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# Distribution of spawning and nursery grounds for deep–water red shrimps in the central western Mediterranean Sea

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## Abstract

The presence of spawning and nursery grounds of Aristeids in the central western Mediterranean Sea were investigated using fishery-independent data (trawl surveys, 1994–2012). Spatial distributions were generated for mature animals and recruits, for both spring/summer and autumn data, using an inverse distance-weighted deterministic interpolation. The persistence index was used to identify stable spawning and nursery grounds in the Sardinian slope region for *Aristaeomorpha foliacea* and *Aristeus antennatus*. Areas of aggregation for recruits and mature females appear to be connected with important physical habitat features. The analysis also suggests a seasonal bathymetric distribution for nursery areas. The recruits of *A. foliacea* are located in the upper part of the continental slope (377-450 m) in spring/summer and reach greater depths (468-628 m) in autumn. For *A. antennatus*, for which nursery areas only emerge in autumn, there is presumably an opposite ontogenic migration, from deep sea to upper slope, during the summer (575-681 m). The results also indicate a partial overlap between the nursery and spawning grounds of both species. In this particular area, local environmental conditions such as upwelling events or the presence of canyons and seamounts seem to play an important role in their distribution. This study also generated relevant information on the spatial and temporal distribution of seasonal or persistent aggregations of spawners and recruits, providing scientific elements to suggest the protection of these important resources.

**Keywords**: Aristeidae, spawning and nursery grounds, persistence, Mediterranean Sea.

## Introduction

The implementation of management measures, aimed at reducing the effects of fishing on juveniles and spawners, among other tools, requires spatial identification of nurseries and spawning grounds (SGMED 09–02, 2009). Description of the space and time patterns of important commercial species is a basic elements for understanding the stock dynamics of fish population (Fiorentino *et al.,* 2003 and reference therein). In the case of nursery habitats, this is usually done on the assumption that the average contribution to the adult population can be expected to be higher for nurseries with higher juvenile density and higher stability in time and space (Colloca *et al.,* 2009). The stability of a population depends on the successful recruitment of juvenile individuals in the nursery areas, and from the nursery areas back to the parental population (Hinckley *et al.,* 2001). The main factors to establish when considering the recruitment of a species are where and when recruitment takes place, and whether individuals recruit to the fishery or to the habitat (Sardà & Company, 2012). Recruitment to the fishery can be seen from the first modal size of small individuals caught by a given mesh size and gear type, depending on the species. The recruitment of many species is also influenced by the condition of mature adults (spawners) as a consequence of their exploitation or specific environmental stimuli (Company *et al.,* 2008; Sardà *et al.,* 2009; Carbonel *et al.,* 2010). Understanding the relationship between environmental variations and the successful recruitment of target species is another emerging issue (Lloret *et al.,* 2001; Bartolino *et al.,* 2008; Massutì *et al.,* 2008; Garofalo *et al.,* 2011).

The seas surrounding Sardinia (central-western Mediterranean Sea) are dynamically very different, given that the western and eastern coasts belong to different Mediterranean sub-basins (the Algero-Provencal and the Tyrrhenian basins, respectively). The northern and southern coasts are further characterized by the narrow Strait of Bonifacio and the Sardinian Channel, respectively, and the latter regulates the flow of Modified Atlantic Water (MAW) towards the Tyrrhenian Sea and the Sicilian Channel. Sardinian, and occasionally also Sicilian, Tuscan and Spanish trawl fleets operate throughout the year in these areas, landing thousands of tons of deep-water red shrimps, *A. foliacea* and *A. antennatus*, every year, with seasonal variations and annual fluctuations (IREPA, 2010). Given their importance to fisheries, in terms of abundance and productivity, there is a large body of literature on their distribution (Cau *et al.,* 2002; Company *et al.,* 2004) and biology (Mura *et al.,* 1997; Kapiris & Thessalou–Legaki, 2009; Orsi Relini *et al.,* 2012, Sardà & Company, 2012), but descriptions of their ecology, the spatial distribution of juveniles and mature animals, and the main factors driving key processes such as recruitment are still lacking.

Consequently, the aim of this paper was to document the location of spawning and nursery grounds of both shrimps using georeferenced information on their abundance, in order to contribute to our understanding of their distribution at different life stages, and identify potential hot spots. Possible implications of major oceanographic processes, such as enrichment due to upwelling events in the shelf-slope area, are also discussed.

## Material and Methods

The study was performed using two trawl surveys, one conducted in autumn (GRUND; Relini, 2000), the other in spring/summer (MEDITS; Bertrand *et al.,* 2002). During both surveys, sampling was distributed according to a stratified scheme, with random sampling from within each stratum. The time series examined covers 19 years for the MEDITS (from 1994 to 2012) and 12 years for the GRUND survey (1994–2005). For the GRUND survey, the vessels were equipped with a typical Italian commercial ‘tartana’ (a gear commonly used by local fishermen), while for the MEDITS survey an experimental bottom trawl net was used (GOC 73). Both gears were equipped with the same cod-end & mesh size was 20 mm, while differed mainly in the vertical opening, which ranged between 2.4 and 2.9 m for the MEDITS net (Fiorentini *et al.* 1999) and between 0.6 and 1.3 m for the GRUND net (Fiorentini *et al*., 1998). The horizontal opening of all types of net was measured using the SCANMAR acoustic system.

The study only considered samplings that caught red shrimps, which amounted to 405, obtained between depths of 345 and 730 m during the spring/summer surveys, and 207 obtained at depths of 236 to 681 m during the autumn surveys (Fig. 1). Catch data (number of specimens per sample) were processed using the swept-area method (Sparre & Venema, 1998) and then standardized to obtain a density index (DI; number/km$^2$) per sample for two fractions of the population analyzed: recruits and spawners (mature females).

