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Fishery and Biology of *Aristaeomorpha foliacea* (Risso, 1827) (Crustacea: Decapoda) in the Northern Tyrrhenian Sea (Western Mediterranean)

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Abstract

The aim of the study was to provide information about the fishery, population size structure, breeding period and size at maturity of giant red shrimp, *Aristaeomorpha foliacea*, of the northern Tyrrhenian Sea, Italy. Data were collected directly at the local auction of Porto Santo Stefano, the main landing port of the study area, from 1991 to 1998 and during monthly surveys carried out during the year 1995. In Porto Santo Stefano the annual landing of red shrimps ranged between 2 and about 17 tons, corresponding to an annual average first sale income of 170–200 000 Euros. The fishery activity depended on season and vessel and the monthly landings per unit effort ranged from less than 1 to 35 kg/day/boat, although the catch of a single boat could reach values up to 80 kg/day. Size composition of *A. foliacea* ranged from 14 to 46 mm carapace length (CL) for males and from 14 to 66 mm CL for females. Recruitment occurred mainly in spring. The overall sex-ratio observed (1.10:1) was significantly biased towards females. Females begin to be mature in March, reaching a peak between July and August. From October to March most females had resting gonads. Mature males were found all year round. Females with spermatophores on the thelycum were found throughout the year, the highest percentages being recorded from March to September. The average size at sexual maturity was 40.59 mm CL. The average size of maximum reproductive potential was 37.15 mm CL.

Key words: *Aristaeomorpha foliacea*, Crustacea, Decapoda, Mediterranean, red shrimp fishery, reproductive biology, Tyrrhenian Sea

Introduction

One goal in studies on reproductive ecology of benthic crustaceans is to make and test generalizations about geographical variations in patterns of reproduction and recruitment. Such paradigms are useful for generating hypotheses about the specific environmental stimuli (proximate factors) and selective pressures (ultimate factors) that are responsible for breeding and recruitment patterns observed, as well as, for making predictions about possible changes in reproduction and recruitment due to natural fluctuations or anthropogenic alterations in these factors (Bauer and Rivera Vega, 1992). Further, knowledge of the dynamics of the reproductive process, which constitutes the basis of resource renewal, provides the suitable background for management direction (Crocos, 1987).

Because of its importance on the bathyal fishery grounds of the Mediterranean Sea, a number of papers have addressed the biology, ecology and fishery of the giant red shrimp *Aristaeomopha foliacea* (Risso, 1827). Most of the information relates to Italian waters of the central Mediterranean (Cau and Deiana, 1982; Cau *et al.*, 1982; Ragonese, 1989; 1995, Mura *et al.*, 1992; Bianchini and Ragonese, 1994; Ragonese *et al.*, 1994, 1997; Matarrese *et al.*, 1995;

Ragonese and Bianchini, 1995; D'Onghia *et al.*, 1998; Bianchini *et al.*, 1998; Bianchini, 1999). Only scanty attention is devoted to the western basin (Lumare and Utzeri, 1973; Bianchini and Ragonese, 1994).

The northern Tyrrhenian Sea (western Mediterranean) is an important commercial fishery area for bathyal decapod crustaceans and *A. foliacea* is the most valuable deep-water resource (De Ranieri *et al*., 1994; De Ranieri, 1995; Ardizzone and Corsi, 1997; Biagi *et al*., 1998). Despite this, very little information is available on the life cycle of the species (Mori *et al*., 1994). The aim of present study was to provide information about the biology and fishery of *A. foliacea* inhabiting the northern Tyrrhenian Sea in order to carry out comparative regional studies and pinpoint differences.

Materials and Methods

The study was conducted at Porto Santo Stefano, Italy, the main landing point of the northern Tyrrhenian Sea, western Mediterranean. Landing data of *A. foliacea* from the bottom trawl fleet were recorded during three to five days per month at the local auction from 1991 to 1998. Monthly total landings were estimated raising the sampled data to the total fishing days of the fleet in that month. The Landing Per Unit of Effort (LPUE) was calculated considering the fishing day as a unit of effort. Fishing effort data were calculated monthly by consulting the official archives. In the years 1995 to 1999 fishing activity was monitored, on a seasonal basis, by observations on board of commercial vessels fishing for Norway lobster and aristeid shrimps. In the sampled period, information from about 500 trawling hours was gathered. The collected data were analysed as hourly yields (kg/hr) and then studied on a seasonal basis.

