

Occurrence and abundance of the deep-water red shrimps *Aristeus antennatus* (Risso, 1816) and *Aristaeomorpha foliacea* (Risso, 1827) in the central eastern Mediterranean Sea

Paola RINELLI¹, Marco L. BIANCHINI², Loredana CASCIARO³, Agnese GIOVE⁴, Alessandro MANNINI⁵,
Chrissi-Yanna POLITOU⁶, Adriana PROFETA¹, Sergio RAGONESE⁷ and Andrea SABATINI⁸

(1) *Institute for the Coastal Marine Environment (IAMC-CNR), Spianata San Ranieri 86, 98122 Messina, Italy*
Tel: +390906015451, Fax: +39090669007, E-mail: paola.rinelli@iamc.cnr.it

(2) *Institute of Agro-environmental Biology and Forestry (IBAF-CNR), Via Salaria km 29.300,
00015 Montelibretti (RM), Italy*

(3) *COISPA Technology & Research, Via Dei Trulli, 18/20, Torre A Mare, Bari, Italy*

(4) *Department of Animal and Environmental Biology, University of Bari, Via E. Orabona 4, 70125 Bari, Italy*

(5) *DISTAV Department of the Science of Earth, Environmental and Life, University of Genoa, Corso Europa 26,
16132 Genova, Italy*

(6) *Hellenic Centre for Marine Research, Institute of Marine Biological Resources, Athens, Greece*

(7) *Institute for the Coastal Marine Environment (IAMC-CNR), Via Vaccara 61, 91026 Mazara del Vallo (TP), Italy*

(8) *Department of Animal and Ecological Biology (DBAE), University of Cagliari, Viale Poetto 1, 09126 Cagliari, Italy*

Abstract: The blue-and-red shrimp *Aristeus antennatus* and the giant red shrimp *Aristaeomorpha foliacea* are among the major economic resources in the Mediterranean Sea and represent the main target of the western and central Mediterranean deep-sea (400-800 m) fisheries. In this paper, data on abundance (both density and biomass) of *A. antennatus* and *A. foliacea* resulting from the MEDITS surveys from 1994 to 2004, carried out with common protocols in seven Mediterranean FAO-GFCM Geographical Sub-Areas (GSAs), have been analysed using standardized methodologies. Both red shrimps species occur almost exclusively on the “meso-bathyal” stratum (500-800 m). The distribution pattern appears quite different for the two species, but no significant trends in density and biomass (neither at geographical nor at temporal level) could be detected. Sardinia shows the highest abundance for both species, although with some local negative tendencies along time. A very high interannual variability was detected in all areas. Comparing the present results to those recorded by Cau et al. in 2002, a rather stable status of the deep-sea red shrimps stocks was observed, which is not an encouraging finding when considering the reduction in fishing capacity and the management measures adopted by the EU in recent years.

Résumé : Occurrence et abondance des crevettes rouges d'eaux profondes *Aristeus antennatus* (Risso, 1816) et *Aristaeomorpha foliacea* (Risso, 1827) en Mer Méditerranée centre-orientale. La crevette rouge *Aristeus antennatus* et le gambon rouge *Aristaeomorpha foliacea* figurent parmi les principales ressources économiques de la Mer Méditerranée et sont les principales espèces cibles de la pêche en profondeur (400-800 m) dans les zones occidentale et centrale. Dans cette

étude, les données d'abondance (en densité et en biomasse) d'*A. antennatus* et *A. foliacea* issues des campagnes MEDITS de 1994 à 2004, menées sur la base de protocoles communs dans sept sous-régions géographiques de la FAO-CGPM (Geographical Sub-Areas GSAs), ont été analysées au moyen de méthodes normalisées. Les deux espèces sont présentes presque exclusivement au niveau méso-bathyal (500-800 m). Le schéma de répartition s'avère sensiblement différent pour les deux espèces, mais aucune tendance significative relative à la densité et à la biomasse n'a pu être détectée (que ce soit au plan géographique ou temporel). La Sardaigne affiche la plus grande abondance pour les deux espèces, malgré quelques tendances négatives locales au cours du temps. Une très forte variabilité interannuelle a été détectée dans toutes les zones. La comparaison des résultats actuels avec ceux enregistrés par Cau et al. en 2002 montre que l'état des stocks de crevettes rouges d'eaux profondes est resté plus ou moins stable, constat peu encourageant si on considère la réduction de la capacité de pêche et les mesures de gestion adoptées par l'UE au cours des années récentes.

Keywords: *Aristeus antennatus* • *Aristaeomorpha foliacea* • Deep-water red shrimps • Trawl surveys • Abundance • Mediterranean Sea

Introduction

The blue-and-red shrimp *Aristeus antennatus* (Risso, 1816) and the giant red shrimp *Aristaeomorpha foliacea* (Risso, 1827) are widely distributed in the Mediterranean Sea, the Eastern Atlantic and the Indian Oceans, with *A. foliacea* reaching as far as the Western Atlantic Ocean and New Zealand (Bianchini & Ragonese, 1994; Cau et al., 2002; Guijarro et al., 2008; Maynou, 2008; Cartes et al., 2011a).

Nowadays, these species represent the main target of the deep-sea fisheries in almost the whole Mediterranean Sea, but the Adriatic Sea (Bianchini & Ragonese, 1994; Rinelli et al., 1999; Carbonell et al., 1999; Papacostantinou & Kaporis, 2001 & 2003; Cau et al., 2002; Sbrana et al., 2003; Sardà et al., 2004; Orsi Relini et al., 2013). Due to their importance, the two species have been intensively studied in the western and central part of the Mediterranean Sea for a long time, both within the classical traditional fisheries methodologies (see the review by Cau et al., 2002) and through a more ecosystemic approach to include the environmental effects (Cartes et al., 2008; Guijarro et al., 2008; Massutí et al., 2008; Maynou, 2008); it should be noted that, in the easternmost sector of the central Mediterranean basin the red shrimps have been targeted by commercial fisheries only in the last years, and scientific studies were carried out on these resources in Greek waters only recently (Papacostantinou & Kaporis, 2001 & 2003; Politou et al., 2004). Both species inhabit preferably the meso-bathyal slope, mainly at depth below 500 m (Cau et al., 2002); *A. antennatus* (although with low abundance) has been reported also in deeper waters down to 2000 m (Sardà et al., 2004; Guijarro et al., 2008). Long-term observations of red shrimps abundances show marked

fluctuations everywhere, with declines of catches in some areas of the Mediterranean Sea (Orsi Relini & Relini, 1985; Relini & Orsi Relini, 1987; Campillo, 1994; Cau et al., 2002; Maynou, 2008; Cartes et al., 2011a). Many authors have tried to explain these phenomena and there is a general agreement that strong correlations exist between distribution patterns and factors such as topography of the continental slope, presence of submarine canyons and seamounts, trophic and hydrological factors, and fishing pressure (Relini & Orsi Relini, 1987; Bianchini & Ragonese, 1994; Sabatini et al., 2007; Carbonell et al., 2008; Cartes et al., 2008; Guijarro et al., 2008; Massutí et al., 2008; Cartes et al., 2011a & b; Sabatini et al., 2011; Orsi Relini et al., 2013). There are also evidences that the environmental processes of the atmosphere and of the surface waters might have an impact on the temporal dynamics of the deep-water red shrimps, at least at depths down to 800 m (Maynou, 2008).