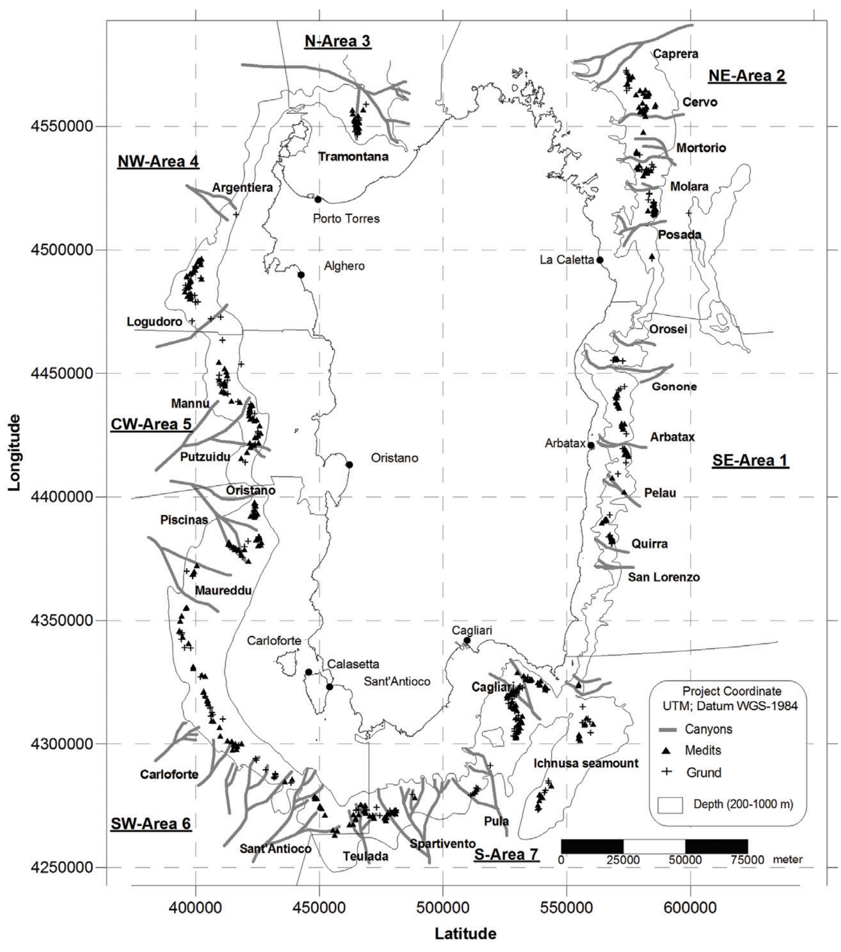


***Fig. 1:*** Haul positions for the MEDITS and GRUND project and shape of the canyons.

Carapace length and stage of maturity were the criteria used to ascertain the recruit and spawner fractions of the population, respectively (Fiorentino *et al.,* 2003; Garofalo *et al.,* 2011). Length frequency distribution (LFD), mean length and standard deviation of the first modal component were analyzed to calculate the cut-off length (mean length ± standard deviation) identifying the juvenile fraction of the population in each survey. The recruitment of giant red shrimp takes place in spring (Mura *et al.,* 1997; D'Onghia *et al.,* 1998), making it easy to identify the first modal component in the LFD for each survey. For giant red shrimp, which showed a discrete LFD by cohort, the analysis was performed using the Bhattacharya routine as implemented in FISAT II (Gayanilo *et al.,* 2006). Blue and red shrimp are recruited to the fishery in spring, when individuals of both sex are one year old (Mura *et al.,* 1997; Cau *et al.,* 2002; AAVV, 2008). The routine used to describe fish growth proved difficult to apply to the *A. antennatus* datasets. Generally speaking, the LFD of females includes several modal components, which are also studied in terms of instars (Orsi Relini *et al.,* 2012), but they were unable to separate the cohorts adequately. Due to difficulties in separating the cohorts by LFD, the mean sizes per annual age group of *A. antennatus* were calculated using the von Bertalanffy growth function (VBGF: $L\infty$=64.67, K=0.247, $t_0$=0, Cau *et al.,* 2002).

The DI of recruits was estimated for both species considering the fraction of males and females combined. To identify the portion of spawners, or mature females (DI), in each sample and both types of shrimp, stage of sexual maturity was identified by macroscopically analyzing the gonads using seven-stage maturity scales (AAVV, 2013; Perdichizzi *et al.,* 2012). Maturity of females was established from the presence of a turgid ovary extending to the entire dorsal portion, well-developed lobes and abdominal extension, and clearly visible oocytes (AAVV, 2013).

Catch data from single samplings were used to generate time-series distribution maps of spawners and recruit DI by means of inverse distance-weighted deterministic interpolations (Isaaks & Srivastava, 1989). The cumulative distribution of the DI for each year was calculated to identify the spawning and nursery grounds. This cumulative distribution was computed after arranging the DI in decreasing order. The density corresponding to the third quartile of this distribution (75%) was used as the threshold for identifying density hotspots (Fiorentino *et al.,* 2003; Colloca *et al.,* 2009; Garofalo *et al.,* 2011). The whole procedure was applied separately for each survey and year to take into account the annual variability in spawner and recruit grounds. To see whether these sites were always located in the same sampling area, a persistence index (PI; Fiorentino *et al.,* 2003) was calculated by superimposing the maps for the whole time series. Using these time-series density maps, the PI for identifying spawning and nursery aggregations was computed as follows:

$$PI=\frac{1}{n}\sum_{k=1}^{n} d_{ij}$$

where dij=1 if the same haul i is within the third quartile in year j, and dij=0 otherwise, and n is the number of surveys considered. Two different scenarios were considered using different levels of persistence: PI≥0.4 and PI≥0.6. A threshold of 0.6 was applied to define a high likelihood of persistence.

