Unione europea
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FSE 2007-2013
POR SARDEGNA
obiettivo competitività regionale e occupazione

Università degli Studi di Cagliari

DOTTORATO DI RICERCA

Biologia e Biochimica dell'Uomo e dell'Ambiente

Ciclo XXVI

ENVIRONMENTAL INFLUENCES ON THE SPATIO-TEMPORAL DISTRIBUTION OF *ARISTEUS ANTENNATUS* (RISSO, 1816) AND *ARISTAEOMORPHA FOLIACEA* (RISSO, 1827) IN THE CENTRAL-WESTERN MEDITERRANEAN

05/C - ECOLOGIA

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Esame finale anno accademico 2012 – 2013

Acknowledgements

Francesco Palmas gratefully acknowledge the Sardinia Regional Government for the financial support of his PhD scholarship (P.O.R. Sardegna F.S.E. Operational Programme of the Autonomous Region of Sardinia, European Social Fund 2007-2013 - Axis IV Human Resources, Objective l.3, Line of Activity l.3.1.)”.

I would like to thank all people that, in different ways, have helped me during this PhD. I am grateful to Prof. Angelo Cau for the opportunity he gave me to deepen and expand my understanding in marine biology.

A special thanks to Andrea Sabatini for his scientific contribution to the thesis and to my scientific education in general. I also want to thank him for having supported my work throughout the years and for giving me great freedom to pursue independent work. Nothing of what was here presented would have been possible without him.

The completion of this thesis has been, of course, made possible by all my colleagues during these years. Thus, at the Department of Life and Environmental Science of Cagliari I had the pleasure of working alongside Paola Pesci, Serenella Cabiddu, Antonello Mulas, Flavio Sacco, Marco Mereu, Cristina Porcu and Manuel Muntoni. Thanks to Antonio Olita for precious support in the environmental spatial analyses and to be always available to provide useful and productive suggestions.

I want to thank all the participants of the MEDITS surveys, especially the captain of the FV ‘Gisella’ Marco Giordano and all the crew for their help during the sampling activities.

I am also grateful to Jacopo Aguzzi, Joan B. Company and Francisco Sardà for hosting me 3 months at the Institute of Marine Science (CSIC) in Barcelona.

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1 GENERAL INTRODUCTION

According to the Food and Agriculture Organization of United Nations, almost 80% of the world fish populations are overexploited, depleted or in a state of collapse. In general the Mediterranean Sea is characterized by the 33% of assessed stocks fully exploited, 50% overexploited and the remaining 17% non-fully exploited (FAO, 2012). Bottom trawling fleets predominate in many Mediterranean fisheries, being responsible for a high share of total catches and, in many cases, yielding the highest earnings among all the fishing sub-sectors (Tudela, 2004). However, not all kinds of bottom fishing are equally exploited, in fact, deep-sea fishing began only in the first decades of the last century, as a result of the development of new technologies that made deep waters fisheries possible (Bensch *et al.,* 2008).

The main target species of the Mediterranean deep-sea bottom fishery are the red shrimps *Aristeus antennatus* (Risso, 1816) and *Aristaeomorpha foliacea* (Risso, 1827), that represent one of the most important commercial species (Cau *et al.,* 2002; Maynou *et al.,* 2006). As technology improved and fleets increased in number in Western Mediterranean bordering countries, the number of captures also increased, until the 1970s when the first collapse of red shrimps fisheries was detected (Bensch *et al.,* 2008; Relini and Orsi-Relini, 1987). By 1985, *A. antennatus* fishing stocks showed signs of recovery but not the *A. foliacea* ones (Fiorentino *et al.,* 1998), which disappeared from Ligurian and Gulf of Lion grounds, remaining restricted to Sardinian and Strait of Sicily areas (Campillo, 1994). Nowadays, declared landings of red shrimps in the entire Mediterranean amounted to 5000 t in 2008 (FAO-GFCM, 2011), but their economic importance is higher because of the high market prices (from 10 €/kg in North African countries to 50 €/kg in Spanish markets, Maynou *et al.,* 2006; Guillen et *al.,* 2012). In the Italian waters, according to the declared landings of the last ten years (IREPA, 2010), the highest catches are recorded in the Sicily Channel (1300 t/year), followed by central Tyrrhenian Sea (263 t/year), Ionian Sea (141 t/year) and Sardinian seas (135 t/year). In the necessity to manage fisheries resources, stocks assessment has been conducted in most of its exploited areas, especially those that have been characterized as overexploited since a long time. Since 2002 stock assessments for *A. antennatus* in Northern Alborán Sea, Northern Spain and Balearic Islands pointed at stocks being fully exploited (GFCM 2002, 2008, 2011). *A. antennatus* in Ligurian Sea was considered overexploited in 2010 (GFCM, 2010). In the waters around Sardinia both red shrimps, *A. antennatu*s and *A. foliacea*, are present, but the stocks were considered overexploited only in some areas, where a progressive increase in fishing mortality rates were recorded (GFCM-SAC, 2004). Stock assessments of *A. foliacea* was conducted only for the strait of Sicily and Maltese Island and the species was considered to be overexploited in 2009 (GFCM, 2009).

In general, in the Mediterranean Sea, where the large part of studies have been undertaken, their distribution is patchy and seems to shows an antagonistic longitudinal gradient (Cau et *al.,* 2002; Company *et al.,* 2004; Politou *et al.,* 2004). In fact, *A. antennatus* being more abundant in the Western Mediterranean basin, with numbers decreasing going eastwards, and *vice versa* for *A. foliacea*. In this context different hypotheses have been formulated by several authors to explain the different distribution observed. Some of them correlated various environmental variables with the presence/absence of these species (Ghidalia and Bourgois, 1961; Company *et al.,* 2008; Maynou *et al.,* 2008; Sardà *et al.,* 2009; Cartes *et al.,* 2011a, b) to explain the spatial distribution and the temporal fluctuations in landings of these two species. Other authors have considered the effect of fisheries pressure as the main factor responsible for the actual different distribution (Relini and Orsi Relini, 1987; D'Onghia et *al.,* 2005; Sardà *et al.,* 2002, 2010). All these factors seems not to act in synergy in determining the spatio-temporal variation of the species and which is the parameter that has a significant predictive effect is still unclear.

Considering the high degree of interaction between marine organisms and the environment, a more holistic approach incorporating interspecific interactions and physical environmental influences would contribute to greater sustainability of the resources by reducing the uncertainty in predictions (Bosford *et al.,* 1997) and promoting an ecosystem based management. A holistic ecosystem approach to fishery management requires the integration of information from a wide range of disciplines, levels of ecological organization and temporal and spatial scales.

In the light of the above, this thesis applies a multi-disciplinary approach to study the dynamic of the Mediterranean deep-water red shrimps. The main purpose of this thesis is to better understand how the abiotic factors could impact on the spatio-temporal distributions of the decapod crustaceans *A. antennatus* and *A. foliacea*.

The first part (chapter 3) provides information on the abundance and geographical distribution of deep-water red shrimps *A. antennatus* and *A. foliacea* in the Sardinia seas. In particular, the aim is to identify the distribution patterns of these species using nineteen years of data from experimental bottom trawl survey (Mediterranean International Trawl Survey - MEDITS, Bertrand *et al.,*2002) in order to give a comprehensive explanation of the distribution in the Sardinian waters. In particular, the temporal evolution of classical abundance indexes with regard to middle slope grounds in seven Sardinian areas (CE-Area1, NE-Area2, N-Area3, NW-Area4, CW-Area5, SW-Area6 and S-Area7) is provided. A synoptic cartographic view of the identified areas using MEDITS time-series (1994-2012) is also presented, allowing the detection of overlapping zones which delineate areas of potentially high environmental and ecological significance.

The second part (chapter 4) aims to investigate the hydrographic conditions of the shelf-slope areas around the Island of Sardinia using *in situ* observation gathered during the fishing activities. The climatological fields have been calculated in the form of yearly seasonal averages over a period of four years

(MEDITS 2009-2012) in order to highlight the horizontal and vertical oceanographic features of the water masses.

The aim of the third part (chapter 5) is to describe for the first time the demersal assemblage related to the Baronie Seamount (North-eastern coast of Sardinia), highlighting the influence that a singular marine environment and its natural dynamics, may have on the spatio-temporal distribution. Day-night vertical movements of the Aristeids which live in the seamount have been studied. In fact, besides the well proven increasing human influence on marine ecosystems, natural dynamics play an important role on shaping the middle-slope assemblages as well as the spatio-temporal distribution of deep-water red shrimps and can be an important source of variability in the data (Sabatini *et al.,* 2007). A reliable testing ground for this hypothesis is the presence of particular geomorphological structures such as canyons and seamount. In the seas around Sardinia a number of submarine canyons with highly variable morphology divide the upper slope and are present mainly along the eastern coast (Western part of Central Tyrrhenian Sea). These areas are peculiar because their richness in nutrients, due to both their geomorphology and hydrographic flows. In fact, in these areas are present strong turbidity currents that can cause morphology changes of the seabed (Shepard et al., 1974). Their influence on the movements of a number of species is widely known (Tudela *et al.,* 2003; Sabatini *et al.,* 2007), but information concerning day-night movements in seamounts is still lacking.

The fourth part (chapter 6) of this thesis provides information on the localization of nursery and spawning grounds for both shrimps correlating georeferenced information with the abundance of the species. Catch data from single samplings were used to generate time-series distribution maps of spawners and recruit by means of inverse distance weighted deterministic interpolations. Using these time-series density maps, the Persistence Index (PI) for identifying spawning and nursery aggregations was computed. Qualitative possible implications with the major oceanographic processes, such as enrichment due to upwelling events in the shelf-slope area, were discussed.

