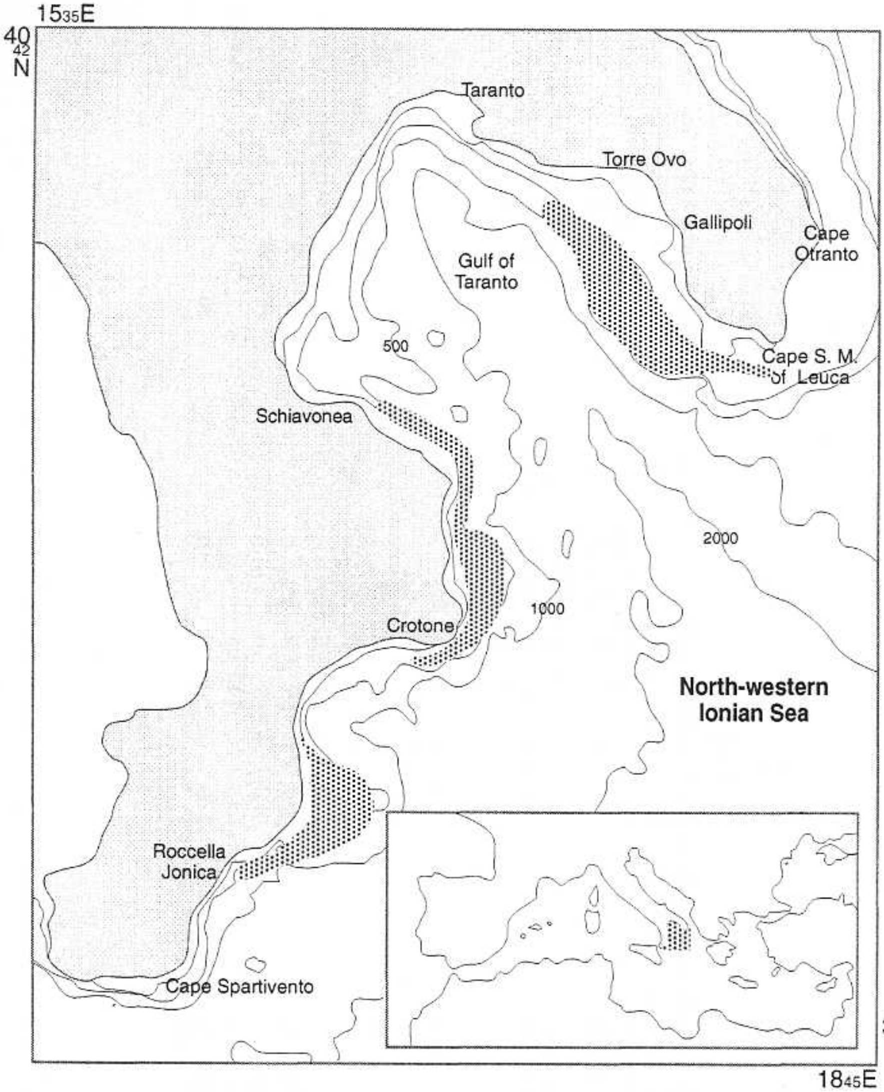


Fig. 1. Areas investigated in the north-western Ionian Sea from August 1993 to July 1995. Northern zone (Gallipoli fishery), central and southern zone (Crotone fishery).

The number of individuals of *Aristaeomorpha foliacea* for each haul swept area was regarded as a measure of density (N/km^2). The "swept area" was estimated according to the wing spread of the net and the speed of the vessel (Pauly, 1983). The former changed with the length of wire which in turn depended on the depth of the haul (Fiorentini et al., 1994).

Density data were analyzed to evaluate eventual differences between surveys, depths and the three zones of the north-western Ionian Sea where shrimps are mostly distributed and that are suitable for deep bottom trawling (Tursi et al., 1993; Vacchi et al., 1995). The northernmost zone was located along the Apulian coast and regards the Gallipoli fishery; the second, the central one, was along the Calabrian coast near Crotone and the third, the southernmost zone, was located near Roccella Jonica (fig. 1). Three bathymetric strata were considered in the analysis of the density by depth: < 500 m; 500-600 m; > 600 m.

Considering the highly patchy distribution of deep water shrimps (Ragonese, 1989, 1993; Sardà, 1993) the non-parametric test of Kruskall & Wallis (1952) was applied using STATISTICA software (StatSoft, Inc., 1995). The Kruskall-Wallis test statistic is a function of the ranks of the observations in the combined sample, for $k \geqslant 2$ independent samples (Conover, 1980). The hypotheses are as follows:

H_0: all of the k sample distribution functions are identical;

H_1: at least one of the samples tends to yield a higher observed value than at least one of the other samples.

For each specimen of *Aristaeomorpha foliacea* the carapace length (CL) was measured to the nearest mm, from behind the orbit of the eye to the posterior border of the cephalothorax. Sex and maturity stage of the gonad were determined macroscopically. The maturity of the ovary was evaluated using the empirical 4-stage scale proposed by Levi & Vacchi (1988). This scale allows a macroscopic estimation of maturity, from flesh coloured ovary (stage 1, immature) to black ovary (stage 4, ripe). The presence of spermatophores on the thelycum was recorded. For males two stages of sexual maturity (immature and mature) were distinguished, based on the presence or absence of sperm sacs on the coxae of the fifth pair of pereiopods (Tunesi, 1987; Sardà & Demestre, 1989).

Statistical differences between changes in the number of females and males with survey and depth were determined using G-test (Sokal & Rohlf, 1969).

The logistic function was used for description of the maturity condition and the presence of spermatophores by size. Maturity was assessed by combining females ready to spawn (stage 4) and almost ready (stage 3). On the basis of two functional criteria (Morizur, 1983), maturity of gonad and presence of spermatophores, the size of "maximum reproductive potential" was estimated according to Ragonese & Bianchini (1995).

Growth was modelled in terms of the Von Bertalanffy equation. Although the physiology of the shrimps is very different from that of fishes, the use of this type of curve means that growth is treated as a continuous function. In fact, since moulting is not simultaneous in all individuals and partial growth occurs during the intermoulting period, the average growth curve of a cohort can be represented by a smooth continuous curve (Garcia & Le Reste, 1981).

Von Bertalanffy growth parameters were estimated using length-based methods with the LFSA program (Sparre, 1987). Particularly, Gaussian components in the length-frequency distribution of each survey in the two year research, were separated with the Bhattacharya (1967) method in the BHATTAC procedure. Each representative component, with a separation index greater than 2 was assumed to be a single cohort and then utilized in the modal progression analysis procedure (MODALPR) of the same package. Since the Von Bertalanffy growth parameters k and L_{∞} are inversely correlated, the "overall growth performance" ϕ' (Munro & Pauly, 1983) was computed in order to compare the growth rate with those of other populations.

Total mortality rate (Z) for each sex was computed by using the Hoenig (1987) method which is based on the hypothesis of discrete recruitment. The value of 30 mm CL was considered as the smallest carapace length fully represented in the catch samples according to the selection curve reported by Ragonese et al. (1995) for a mesh size of 20 mm side as in this case.

RESULTS

Distribution

A total of 9,637 individuals of *Aristaeomorpha foliacea*, 5,570 females and 4,067 males, was caught on the muddy bottoms of the whole study area during the research period. Specimens were found in 129 of the 204 hauls carried out. High changes in density values were observed within each survey, depth and zone from many zero values and others lower than 100 N/km^2 up to a maximum of 5,193 N/km^2 (figs. 2, 3). No significant differences ($P > 0.05$) were shown in the distribution of the density values among the surveys.