Aristeus antennatus is a rare case in the Mediterranean Sea and the Atlantic Ocean of species with deep-water recruitment but with eurybathic distribution; Sardà & Company (2012) stated that some eurybathic species, having a spatial distribution that spans from the middle slope to the bathyal zone, could recruit in relatively poor environments, which are relatively safe from competition. The relationship between physiological conditions and recruitment success of *A. antennatus* was studied in the Balearic Sea by Carbonell et al. (2008), showing that fitness, particularly in males, is an important factor for the reproductive and recruitment success of *A. antennatus*.

The life history of *A. foliacea* seems linked to the "Levantine Intermediate Waters" (LIW) (Cartes et al., 2011a; and references therein), lying under the surface

layer (200-700 m) and characterized by relatively high salinity and temperature (Millot, 1999), that originates from the eastern Mediterranean Sea and flow towards the Strait of Gibraltar, through the Greek Ionian Sea and the Strait of Sicily. Changes in water salinity rather than temperature variability could explain the disappearance of *A. foliaceae* in some Mediterranean sites (Murenu et al., 1994). Cartes et al. (2011a) found that the sudden decline of *A. foliaceae* population in the Balearic basin can be attributed more to environmental changes than to the fishing activities, while Bianchini (1999) stated that the high fishing pressure could have caused in the past a decrease of some Sicilian populations of *A. foliaceae*. Moreover, as hypothesized by Orsi Relini & Relini (1985), some disease, water pollution or failures in the recruitment may have influenced the decline of this species in the Ligurian Sea.

The movement patterns of the red shrimps have been examined by many authors (Sardà et al., 1997; Tudela et al., 2003) who noticed the ability of these species to adapt their life cycle to the morphology of canyons and seamounts (Maynou, 2008; Sabatini et al., 2011). Moreover, in the Quirra Canyon and in the Baronie seamount (Sardinia), Sabatini et al. (2007 & 2011) found that red shrimp species move following a nictemeral cycle; finally, Orsi Relini et al. (2013) hypothesized also horizontal displacement for *A. antennatus*.

In this paper, data on distribution and abundance of *A. antennatus* and *A. foliaceae* coming from the international bottom-trawl surveys MEDITS (Anonymous, 2012), carried out with common protocols in seven Mediterranean Geographical Sub-Areas (GSAs) of FAO-GFCM, have been analysed using standardized methodologies (EU project "RedS"; Anonymous, 2008). The aim of this paper is to present information about the distribution patterns of the two deep-waters red shrimps in the Mediterranean Sea and to analyse temporal trends in density and biomass.

Material and Methods

The information about the geographical distribution and abundance of deep-water red shrimps were collected during 11 experimental bottom trawl surveys carried out from 1994 to 2004 in the framework of the MEDITS projects (Anonymous, 2012), in 7 GSAs located in the central and eastern Mediterranean Sea (Fig. 1). In the eastern Ionian Sea (GSA 20), MEDITS surveys started only in 1998, and were not carried out in 2002. The sampling procedures were the same in all surveys, as described in the MEDITS Project protocol (Anonymous, 2012): in particular, daylight hauls, lasting 0.5 h and 1 h for shelf (10-200 m) and upper slope bottoms (> 200 m) respectively, were conducted using a depth-stratified sampling design, employing an experimental net (GOC 73) with 20 mm (stretched)

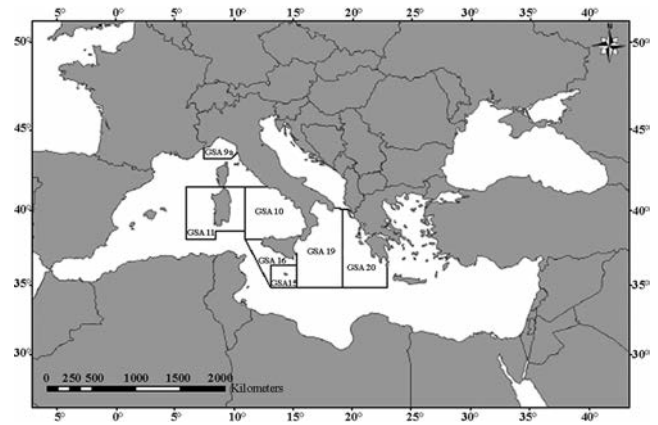


Figure 1. The study area: in evidence, the geographical sub-areas (GSA) boundaries.

diamond mesh size in the cod-end and a SCANMAR system to record the vertical and horizontal mouth opening and its distance from the bottom.

In each GSA, distribution and abundance indices were estimated following a standard methodology (Anonymous, 2008). The abundance indices were estimated by species, year and depth stratum (200-500 m, 500-800 m and pooled 200-800 m).

Five parameters were computed:

- the frequency of occurrence (F_{oc}), as the proportion of hauls with red shrimps;
- the density index (DI), expressed as $N.km^{-2}$;
- the biomass index (BI), expressed as $kg.km^{-2}$;
- the mean individual body weight (MW), resulting from the BI/DI ratio (in g);
- the species proportions, both in density

$$DI_p = DI_{Aa} / (DI_{Aa} + DI_{Af}) \quad (1)$$

and in biomass

$$BI_p = BI_{Aa} / (BI_{Aa} + BI_{Af}) \quad (2)$$

where A_a and A_f denote the *A. antennatus* and *A. foliaceae* indices respectively.

The relationships between F_{oc} and year of sampling were tested with the non-parametric Spearman rank correlation coefficients. The DI and BI were estimated according to the classical swept-area approach (Gundersen, 1993), considering the area effectively trawled in the given stratum (Anonymous, 2012). A total mean was calculated, for each GSA, from all the yearly means for both DI and BI. Moreover, an overall total mean was elaborated from all the yearly means. For each mean, the coefficient of variation, expressed as the percentage ratio between the standard deviation (SD) of the sample mean and the mean ($CV = SD / \text{mean} \times 100$), was calculated and put in square brackets [CV%]. For each GSA, total means were standardized according to the overall total mean (GSA total

mean / overall total mean). Thereafter, single year values were standardized according to the GSA total mean (1994-2004) and a bivariate plot (total mean values vs. years) was elaborated to highlight the general trends in all the GSAs. For each GSA, Kendall non-parametric rank coefficient (r_k) values were calculated between standardized (according to the overall total mean) DI and BI and year. Besides the Kendall statistic, the yearly data plots were interpolated by simple arithmetic-mean linear regressions; in case that the residuals analysis showed an evident departure from the linear relationship, data were fit arbitrarily by a third-order polynomial line.