## Results

### *Aristaeomorpha foliacea spawning areas*

The MEDITS surveys indicated a patchy distribution of spawners, which were located mainly off the southern and western coasts of Sardinia (Fig. 2A). Based on PI analysis, there was a spawning ground (PI≥06) on the open edge of the southern tributary of the Pula canyon in the southern sector of the Sardinian sea (S-Area 7), at depths between 545 and 573 m, and on the slope between Spartivento and the Teulada canyon, at depths between 461–719 m (Fig. 2A). A third spawning area was located near the Maureddu canyon at depths between 595 and 610 m (SW-Area 6), and others were identified with a PI=0.4 on the continental slope in the central western sector at depths from 465 to 617 m (NW-Areas 4, CW-Area 5 and SW-Area 6), and to the south of Sardinia, in the northern part of the Ichnusa seamount (580-674 m) (S-Area 7).

Unlike the spring/summer data, our analysis of the GRUND time-series maps showed no persistent areas for giant red shrimp, even though the still mature females were found to the south and south-west of Sardinia (SW-Area 6; S-Area 7) in several years (Fig. 2B).

### *Aristeus antennatus spawning areas*

The spawner distribution map for *A. antennatus* in the Sardinian sea (MEDITS) revealed a clear pattern characterized by a few dense patches, or hot spots (Fig. 3A). The highest concentrations most frequently recorded during the time-series, with two important areas of spawner concentration at PI≥06 (Fig. 3A). One was off the south coast of Sardinia, on the slope between the Teulada and Sant'Antioco canyons at depths of 551–730 m (between SW-Area 6 and S-Area7). The other was on the slope to the north-west of Carloforte Island (SW-Area 6), at depths between 479 and 617 m. At this same location, small concentrations (PI≥04) of spawners were less frequently identified on the slope to the west of the Islands of Carloforte and Sant'Antioco, at depths between 464 and 640 m deep (SW-Area 6). These areas partially overlapped and the presence of density hotspots underscores the great importance of this area. Other areas were found further north: on the upper slope between the northern and central tributaries of the Piscinas canyon, at depths of 466-574 m (SW-Area 6), on the slope near the Mannu canyon head at depths of 465-598 m (CW-Area 5), and in the fishing ground off Capo Caccia at depths of 527-617 m (NW-Area 4).

The temporal persistence maps obtained by the GRUND survey revealed fewer hot spots where mature female blue and red shrimps were more persistent (Fig. 3B). The only spawning ground identified as PI≥06 was found to the south-west of Carloforte Island at depths between 575 and 601 m (SW-Area 6), near the areas identified in the summer. Spawning grounds were also recognized (PI≥04) on the slope in the Gulf of Cagliari at depths of 595-673 m (S-Area 7) and on the northern open edge of the Posada canyon at depths of 504-635 m (NE-Area 2).

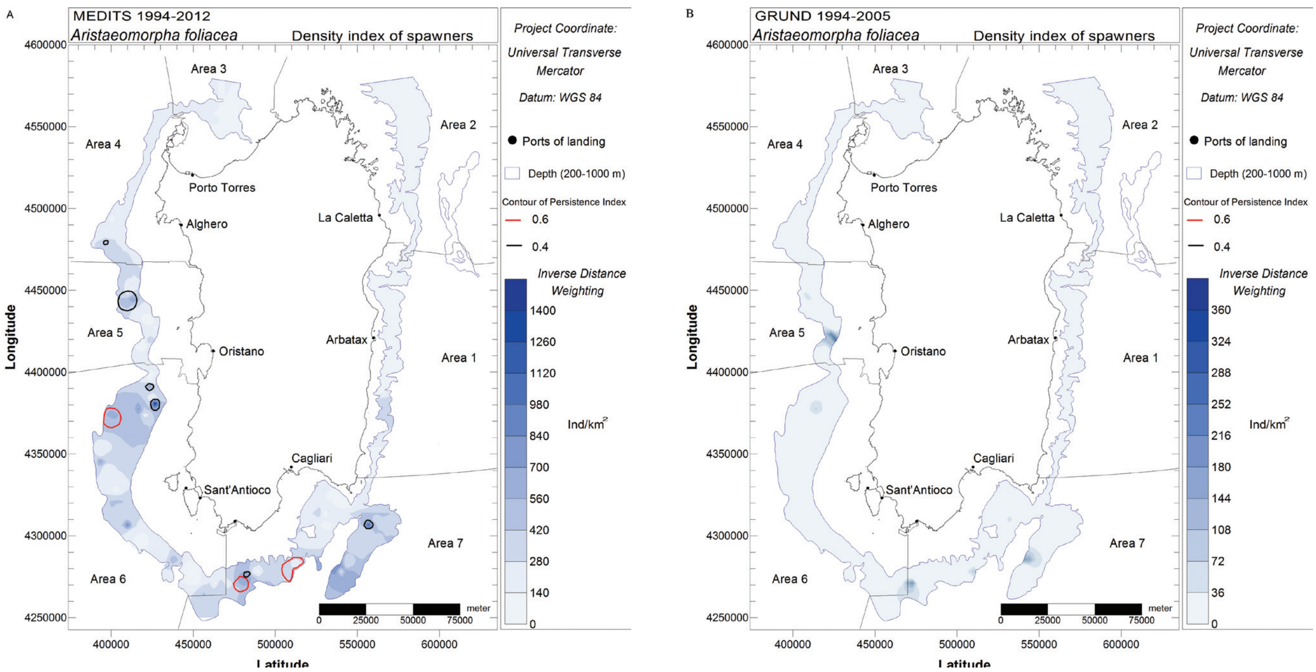


*Fig. 2:* Temporal persistence of giant red shrimp spawning grounds calculated from MEDITS (A) and GRUND (B) time-series density maps.