Finally, the fifth part (chapter 7) analyzes the influences of *in situ* environmental variables on the spatio-temporal distribution of deep water red shrimps along the slope of the Sardinia island. To investigate the spatio-temporal variability of abundance and to generate standardized information about environmental variables that took into account likely sources of variation, we assumed a General Linear Modeling approach to conduct analysis of variance.

Information about the relationship between the spatio temporal distribution of the deep water red shrimps and environmental variables can provide important indications that could be used as a scientific base regulating the exploitation of these important resources.

2 GENERALITIES

2.1 ARISTEUS ANTENNATUS

2.1.1 Diagnostic characters

Aristeus antennatus **(Risso, 1816)**

Frequent synonyms/misidentification: None

FAO names: En – Blue and red shrimp; Fr – Gambon rouge; Sp – Gamba rosada; Gambero rosso.

Habitat: Mud bottoms from 80 to 3300 (Sardà *et al.,* 2004)

Fisheries: Bottom trawls

Colour: Nacreous pink profusely interspersed with violet on dorsal regions of carapace and around the join of abdominal segment

Distinctive characters: Rostrum long in females and short in males with 3 dorsal teeth, absence of hepatic spine

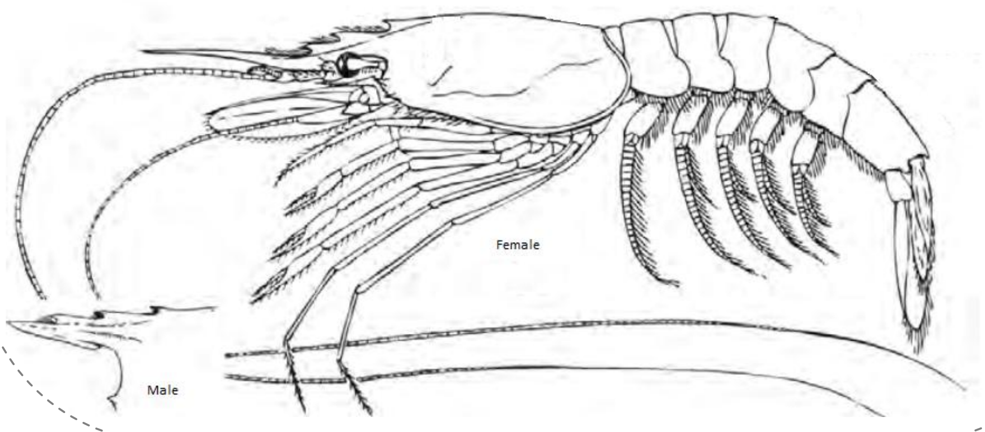


Figure 2-1. The Blue and red Shrimp description (from Prez Farfante and Kensley, 1997).

Laterally compressed body with well-developed abdomen and pleopods (Bas and Sardà, 1998). Adult show sexual dimorphism. The rostrum differentiates between males and females once sexual maturity has been reached. In males it undergoes spectacular reduction, while in females it is always long and stiletto-like (Cau *et al.,* 1982; Demestre and Fortuno, 1992). The rostrum shows only three teeth on the basal part and has neither carina and hepatic spine. The shrimp is nacreous pink, profusely interspaced with violet on dorsal carapace and around the abdominal segments.

2.1.2 Distribution

The blue and red shrimp is distributed in the Mediterranean Sea and in the eastern part of Atlantic Ocean from Cape Verde to Portugal (Holthuis, 1980) (Figure 2-2).

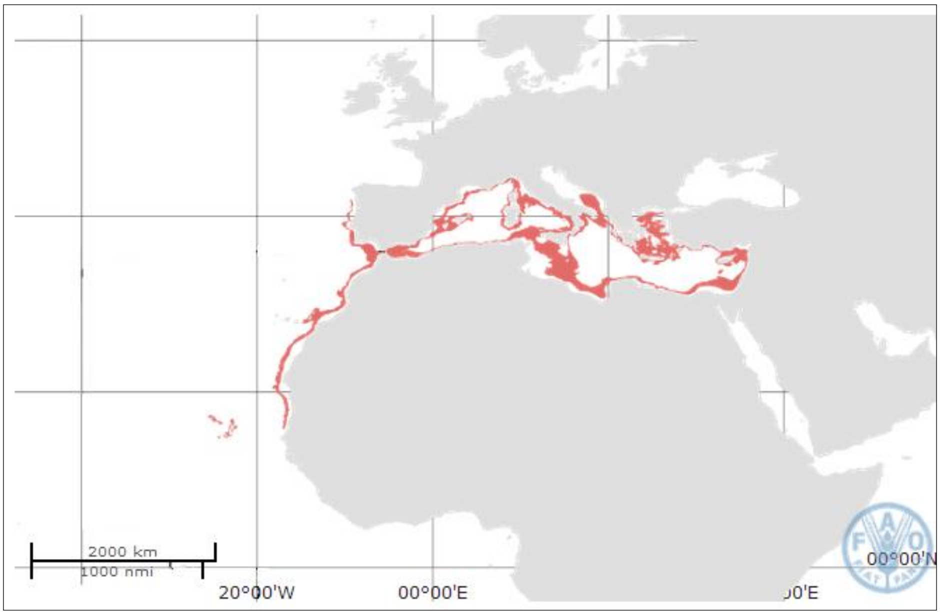


Figure 2-2. Distribution of blue and red shrimp (modified from http://www.fao.org/fishery/species/3422/en).

Experimental catches of this species showed a wide depth distribution comprised from 80 to 3300 m (Sardà *et al.,* 2004). Vertical displacement toward the shallower waters during the night were observed by some authors (Sabatini *et al.,* 2007). Differently from *A. foliacea, A. antennatus* increases in abundance from the eastern to the western Mediterranean basin (Politou *et al.,* 2004). In the Italian seas the geographic distribution of this specie is rather irregular: it is totally absent from northern to central Adriatic and rare in the southern Adriatic. Blue and red shrimp is, however, abundant in the Ionian and Tyrrhenian Seas with the exceptions of the northern part, the Ligurian Sea, the Strait of Messina and along the Sardinian Seas (AAVV, 2008). Depth seems to influence the sex ratio: females dominate at depths comprised between 400 and 700 m (Mura, 1987; Ragonese *et al.,* 1994) while males are mainly found between 1000 and 2200 m (Sardà *et al.,* 2004).

2.1.3 Habitat

The blue and red shrimp is a demersal species that inhabit muddy bottoms (Chartosia *et al.,* 2005; Cannas *et al.,* 2011), sometimes in association with the bamboo coral *Isidella elongata* (Bombace, 1975; Nouar *et al.,* 2011; Cartes *et al.,* 2013) where they reach maximum densities (Maynou and Cartes, 2012). The shrimp is found in the continental slope mainly near submarine canyon (Cau *et al.,* 2002; Tudela *et al.,* 2002; Sabatini *et al.,* 2007).

2.1.4 Feeding habits

The diet of *A. antennatus* is highly variable and mainly based on benthonic organism (Cartes *et al.,* 2008; Kapiris *et al.,* 2010). According to Cartes (1994) *A. antennatus* has the most diverse diet among deep-sea megafauna in the Mediterranean. The blue and red shrimp could be considered a less active and lower hunter among Aristeid shrimp species found in the same area so it occupies a lower position in the benthopelagic food web (Maynou and Cartes 1997). Cartes and Sardà (1989) studied some ontogenic changes in the diet. A differentiation is presented in its diet according to the depth (Cartes, 1994), the feeding time (Cartes, 1994) and daily consumption of food (Maynou and Cartes 1997). Moreover, significant changes of feeding intensity in *A. antennatus* in pre-reproductive periods were observed off the Balearic island (Cartes *et al.,* 2008) and off Algeria (Nouar *et al.,* 2011). A lower degree of cannibalism and the presence of remains of *A. foliacea* in the stomach of *A. antennatus*, were observed by several authors (Chartosia *et al.,* 2005; Kapiris and Thessalou-Legaki, 2011).

2.1.5 Sexual maturity and reproduction

The reproductive period, although with some differences between the various geographic areas of Mediterranean, is somewhat extended, starting in spring, peaking in summer when most of the females reach sexual maturity and ending in autumn (Mura *et al.,* 1992; Follesa *et al.,* 1998). In males reproductive phase appears longer and mature males were collected even during autumn and winter time (Kapiris and Thessalou-Legaki, 2009 and references therein).

Fewer data are available concerning the size of first maturity (SFM) of *A. antennatus*: females at SFM sized between 27 mm CL in the Catalan Sea (Sardà and Demestre, 1987), 25 mm CL in Sardinian waters (Follesa *et al.,* 1998) and 29.45 mm CL in the eastern Ionian Sea (Kapiris and Thessalou-Legaki, 2009). Immature females were caught exclusively during autumn and winter period in the whole basin (Kapiris and Thessalou-Legaki, 2009). SFM for males varied between 15 and 31 mm CL moving from Catalan Sea to the Ionian Sea (Garcia-Rodriguez and Esteban, 1999).

The Aristeid shrimps showed high fecundity (fourfold *A. foliacea*) (Orsi Relini and Semeria, 1983) due to direct release the eggs in to the water (Carbonell *et al.,* 2010). Larval life of *A. antennatus* is about four or five months (Mura *et al.,* 1997). The larval stages develop in the more productive surface layers and move to deeper waters to reach the benthic habitat of adults (Sardà *et al.,* 2004; Carbonell *et al.,* 2010; Orsi Relini *et al.,* 2012).

2.2 ARISTAEOMORPHA FOLIACEA

2.2.1 Diagnostic characters

Aristaeomorpha foliacea **(Risso, 1827)**

Frequent synonyms/misidentifications: None.