Results

Both species occur within 200-500 m only sporadically, and with scarce abundances, no matter the GSA considered.

The number of hauls for each GSA and year and the frequency of occurrence (F_{oc} , %) of *A. antennatus*, considering the overall bathymetrical range (200-800 m), are reported in Table 1. The highest F_{oc} (68%) was observed in the western Ionian Sea (GSA 19), while the lowest values were recorded near the Maltese Islands and the southern Sicilian coast (GSA 15 & 16: 9%) and in the eastern Ionian Sea (GSA 20: 8%), and no significant temporal trend could be detected in any GSA.

The blue-and-red shrimp showed in the 200-500 m stratum a total mean biomass of less than 1 kg.km⁻² and density values ranging from 0 to 11 N.km⁻².

No spatial contiguity was detected for the abundance of *A. antennatus*; in fact, the highest abundances (Table 2) were recorded in Sardinia (GSA 11, total mean: 13.2 kg.km⁻² [53.7%] and 712 N.km⁻² [42.5%]), in the western Ionian Sea (GSA 19, total mean: 13.4 kg.km⁻² [37.3%] and

638 N.km⁻² [41.6%]) and in the Ligurian Sea (GSA 9, total mean: 8.7 kg.km⁻² [52.7%] and 343 N.km⁻² [62.2%]). On the contrary, GSA15&16 presented the lowest catches (total mean 1.5 kg.km⁻² [63.4%] and 56 N.km⁻² [73.6%]), whereas no special geographical pattern was evident by comparing the total mean/overall total mean ratios (Fig. 2A & B), given also considering the high corresponding CVs.

As regards the temporal evolution of the ratios within each GSA (GSA yearly mean / GSA total mean), significant trends (r_k , $p < 0.05$) were observed only for the biomass index in three sub-areas, i.e. GSA 11 (positive nonlinear, Fig. 3A), GSA 19 and GSA 20 (both negative nonlinear, Fig. 3B & C); on the contrary, no significant (r_k , $p > 0.05$) trend was observed for the density index in any GSA.

The yearly mean weight values (MW = DI / BI) for *A. antennatus* (Table 3) highlighted the occurrence of large "average size" values in the Ligurian Sea as well as in southern Sicily-Maltese Islands.

The relative contribution of *A. antennatus* on the red shrimps abundance shows values near to 1 in the Ligurian Sea (GSA 9), where the bulk of the red shrimps catches was represented almost exclusively by *A. antennatus* in every years, with the exception of 1996 (Table 4); also in GSA 19 (Western Ionian Sea) *A. antennatus* is clearly prevalent, with the exception of the last two years. On the contrary, in the southern Tyrrhenian Sea (GSA 10a & 10b), the proportions show a prevalence of *A. foliacea*, which prevails in the Maltese Islands and in southern Sicily (GSA 15 & 16) too; moreover, *A. foliacea* is always dominant in the eastern Ionian Sea (GSA 20), where it is the only species caught in 2000, 2001 and 2004. In Sardinia, the ratios indicate that the abundances of the two species are more or less balanced in every year.

Comparing the BI_P and DI_P (standardized to the equilibrium proportion of 0.5) of each GSA, only the

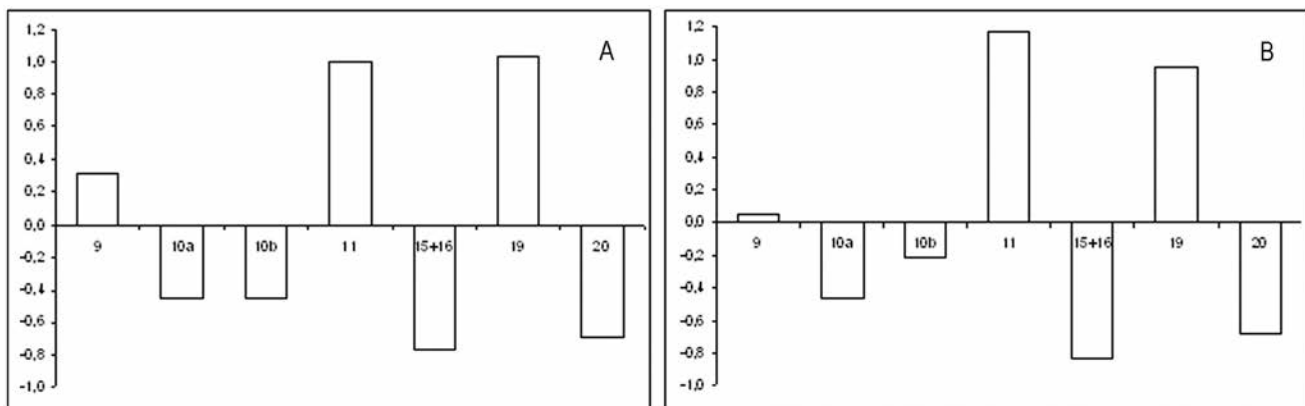


Figure 2. *Aristeus antennatus*. Ratios between the mean biomass (BI) [A] and density (DI) [B] indices by geographical sub-areas (GSA) and the overall mean biomass and density indices (all GSA pooled) in the stratum 500-800 m (Y axis); numbers/letters inside or near the bars indicate the corresponding geographical sub-area (GSA).

Table 1. *Aristeus antennatus*. Frequency of occurrence (F_{oc} ; %) and number of hauls (200-800 m) by year in each geographical sub-area (GSA).

GSA		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
9	F_{oc} %	38	44	25	44	44	44	44	31	31	31	46
	n° hauls	16	16	16	16	16	16	16	16	13	13	13
10a	F_{oc} %	53	14	39	28	42	36	50	44	45	45	41
	n° hauls	36	36	36	36	36	36	36	36	29	29	29
10b	F_{oc} %	36	14	21	29	36	23	36	36	25	25	17
	n° hauls	14	14	14	14	14	14	14	14	12	12	12
11	F_{oc} %	33	27	35	45	54	33	47	49	48	41	25
	n° hauls	58	45	51	51	50	52	51	51	36	39	39
15&16	F_{oc} %	24	15	9	26	24	24	28	24	22	14	21
	n° hauls	33	33	34	34	34	34	36	37	72	73	71
19	F_{oc} %	60	49	66	60	68	64	62	64	67	35	35
	n° hauls	47	47	47	47	47	47	47	47	43	43	43
20	F_{oc} %	-	-	-	-	17	8	0	0	-	8	0
	n° hauls	-	-	-	-	12	12	12	12	-	13	12

western Ionian (GSA 19) and the Ligurian Seas (GSA 9) show positive values, this last zone revealing the highest value (Fig. 4).