Specimens of the giant red shrimp were collected by means of monthly sampling performed between January and December 1995 off the Tuscan Archipelago (northern Tyrrhenian Sea) at depths between 400 and 650 m. The study area is shown in Fig.1. Samples were collected by trawlers using a professional trawl net with mouth height of about 1 m and codend width of about 20 m. Mesh size was about 40.0 mm stretched. During the months of February and December the sampling was not carried out because of bad weather.

For each specimen, the carapace length (CL) was measured, to the nearest mm below, from the right orbital margin to the mid posterior edge of the carapace. Males were distinguished from females by the presence of the petasma and assigned to two maturity stages, according to the scale proposed by Sardà and Demestre (1989) for the companion species *Aristeus antennatus*. The two stages, immature and mature, were based on the presence or absence of sperm sacs on the coxae of the fifth pair of pereiopods. Maturity stages for females were assigned according to the macroscopic colorimetric scale given by Levi and Vacchi (1988) and Kao *et al.* (1999), based on the different colours presented by the ovaries: flesh-colored, immature or spent, Stage I; light gray, maturing, Stage II; dark gray, early mature, Stage III; pale black, ripe, Stage IV. The presence of spermatophore was checked by visual examination of the thelycum.

Maturity condition and presence of spermatophores by size were estimated by fitting a logistic equation; in order to estimate the percentage of mature females in each size class, Stage III and Stage IV were combined. On the basis of two functional criteria (Morizur, 1983), maturity of gonads and presence of spermatophores, the size at the "maximum reproductive potential" was estimated. It was defined as the size corresponding to the intersection of the gonadic maturity curve and the mating complementary curve (i.e. absence of spermatophore) during the maximum reproductive activity of the stock (Ragonese and Bianchini 1995; D'Onghia *et al.,* 1998).

Two moult stages were determined for both sexes, intermoult and postmoult, depending on the state of the exoskeleton: completely calcified in the former and at the beginning of calcification with a paper-like consistency in the latter. Significant deviations from the expected 1:1 sex ratio were tested using a χ^2 test (Scossiroli and Palenzona, 1978).

Results

The observations on board of trawlers of Porto Santo Stefano allowed the identification of two fishing grounds for red shrimps located on bottoms from about 450 to 650 m. The first is located westward of Pianosa and Montecristo Isles, the second between the Isles of Giglio and Montecristo (Fig. 1). Only a few boats operate in the area westward of Pianosa and Montecristo Isles. In the second area, the majority of trawlers of medium-large size (up to 700 kW engine power) from Porto Santo Stefano carry out their