FAO names: En - Giant red shrimp; Fr - Gambon rouge; Sp - Gamba roja; It – Gambero rosso:

Habitat: Mud bottoms from 123 m to 1100 m (Politou *et al.,* 2004)

Colour: red scarlet

Distinctive Characters: Rostrum long in females, shorter in males, with 4–10 dorsal teeth; hepatic spine present and strong; telson with 4 pairs of movable spines

Fisheries: Bottom trawls

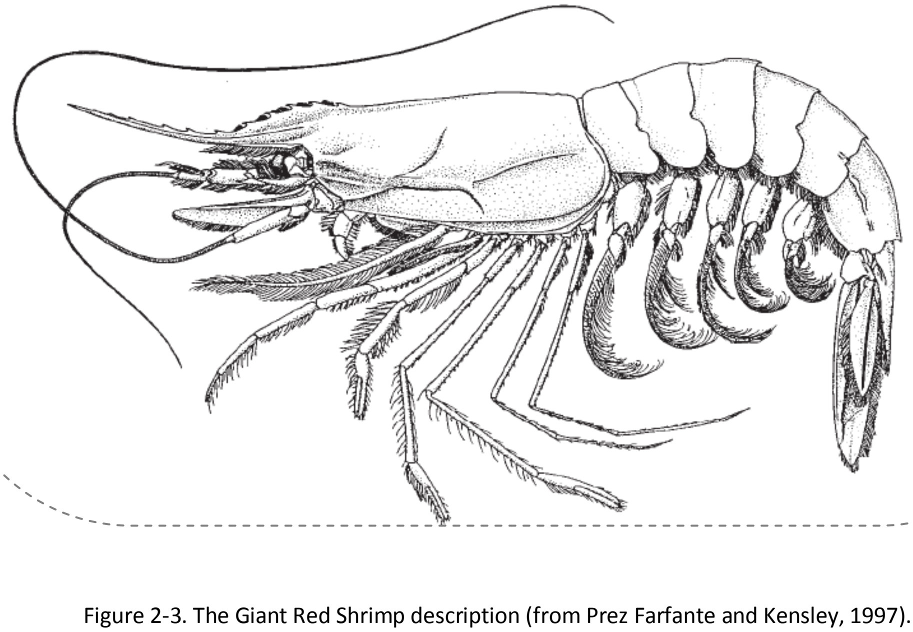


Figure 2-3. The Giant Red Shrimp description (from Prez Farfante and Kensley, 1997).

The giant red shrimp, *A. foliacea* is a decapod crustacean belonging to the family Aristeidae. It shows a laterally compressed body with well-developed abdomen. The adult individuals show a sexual secondary dimorphism: in males the rostrum is short, while in females it extends beyond the antennal scale. Young specimens and sub-adults, who have not yet reached sexual maturity do not have this feature, since males too have a long rostrum (Cau *et al.,* 1982; Ragonese and Bianchini, 1995). This shrimp is scarlet colored. Differs from *A. antennatus* for the presence of robust hepatic spine and for the presence in the dorsal edge of the rostrum of four-six teeth. Males mature earlier and reach a smaller maximum size than females (Ragonese *et al.,* 2012 and references therein). Maximum carapace length: females (76.29 mm), males (49.70 mm) (Cau *et al.,* 2002 and references therein).

2.2.2 Distribution

The giant red shrimp, *A. foliacea* is a cosmopolitan species widespread in the eastern and western Atlantic, western Pacific, the Indian Ocean and the Mediterranean Sea (Holthuis, 1980) (Figure 2-4).

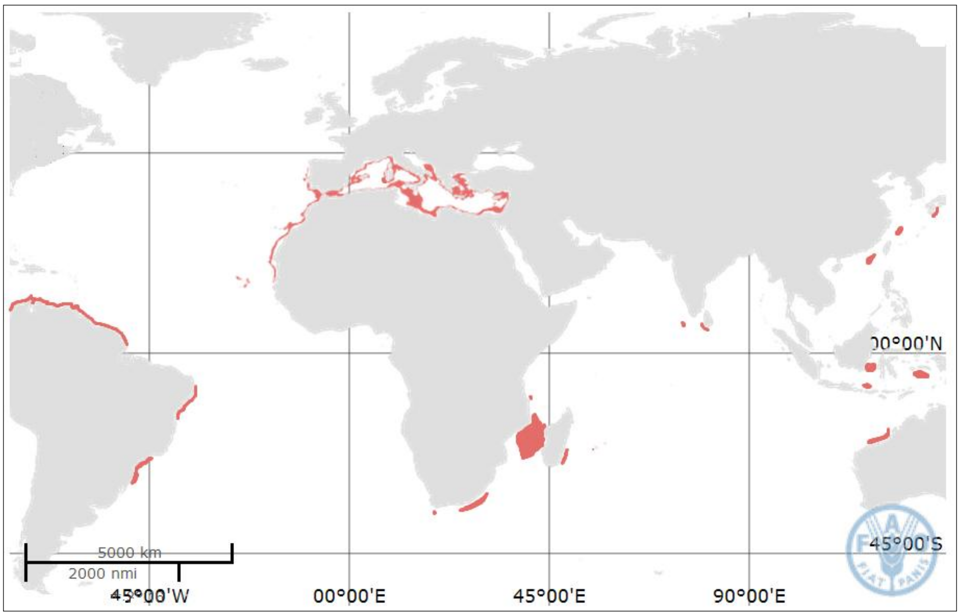


Figure 2-4. Distribution of giant red shrimp (modified from http://www.fao.org/fishery/species/3422/en).

This shrimp is mainly found in the epibathyal and mesobathyal waters. It lives primarily at depths between 400 to 700 m (e.g. Bianchini and Ragonese, 1994; Kapiris *et al.,* 2001; Politou *et al.,* 2004), but can be found in both shallower and deeper waters (Cau *et al.,* 2002). The giant red shrimp shows a nocturnal upward nektobenthic displacement mainly linked to particular geomorphological structures like canyons (Matarrese *et al.,* 1995; Sabatini *et al.,* 2007).

The longitudinal distributions vary among the different areas of the Mediterranean Sea: *A. foliacea* predominates in the eastern and central part of the basin while it is rare or absent in the western and northern part (Cau *et al.,* 2002; Politou *et al.,* 2004; Cartes *et al.,* 2011a). The geographical variability of this species seems to be closely connected to hydrological and oceanographic factors and the distribution of red shrimps may be correlated to water mass properties such as salinity and temperature (Ghidalia and Bourgois, 1961; Politou *et al.,* 2004). In Italian seas the longitudinal distribution of *A. foliacea* shows a somewhat irregular pattern. The giant red shrimp is not found in the northern and central Adriatic sea, while is however more abundant in the Central Tyrrhenian, Central Southern Tyrrhenian, Sicily Channel, Ionian Sea and Sardinian seas (Ardizzone *et al.,* 1994; Spedicato *et al.,* 1994; Cau *et al.,* 2002; Carlucci *et al.,* 2006). Low concentrations have also been reported in the southern Adriatic (Vaccarella *et al.,* 1986; Ungaro *et al.,* 1999).

2.2.3 Habitat

A. foliacea is a characteristic species of the muddy bottoms of the middle continental slope in the Mediterranean (Pérès, 1982; Mura *et al.,* 1997; Ragonese *et al.,* 1997). The giant red shrimp is caught especially near submarine traches, canyons and seamounts (Kapiris and Thessalou-Legaki, 2009). This species seems to adapt its life cycle to the geomorphology of the sea bottom. The canyons and seamounts, due to their geomorphological conformation, offers these species the opportunity to very quickly span a considerable range of depths (Sabatini *et al.,* 2007).

2.2.4 Feeding habits

The giant red shrimp shows a highly diversified diet (Cartes, 1995; Kapiris *et al.,* 2010). *A. foliacea* is a fast and active predator of large and mobile organisms (Bello and Pipitone, 2002) but also an occasional scavenger. According to Kapiris *et al.,* (2010), the presence of fish remains (bones, scales) in their foregut most probably reflects a scavenging ability of this species. It could be considered a more active predator with higher feeding activity than *A. antennatus* found in the same area even if some authors (Chartosia *et al.,* 2005) stated that the diets of the two species significantly overlap. The feeding activity of *A. foliacea* is generally comparable in the different regions of the Mediterranean, such as in the Catalan Sea (Cartes, 1995), Sicilian Channel (Gristina *et al.,* 1992), Aegean Sea (Chartosia *et al.,* 2005) and in the Eastern Ionian Sea (Kapiris *et al.,* 2010). Differences in its feeding activity among areas in the Mediterranean, such as different prey food categories and mean number of prey, could be due to depth, bottom morphology, seasons or daily vertical migrations (Cartes, 1995). The most dominant prey items include both organisms typical of the muddy bottoms and pelagic organisms, particularly crustaceans (e.g. decapods, Plesionika spp), cephalopods and fishes (e.g. Myctophidae, Macrouridae) (Kapiris and Thessalou-Legaki, 2011). A differentiation in the feeding patterns is presented according to the season, indeed, the feeding activity increases during the reproductive period in spring and summer. Females seem to be more active predators than males, feeding preys with greater swimming ability. It could be attributed to sexual dimorphism and to size differences between sexes (Kapiris *et al.,* 2010).