Considering *A. foliacea*, the overall (200-800 m) highest frequency of occurrence (Table 5) was recorded in the southern Tyrrhenian Sea off the Italian peninsula (GSA 10a, 72%); the values were stable over time in all the GSAs, with the exception of GSA 19, where it significantly increased during the years ($r_0 = 0.703$, $P < 0.01$).

The total means in the 200-500 m stratum were less than 1 kg.km⁻² of biomass and ranged from 0 to 196 N.km⁻² densities.

The dominance indices of *A. foliacea* did not suggest any apparent geographical trend. The mean biomass and density indices recorded for *A. foliacea* in each GSA by year (Table 6) show the highest yields in weight in southern Sicily-Maltese Islands (GSA 15 & 16, total mean: 24.5 kg.km⁻² [40.9%]), eastern Ionian Sea (GSA 20 total mean: 20.1 kg.km⁻² [82.7%]) and the southern Tyrrhenian Sea (GSA 10a total mean, : 17.3 kg.km⁻² [39.7%] and GSA 10b: 17.2 kg.km⁻² [29.5%]). The sub-area of the eastern Ionian Sea recorded the highest DI values (total mean 1408 N.km⁻² [87.4%]) followed by the southern Tyrrhenian Sea (total mean 1178 N.km⁻² [69.9%] and 1222 N.km⁻² [50.6%] for 10a & 10b, respectively) and southern Sicily-Maltese Islands (total mean 1021 N.km⁻² [42.3%]) sub-areas.

The standardized abundances ratios (BI and DI total means / overall total mean) of *A. foliacea* of each year, computed to compare the different GSAs, are reported in figure 5A & B. Both indices show very similar results: only the western Ionian (GSA 19) and the Ligurian Seas (GSA 9) show negative values. The highest values respect to the overall total mean were recorded for in southern Sicily-Maltese Islands and in the eastern Ionian Sea for BI and DI, respectively.

The standardized BI values (GSA yearly mean/GSA total mean) show a significant positive temporal trend (r_k ; $p < 0.05$) only in GSA 11 (Sardinia) (Fig. 6A, linear) and GSA 19 (western Ionian Sea) (Fig. 6B, nonlinear). The standardized DI values show a positive significant temporal trend

Figure 3. *Aristeus antennatus*. Standardized biomass index (BI) vs. year in the geographical sub-areas GSA 11 [A], GSA 19 [B] and GSA 20 [C], with polynomial interpolation overimposed (rk, Kendall non-parametric rank coefficient; s = significant).

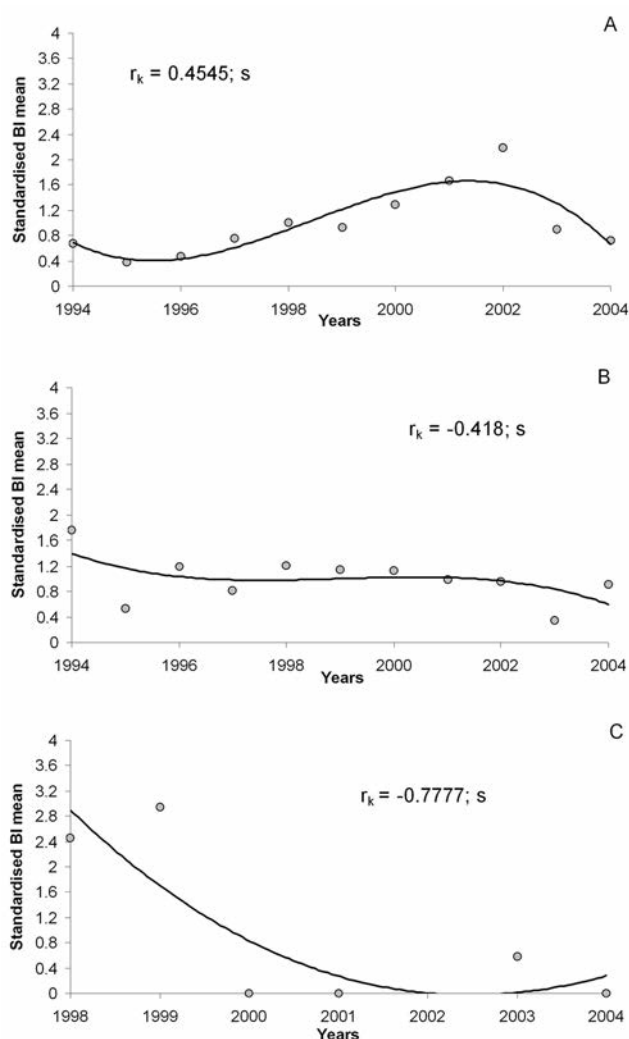


Table 2. *Aristeus antennatus*. Mean abundance indices (BI; DI) and corresponding coefficient of variation (CV; %) (500-800 m), by year and geographical sub-areas (GSA). In the rightmost column, the GSA overall mean is reported.