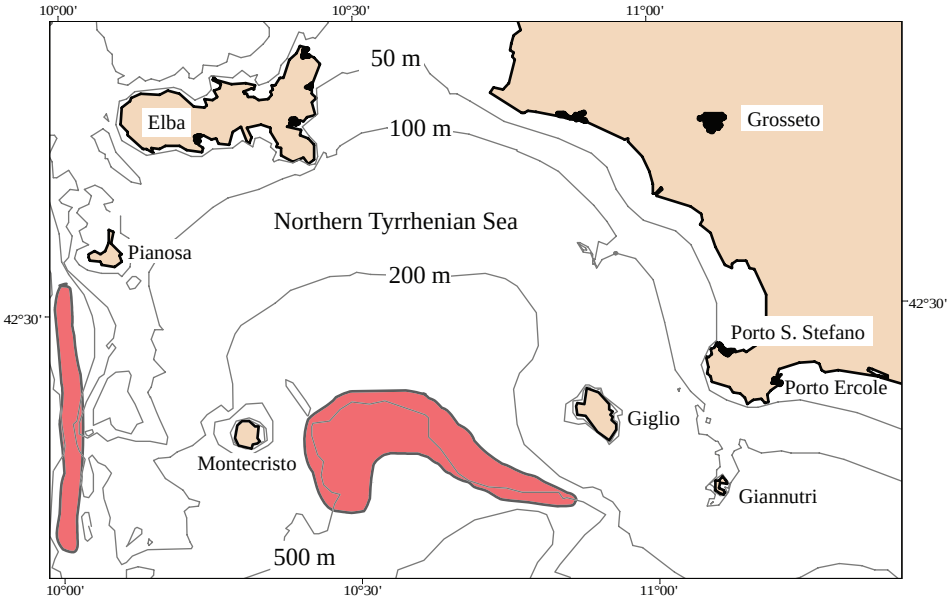

Fig. 1. Study area in the western Mediterranean.

fishing activity, devoted to red shrimps and Norway lobster, mostly during spring and summer. In both fishing grounds, *A. foliacea* was one of the target species, representing up to one third of the total commercial catch and was more important with respect to the companion species *A. antennatus,* ranging from 72% to 99% of the red shrimp average yield (kg/hr). The maximum yields observed were reached during the spring; due to the low fishing activity, data were not available for the winter season (Table 1).

In the period analysed, the annual landing in Porto Santo Stefano of red shrimps ranged between 2 and 17 tons, corresponding to an annual average first sale income of 170–200 000 Euros. Basically, the fishing activity depended on season and vessel; the monthly LPUE registered at the Porto Santo Stefano auction ranged from less than 1 to 35 kg/day/boat, although the catch of a single boat could reach values up to 80 kg/day (Fig. 2). Monthly average LPUE were characterised by a clear seasonality, with the highest values in late spring-summer.

During the monthly sampling at sea, a total of 5 293 individuals of *A. foliacea* (2 780 females and 2 513 males) were collected in the investigated area. The maximum carapace lengths observed for males and females were 46 mm and 66 mm, respectively, females attaining larger sizes than males (Fig. 3). The minimum size recovered was 14 mm CL. Small individuals with modal length around 20–22 mm CL were present during the spring months.

The overall sex-ratio observed (1.10:1) was significantly biased towards females ($\chi^2 = 13.5$; $P<0.005$). The sex-ratio was near unity in the smallest size classes, but favoured males in intermediate classes and females in the largest classes. The monthly sex ratio showed a predominance of females from January to April, in September and November, while males predominated in August and October; from May to July the sex ratio did not differ significantly by 1:1 (Fig. 4).

Reproductive biology

Females of *A. foliacea* displayed seasonal sexual maturity (Fig. 5). Females started maturing in March and reached peak values between July and September. From October to March–April, most females were immature or had resting gonads (Stage I). The rare females caught in October with gonads at the Stage II probably reabsorbed their ovaries. The smallest mature female was observed in July at the size of 28 mm CL. Sexually mature males were always present, showing no evidence of a seasonal maturity cycle. The smallest mature male was registered at the size of 30 mm CL.

Females with spermatophores on the thelycum, indicating that mating had taken place, were observed throughout the year, although most of them were found from March to September (Fig. 6). The smallest females bearing spermatophores, measured 28 mm CL and was found in September.

TABLE 1. Seasonal mean yields per hour of red shrimps from 1995 to 1999; SE = standard error.

	Winter	Spring		Summer		Autumn	
		Mean	SE	Mean	SE	Mean	SE
A. foliacea		3.274	0.765	0.837	0.535	0.973	0.954
A. antennatus		0.505	0.061	0.324	0.301	0.053	0.051