2.2.5 Sexual maturity and reproduction

The reproductive period is similar in all the Mediterranean basin, with a peak from May to September (Mura *et al.,* 1992; Ragonese and Bianchini, 1995; Papacostantinou and Kapiris, 2003). In most areas, the sex ratio is in favor of females, while in the Greek Ionian Sea males are dominant. In the seas off

Sardinia (Mura *et al.,* 1997), as well as in the Sicilian Channel (Ragonese and Bianchini, 1995) the sex ratio varied from 3:1, in favor of females, to 1:1. In the north Tyrrhenian Sea females were always more abundant than males (Righini and Abella, 1994), while in the Latium coast the proportion was 1.06:1 in favor of males (Leonardi and Ardizzone, 1994). The fertility of *A. foliacea* has been estimated as being equal approximately to 1/3 of the fertility of *A. antennatus* (Orsi Relini and Semeria, 1983). In the northern Tyrrhenian the smallest female with spermatophore had a carapace length of 40 mm (Righini and Abella, 1994). In the central Tyrrhenian (southern Tuscan Arcipelago), the smallest mature female measured 28 mm, and the smallest mature male 29 mm (Mori *et al.,* 1994). In the central Tyrrhenian (Latium), the size of first maturity is 30-31 mm for males and the smallest female with spermatophore measured 33 mm (Leonardi and Ardizzone, 1994). In the central-southern Tyrrhenian, the smallest mature female had a carapace length of 38 mm (Spedicato *et al.,* 1994). In the southern Tyrrhenian, the size of which 50% of the females had their spermatophore was 34 mm. In the Sardinian seas, the smallest mature female measured 35 mm (Mura *et al.,* 1992). In Ionian Sea, the smallest mature female was 35 mm, while the smallest mature male was 27 mm. The size at first maturity was 39 mm for the females and 29 mm for the males (D'Onghia *et al.,* 1998). In the Greek Ionian Sea the minimum length of females with spermatophores (25 mm CL) was found in January, at a depth of 637 m. Females matures mainly from summer to early autumn, with a peak between June and August (55–79%) (Papaconstantinou and Kapiris, 2002). On the basis of the colour and shape of the ovary and testis, the specie was classified according to the macroscopic maturity scale adopted in MEDITS programme. Males maturity was checked by the presence of the spermatophores in the terminal ampoullae of *vasa deferentia*.

2.3 GENERAL MORPHOLOGY OF SARDINIA SEAS

Sardinia is one of the most interesting areas of the central Western Mediterranean basin, not only for its geographic location and its geomorphologic characteristics but also for the presence of extended fishing bottoms (Cau *et al.,* 1994). The sea bottom surrounding the island into the deep range 0- 800 m cover an area of 26.975 Km^2. The sea bottoms along the coasts are not homogeneous both for their extension and for their bionomic and geomorphologic characteristics.

The morphology of sea bottoms is different and varied in the different areas of Sardinian Seas. The southern and western fishing bottoms are extended and the seafloor is characterized by a wide continental shelf with a gradual decline that ends 200 m depth. The eastern bottoms are characterized by a limited continental shelf (ca 602 km^2) that terminates at about 60-100 m of depth. In this part the continental slope is characterized by a marked variation in depth in few nautical miles and cover an area of about 481 km^2. Indeed in the Eastern coast, the continental shelf and slope are connected to the peculiar inland orographic structure and river basin: narrow inlets, interspaced by high and steep mountains, correspond to a very narrow continental shelf with irregular bottoms, and to a slope interspaced by very deep canyons (Figure 2-5). On the base of their geomorphic differences between active and passive continental margins the canyons are mainly divided into three main types. Type 1 shelf-incising canyons having heads with a clear bathymetric connection to a major river system. Type 2 shelf-incising canyons with no clear bathymetric connection to a major river system and Type 3 blind canyons incised onto the continental slope. All three canyon types include at least one major canyon with possible tributary forming dendritic complexes (Harris and Whiteway, 2011).

A complex system of 29 canyons incised the continental slopes of the Island of Sardinia (Wurz, 2012). Canyon density is higher in the eastern and southern coast (Caprera, Cervo, Mortorio, Molara Posada, Orosei, Gonone, Arbatax, Pelau, Quirra, San Lorenzo, Carbonara). The south margin is incised by 10 canyons: Cagliari, Pula, Spartivento, Teulada, Sant'Antioco, Toro and at last 4 canyons in front of Carloforte island which still remain unnamed. The western portion of the Sardinian Sea is characterized by only seven canyons: Maureddu, Piscinas, Oristano, Putzu Idu, Mannu, Logudoro and Argentiera. Castelsardo is the canyon name located off the northen side of the gulf of Asinara. This canyon is characterized by two main branches: Scorno not far from the Asinara archipelago and Tramontana in front of Porto Torres (Figure 2-6).

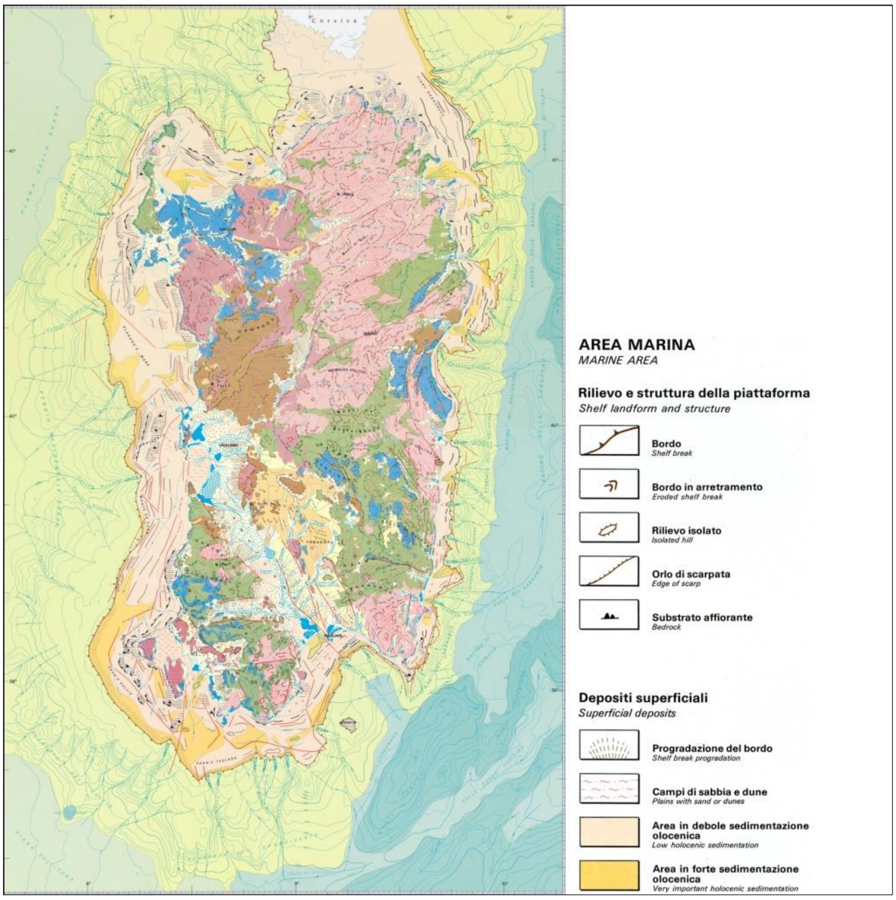


Figure 2-5. Marine and Continental geomorphology map of Sardinia island. (modified from Ulzega, 1988).

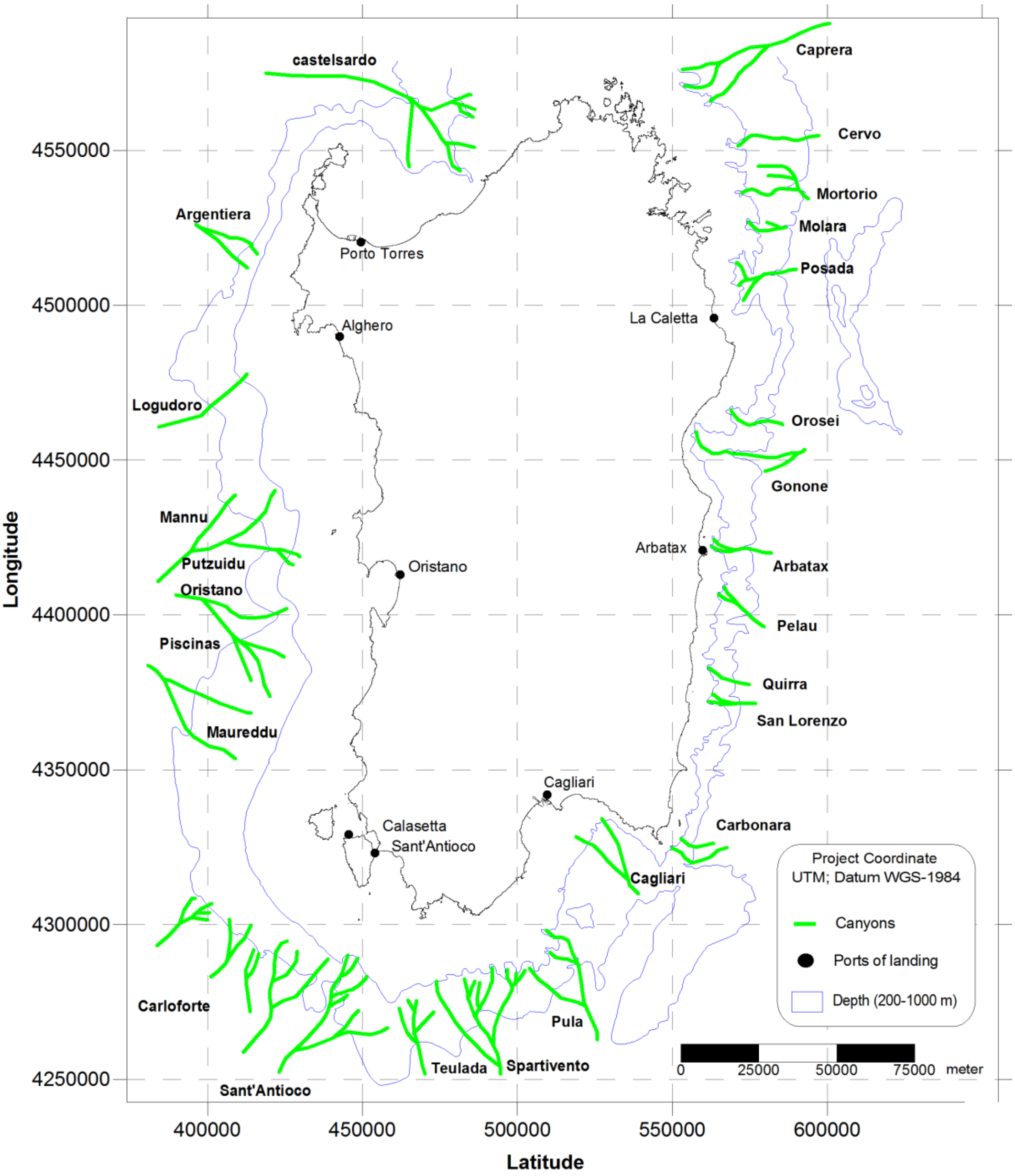


Figure 2-6. Distribution of the main submarine canyons in the Sardinian seas.