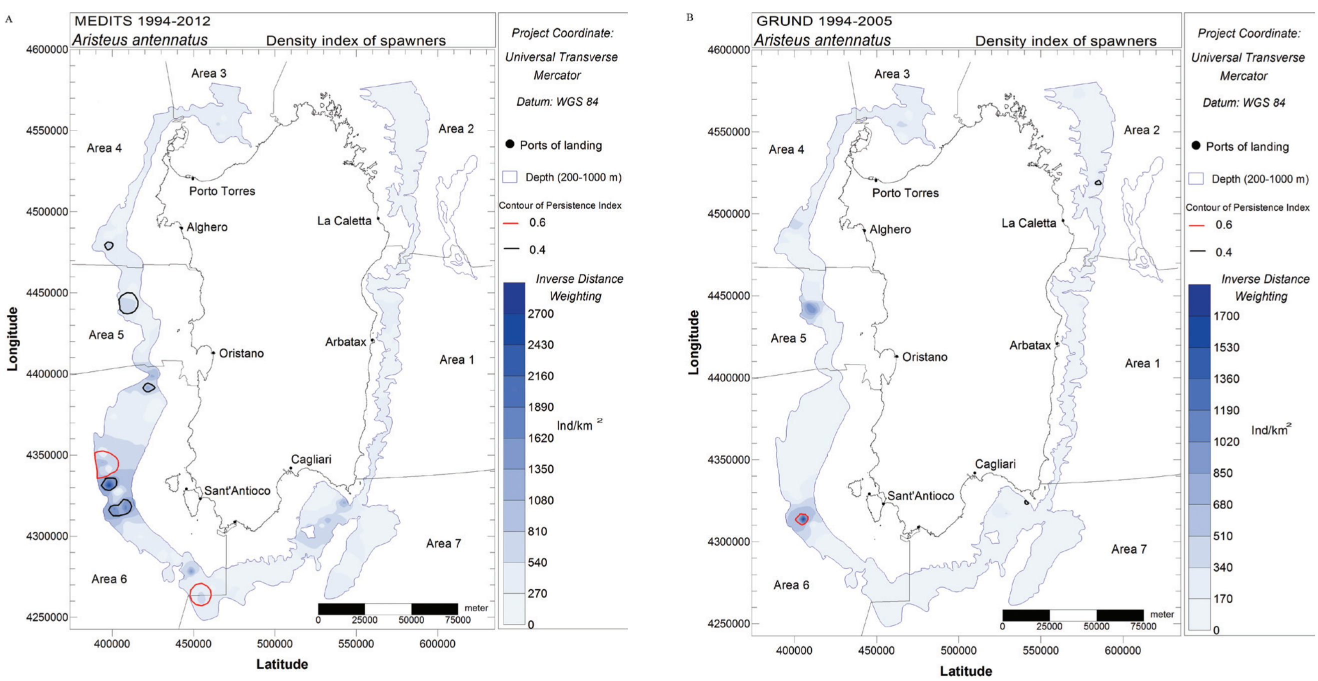


*Fig. 3***:** Temporal persistence of the blue and red shrimp spawning grounds calculated from MEDITS (A) and GRUND (B) time-series density maps.

### *Aristaeomorpha foliacea* nursery areas

For the spring/summer datasets, the mean cut-off length (mean CL ± sd) was around 25 and 30 mm for males and females, respectively. In autumn, it was higher, and varied on average between 35 and 40 mm for males and females (early juveniles), respectively. In general, the chosen cut-off was consistent with the VBGFs (females: $L\infty=70.7$, $K=0.54$, $t_0=0.27$, Cau *et al.,* 2002; males: $L\infty=42.71$, $K=0.77$, $t_0=-0.27$, AAVV, 2008).

The giant red shrimp recruits showed a patchy distribution with some main density hot spots (nurseries), more often to the south and east of the island (Fig. 4A). The PI estimated from the MEDITS data, showed two clear nursery areas (PI≥0.6): on the continental slope between the Pelau and Quirra canyons (420-450 m) (SE-Area 1) and on the slope off the Costa Verde at depths of 377-429 m (SW-Area 6).

The highest density values were recorded in the southern sector of the Ichnusa seamount at depths of 571-678 m (S-Area 7), although the PI was only 0.5. This could be due to the seabed's shape, which prevented samplings beyond a depth of 570 m. Other areas of persistence (PI≥0.4) were identified on the left open edge of the Gonone canyon, at depths of 530-615 m (SE-Area 1), to the south-west of the Island of Sant'Antioco at depths of 478-600 m (SW-Area 6), and on the slope between the two main tributaries of the Mortorio canyon at depths of 358-410 m (NE-Area 2).

Based on the GRUND survey, there were four areas where nurseries persisted at PI≥0.6, located mainly in southern Sardinia (S-Area 7) and to the south-west of the island (SW-Area 6) (Fig. 4B). In southern Sardinia (S-Area 7) two persistent nurseries were identified in the southern and northern sectors of the Ichnusa seamount, at depths of between 590-623 m and 468-628 m, respectively. The third nursery was located in the same Southern Area 7 on the slope near the Pula canyon, between 548 and 603 m. In the south-western sector (SW-Area 6), the main nursery density hot spots were identified in a large portion of the slope off Carloforte Island (fourth area), between 548 and 603 m. Smaller areas of persistence (PI≥04) were also identified on the upper slope near the Teulada canyon heads, off southern Sardinia (SW–Area 6), and on the slope between two tributaries of the Oristano canyon (499-572 m).

### *Aristeus antennatus* nursery areas

Analyses conducted to separate the modal components using the Bhattacharya method generated unsatisfactory results for the blue and red shrimp. Following the VBGF proposed by Cau *et al.,* (2002), a cut-off (for both genders) by carapace length was used that identified the juvenile fraction (recruits) of the population according to the date of the sampling cruise: CL<20 mm in summer (MEDITS) and CL<23 mm in autumn (GRUND).