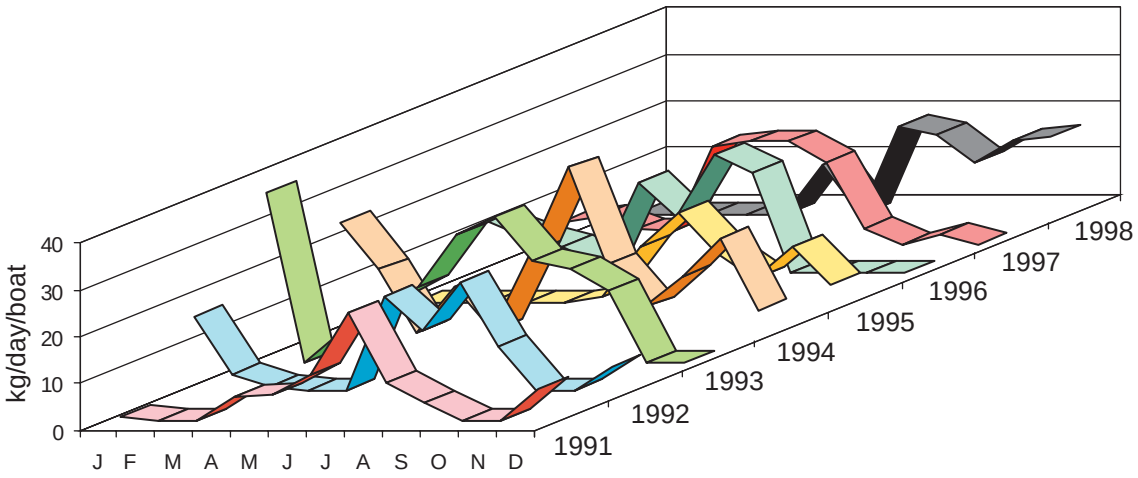

Fig. 2. Monthly LPUE of red shrimps *A. foliacea* and *A. antennatus* recorded at Porto S Stefano, the main landing point of the northern Tyrrhenian Sea.

The reproductive aspects by size were evaluated pooling data from April to September, the period of maximum reproductive activity. The size at which 50% of females were mature (Stage III and IV) was 40.59 mm CL, while 35.54 mm CL corresponded to the size at which 50% of females had spermatophores (Fig. 7 and 8). Large females without spermatophores were very few; they had probably lost them accidentally. The intersection of the logistic function for maturity and for absence of spermatophores gave the size of the "maximum reproductive potential" of 37.15 mm CL (Fig. 9).

Moulting

Moulting activity was performed all year long. Figure 10 shows the percentage of postmoulting males and females caught during the monthly samplings. In both sexes, catches of postmoulting individuals were high in spring and autumn, and very low in summertime. In males, moult took place mainly in May and September; in females, moult was greater in March and November, before and after the reproductive season.

Discussion

In the northern Tyrrhenian Sea *A. foliacea* is one of the most valuable resources exploited by deep-sea fishery. Catches from fishing grounds at bottom depths greater than 450 m showed that this was an important target species. *A. foliacea* represented up to one third, as biomass, of the total commercial catch, corresponding to a high economic income (first sale price ranging from 20 to 30 Euros/kg). According to the national data series recorded by ISTAT (Italian Central Institute of Statistics), 43 505 tons of red shrimps were landed in the period 1985–96 (ISTAT, 1988–99). This commercial category includes the two species *A. foliacea* and *A. antennatus*, making it impossible to assess individual catch levels. Our investigation and experimental trawl surveys conducted over the last fifteen years (Biagi *et al*., 1998) showed that in the area studied, *A. foliacea* was much more abundant