Submarine canyons, however, are not the only geomorphological structures characterizing the seabed topography. Two seamounts far from the coasts are present (Baronie and Ichnusa).

The Baronie seamount is located off the north-eastern coast (in the western part of the central Tyrrhenian Sea) (Figure 2-7). It is characterized by a rise in the continental shelf, which results in a decrease in sea depth. The seamount rises from the sea bottom to two levels lying at 162 m and 168 m, characterized by a flat morphology and a thin sedimentary cover (Bellagamba *et al.,* 1979). It has an elongate shape, running from north to south, parallel to the coast line.

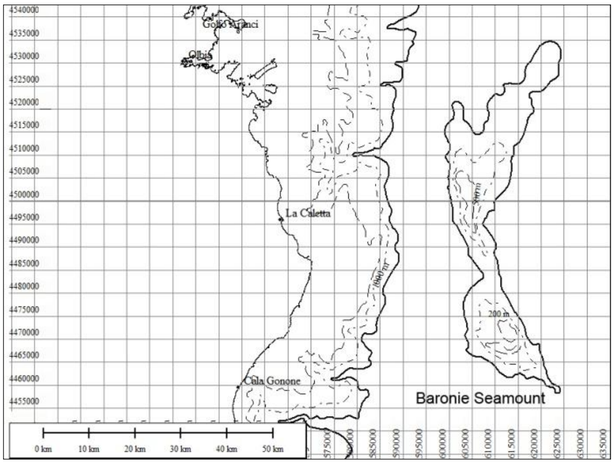


Figure 2-7. Baronie seamount. Continuous lines, 1000 m; Dash-dot, 500 m and dot 200 m.

The Ichnusa seamount is located in the south-east Tyrrhenian basin. It is NE-SW trending high feature on the slope. It is about 75 km long and 18 km wide with a relief up to 1800 m (Figure 2-8). The sediments are thin as a results of seafloor erosion by flowing water masses, spill-over and downslope re-depositional processes (Gennesseaux and Stanley, 1983).

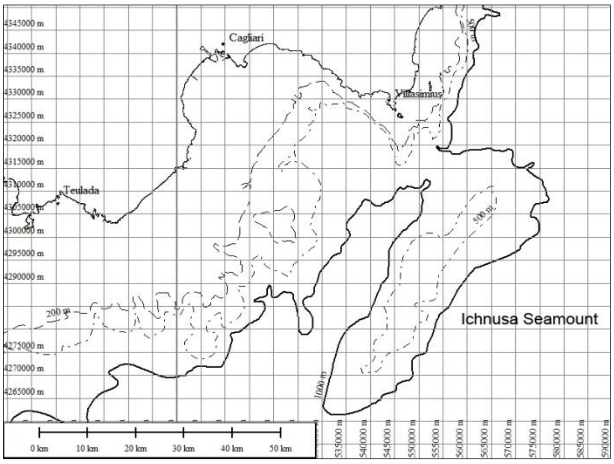


Figure 2-8. Ichnusa seamount. Continuous lines, 1000 m; Dash-dot, 500 m and dot 200 m.

2.4 GENERAL DESCTRIPTION OF TRAWL FISHERIES IN SARDINIA

According to the official data (http://ec.europa.eu/fisheries/fleet/index.cfm), Sardinia has 175 bottom fishing trawlers and the sector provides employment for about 400 fishermen. The trawling sector is characterized by prominent small-scale coastal fishing as well as by a marked polyvalence. Most of the trawl effort is concentrated around the major harbours (mainly Cagliari, Sant'Antioco, Oristano, Siniscola, Arbatax and Porto Torres) (Figure 2-9).

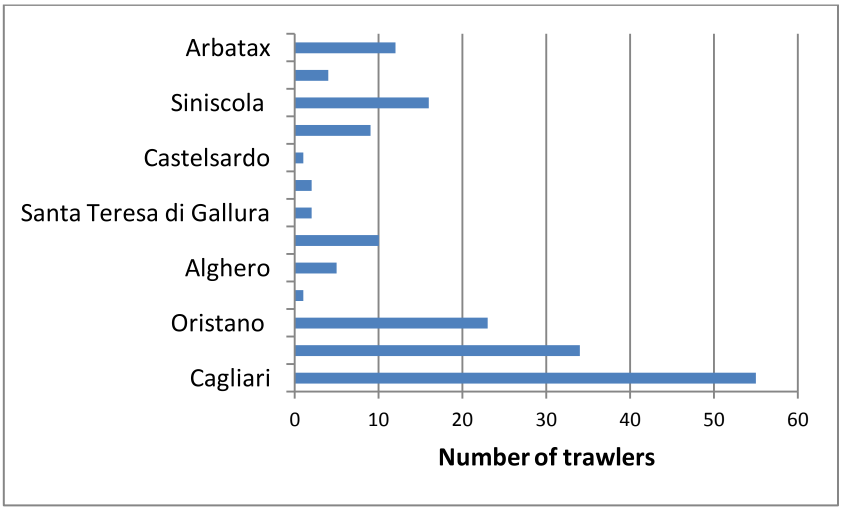


Figure 2-9. Trawl vessels in the Sardinian ports.

In accordance with Regional Fisheries Law n.4/2007, the Sardinian adopted management plans for fishing in its territorial waters (12 miles) for different types of fishing. The management plans introduced 5 fisheries and aquaculture districts that includes five Sardinian areas (Table 2-1). The fishing and aquaculture districts represent areas with as homogeneous as possible environmental, social and economic characters.

Table 2-1. Fisheries and aquaculture districts in Sardinian Seas

Number	Districts	Limit
1	Porto Torres – La Maddalena	Porto Tangone - Capo Ferro
2	Olbia - Arbatax	Capo Ferro - Capo Ferrato
3	Cagliari	Capo Ferrato - Capo Teulada
4	Portoscuso	Capo Teulada – Capo Pecora
5	Oristano	Capo Pecora - Porto Tangone

According to the Length Overall (LOA), the trawlers can be divided into three categories. The first consists of small boats (up to 12 meters), which are characterized by the fact that they operate in a narrow coastal area near the home port. The second group are vessels from 12 to 20 meters, and consists of vessels that fish both coastal and offshore areas. Large vessels are those over 20 meters and they typically fish in the open sea for a few days being less connected to the home port. The Sardinian big trawlers usually work from Monday to Saturday, generally coming back daily to the closest port in the early morning to land the fish. In the first category there are 34% trawlers, in the second category 38% and in the third there are 25% (Figure 2-10).

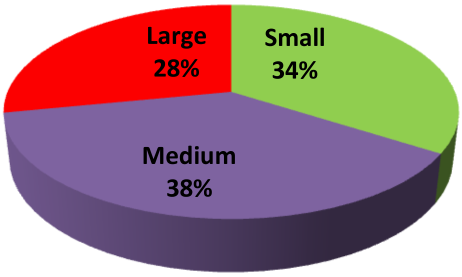


Figure 2-10. Trawlers by LOA in Sardinia.

The number of vessels and mean gross tonnage (GT) recorded in the main fisheries ports of Sardinia are reported in Figure 2-11. The European official statistics (http://ec.europa.eu/fisheries/fleet/index.cfm) report the highest percentage of large gross tonnage vessels (> 50 GT) in Cagliari (11%) followed by Sant’Antioco (3%), while Porto Torres, Siniscola and Alghero fisheries are mainly made up by medium vessels.

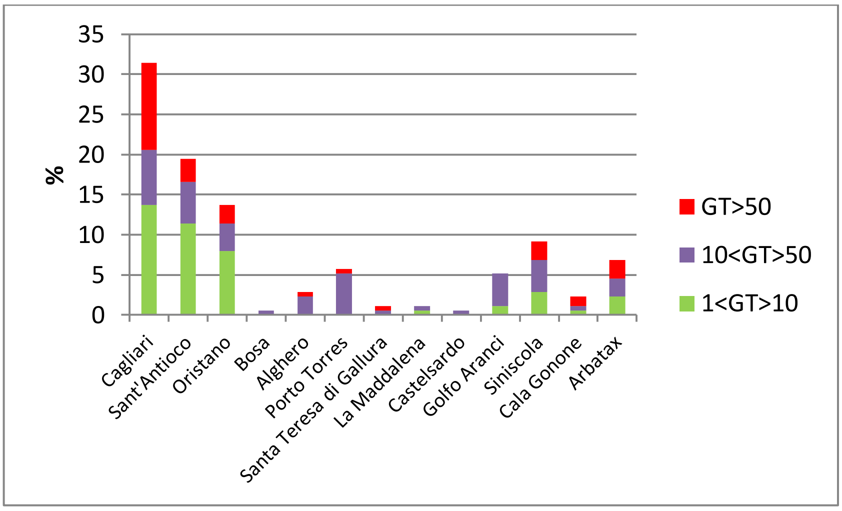


Figure 2-11. Distribution of trawlers by GT (Gross Tonnages) in the Sardinian ports.

Smaller vessels operate almost exclusively on the continental shelf targeting mullets, octopuses, hake and sea breams. They usually operate daily trips not far from the port of landing. The Figure 2-12 shows the main fishing grounds (FGs) of the inshore trawlers in the Sardinian coast identified using the fishermen logbooks.