		<i>Biomass Index</i>													
		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	94-04		
GSA	9	kg.km ⁻²	15.4	11.1	0.5	12.0	10.1	11.2	8.8	5.5	2.2	6.3	12.5	8.7	
		CV %	54.2	36.3	63.0	43.3	31.4	48.1	44.5	67.9	77.9	65.4	44.4	52.7	
	10a	kg.km ⁻²	9.7	0.3	1.0	3.6	4.6	2.7	3.3	5.5	2.2	3.9	2.8	3.6	
		CV %	22.1	75.3	32.0	41.2	29.0	26.0	27.1	28.6	27.3	36.6	37.1	69.8	
	10b	kg.km ⁻²	6.2	0.6	1.3	10.2	3.3	3.9	2.6	7.6	1.0	1.6	1.5	3.6	
		CV %	28.4	62.7	87.7	97.0	33.8	83.3	52.0	33.3	106.7	75.4	66.1	86.1	
	11	kg.km ⁻²	9.0	4.9	6.3	10.0	13.4	12.3	17.1	22.0	29.0	11.8	9.5	13.2	
		CV %	29.6	43.2	23.0	14.6	17.2	47.2	25.0	15.3	39.5	27.8	9.9	53.7	
	15&16	kg.km ⁻²	1.9	1.0	0.5	1.0	1.6	0.9	3.2	3.4	1.3	0.5	1.7	1.5	
		CV %	57.2	58.8	66.2	41.6	51.0	60.2	53.9	47.8	34.0	33.8	35.5	63.4	
	19	kg.km ⁻²	23.7	7.1	16.1	11.0	16.2	15.3	15.2	13.3	12.9	4.7	12.3	13.4	
		CV %	19.1	30.5	38.1	16.0	17.3	22.3	26.0	20.1	20.1	28.4	24.2	37.3	
	20	kg.km ⁻²	-	-	-	-	5.0	6.0	0.0	0.0	-	1.2	0.0	2.0	
		CV %	-	-	-	-	37.9	57.7	0.0	0.0	-	26.4	0.0	134.9	
			<i>Density Index</i>												
			1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	94-04	
	GSA	9	N.km ⁻²	570	462	22	702	378	506	296	135	88	216	395	343
			CV %	58.5	42.1	74.7	60.1	33.5	45.7	44.4	71.1	83.6	61.0	44.7	62.2
10a		N.km ⁻²	459	16	61	146	211	153	167	252	130	180	150	175	
		CV %	20.2	59.5	29.5	44.1	28.4	27.5	30.4	30.2	24.1	32.1	38.9	65.2	
10b		N.km ⁻²	318	30	88	1284	160	218	163	429	46	60	65	260	
		CV %	29.5	65.3	74.7	105.1	37.1	81.5	62.7	35.9	98.7	66.7	70.7	139.1	
11		N.km ⁻²	539	295	434	714	829	686	963	1084	1254	677	358	712	
		CV %	28.4	37.3	22.2	15.3	16.4	52.3	21.5	15.8	43.8	24.7	11.6	42.5	
15&16		N.km ⁻²	70	31	13	38	41	31	137	125	47	17	63	56	
		CV %	57.9	55.5	56.7	34.7	47.7	46.8	54.0	52.4	34.9	35.2	35.1	73.6	
19		N.km ⁻²	760	284	726	478	1092	796	962	590	518	218	599	638	
		CV %	20.1	29.7	32.5	16.6	18.1	20.9	26.4	20.1	20.8	33.1	26.2	41.6	
20		N.km ⁻²	-	-	-	-	295	290	0	0	-	39	0	104	
		CV %	-	-	-	-	37.8	58.2	0.0	0.0	-	29.4	0.0	141.2	

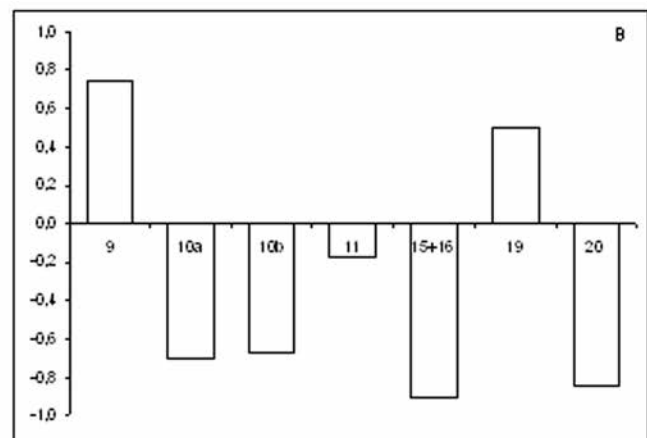
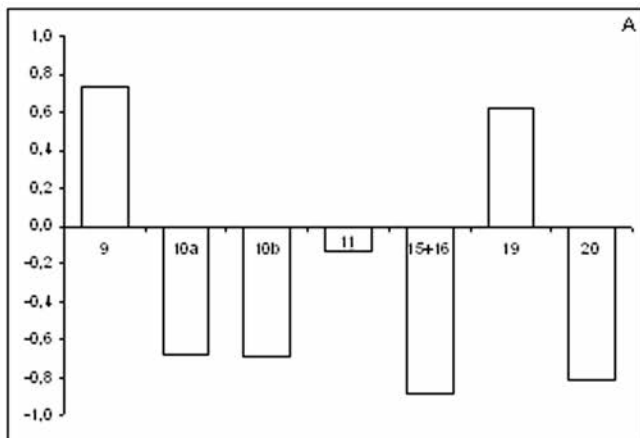


Table 3. *Aristeus antennatus*. Mean weight (BI/DI; g) by geographical sub-areas (GSA) and year (500-800 m).

		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
GSA	9	27.0	24.0	22.7	17.1	26.7	22.1	29.7	40.7	25.0	29.12	31.7
	10a	21.1	18.8	16.4	24.7	21.8	17.7	19.8	21.8	16.9	21.7	18.7
	10b	19.5	20.0	14.8	7.94	20.6	17.9	16.0	17.7	21.7	26.7	23.1
	11	16.7	16.6	14.5	14.01	16.2	17.9	17.8	20.3	23.1	17.4	26.5
	15&16	27.1	32.3	38.5	26.3	39.0	29.0	23.4	27.2	27.7	29.4	26.9
	19	31.2	25.0	22.2	23.0	14.8	19.2	15.8	22.5	24.9	21.6	20.5
	20	-	-	-	-	16.7	20.8	0.0	0.0	-	32.0	0.0

Table 4. *Aristeus antennatus*. The Biomass (BIP) and Density (DIP) abundance proportion (500-800m), by year and geographical sub-areas (GSA).

		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
GSA		<i>BI_p</i>										
	9	1.0	0.9	0.2	1.0	1.0	0.9	0.9	0.8	0.9	1.0	0.9
	10a	0.3	0.0	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.2
	10b	0.2	0.0	0.1	0.3	0.1	0.2	0.1	0.4	0.1	0.1	0.1
	11	0.6	0.4	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.3
	15&16	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1
	19	1.0	0.8	0.9	1.0	1.0	1.0	0.8	0.9	0.8	0.3	0.5
	20	-	-	-	-	0.3	0.2	0.0	0.0	-	0.0	0.0
GSA		<i>DI_p</i>										
	9	1.0	1.0	0.3	1.0	1.0	0.9	0.9	0.8	0.9	1.0	0.9
	10a	0.4	0.0	0.1	0.0	0.2	0.1	0.1	0.2	0.2	0.1	0.2
	10b	0.2	0.0	0.1	0.4	0.1	0.2	0.1	0.5	0.0	0.0	0.1
	11	0.6	0.3	0.4	0.5	0.3	0.4	0.5	0.6	0.4	0.4	0.2
	15&16	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0
	19	0.9	0.7	0.9	0.9	1.0	0.9	0.9	0.8	0.6	0.1	0.5
	20	-	-	-	-	0.3	0.1	0.0	0.0	-	0.0	0.0

in GSA 11 (Sardinia; Fig. 7A, linear), GSA 15&16 (South of Sicily and Maltese Islands; Fig. 7B, linear) and GSA 19 (western Ionian Sea; Fig.7C, nonlinear). The other GSAs did not show any significant temporal trend.

The mean weights (MW = BI / DI) of *A. foliaceae* show the same pattern of those observed for *A. antennatus* (Table 7); large “average size” values were observed in the same GSAs (Ligurian Sea and southern Sicily-Maltese Islands).