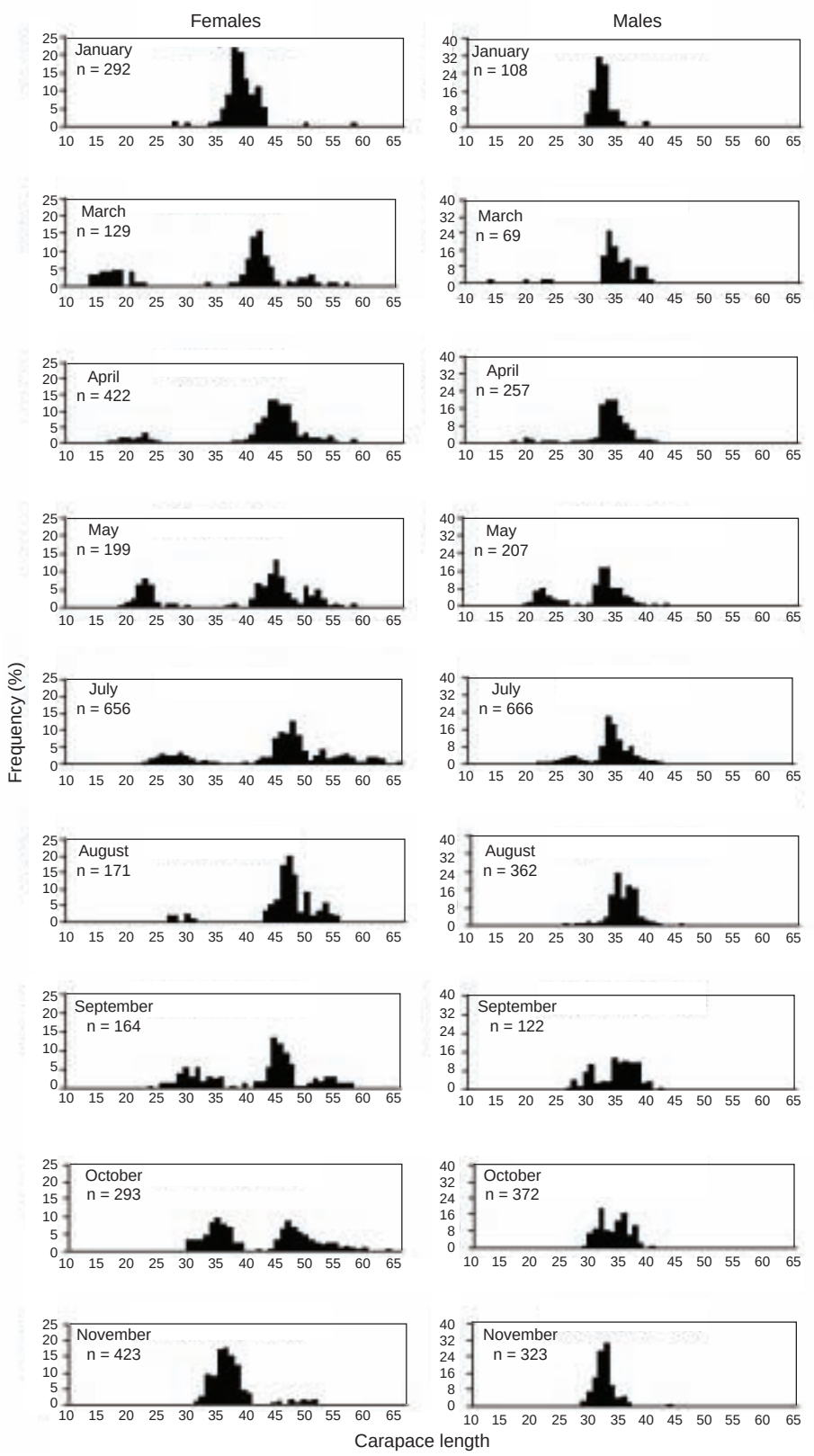

Fig. 3. Size frequency distributions of female and male *A. foliacea* collected during monthly samplings in the northern Tyrrhenian Sea. Samples that did not exceed 50 specimens were excluded.

than the companion species *A. antennatus*, with percentages ranging from 72 to 99% of the total red shrimp catch.

In other areas of the western Mediterranean the opposite trend was observed. In the eastern basin, along the Mediterranean coast of Israel (Thessalou-Legaki, 1994) and in Greek waters (Kapiris *et al*., 1999, 2001) a significantly higher abundance of *A. foliacea* has been reported recently, suggesting that the scanty presence registered previously was due to lack of investigation at greater depths in this area. These recent data on the eastern side of the Mediterranean confirm the general assumption that the abundance of *A. foliacea* seems to follow longitudinal and latitudinal gradients (Campillo, 1994; D'Onghia *et al*., 1998). However, a patchy distribution is also observed. Thus the species is scarce or absent in the Catalan Sea, in the Gulf of Lions and in the Ligurian Sea (Sardà, 1986, Campillo, 1994; Orsi Relini and Relini, 1994), abundant in Tunisia (Ben Marien, 1994) and weakly present in Algeria (Yahiaoui, 1994), outnumbers *A. antennatus* in the northern Tyrrhenian Sea (Campillo, 1994; Biagi *et al*. 1998) and in the Sicilian channel (Ragonese and Bianchini, 1995), is present in almost equal proportions in the southeastern Tyrrhenian Sea (Greco *et al*., 1994) and again less abundant in the Ionian Sea (Pipitone and Andaloro, 1994; D'Onghia *et al*., 1998).