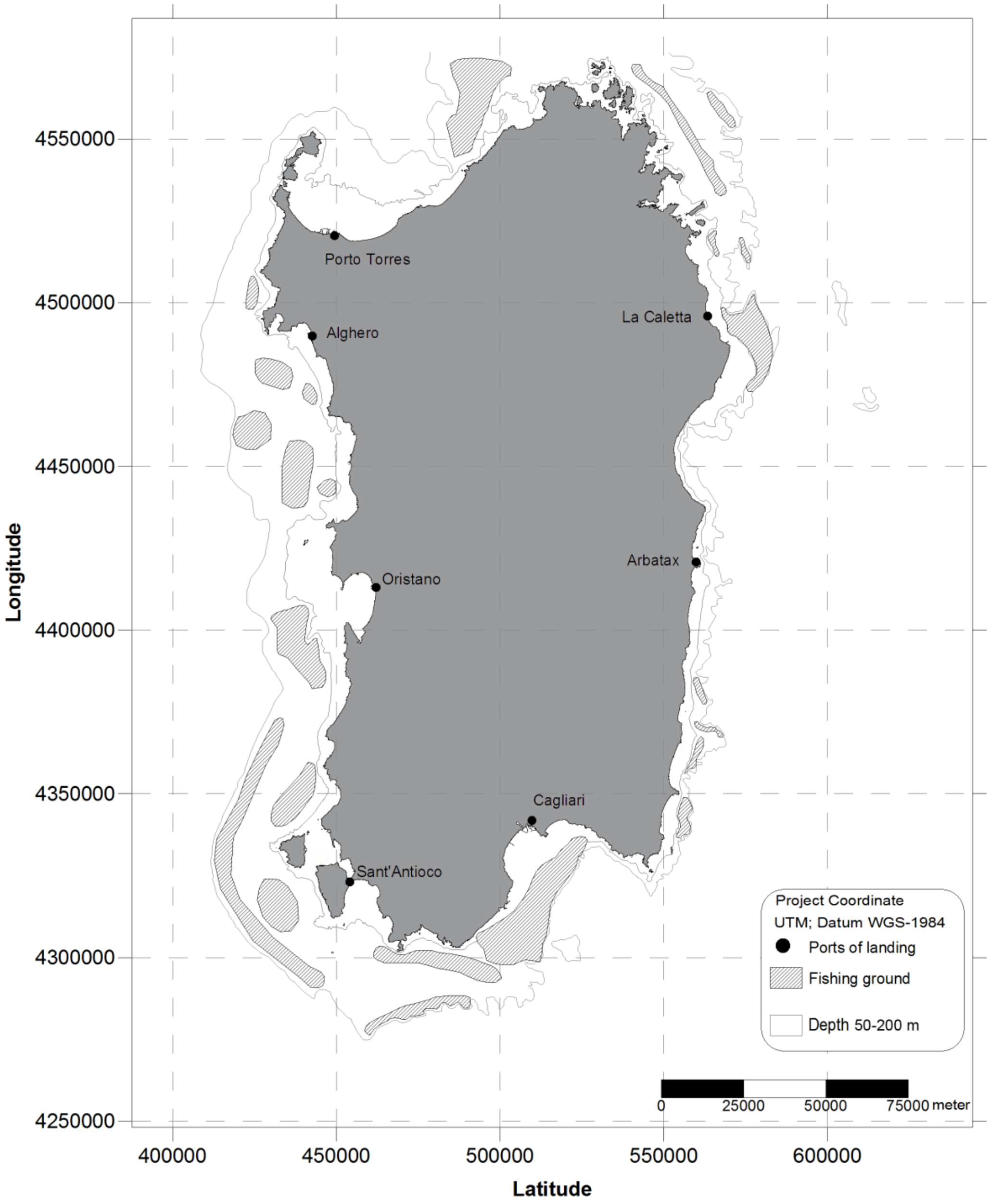


Figure 2-12. Inshore fishing grounds in Sardinia.

Medium vessels can operate on the continental shelf and sometimes in the slope fishing grounds (Figure 2-13). The large vessels generally operate both on the continental shelf and at depths of up to 700–800 m depending on the target species. During the daylight operate almost exclusively on the continental slope (targeting decapod crustaceans) while after the sunset they fished on the continental shelf (targeting mixed fishes).

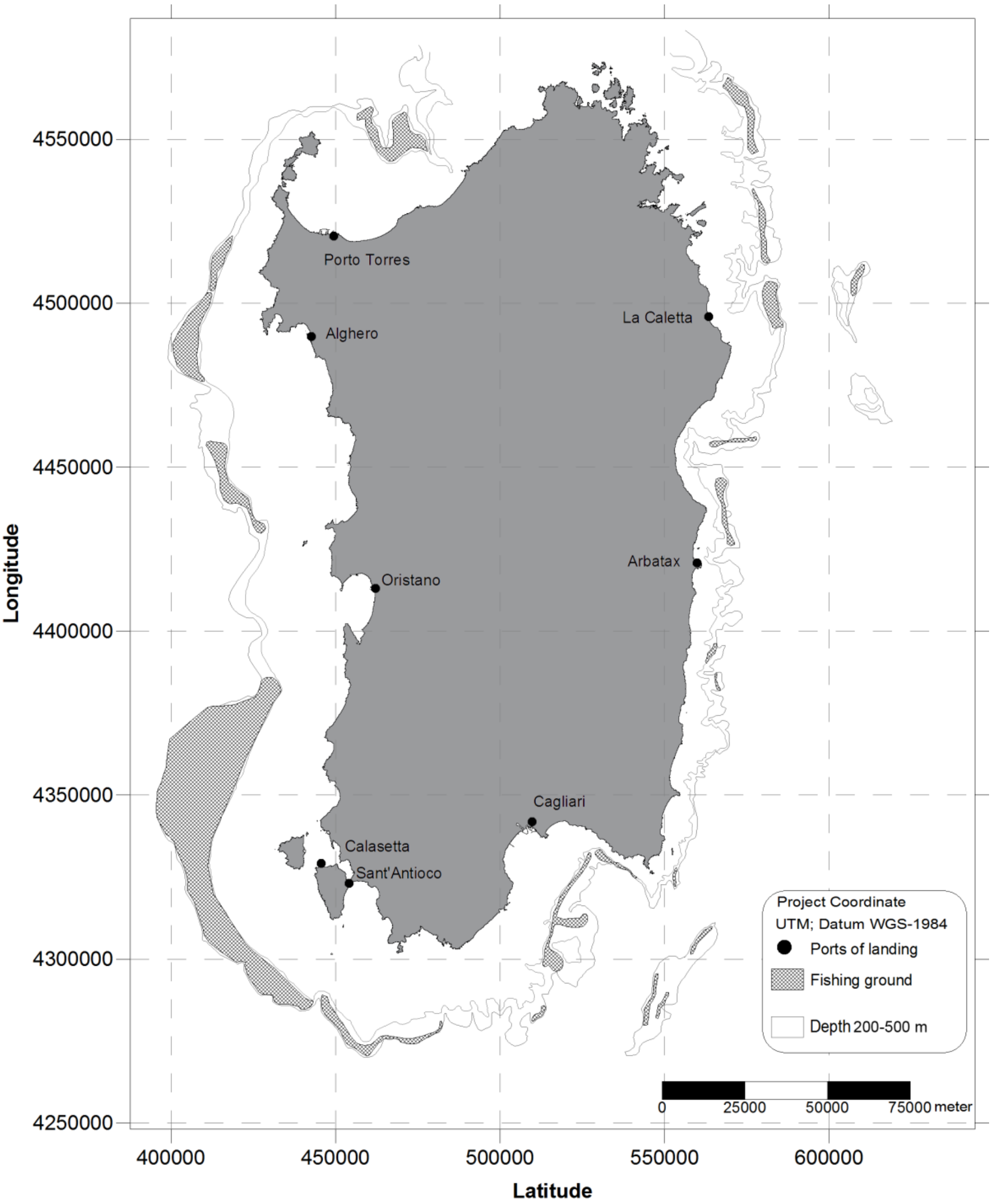


Figure 2-13. Offshore fishing grounds in Sardinia.

2.4.1 The red shrimp trawl fisheries

In the Sardinian Seas the blue and red and the giant red shrimp represent the most important demersal resources for the trawling fleet (Cau *et al.,* 2002). In general, before the 1960s few low tonnage wooden boats operated almost exclusively on the middle slope (400 m depth) and only with really good sea conditions (Cau *et al.,* 1994). In the early 1990s, the Sardinian fishing fleet was renewed as a consequence of government policy (DM 26/07/1995) with the aims of reducing the fishing effort in shallower waters (GFCM-SACS, 2004). The main change involved the replacement of old, low tonnage wooden boats with large steel boats suitable for operate on deeper fishing grounds. In Sardinian seas the red shrimps are actively exploited by Sardinian fleets and occasionally by Sicilian, Tuscanian and Spanish trawl fleets. Nowadays about 1300 tons of both shrimps are landed each year with seasonal variation and annual fluctuations (IREPA, 2010) (Figure 2-14). The deep water red shrimps represent one of the most important deep-water fishing resources in Sardinia (up to 15–20%, as biomass; IREPA, 2003–2010) which correspond to a high economic income (Sabatini *et al.,* 2013).

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 (European Council Regulation n. 1967/2006).