The MEDITS spring/summer surveys enabled the nursery areas of *A. antennatus* to be identified. Recruits showed a patchy distribution on the continental slope around the Island of Sardinia (Fig. 5A). Our analysis revealed two areas of persistence at PI≥04. One was identified on the open edge of the Tramontana canyon, at depths between 570 and 660 m (PI=0.5) to the north of Sardinia (N-Area 3), while the other was in the south (SW-Area 6) on the open slope of the Teulada canyon, at depths from 561 to 719 m (PI=0.45).

Analyzing the areas using the GRUND survey showed

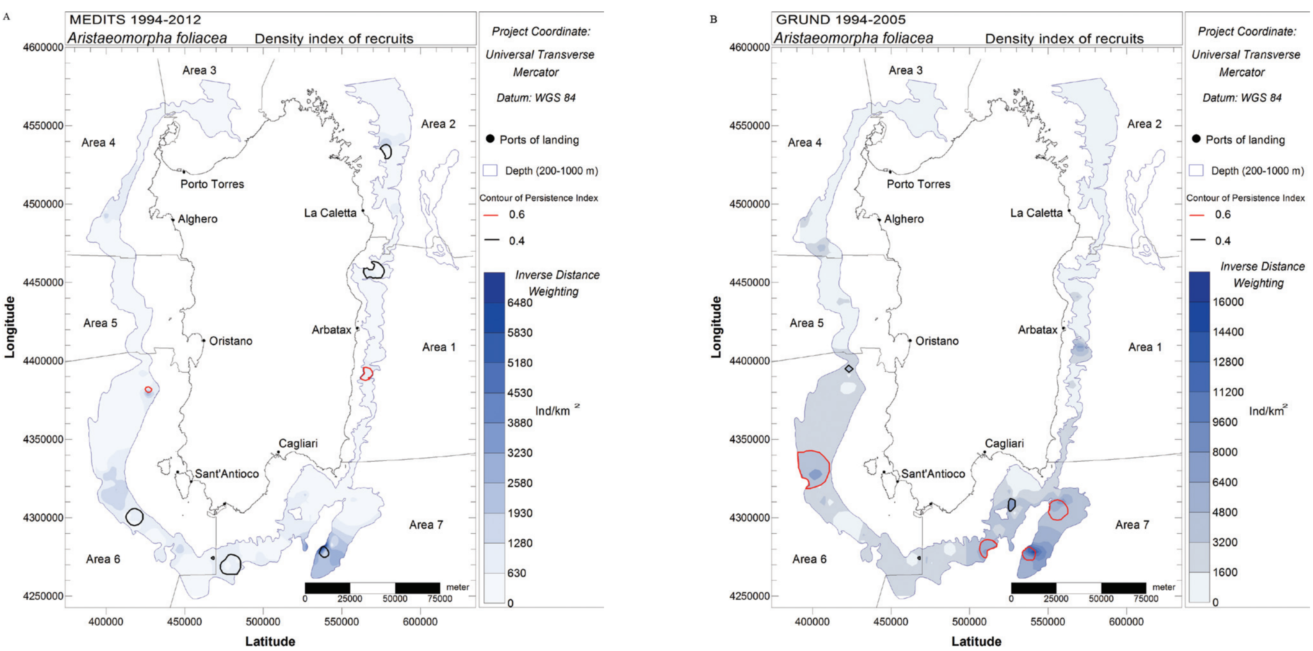


***Fig. 4:*** Temporal persistence of giant red shrimp nurseries calculated from MEDITS (A) and GRUND (B) time-series density maps of recruits.

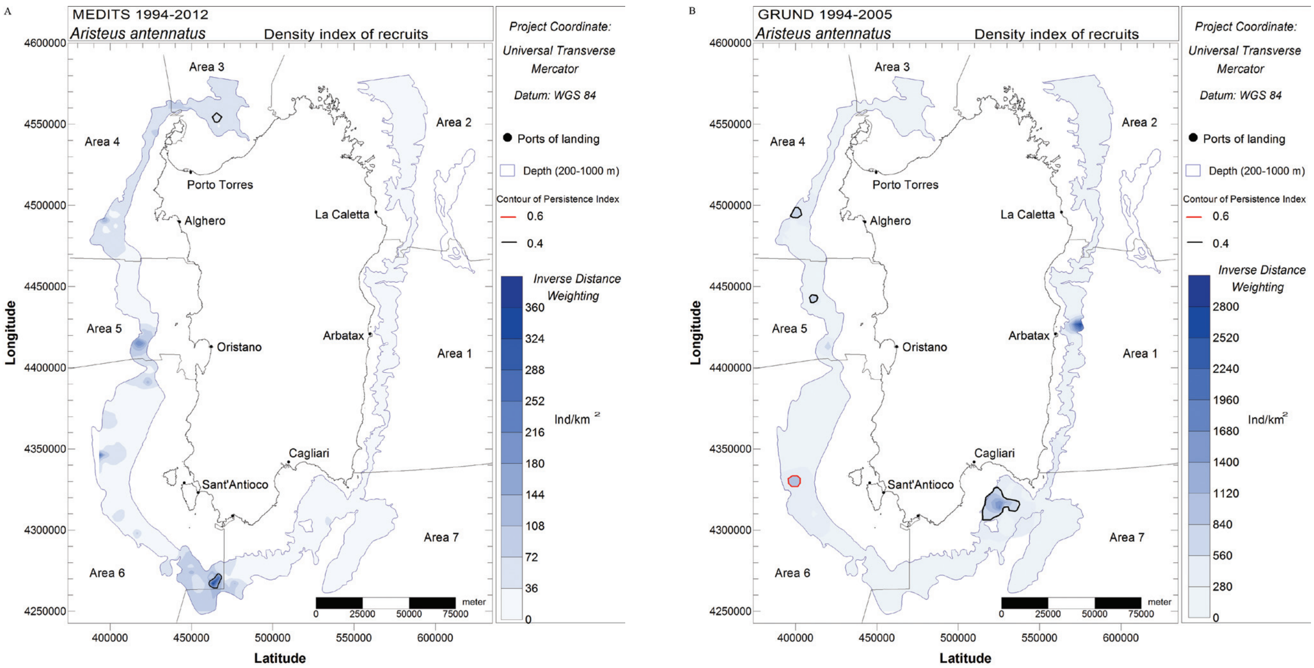


*Fig. 5:* Temporal persistence of the blue and red shrimp nurseries calculated from MEDITS (A) and GRUND time-series density maps of recruits.