Discussion

Medium-term data, collected with a standardized methodology in different part of the Mediterranean Sea in

the framework of the MEDITS project (Anonymous, 2012), allowed a global comparative study of the distribution and abundance of the deep-water red shrimps *A. antennatus* and *A. foliaceae*. Overall, present results tend to confirm, in spite of the short time interval occurred, some basic features of these species such as spatio-temporal distribution. In particular, the grounds below 400-500 m remain the preferred habitat for both species (Relini, 2000; Cau et al., 2002; Sardà et al., 2004).

The biomass and density data of both species show that only some GSAs present a clear trend (negative or positive) over the time. Otherwise, an extreme interannual variability in the catches for both species was present in the studied



Figure 4. *Aristeus antennatus*. Overall mean of standardized biomass (BI_p) [A] and density (DI_p) [B] indices vs GSA in stratum 500-800 m; numbers/letters inside or near the bars indicate the corresponding geographical sub-area (GSA).

Table 5. *Aristaeomorpha foliacea*. Frequency of occurrence (Foc; %) and numbers of hauls (200-800 m) by year in each geographical sub-areas (GSA).

GSA		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
9	F _{oc} %	13	25	13	0	19	31	31	13	15	8	39
	n° hauls	16	16	16	16	16	16	16	16	13	13	13
10a	F _{oc} %	61	64	56	67	67	72	67	64	55	59	69
	n° hauls	36	36	36	36	36	36	36	36	29	29	29
10b	F _{oc} %	50	43	50	43	57	46	50	50	33	50	67
	n° hauls	14	14	14	14	14	14	14	14	12	12	12
11	F _{oc} %	41	42	49	53	60	54	51	57	52	41	44
	n° hauls	58	45	51	51	50	52	51	51	36	39	39
15&16	F _{oc} %	55	52	50	56	59	62	56	54	50	55	56
	n° hauls	33	33	34	34	34	34	36	37	72	73	71
19	F _{oc} %	45	45	43	53	57	57	68	55	49	67	58
	n° hauls	47	47	47	47	47	47	47	47	43	43	43
20	F _{oc} %	-	-	-	-	17	17	8	8	-	23	15
	n° hauls	-	-	-	-	12	12	12	12	-	13	12

area. In particular, *A. antennatus* and *A. foliacea* significantly increased over time in the western Tyrrhenian Sea, while in the Ionian Sea diverging trends were observed in the biomass for the two species, i.e. *A. antennatus* decreased and *A. foliacea* increased during the time observed. Finally, a positive increase in the catches of *A. foliacea* was detected in Sicilian Channel. These results confirm the

Table 6. *Aristaeomorpha foliacea*. Mean Abundance Indices (BI; DI) and corresponding coefficient of variation (CV; %) for (500-800 m), by year and geographical sub-areas (GSA). In the rightmost column, the GSA overall mean is reported.

		Biomass Index												
		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	94-04	
GSA	9	kg.km ⁻²	0.8	0.9	1.6	0.0	0.2	0.9	1.5	1.1	0.3	0.1	0.7	0.7
		CV %	92.8	71.0	94.4	0.0	0.0	49.3	48.9	80.7	110.0	0.0	49.0	73.7
	10a	kg.km ⁻²	21.4	8.8	10.0	28.5	19.7	26.3	20.9	18.3	8.6	16.3	11.9	17.3
		CV %	14.9	21.6	24.5	32.6	24.2	17.9	14.4	17.2	33.6	26.7	13.8	39.7
	10b	kg.km ⁻²	24.1	16.3	10.4	23.4	19.9	20.4	19.6	11.8	13.2	20.2	10.3	17.2
		CV %	37.9	45.4	27.1	44.0	32.8	55.0	34.1	36.4	39.5	42.0	38.5	29.5
	11	kg.km ⁻²	7.2	7.5	15.2	13.3	19.4	18.3	18.7	18.1	24.8	14.6	21.0	16.2
		CV %	31.9	26.1	21.5	22.2	26.9	16.9	20.9	19.0	21.2	28.1	10.8	33.3
	15&16	kg.km ⁻²	39.9	11.5	15.2	15.7	19.5	26.5	40.7	30.5	22.8	16.5	30.9	24.5
		CV %	24.7	25.4	24	28.1	21.6	20.9	15.8	16.9	16.2	13.7	12.6	40.9
19	kg.km ⁻²	1.1	1.6	1.8	0.5	0.6	0.7	2.7	1.7	3.6	11	10.5	3.3	
	CV %	29.6	35.9	52	29	36.9	25.5	35.9	28.3	40.3	16.4	27.4	117.4	
20	kg.km ⁻²	-	-	-	-	9.6	26.0	4.5	42.6	-	34.7	3.4	20.1	
	CV %	-	-	-	-	37.4	55.9	71.3	66.8	-	25.4	42.6	82.7	
		Density Index												
GSA	9	N.km ⁻²	19	18	56	0	18	40	52	33	9	3	34	25.6
		CV %	85.1	67.0	99.7	0.0	72.6	55.4	44.9	68.0	81.6	109.5	46.3	73.5
	10a	N.km ⁻²	674	913	458	3336	1141	1890	1032	1134	514	1252	620	1178.5
		CV %	17.3	30.9	27.7	46.8	24.6	26.7	19.3	30.2	51.7	38.1	14.6	69.9
	10b	N.km ⁻²	1191	1676	527	2237	1698	886	968	502	1141	2065	548	1221.7
		CV %	46.4	61.7	27.4	48.9	42.8	52.3	33.0	47.8	43.8	42.9	43.9	50.6
	11	N.km ⁻²	291	681	774	847	1809	905	1166	776	2032	877	1812	1088.2
		CV %	31.3	42.8	24.8	29.7	54.6	17.3	22.9	25.5	25.4	32.0	12.7	51.0
	15&16	N.km ⁻²	1612	467	583	668	725	1058	1685	1059	1105	728	1543	1021.2
		CV %	30.6	25.9	19.6	27.2	24.4	21.3	18.4	18.3	23.8	17.7	19.1	42.3
19	N.km ⁻²	82	124	85	35	28	51	136	146	303	1412	715	283.4	
	CV %	32.3	41.9	42.4	27.9	34	24.4	34.7	44.9	44.5	18	21.5	149.2	
20	N.km ⁻²	-	-	-	-	607	1743	558	3548	-	1764	227	1407.8	
	CV %	-	-	-	-	37.5	55.9	70.7	66.8	-	24.9	34.3	87.4	