With regard to depth, shrimps were caught between 350 and 715 m. The differences in density distribution among the depth strata were highly significant (T = 17.227; d.f. = 2; $P < 0.01$) resulting in a higher concentration of specimens between 500 and 600 m.

Concerning to the three geographic zones, the frequency of the shrimps finding within the total hauls in each of them ranged from 57.0% in the central zone to 67.9% in the southern one. Significant differences (T = 7.704; d.f. = 2; $P < 0.05$) were exhibited in the distribution of density values between the three zones. The southernmost zone yielded generally higher values than the others.

Considering the spatio-temporal distribution of the specimens in the whole study area, the same pattern was shown in females and males (figs. 4a, 4b). In particular, the population distributed across the whole bathymetric range during August 1993 exhibited a displacement towards the uppermost depths in succes-

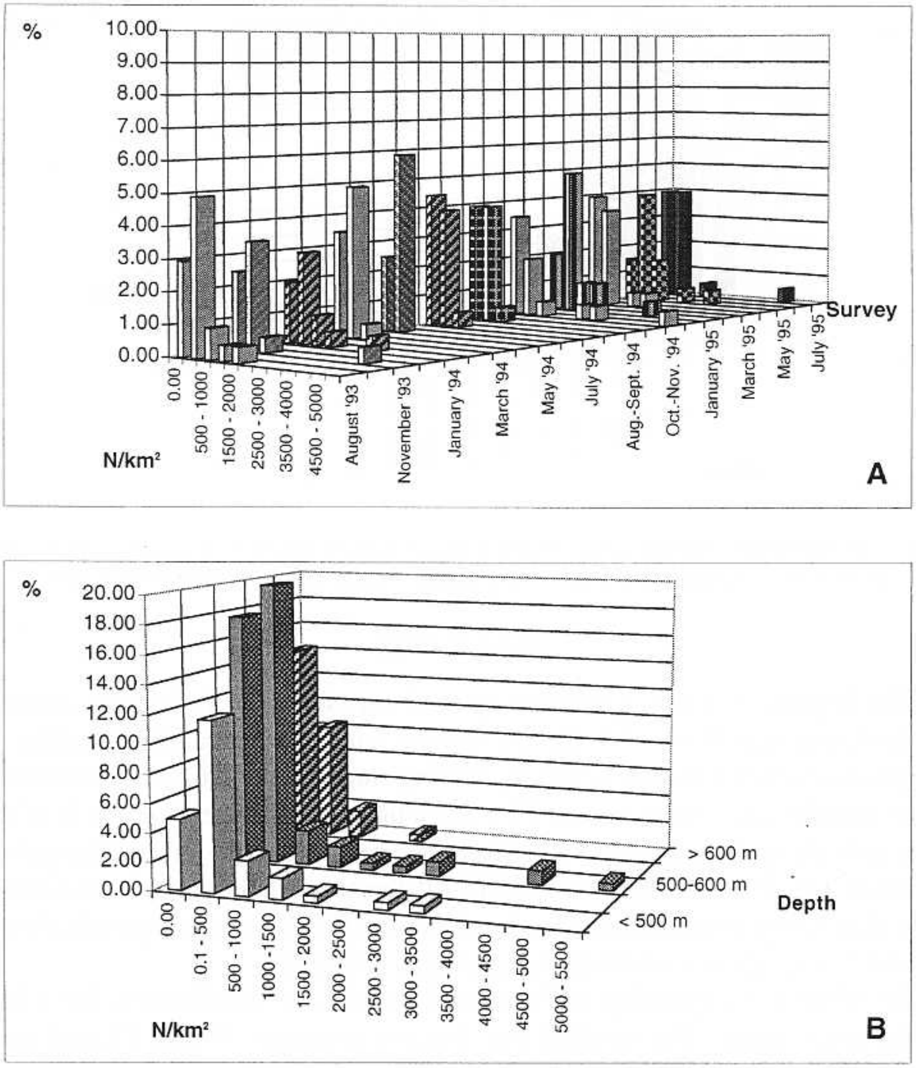


Fig. 2. Distribution of density values (N/km^2) related to each survey (A) and depth range (B) for *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea from August 1993 to July 1995.

sive months until May, when very small individuals were mainly caught in the upper 500 m. According to their growth these juveniles together with the adults first, during summer, shifted to the greatest depths and then, during autumn, rose again to the uppermost bottoms (i.e., the shallowest areas). However, during May and July 1995 the population was mainly found between 500 and 600 m.

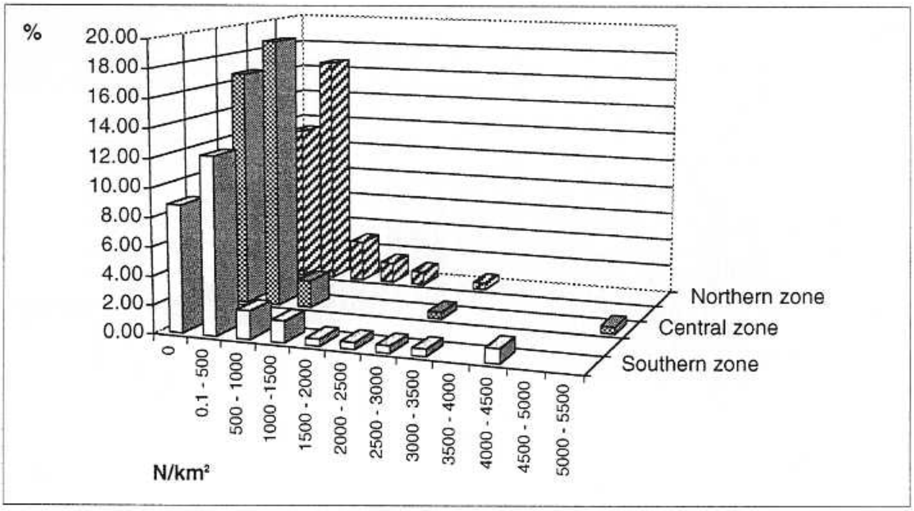


Fig. 3. Distribution of density values (N/km^2) related to each zone for *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea from August 1993 to July 1995.

Reproduction

The beginning of the reproductive period was shown to be in May with females larger than 36 mm CL (fig. 5). Mature females were caught from May to September with the highest percentage during August 1993 (26.85%, considering only females larger than 36 mm CL). The immature specimens (stage 1) of the first cohort found during May will reach the spawning stages during the spring-summer season of the successive year. All females caught between November and March of both years were immature; during this latter month gonadic development (stage 2) was observed in some large specimens.

Both immature, maturing and mature females were found across the whole bathymetric range. The smallest ripe females measured 33 mm CL and were found during July 1994.

Concerning the presence of spermatophores on the thelycum, females with these sexual structures were observed in each period with the highest percentage during March and May of both years. The smallest females bearing spermatophores measured 23 mm CL and were found during summer (fig. 6).

Considering the size involved in mating, this process was observed to start in March and to continue even after the reproductive season for almost all largest females. Females without spermatophores were generally immature while mature females without sexual structures represented 6.5%.

Concerning reproductive aspects by size, the logistic function better fits data on the presence of spermatophores than those of maturity for each size (fig. 7).