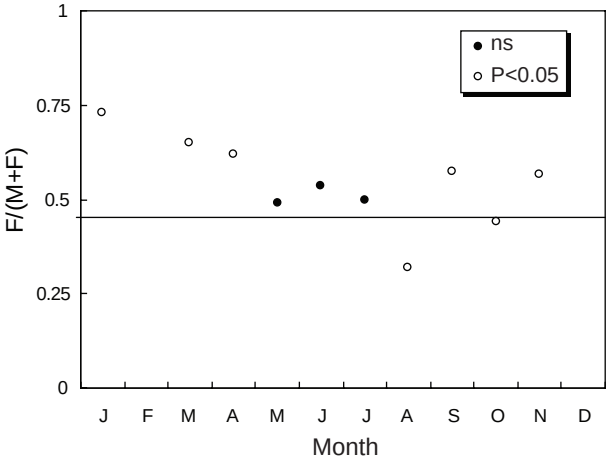

Fig. 4. Monthly sex ratio of *A. foliacea* from the northern Tyrrhenian Sea.

Long term observations of the catches revealed an abrupt decline in certain areas, such as the Gulf of Lions and the Ligurian Sea, followed by a sharp increase of *A. antennatus* (Relini and Orsi Relini, 1987; Campillo, 1994; Orsi Relini and Relini, 1994). Distribution and abundance of the giant red shrimp appear to be linked to the topography of the continental slope and submarine canyons and to trophic and hydrological factors. Although the species has been heavily exploited in the western Mediterranean, the wide fluctuations and decline do not appear to be related to an increase in fishing pressure. Instead, they have

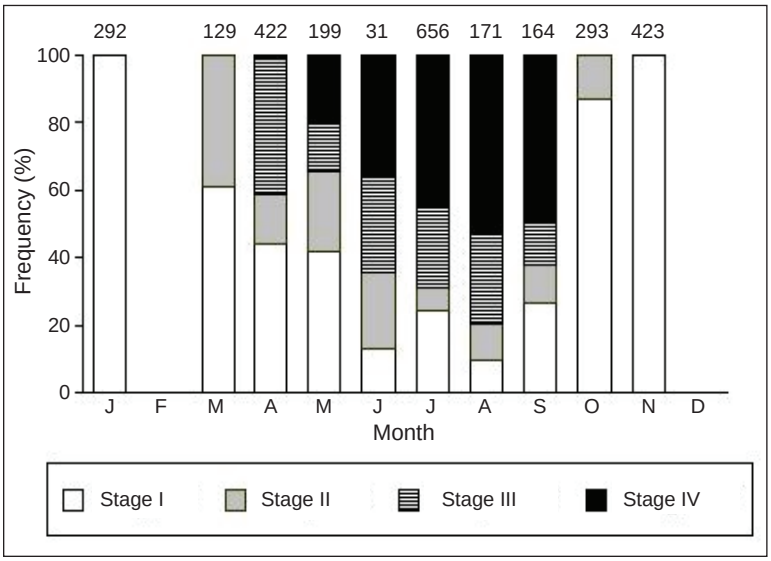

Fig. 5. Maturity stages of female *A. foliacea* from the northern Tyrrhenian Sea. Numbers above each histogram indicate the size of the sample.