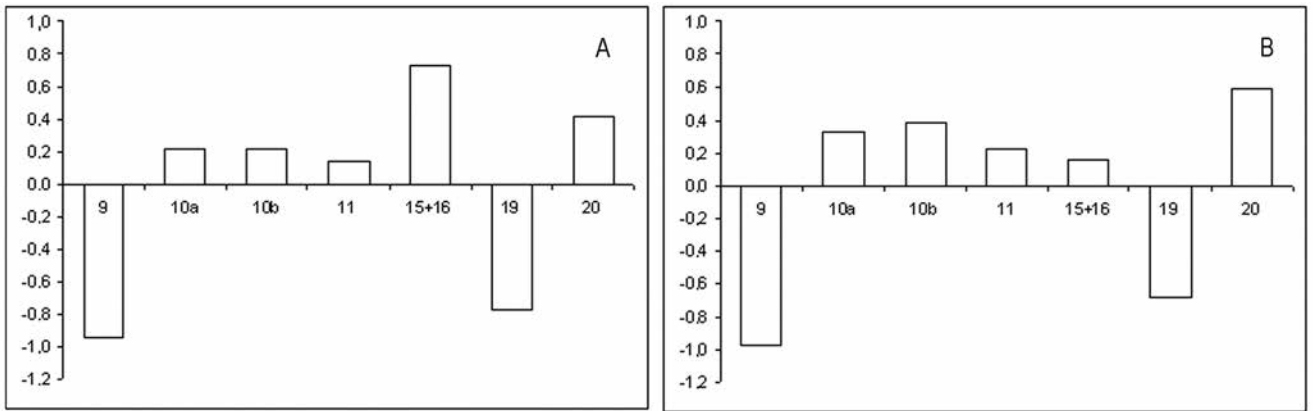


Figure 5. *Aristaeomorpha foliacea*. Ratios between the mean biomass (BI) [A] and density (DI) [B] indices, by geographical sub-areas (GSA) and the overall mean biomass and density indices (all GSA pooled) in the stratum 500-800 m (Y axis); numbers/letters inside or near the bars indicate the corresponding geographical sub-areas (GSA).

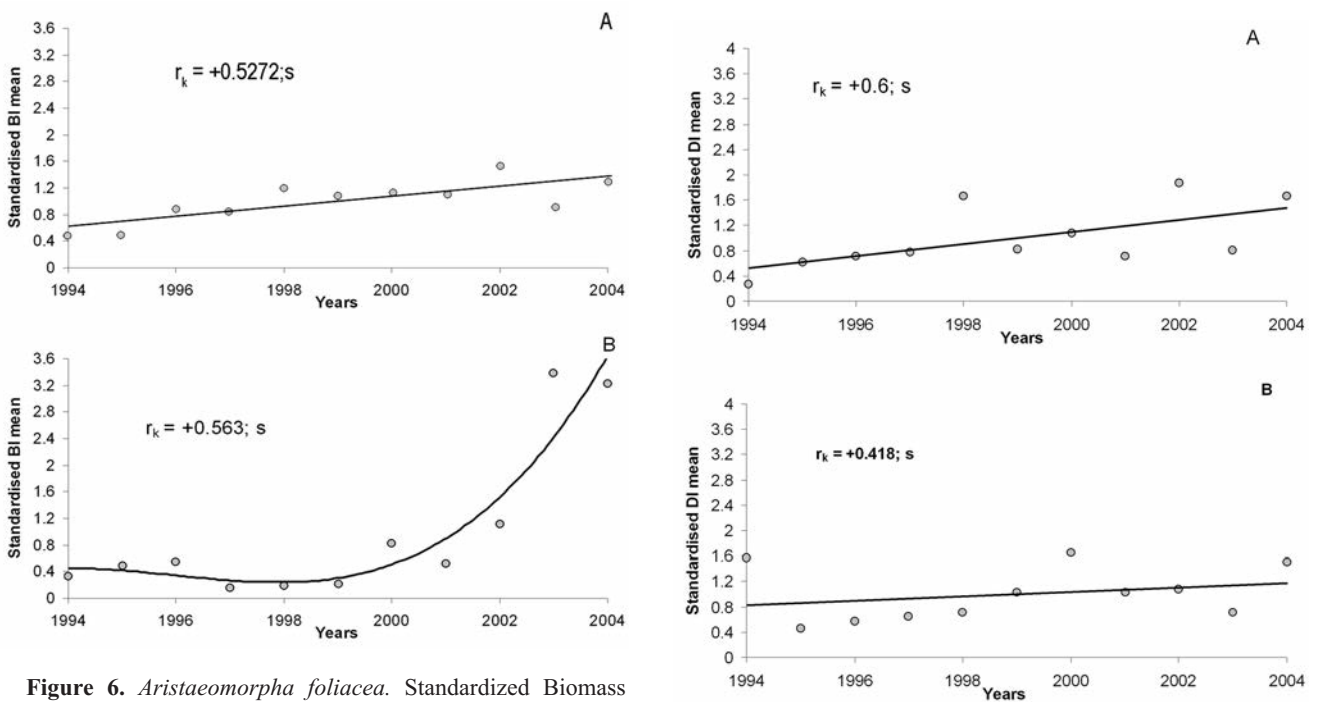


Figure 6. *Aristaeomorpha foliacea*. Standardized Biomass Index vs. year in the geographical sub-areas GSA 11 [A] and GSA 19 [B] with linear or polynomial interpolation overimposed (r_k , Kendall non-parametric rank coefficient; s = significant).



Figure 7. *Aristaeomorpha foliacea*. Standardized density index values vs. year in the geographical sub-areas GSA 11 [A], GSA 15&16 [B] and GSA 19 [C] with linear or polynomial interpolation overimposed (r_k , Kendall non-parametric rank coefficient; s = significant).

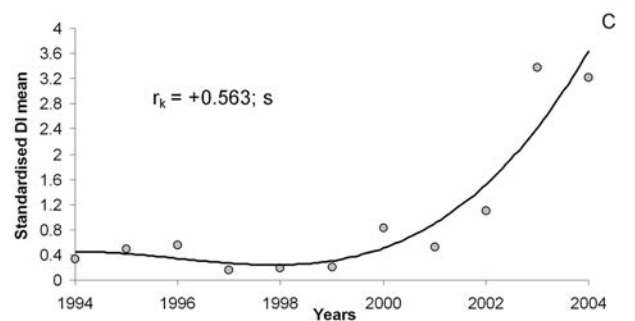


Table 7. *Aristaeomorpha foliacea*. Mean weight (BI/DI; g) by geographical sub-areas (GSA) and year (500-800 m).

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	
GSA	9	42.1	50.0	28.6	0.0	11.1	22.5	28.8	33.3	33.3	33.3	20.6
	10a	31.8	9.6	21.8	8.5	17.3	13.9	20.3	16.1	16.7	13.0	19.2
	10b	20.2	9.7	19.7	10.5	11.7	23.0	20.2	23.5	11.6	9.8	18.8
	11	24.7	11.0	19.6	15.7	10.7	20.2	16.0	23.3	12.2	16.6	11.6
	15+16	24.8	24.6	26.1	23.5	26.9	25.0	24.2	28.8	20.6	22.7	20.0
	19	13.4	12.9	21.2	14.3	21.4	13.7	19.9	11.6	11.9	7.8	14.7
	20	-	-	-	-	15.9	14.9	8.2	12.0	-	19.7	15.2

temporal trends previously observed for the deep-sea red shrimps (Cau et al., 2002).