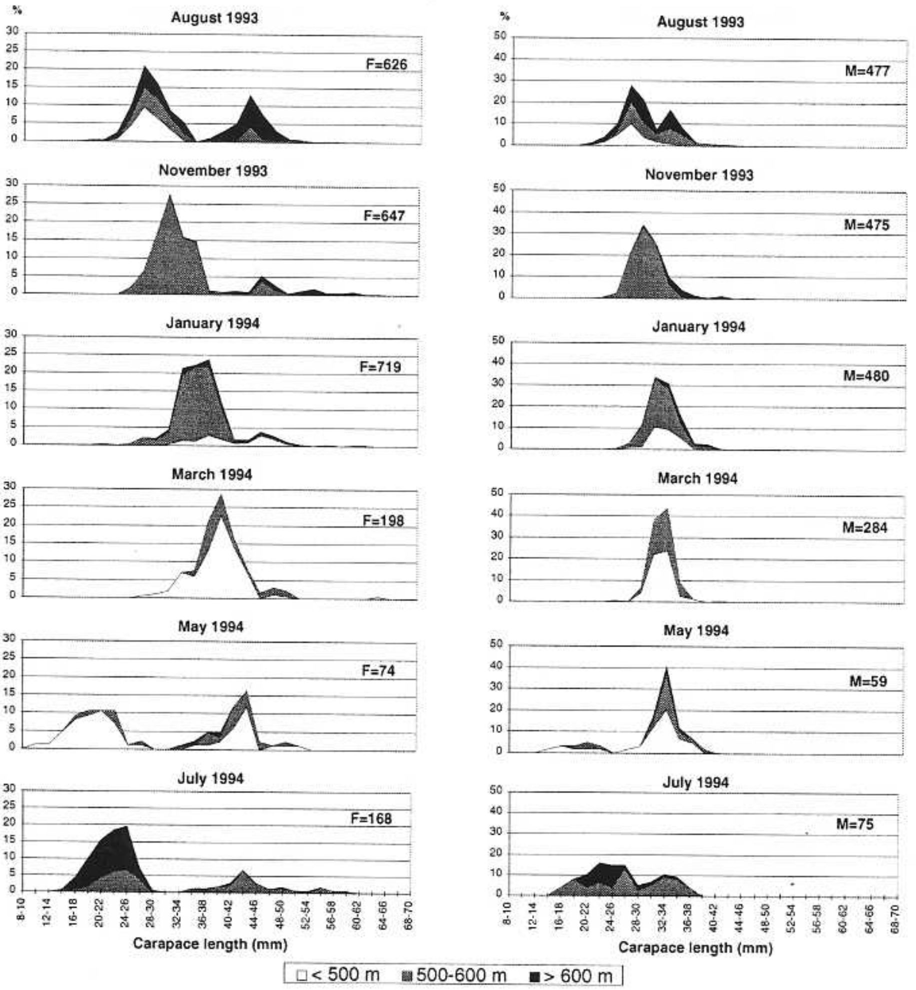


Fig. 4a. Length-frequency distribution by depth of females and males of *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea from August 1993 to July 1994.

In fact, the proportion of ripe females of each size, evaluated for pooled data of the reproductive season, shows a sharp increase with carapace length and high changes over 51 mm CL. Such a heterogeneity gave a marked difference between the observed and expected size at which 50% of females was mature: 43 mm CL and 47 mm CL, respectively.

The percentage of females bearing spermatophores at each size increases quickly with size exhibiting, however, some shifting from 100% even for the largest carapace lengths. These large females had probably only accidentally lost spermatophores. The size at which 50% of females had spermatophores was 39.34 mm CL.

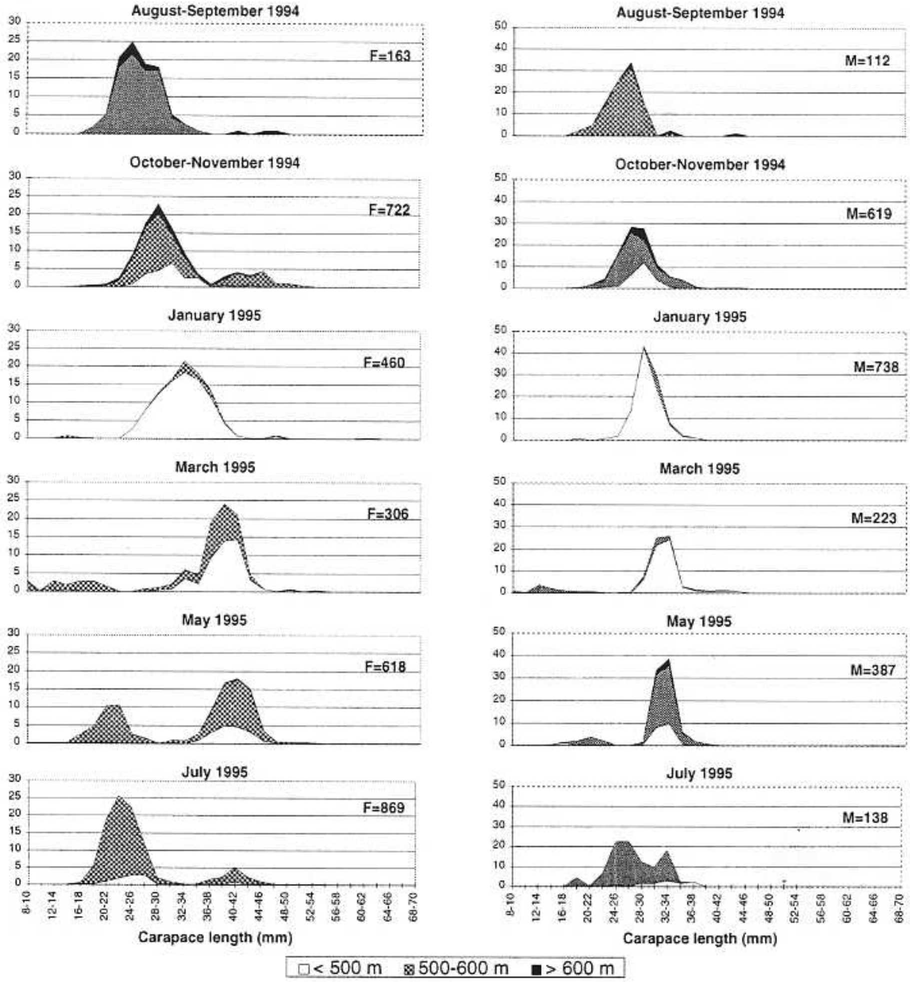


Fig. 4b. Length-frequency distribution by depth of females and males of *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea from August-September 1994 to July 1995.

The intersection of the logistic function for maturity and absence of spermatophores for each size gave the size of "maximum reproductive potential" of 37.11 mm CL (fig. 8).

With regard to the maturity stage of gonad in males, mature individuals were found during each survey with the highest percentage between January and May of both years (fig. 9). From August-September to November the majority of males was immature and only individuals larger than 25 mm CL presented developed spermatophores.