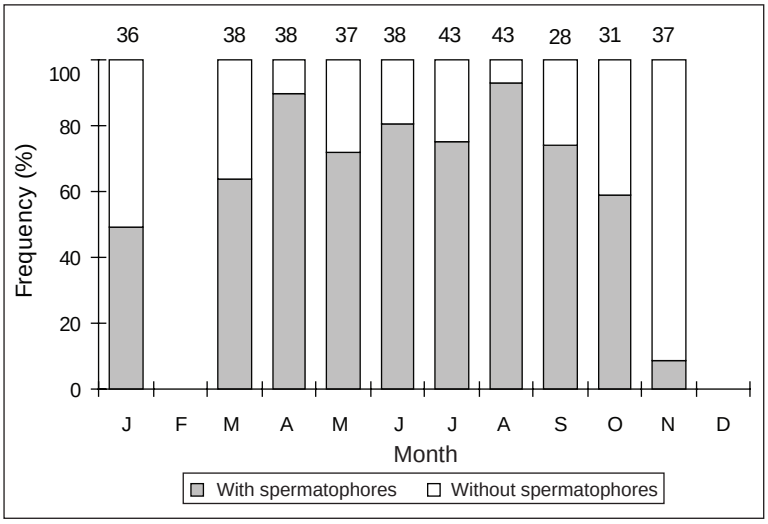

Fig. 6. Monthly percentage of female *A. foliacea* showing the presence or absence of spermatophores. For each month, the minimum size at which females bear spermatophores is indicated above the histograms.

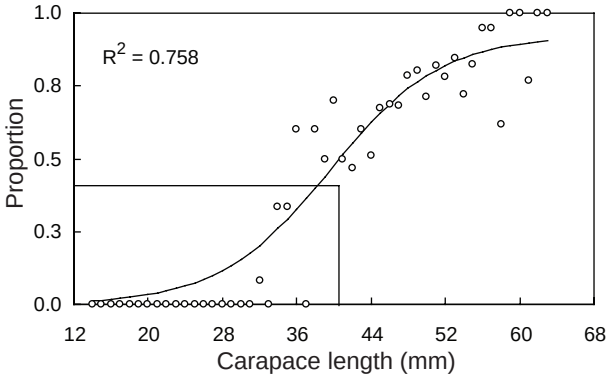

Fig. 7. Percentage by size of mature females (Stages III and IV).

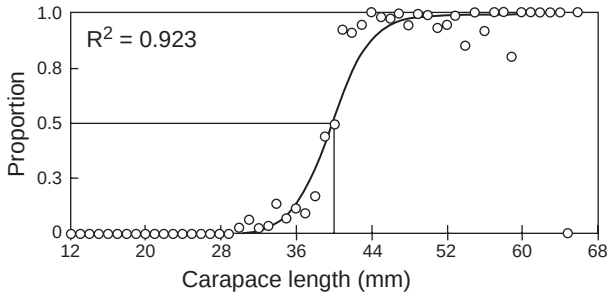

Fig. 8. Percentage by size of females with spermatophores.

been attributed to a close correlation between the presence of the species and variations of hydrological factors. Changes in the water salinity rather than in temperature could explain its disappearance in certain regions of the Mediterranean, as in the Ligurian Sea, where the "Eastern or intermediate water" disappears after mixing with the superficial and deep waters (Murenu *et al.*, 1994).

The marked seasonality of the landings observed in this study is likely to be related above all to the fact that adverse weather conditions during winter often prevent fishing vessels from operating at a distance from the coasts. Size frequency distributions exhibit a wide size range, with females attaining larger sizes than males. The distributions reflect those computed in the same area with specimens gathered by means of experimental trawl surveys based on stratified random samplings (Biagi *et al.*, 1998). Percentage of large individuals is very low. During the spring months, an early component can be found, corresponding to the cohort of trawl net recruits, as already reported in the literature (Ragonese and Bianchini, 1995; D'Onghia *et al.*, 1998; Spedicato *et al.*, 1998).