hot spots distributed on the slope along the Sardinian coast, which is consistent with the spring/summer survey. The DI of recruits showed a higher abundance in autumn when the individuals had been fully recruited (Fig. 5B). The distribution maps of recruits identified several areas where recruits were concentrated. The first area of persistence was located to the south-west of Sardinia, off Carloforte Island, at depths between 575 and 601 m (SW-Area 6), with a PI of 0.6. There was a lower persistence (PI≥04) of recruits, at depths between 540 and 586 m, on the slope to the north of the Putzuidu canyon (CW-Area 5), in the Gulf of Cagliari at depths between 500 and 681 m, and off Capo Caccia of Alghero, at depths from 505 to 581 m.

## Discussion

Studying time–series data from the spring/summer (MEDITS) and autumn (GRUND surveys) revealed important, persistent and stable spawning grounds and nurseries in the Sardinian slope region for the giant red shrimp, and the blue and red shrimp.

In terms of the spatial distribution of *A. antennatus* life stages, data from both surveys indicated that the main spawning grounds were on the slope off the south and south-western coast of Sardinia. The area where spawners were mainly concentrated (judging from both surveys) was on the slope off Carloforte Island (south-west Sardinia; SW-Area 6). Another spawning ground was found on the slope between the Teulada and Sant'Antioco canyons (between SW-Areas 6 and S-Area 7). In the spring/summer surveys, the main spawning grounds were on the slope at depths from 464 to 730 m, confirming a broad bathymetric distribution of mature females (Sardà *et al.,* 2004). During the autumn surveys, the density of mature females dropped and only one persistent spawning ground was identified. According to several authors, the reproductive period of the blue and red shrimp starts in spring, peaks in summer (when most females reach sexual maturity) and ends in autumn (Mura *et al.,* 1992; Follesa *et al.,* 1998). The fecundity of *A. antennatus* is mainly a function of length while the stock's reproductive potential depends largely on the biggest mature females (Orsi Relini and Semeria, 1983; Kapiris & Thessalou–Legaki, 2006; Orsi Relini *et al.,* 2012).

Hot spots identified as spawning grounds may represent an important influx of larvae in the water column, but no persistent nursery areas emerged for *A. antennatus* from the MEDITS time-series data. In summer, spawners release their eggs and the hatched pelagic larvae subsequently engage in an ontogenic migration through the water column towards surface waters where more food is available (Sardà *et al.,* 2004; Carbonel *et al.,* 2010). In the surface layers, Mediterranean currents such as the Modified Atlantic Water drift play an important part in the horizontal displacement of the larvae (Orsi Relini *et al.,* 2012). This displacement can take around 5 months, from late July to December (Mura *et al.,* 1997), when the decapodid-stage larvae move to deeper waters to reach the deep sea grounds (Sardà *et al.,* 2004; Sardà & Company, 2012). Differences in some aspects of the recruitment process (abundance, size-frequency distribution) have been observed in different areas of the Mediterranean Sea, probably due to the topography of the continental slope (Sardà *et al.,* 2004; D'Onghia *et al.,* 1998) or the physiological condition of adults during the month prior to spawning (Carbonell *et al.,* 2008). Hydrological factors that are linked to environmental variability could also influence the recruitment dynamics of this species Cartes *et al.,* 2008; Massutti *et al.,* 2008). Several authors have suggested that *A. antennatus* recruitment is a process exclusive to deep waters with maximum presence of early juveniles at a depth of over 1000 m (Sardà *et al.,* 2004; Cartes *et al.* 2008; Sardà & Company 2012). In the Mediterranean Sea very small individuals were also found in shallower waters. On the southern coast of Sardinia, the presence of recruits of *A. antennatus* was recorded at depths between 450-650 m (Mura *et al*., 1997). Recruitment of both sexes has been observed in the Greek Ionian Sea in a shallower depth zone (<550 m) (Papaconstantinou & Kapiris, 2001). Blue and red shrimp recruitment to the fishery starts mainly during the spring/summer when individuals of both sexes are more than a year old (from 18 to 20 mm CL) (Mura *et al.,* 1997; AAVV, 2008) but they appear to be fully recruited in autumn (Ragonese & Bianchini, 1996). This is confirmed by their higher abundance during the GRUND survey (autumn).

As seen for *A. antennatus*, the spawner distribution maps for *A. foliacea* around the island of Sardinia revealed few patches of dense concentration. Unlike *A. antennatus*, however, their density was also higher in the south-eastern slope region of Sardinia. Based on the PI analysis (PI≥06), the most persistent *A. foliacea* spawning grounds were on the southern (Pula canyon, between the Spartivento and Teulada canyons; S–Area 7) and central-western slope of Sardinia (Maureddu canyon, SW-Area 6). During the autumn, there were no detectable areas of persistent *A. foliacea* spawning. The spawning grounds were clearly identifiable, however, from the presence of spawning females throughout the study period. In general, the reproductive period is similar in different parts of the Mediterranean, peaking from May to September (Mura *et al.,* 1992; Ragonese & Bianchini, 1995; D'Onghia *et al.,* 1998; Papacostantinou & Kapiris, 2003).