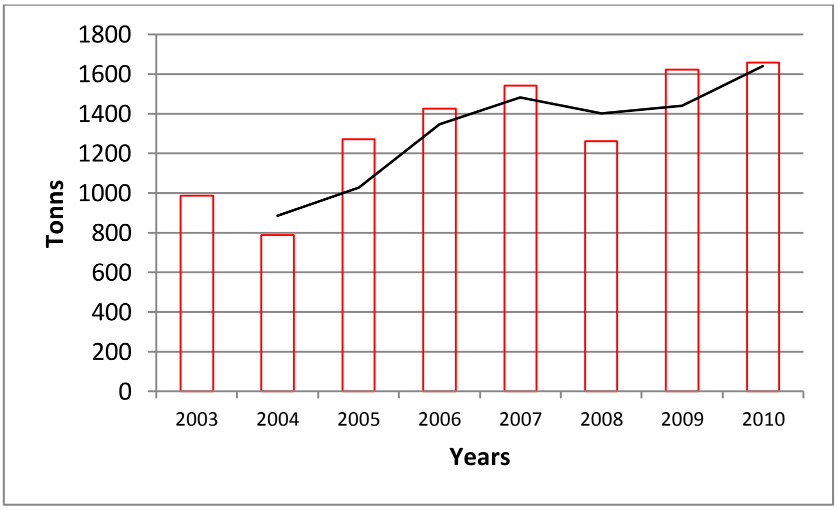


Figure 2-14. Bars denoted annual landings for both Aristeid in Sardinian Seas (2003-2010) (IREPA, 2010) and line black denotes moving everage.

The Aristeid fishing grounds are characterized by sandy muds (until 400 m) and deep muds (>500 m depth), situated near to submarine trenches, canyon and seamounts (Cau *et al.,* 2002; Sabatini et. 2011) (Figure 2-15).

The main fishing grounds are located in the southern part of Sardinia (Sardinia Channel) and they are mainly exploited by several trawlers of Cagliari and Sant'Antioco which operate two days fishing trips (Figure 2-16).

Other important fishing grounds are located in the western coast between Sant'Antioco and Alghero. In the northern Sardinia they are mainly located in front of Porto Torres near the Tramontana canyon. The usual fishing grounds of the eastern areas are situated between the Corsica border, and the Quirra canyon, at south. In this area most of the boats fished on the Baronie Seamount (also called by fishermen "K bank") and in the several bathyal canyons of the east coast.

A consistent part of landings is sold in the local markets, directly by the fishermen; the most valuable qualities are picked up by a local wholesaler, while the massive product is taken to the Cagliari's market.

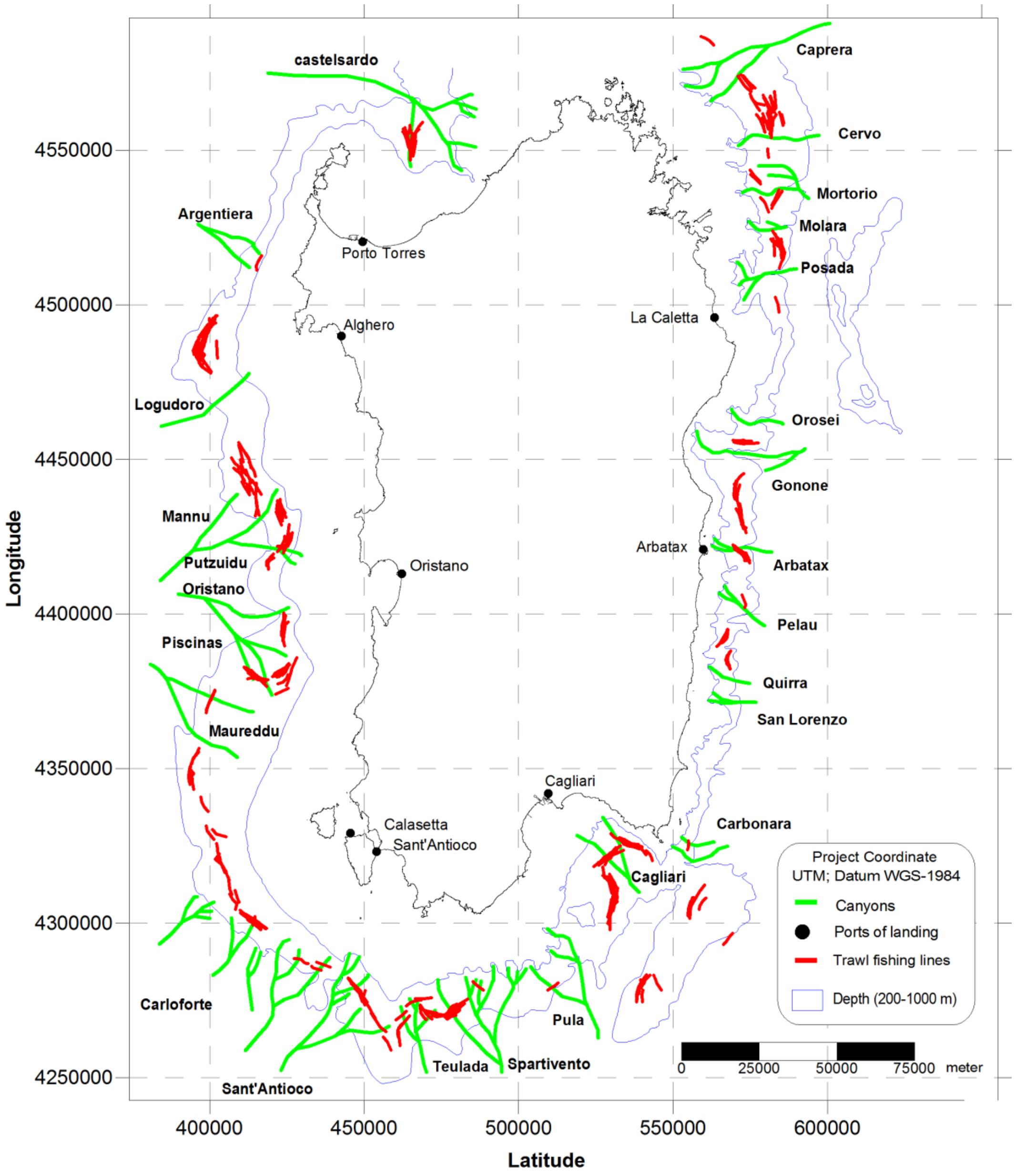


Figure 2-15. Distribution of trawl fishing lanes in relation to the presence of submarine canyons.

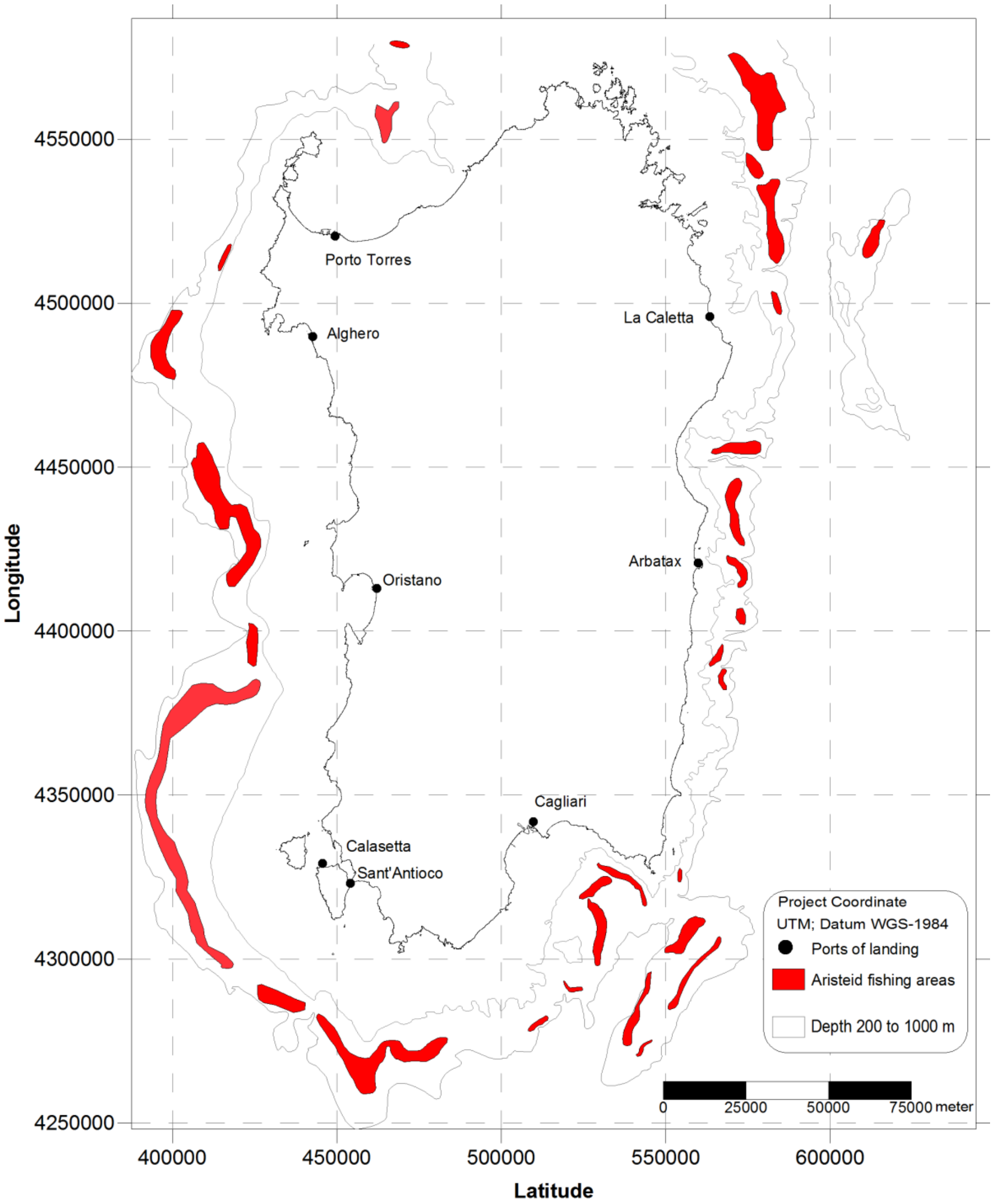


Figure 2-16. Aristeid fishing grounds in the Sardinian Seas.