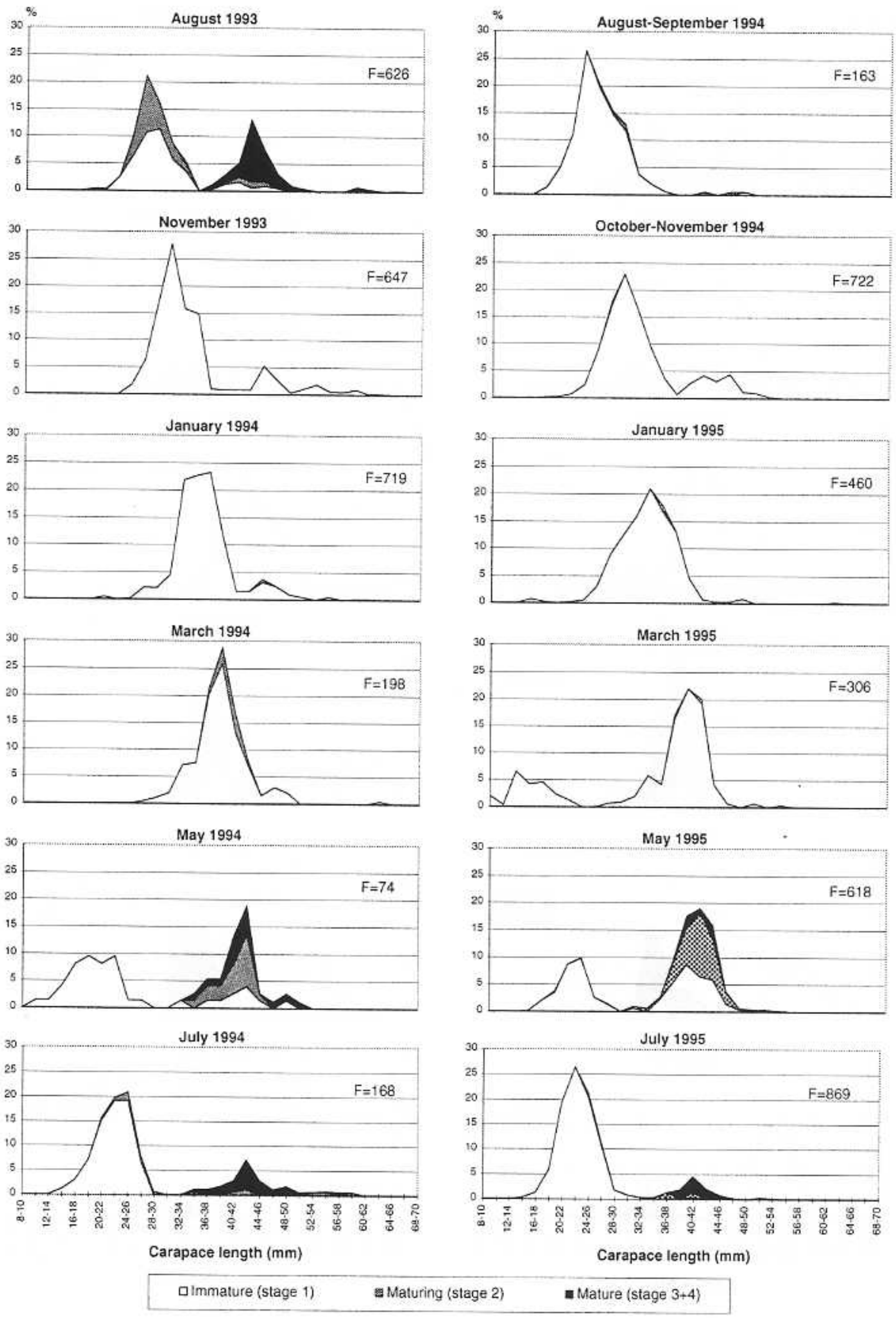


Fig. 5. Length-frequency distribution by maturity stage of *Aristaeomorpha foliacea* (Risso, 1827) females caught in the north-western Ionian Sea.

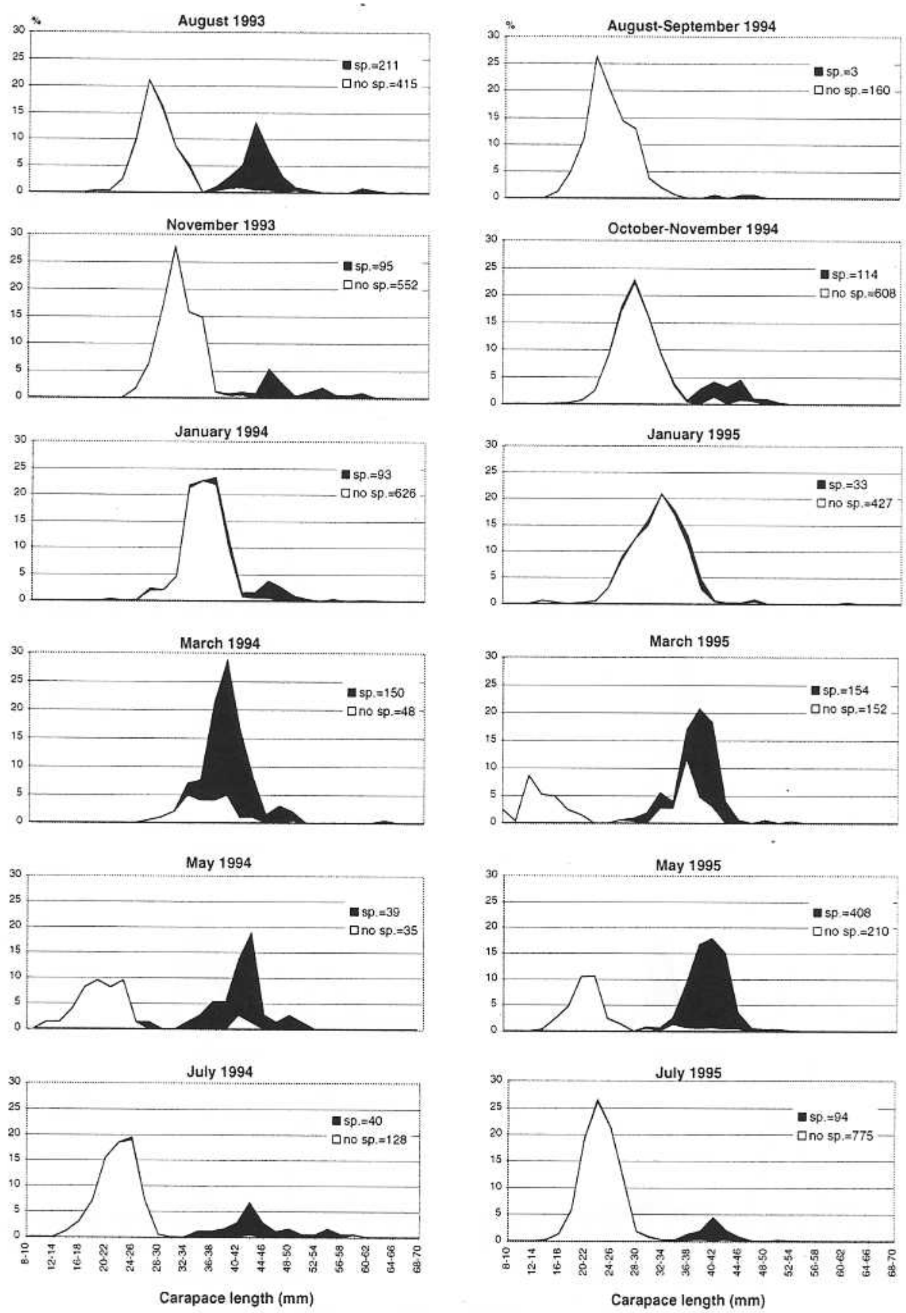


Fig. 6. Length-frequency distribution by presence (sp.) and absence (no sp.) of spermatophores for *Aristaeomorpha foliacea* (Risso, 1827) females caught in the north-western Ionian Sea.