Analyzing the spring/summer data for giant red shrimp, the distribution of recruits showed two areas of persistence, one on the continental slope to the east, between the Pelau and Quirra canyons (SE-Area 1), the other on the upper continental slope in the northern part of the SW-Area 6. More areas of persistence were identified using the autumn dataset. The main nurseries were located off the south and south-west coast of Sardinia (SW-Area 6 and S-Area 7).

The analysis also seems to suggest a seasonal trend of the bathymetric distribution for spawning and nursery areas. On the Sardinian continental slope, the spawning areas for both shrimps were located over a broad bathymetric range between 461 and 730 m. Mature females have likewise been caught over the whole upper-middle slope of the Greek Ionian Sea, at depths between 446 and 728 m (Kapiris & Thessalou-Legaki, 2009), and in the Catalan Sea at depths mainly between 500 and 800 m (Cartes & Sardà, 1993). The most notable difference between the two shrimps is highlighted in a more pronounced seasonality of the reproductive activity of *A. antennatus* compared with that of *A. foliacea* (Mura *et al.,* 1992; Follesa *et al.,* 1998), as demonstrated by the absence of areas of persistent spawning emerging from the GRUND survey.

After the reproduction period (spring/summer), recruits of *A. foliacea* were fished in the upper parts of the continental slope at depths of over 450 m, while the same age cohort reached greater depths, up to 628 m, later in the autumn. Conversely, the areas of persistent *A. antennatus* nurseries were only identified during the autumn. This could be due to a longer reproductive period, or to deep-sea recruitment beyond the fishing areas investigated (236-730 m). Although both these factors may help to justify our results, the latter hypothesis seems more likely. Sardà & Company (2012) documented an ontogenic migration of juvenile individuals from deep-sea grounds to the upper slope, and these movements are in agreement with our observation of recruitment taking place at deeper depths in summer, with a subsequent migration of juveniles to shallower waters in autumn (Fig. 6).

Regarding the geographic distribution of both recruits and spawners, the time-series density (DI) maps highlighted different streaking features. The species showed a mosaic partner, for both species and life stages, with no clear correlation either with time or geographical area. These data confirms the small-scale geographical differences already detected for the overall density indexes in Sardinian waters (Murenu *et al.,* 1994; Cau *et al.,* 2002; Rinelli *et al.,* 2013). The spatial maps evidenced local higher abundance (hotspots), but not always persistent during the years, where the species are mainly concentrated. In particular, the south and central-western areas showed the highest abundance values and persistence areas for both species. The variation in the catches that are evident for both abundance indexes suggest a relationship with some biotic and abiotic factors that we try to discuss in this paper.

To conclude, some valuable findings emerged from the synoptic view of nurseries and spawning areas obtained by this study. In general, our results show a broad area of overlap between recruits and spawners of the two shrimp species located to the west of Carloforte Island (SW-Area 6) (Fig. 7). Nurseries of giant red shrimps, and blue and red shrimps partially overlap during the autumn and, at the same location, *A. antennatus* spawning grounds partially overlap with the nursery areas.

Based on current knowledge, the location of the areas identified appears to be connected with the spatial pattern of the main persistent oceanographic processes identified in the Sardinian Sea (Ribotti *et al.,* 2004), such as enrichment due to upwelling events, described for the first time for the shelf-slope area by Olita *et al.* (2013a). These authors found that the area is characterized by the

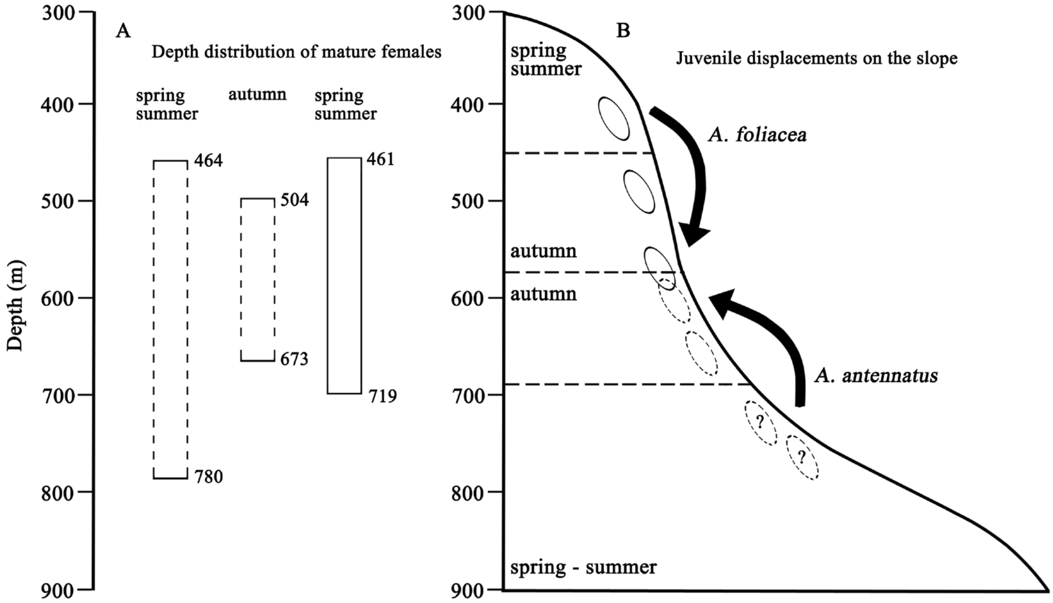


***Fig. 6:*** Depth and seasonal distribution of the spawning (A) and nursery (B) grounds of *A. foliacea* (thick rectangle and circle) and *A. antennatus* (dotted rectangle and circle).