Monthly variations in the sex ratio, slightly in favour of females or males according to season, indi-

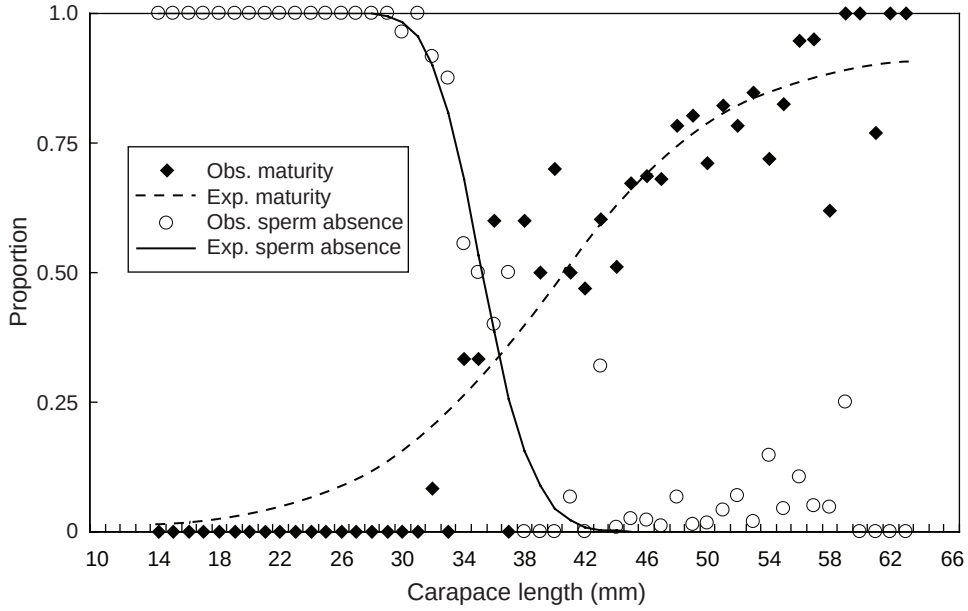

Fig. 9. Size at "maximum reproductive potential" for female *A. foliacea* caught in the northern Tyrrhenian Sea.

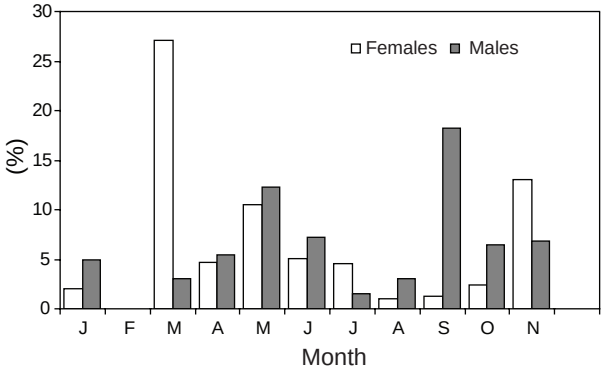

Fig.10. Postmoulting males and females of *A. foliacea* caught in the northern Tyrrhenian Sea.

cate very little segregation between sexes, although the overall sex ratio was biased toward females. The increase in number of males in late spring-summer is ascribed to their rising out of canyons or from the deepest areas for mating, as hypothesized by D'Onghia *et al.* (1998).

Data on reproductive activity are consistent with findings for the central Mediterranean (Cau and Deiana, 1982; Cau *et al.*, 1982; Mura *et al*., 1992; Ragonese and Bianchini, 1995; D'Onghia *et al.*, 1998). Females exhibit an extended reproductive period, from spring to autumn, with a peak between July and September. Mating activity is observed all year long, but the percentage of females bearing spermatophores is lower during autumn and winter. In the southeastern Mediterranean, the overall reproductive period is similar, but the peak is shifted one month earlier, in June (Kapiris and Thessalou-Legaki, 2001). Our findings on size at first maturity and at maximum reproductive potential are similar to those estimated for other areas (Ragonese and Bianchini, 1995; D'Onghia *et al.,*1998).

In the northern Tyrrhenian Sea, the exploitation of *A. foliacea* begins in the first juvenile stages or before reaching the maximum reproductive potential, as observed for other areas of the Mediterranean (Ragonese *et al.,* 1997; D'Onghia *et al.,* 1998; Spedicato *et al*., 1998; Bianchini, 1999). Studies previously carried out in the northern Tyrrhenian Sea on the exploitation state of *A. foliacea* indicated a condition close to the equilibrium (De Ranieri, 1999). These results and the recently observed reduction in this area of the trawl fleet exploiting this resource, indicate that no further modification of the current exploitation strategy is required.

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