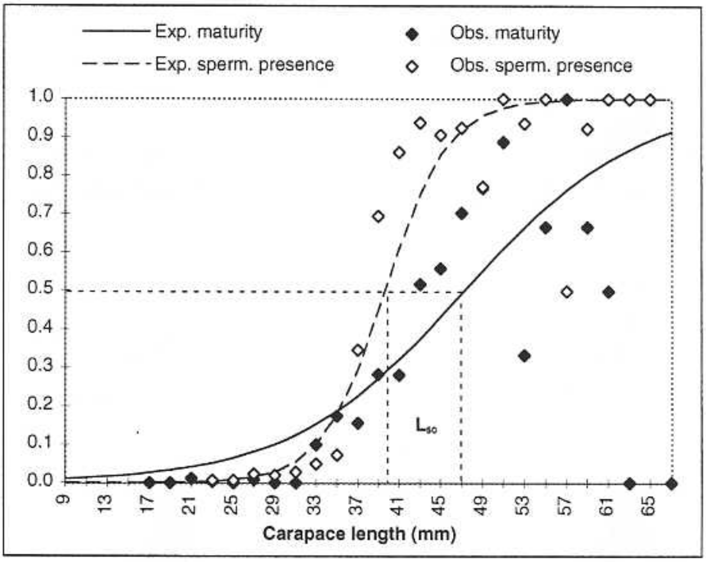


Fig. 7. Expected and observed percentage by size of mature females and females with spermatophores of *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea.

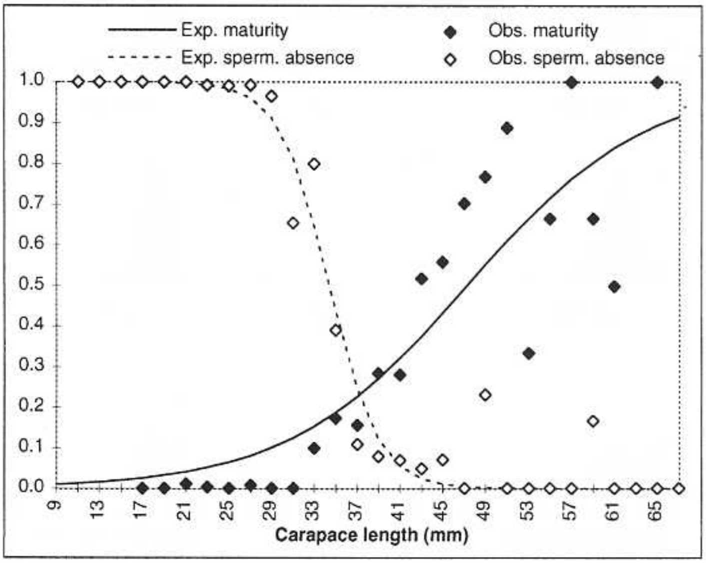


Fig. 8. The size of "maximum reproductive potential" for females of *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea.

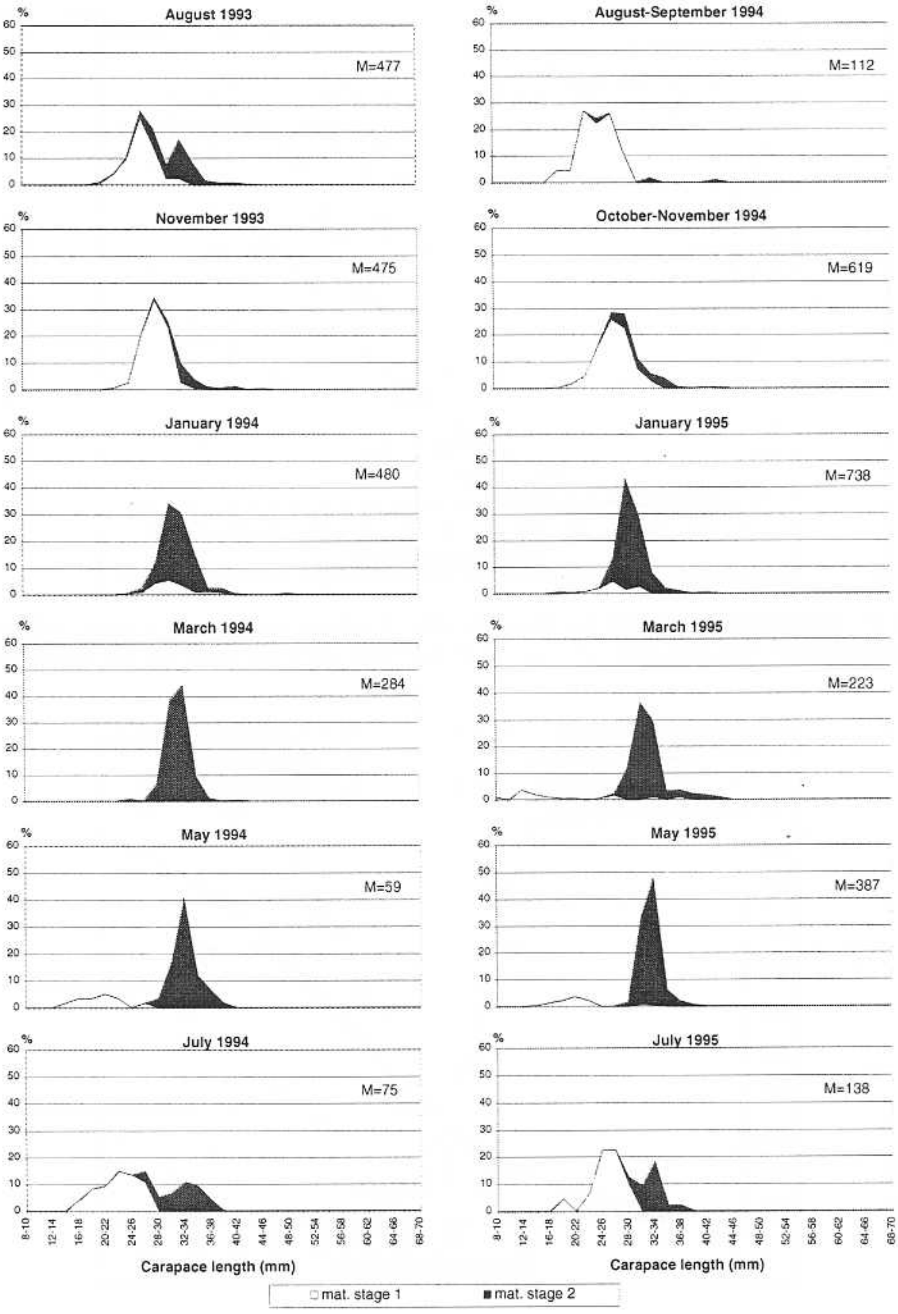


Fig. 9. Length-frequency distribution by maturity stages of *Aristaeomorpha foliacea* (Risso, 1827) males caught in the north-western Ionian Sea.

The smallest mature male measured 26 mm CL and was found in July 1994. Size at first maturity changed during the year. Both immature and mature males were caught in the whole investigated depth range.

Sex ratio

The sex ratio of *Aristaeomorpha foliacea* was in favour of females during each survey with exception of March 1994 and January 1995 when males were more abundant than females (fig. 10). G-test for the whole study period gave highly significant result ($G_{11} = 653.2$; $P < 0.01$).

Considering the sex ratio by season and depth, the females were more abundant than males in summer and spring in all depth strata and during autumn on the deepest bottoms while males were around 50% and outnumbered females above 500 m during autumn and winter respectively (fig. 11). The difference between changes in the number of females and males with depth was statistically significant during each season (summer: $G_2 = 10.2$, $P < 0.01$; winter: $G_2 = 72.2$, $P < 0.01$; spring: $G_2 = 16.8$, $P < 0.01$) with the exception of autumn ($G_2 = 3.2$, $P > 0.05$).