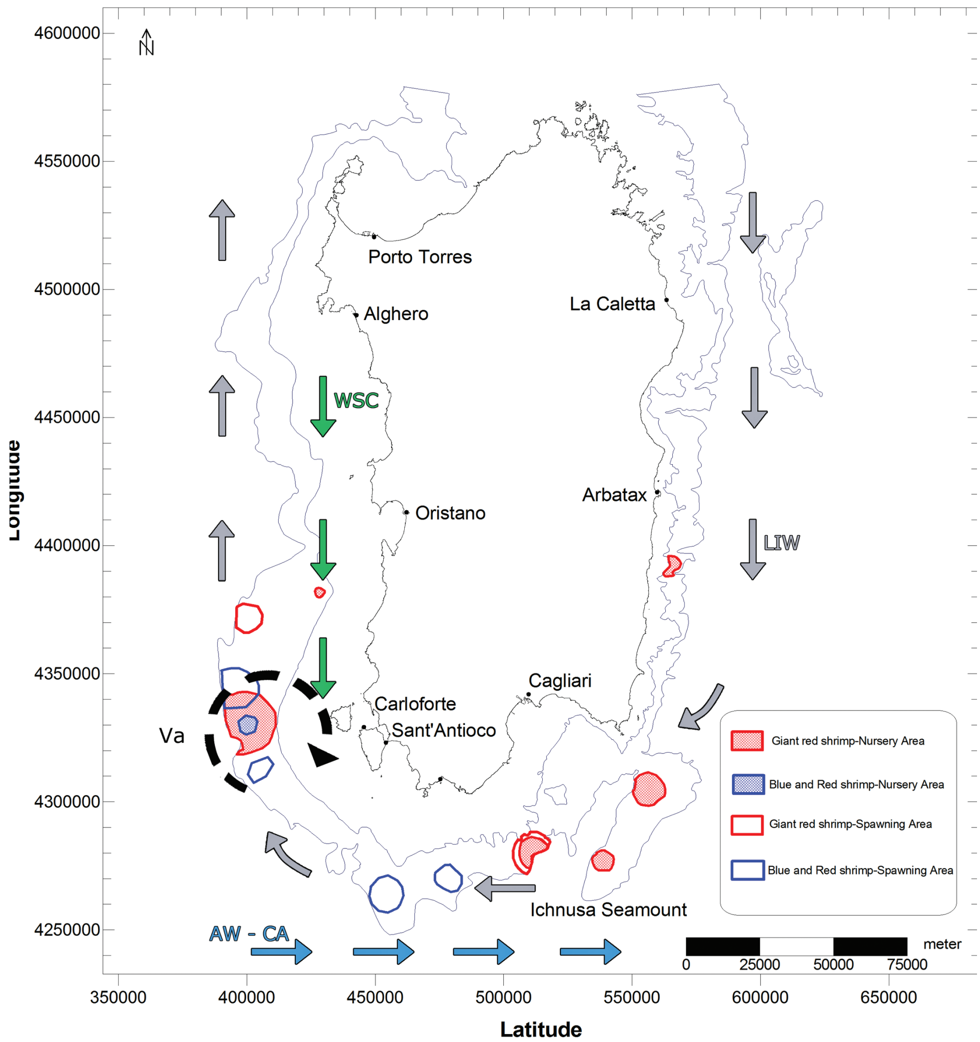


***Fig. 7*:** Synoptic view of the persistent nursery and spawning areas identified for both the MEDITS and GRUND surveys. Surface (AW–CA; Algerian Current carrying on Atlantic Waters, blue) intermediate water mass circulation (LIW; Levantine Intermediate Water, Grey) and Western Sardinian Current (green). Mesoscale structures (black): Va anticyclonic eddies.

presence of the Western Sardinian Current (WSC), which reaches its maximum intensity in the south-west corner of the island due to topographic constraints and to the action of mesoscale features. These characteristics set the scene for upwelling in the southern area (Olita *et al.,* 2013a), whicht is actually triggered by the mistral wind commonly occurring in this region. The area is influenced by the presence of anticyclonic eddies (Sardinian Eddies) forming in the intermediate to deep layers, at a depth of about 500 m (at Levantine Intermediate Water [LIW] level), and also by Anticyclonic Algerian Eddies forming along the Algerian Current and directly or indirectly influencing the slope area of Southern Sardinia (through filaments and sub-mesoscale eddies).

Another branch of LIW was found to the south in the Sardinian channel, from Capo Carbonara to the Spartivento Canyon, where the path of LIW changes due to interaction with the Algerian eddies and topographical features (Olita *et al.,* 2014, and references therein). The interaction between the LIW and Algerian eddies gives rise to two different environmental conditions: the south-eastern part becomes favourable for *A. foliacea* spawning and nursery grounds, the south-western part for *A. antennatus*. In all cases where the oceanographic conditions persist throughout the year, the spawning and nursery areas are also persistent.

Other important areas of aggregation for both juveniles and mature females were found over the bathyal zones in canyon areas, where productivity is reportedly higher than elsewhere (Sardà *et al.,* 2004; Moranta *et al.,* 2008). The variations in canyon dynamics also differ from year to year (due to the effects of different environmental factors), and so do the concentrations of deep-water red shrimps (Company *et al.,* 2008; Würtz, 2012). These geomorphological features represent an 'ecological refuge' for deep-water red shrimp habitats that are unsuitable for trawling and ensure some stock renewal (Caddy, 1990).

Concerning the management of deep-water resources, there is no specific regulation at basin level. In 2005, the General Fisheries Commission for the Mediterranean (FAO-GFCM) adopted recommendations requiring members to prohibit the use of trawl net fisheries at depths greater than 1000 m. In Sardinia (GSA 11) the regulation of fisheries has so far been based on limitations of fishing capacity (licenses), minimum landing sizes, net mesh sizes and temporary fishing closures (45 days during the fall), but the establishment of no-fishing zones has been increasingly advocated as a further component of the fishery management strategy (Council Regulation (EC) No. 1967/2006). In this context, this study provides relevant information on the spatial and temporal distribution of seasonal or persistent aggregations of spawners and juveniles, and also scientific elements indicating that possible protection of these areas may reduce the risk of stock collapse and maintain the reproductive capacity of the exploited stocks.


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