As regard the spatial distribution, its ample heterogeneity, even inside the same GSA, should be stressed. By definition, in fact, the population inside a given GSA should, and is, treated as a unit stock; however, there are evidences of local higher abundances (“hotspots”) and of discontinuities in the distribution of both species, suggesting the presence of different unit stocks: in fact, the official GSA may just represent an average picture of many stocks responses.

Concerning the red-and-blue shrimp, “hotspots” were observed in the eastern sector of the Ligurian Sea, in western Sardinia, in the southern Tyrrhenian Sea, where the species was more consistent North of Messina, in southern Sicily and in the western sector of the Ionian Sea (a different distribution amongst the western and eastern part of the Ionian Sea is in accordance with previous findings in the area and was attributed mainly to different hydrographic characteristics and fishing exploitation levels; D’Onghia et al., 2003).

The giant red shrimps show three “hotspots”, located in Sardinia, where the species was more abundant in the southern grounds, in the central Tyrrhenian Sea, where *A. foliacea* had greater numbers in the southern sector (in particular the Calabrian coast of the southern Tyrrhenian Sea presented larger concentrations than those in northern Sicily), and finally in the eastern Ionian Sea (Greece), where this species showed a consistent southern aggregation.

The geographical distribution of *A. foliacea* and *A. antennatus* observed in this study confirms the rather different spatial pattern of the two species, already detected by the literature (Cau et al., 2002). In particular, previous studies demonstrate that *A. antennatus* is clearly dominant in Spanish waters (Sardà & Cartes, 1994) and in the Ligurian Sea (Orsi Relini & Relini, 1985), and less abundant in the Sicilian Channel; *A. foliacea* on the contrary is the most common species in Sardinia, the Tyrrhenian Sea and the Sicilian Channel (Ragonese et al., 1994; Cau et al., 2002).

The present results allowed to conclude that there are no clear, evident gradients for the distribution and abundance

of both shrimp species. On the contrary, Cau et al. (2002) observed, although the geographical aggregation was quite different, a longitudinal gradient of the space distribution of the two species: *A. antennatus* was relatively more abundant in the westernmost Mediterranean Sea, while *A. foliacea* prevailed in the central and easternmost part.

Given that higher occurrences and abundances were detected in areas distant from each other, and therefore likely subject to different conditions, and that even intra-zone variability is anyway very large, the overall distribution and abundance patterns of these species might reflect several intermingling factors such as natural noise, fishing pressure, oceanographic features, food availability and recruitment success (Cau et al., 2002; Carbonell et al., 2008; Maynou, 2008; Cartes et al., 2011a). Usually, multiple factors do not act in synergy, pushing the events in the same direction, but there are evidences that in some circumstances that may happen: e.g., the disappearance of *A. foliacea* in the Balearic basin (Cartes et al., 2011a) has occurred almost at the same time in other areas of the north-western Mediterranean Sea (Ligurian Sea: Relini-Orsi & Relini, 1985; Gulf of Cadiz: Campillo, 1994). On the other hand, similar events of drastic changes are often not permanent and recovery may without plausible or evident explanations. The same argument can be used to justify the “replacement” phenomenon often reported between the two species: as a matter of fact, the deep-water red shrimps community is sometimes dominated by one species or the other with alternate destiny, or is shared by the two species, without any definitive explanation.

Obviously, the knowledge of the variations of fishing pattern (but it is almost impossible to get disaggregated data for these species; cfr. Sbrana et al., 2003), as well as of the oceanographic characteristics in the various GSAs, might have improved the interpretation of present results.

Many authors have correlated various environmental variables to explain the spatial distribution and/or the temporal fluctuations of these two species (Sardà et al., 1997; Guijarro et al., 2008; Massuti et al., 2008; Maynou, 2008), although it remains still unclear which parameter has significant predictive effects. Some environmental phenomena - such as the cascading effect (Company et al.,

2008), the depth and the type of bottom (Cartes et al., 2008), the presence of canyons and seamounts (Tudela et al., 2003; Sabatini et al., 2007 & 2011) - may have a direct impact. On the other hand, variations of temperature and salinity in the LIW have been correlated with their presence/absence of the red shrimps (Cartes et al., 2011a), and this fact might depend from an indirect effect on prey availability changes or on the physiological responses linked to the O₂ concentration, such as reproduction or larval distribution, therefore determining the temporal fluctuations. All these factors are associated with a heavy and prolonged fisheries exploitation, resulting in a masking effect that makes it difficult to interpret the whole picture on the distribution of the two shrimp species.

Furthermore, it is well described in literature that species not only respond in different ways to environmental changes but that even populations of the same species do so in different localities (Alheit & Bernal, 1993; Hare & Mantua, 2000), because of small-scale geographical differences; this phenomenon is true also at the level of different age-classes of the same population (Coulson et al., 2001). The present study suggests that the population response to change of intensity of certain environmental parameters may even go in opposite direction at different locations. It is important to remember the difficulties in incorporating environmental variability in the stock assessments, because the greater number of parameters introduces more complexity, and hence higher statistical errors. Furthermore, the temporal interval of available data is crucial: for example, “climate” is “average weather”, i.e. the statistical description in terms of mean and variability of relevant variables (e.g., temperature, precipitation, wind) over a period of time classically assumed to be of at least 30 years. Despite the plausible role of the environmental factors for many Mediterranean deep-water stocks, and in particular global warming trends and cycles of coupled climatic-oceanographic patterns (such as those quantified by indices like the North Atlantic Oscillation, a.k.a NAO; Massuti et al., 2008; Maynou, 2008), in the present paper the classic fisheries biology approach (Quinn & Deriso, 1999; Haddon, 2001) does not allow to give further indication, which are, moreover, beyond the aim of this work.

Comparing the present results to those recorded by Cau et al. in 2002, a more or less stable status of the deep-sea red shrimps stocks was observed, which is not an encouraging finding when considering the reduction in fishing capacity and the management measures (e.g., the adoption of a more selective mesh size in the trawl codends) adopted by the EU in recent years.

Present results pinpoint the necessity to identify the different unit stocks occurring in the Mediterranean Sea and to analyse their life-history evolution in the medium-

and long-term with newer and more focused information on fishing pattern variations and on environmental modifications, especially the climate changes. Still, a meta-analysis approach should obviously be maintained, in order to help the comprehension of the whole phenomena, in the meantime reducing the risk of spurious correlations.

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