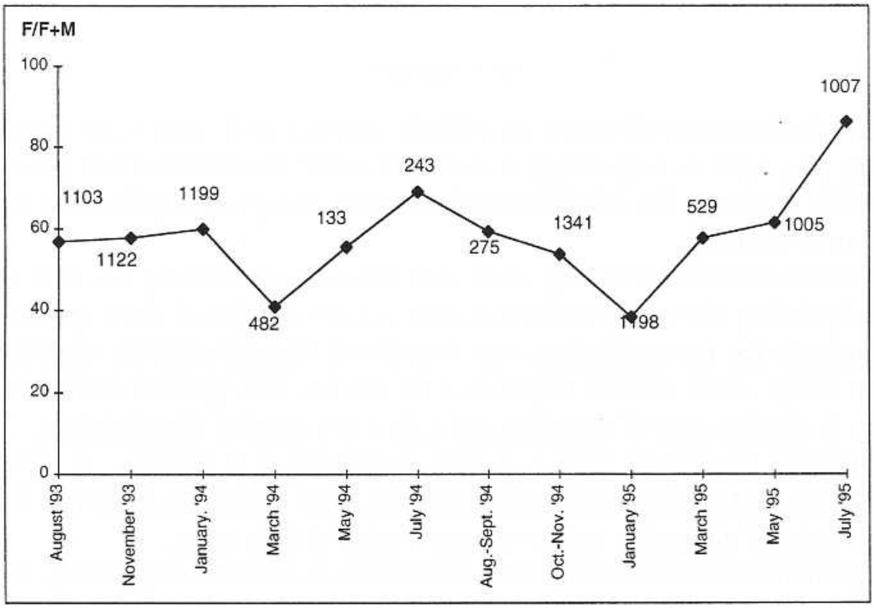


Fig. 10. Sex ratio, with indication of the total number, of *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea.

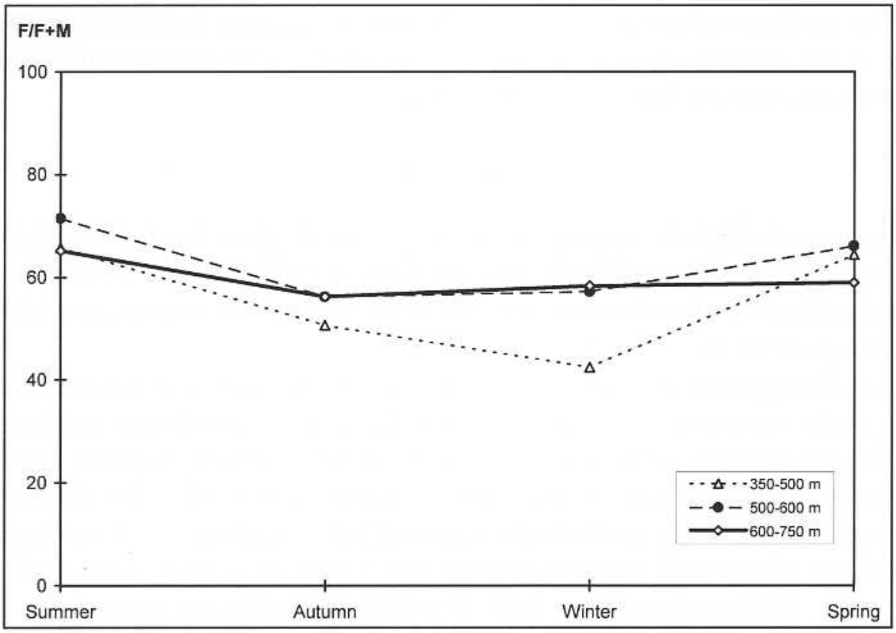


Fig. 11. Sex ratio by season and depth of *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea.

Size structure

The size-frequency distributions of both sexes in each survey are presented in figs. 12a, 12b. A wide range of size with a multimodal trend was generally shown in females. The minimum and maximum carapace lengths were 9 and 65 mm, respectively.

A remarkable number of very small individuals (< 24 mm CL) was found particularly during the spring-summer season. A large number of these specimens, belonging to the new generation, was found from March during the second year of the study. Adult females larger than 50 mm CL were present almost exclusively in the first year of sampling and with a low number of individuals.

The range of sizes in males was more limited than in females. A compact distribution appeared concentrated around the mean size value, however, it was rather bimodal during the spring-summer period of both years.

The minimum and maximum sizes were 9 and 45 mm CL, respectively. Small specimens (< 24 mm) in males were also mostly observed during spring-summer. Individuals larger than 40 mm were mainly found during August in 1993 and from August-September 1994 until March 1995.

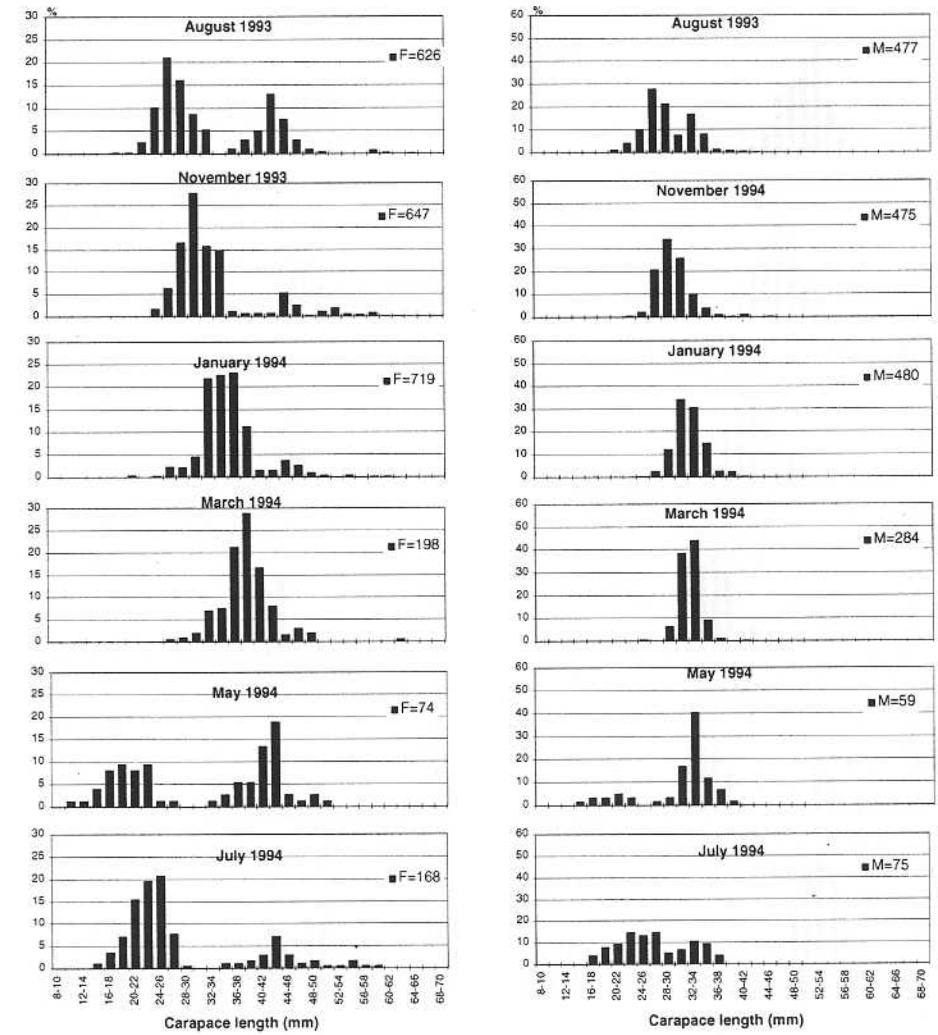


Fig. 12a. Length-frequency distribution of females and males of *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea from August 1993 to July 1994.

While a very slight increase in size was shown with depth in both sexes no differences were observed in the length-frequency distribution pattern of both females and males in the three investigated zones.

Growth

The size-frequency distributions of both sexes showed a clear modal progression (figs. 12a, 12b). Particularly, the female size classes of 26-28 mm and 42-44 mm CL found in August 1993 reached the length of 42-44 mm CL and 54-56

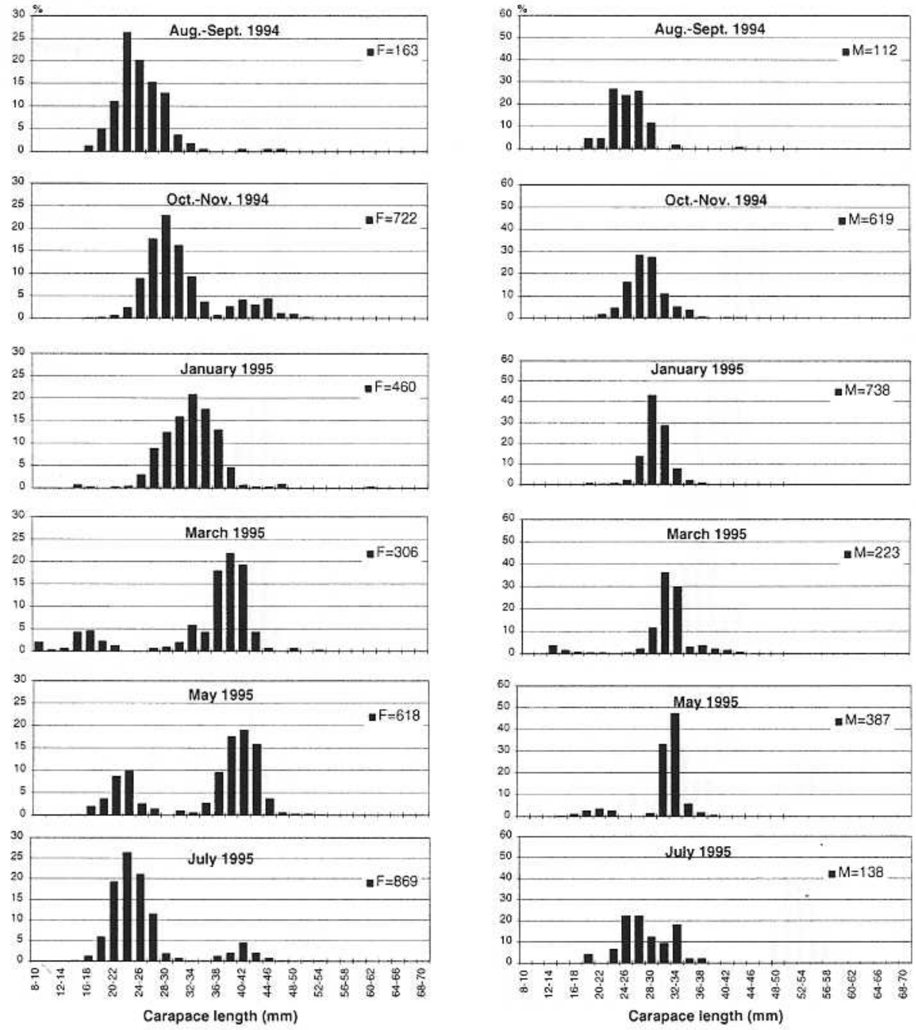
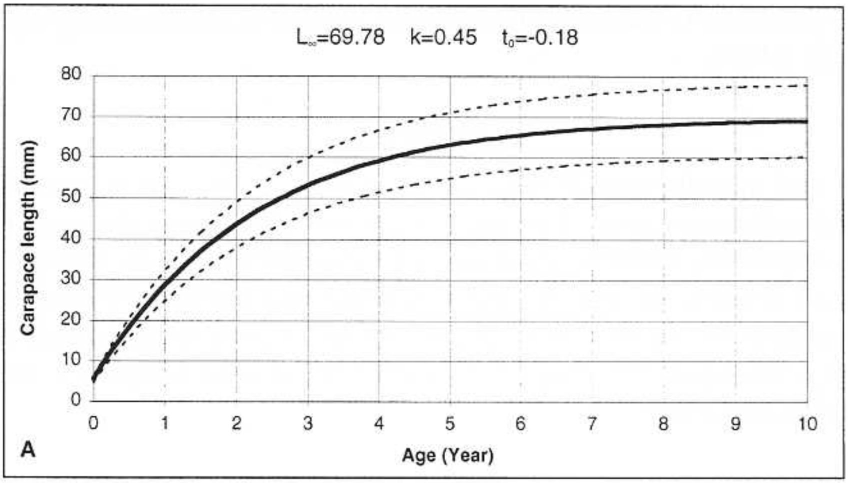


Fig. 12b. Length-frequency distribution of females and males of *Aristaeomorpha foliacea* (Risso, 1827) caught in the north-western Ionian Sea from August-September 1994 to July 1995.

mm CL respectively during July 1994. Juveniles found in May 1994 attained a size of 40-42 mm CL after one year (May 1995). The young-of-the-year observed in March 1995 reached the size of 22-24 mm CL in July of the same year.

Males also exhibited a clear progression of the modes. Individuals of about 26 mm CL found in August 1993 reached about 34 mm CL during July 1994. The same trend was shown from this latter survey to July 1995. Recruits found in March 1995 attained the size of about 24 mm CL in July.



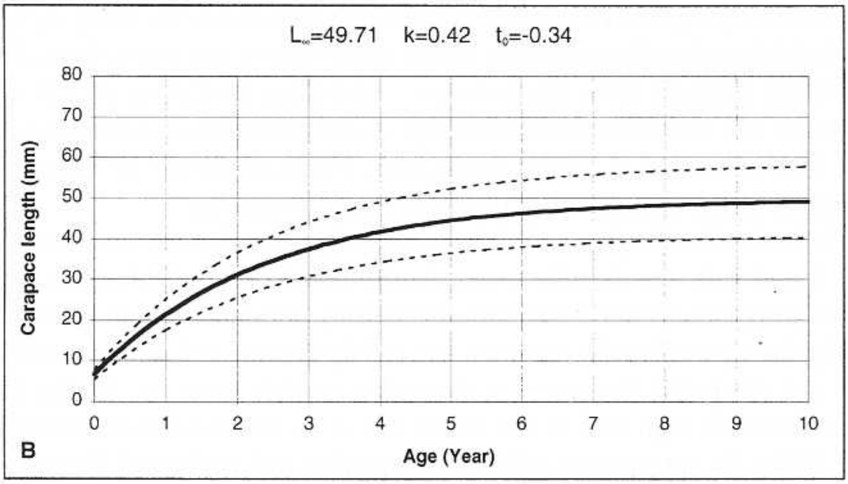


Fig. 13. Growth curve, with relative confidence interval, of *Aristaeomorpha foliacea* (Risso, 1827) females (A) and males (B) caught in the north-western Ionian Sea from August 1993 to July 1995.

By means of the Bhattacharya method it was possible to distinguish up to 4 modal groups in females and 3 in males. Growth rates of the modal groups fitted a Von Bertalanffy function (fig. 13) with the following parameters (confidence intervals are in brackets):

females: $L_\infty = 69.78$ mm CL (60.83-78.73); k = 0.45/year (0.29-0.61); $t_o = -0.18$

males: $L_\infty = 49.71$ mm CL (40.87-58.54); k = 0.42/year (0.30-0.53); $t_o = -0.34$

The parameter t_0 was computed by using the empirical relationship reported by Pauly (1983).

Mortality

The total mortality rate (Z) was estimated for the pooled data and considering the first and second years of research separately. Concerning the pooled data (August 1993/July 1995) the Z values for females and males were 0.95/year and 1.25/year, respectively. For the first year of research (August 1993/July 1994) total mortality rate was 0.87/year in females and 1.12/year in males while in the second year (August 1994/July 1995) it was 1.30/year and 1.73/year in females and males, respectively.

DISCUSSION AND CONCLUSIONS

Aristaeomorpha foliacea was found on muddy bottoms of the bathyal grounds with the highest densities generally in the upper 600 m and along the Calabrian coast where canyons cross the bottoms. According to Cau et al. (1987) the distribution and abundance of this shrimp, as shown for *Aristeus antennatus* (see Sardà, 1993; Cartes et al., 1994; Sardà et al., 1994), could also be linked to the topography of the continental slope and submarine canyons.

In the Ionian Sea the giant red shrimp is less abundant than *Aristeus antennatus* and is found with significantly lower density than in the neighbouring Sicilian Channel (Ragonese, 1989). This different density does not seem to be explained either by the type of benthic communities and by thermic and salinity conditions, which are practically the same in these two marine areas, or by the fishing pressure which is high both in the Ionian and in the Sicilian Channel (Ragonese et al., 1994). In our opinion, other oceanographic and ecological factors, some of which have been discussed for the companion species *Aristeus antennatus* by Relini & Relini Orsi (1987), Sardà & Demestre (1987), Tobar & Sardà (1987, 1992), should be investigated in order to explain the latitudinal gradient shown for the spatial distribution of *Aristaeomorpha foliacea* in the Mediterranean.

Although no significant change of density distribution was observed during the year, a spatio-temporal distribution correlated to bio-ecological aspects was shown in the population. In fact, within a sex ratio slightly in favour of females, indicating very little segregation between the sexes, an increase in males on the fishing bottoms was shown during winter when maturity of this sex begins and shortly after mating occurs in the population. During the winter-spring season males probably rise out of the canyons or from the deepest areas and together with females and juveniles migrate to the upper slope. After the mating peak, in summer, when spawning is at its maximum, the population is again displaced on the deeper grounds, as shown in Sardinian waters (Cau et al., 1987).

An increase in the number of males was also observed in *Aristeus antennatus* during late spring according to mating (Orsi Relini & Relini, 1979; Arrobas & Ribeiro-Cascalho, 1987; Sardà & Demestre, 1987) and the deeper distribution of shoals during summer was correlated to the peak of luminosity in the waters (Tobar & Sardà, 1992). This latter aspect, as reported by Tobar & Sardà (1992), is in agreement with the conviction of fishermen that both *Aristaeomorpha foliacea* and *Aristeus antennatus* have a shallower distribution during winter-spring and shift to the deepest bottoms during summer-autumn.

Data on the reproduction of the Ionian population are in agreement with observations made in the Sardinian (Mura et al., 1992) and Sicilian Channels (Ragonese & Bianchini, 1995). The lowest percentage of females bearing spermatophores were found between November and January with a sharply increasing percentage of mated females, even for small sizes, during March. The ovary maturation period occurs between May and September with the highest frequency of ripe females found in the full summer season. The largest specimens are the first to mate and reach sexual maturity.

The size at which females mate and attain maturity is within the range of observations made in other Mediterranean areas (Cau et al., 1982; Levi & Vacchi, 1988; Mori et al., 1994; Spedicato et al., 1994) while the size of the "maximum reproductive potential" is barely smaller (37.11 mm CL) than that reported by Ragonese & Bianchini (1995) (39.667 mm CL).

Considering that the spawning peak takes place in summer, the young-of-the-year found in March could have an age of 6-7 months while the first cohort identified during July-August could be represented by one year old specimens. In the second year, females and males attain maturity and at the end of the second year of life they reach the size of about 44 mm CL and 32 mm CL, respectively.

The size-frequency distributions were consistent during the two years of research and both sexes showed a clear asymptotic growth pattern. The overall growth performance is in agreement with that estimated in the central-southern Tyrrhenian Sea (Spedicato et al., in press) and in the Sicilian Channel stock (Ragonese et al., 1994) even though, the Von Bertalanffy parameters estimated by the latter authors indicated a faster growth for both sexes within the first two years.

On the basis of the maximum sizes observed in the Ionian population a life span of about 7-8 years in females and 5-6 years in males can be assumed to be realistic.

However, the Ionian stock of the giant red shrimp mostly consists of young individuals. Indeed individuals older than the first two age classes are not abundant in bottom trawl catches probably due to the fishing carried out in the area. This size/age structure resembles that observed in the central-southern Thyrrenian Sea (Spedicato et al., in press) while it is different from that reported from Sardinia (Cau et al., 1982) and more so from the Sicilian Channel stock (Ragonese et al., 1994) where both juvenile and adult individuals are abundant throughout the year.

The size-frequency distribution of a particular stock derives from its pattern of recruitment, growth and mortality. So that differences in size structure between stocks of the same species depend on changes in this population parameters. The Ionian stock of *Aristaeomorpha foliacea* appears to be "mortality-dominated" ($Z/k > 1$) (Barry & Tegner, 1990). Even though for this species a "type III survivorship curve" (Deevey, 1947), with high juvenile mortality followed by high adult survival, can be assumed, the fishing mortality maintains a high Z value even for adult individuals. For the Ionian giant red shrimp stock, Z seems always to be greater than k and size-frequency distributions are dominated by juveniles. This is even more probable considering that *Aristaeomorpha foliacea*, as predator species at the top of its trophic web (Lagardère, 1972), is particularly subject to the "top-down" effect of fishing (Larkin, 1996).

Thus a total mortality rate (Z) for the Ionian stock higher than that for the Sicilian Channel (Ragonese et al., 1994) appears to be reliable. Moreover, considering the discrete recruitment observed in a restricted period of the year, the Hoenig (1987) approach seems to be suitable for this shrimp, although significant changes can occur from year to year.

Total mortality rate would result higher if "constant parameters system" methods, such as "length converted catch curve" (Sparre et al., 1989), were employed, as observed for the same stock (unpublished data) and for the central-southern Tyrrhenian stock (Spedicato et al., in press) with a similar size-frequency pattern.

Although a lot of literature exists on the estimation methods for natural mortality rate (Vetter, 1988), the assessment of this population parameter remains an open question. Various empirical methods provide controversial results. With the available information on the life-history of marine species, to say what is the most suitable estimate of natural mortality rate becomes a purely speculative exercise often deriving from the necessity to evaluate exploitation conditions of a stock.

Concerning deep water shrimps, *Aristaeomorpha foliacea* and *Aristeus antennatus*, the average values of 0.5 for females and 0.6 for males seem to be suitable

(Yahiaoui et al., 1986; Sardà, 1988; Demestre & Martin, 1993; Ragonese et al., 1994; Spedicato et al., 1994; Ragonese & Bianchini, 1996).

Considering the range of Z values obtained for the two sexes of *Aristaeomorpha foliacea* in the Ionian Sea and M values of 0.5 and 0.6 for females and males respectively, the exploitation ratio ($E = F/Z$) for this shrimp, in this Mediterranean basin, would be between 0.43 and 0.62 in females and between 0.46 and 0.65 in males. These estimated values, for females, are also higher than that observed in Sicilian Channel stock (Ragonese et al., 1994) and in agreement with those indicated for the central-southern Tyrrhenian stock (Spedicato et al., in press). Despite differences that may derive from different estimation methods, the above exploitation ratio values appear to be reasonable in view of the above discussion on size-frequency distribution, confirming for the giant red shrimp a high vulnerability to trawling in the Ionian Sea (Tursi et al., 1993; Matarrese et al., 1997).

Since exploitation begins in the first juvenile stages, the closed season during the recruitment period together with the regulation of a larger mesh size for deep-water trawling (Caddy, 1990, 1993) represent necessary management measures for this resource.

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