2.5 DATA COLLECTION: DEMERSAL TRAWL SURVEYS

Knowledge on the abundance of fish stocks and exploited ecosystems is obtained primarily by analyzing commercial catch data and from research vessel surveys that provide a wider scope of biological data (Bertrand *et al.,* 2002). Bottom trawl survey represents one of the most reliable methods of population sampling in areas where depth makes more direct observations technically and economically unfeasible (Raffaelli *et al.,* 2003). Systematic studies on the demersal resource are mostly carried out as part of national research programs. The information provided in this thesis derived from the data collected during experimental trawl survey GRUND and MEDITS carried out in the Sardinian Seas. The MEDITS (Mediterranean International Trawl Survey) project started in 1994 within the cooperation between several research institutes from Mediterranean member States of the European Union. Countries conducting this survey include seven European Union Mediterranean countries (Cyprus, France, Greece, Italy, Malta, Slovenia and Spain) together with Albania, Croatia, Montenegro and Morocco which have conducted the survey periodically over the years (GFCM-SAC, 2008) (Figure 2-17).

The main scope of the MEDITS project is to produce basic information on benthic and demersal species in term of population distribution as well as demographic structure, on the continental shelves and along the upper slopes at a global scale through systematic bottom trawl surveys (Medits Handbook, 2013). This protocol was defined taking into account the complexity and differences of the areas covered by the survey. The same protocol includes the design of the survey, the sampling gear and the management of the data as far as the production of common standardized analysis. The standardized protocol intend to include as much as possible all the trawlable areas over the shelves and the upper continental slopes from 10 to 800 m depth off the coasts of the partner countries. These limits have been adopted to cover at best the distribution areas of the main potentially exploitable demersal resources, considering the administrative and technical constraints of the project.

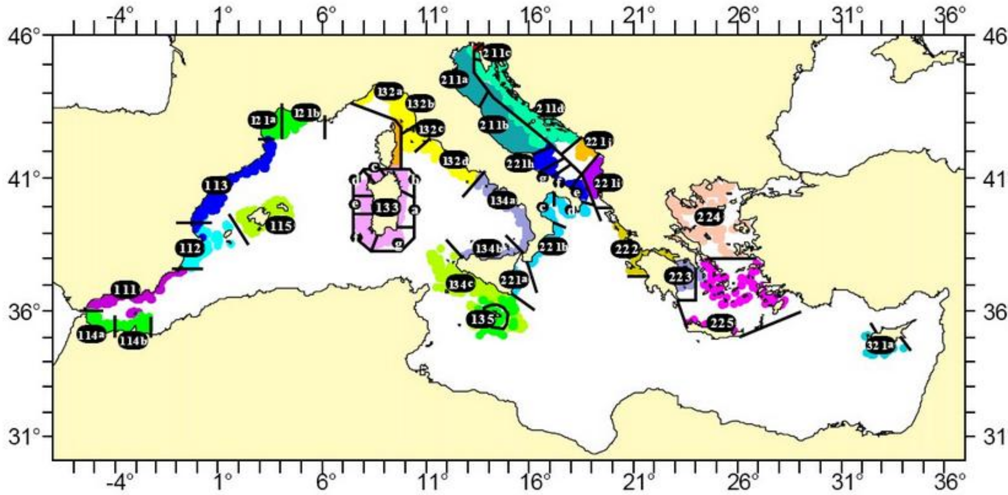


Figure 2-17. Medits stratum in the areas covered by Medits surveys (from Manual MEDITS 2013).

The other survey is the GRUND (Gruppo Nazionale Risorse Demersali), an Italian demersal trawl survey which started in 1984-1985 in all Italian seas within the framework of Italian Law 41/1982 regarding multi-annual plans to improve fishery management and fish farming (GFCM-SAC, 2007).

Haul duration is 1 h for GRUND hauls; for MEDITS surveys it was 0.5 and 1 h for hauls conducted on the shelf (10–200 m depth) and on the slope (200–800 m depth), respectively (Bertrand *et al.,* 2002).

For both surveys the sampling stations are distributed applying a stratified sampling scheme with random drawing inside each stratum. The stratification parameter adopted is the depth, with the following bathymetric limits: 10, 50, 100, 200, 500 and 800 m (Figure 2-18). Each position has been selected randomly in small sub-areas defined to get a compromise between the constraints of statistics based on random sampling and those of geostatistics (Green, 1979; Hilborn and Walters, 1992).

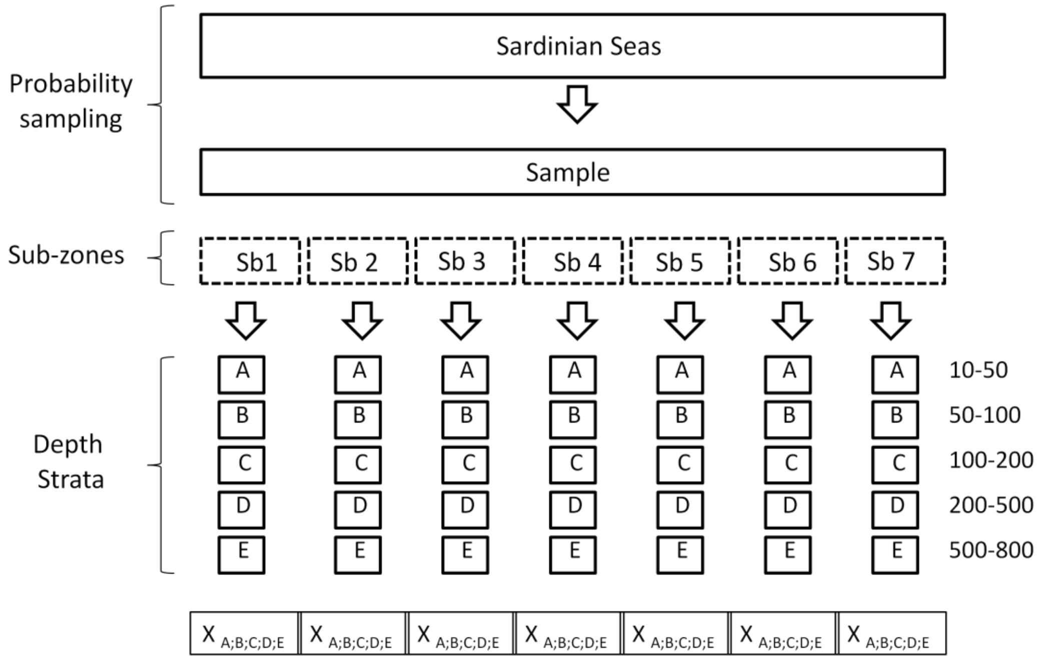


Figure 2-18. Depth stratified sampling scheme adopted for the MEDITS and GRUND projects.

Research vessels and chartered fishing vessels are used, depending on local possibilities. As much as possible, the same vessel is used every year in each area. In the case of FAO GSA 11 (Sardinian Seas) from 1994 to 2002 the vessel utilized in the MEDITS survey was the “Nuovo Spendore”. In 2003, “Nuovo Splendore” was withdrawn and substituted with the new “Nuovo Splendore II”. Nevertheless, the captain and the crew of the Nuovo Splendore II didn’t change. In 2004, because the Nuovo Splendore II was not available for the survey period a new boat and captain were chosen. However the new boat “Gisella”, was built in the same shipyard of the Nuovo Splendore II using a very similar project and therefore the main characteristics are very similar.

2.5.1 Biological parameters

A list of target species (including fish, molluscs and crustaceans) was established at the beginning of the project with reference to their commercial production, their accessibility by a bottom trawl and their potential interest as biological indicator in the different areas. Observations on these species are the total number of individuals, length frequency distribution, sex (including sexual maturity stage) and total weight.

For this thesis only hauls carried out at 200–800 m depth were used for *A. antennatus* and *A. foliacea*. For these species the total number and total weight are reported for each haul. Carapace length (CL) of each specimen was measured to the nearest millimeter, from the orbit of the eye to the posterior border of the cephalothorax, using calipers. The maturity stage was assessed using a four-step colour scale that corresponds to stages of gonads maturation (Medits Handbook, 2013) (Table 2-3).

The organization of the work at sea mainly depends on the facilities given aboard the vessels. From 2010, the samples are only taken and preserved on board and all the biological analyses are carried out in the laboratories. On the contrary before 2010 the whole biological analyses of the samples were conducted on board.

Table 2-2. Macroscopic maturity scale adopted in Medits trawl survey (Medits Instruction Manual v.5.0, 2008).

Sex	*Reproductive apparatus aspect*	*Couloring of fresh ovary*	*Maturation state*	*Stage*
	Sex not distinguished by naked eye. Sex undetermined	Traslucid	**Undetermined**	0
F	Ovary hardy visible in transparence. After dissection of the tegument ovary is small and lobes are flaccid, stringy and poorly developed. No sphermatophores on thelycum.	Whitish or traslucid	**Immature = virgin**	1
M	Petasma is notmuch visible, and there is not spermatic masses (emi-spermatophores) on the seminal ampullae, located on side of the V pair of pereiopods. Long rostrum.			
F	Ovary status to develop. Cephalic and lateral lobes are small but distinguishable with the naked eye. Abdominal extension are thin and just visible.	Flesh coulored	**Virgin developing**	2a
M	Petasma appears visible and nearly or completely joined, but there are no spermatic masses in the seminar ampullae. Long or intermediate rostrum.			
F	Ovary status to redevelop. Cephalic and lateral lobes are small but distinguishable by naked eye. Abdominal extension is thin and just visible. Occasionally presence of spermatophores.	Flesh coulored	**Recovering**	2b
M	Petasma appears completely joined, but there are no spermaticmasses in the seminar ampullae. Short rostrum.			
F	Ovary developed and occupies almost entirely the dorsal portion. The cephalic and lateral lobes aremuch developed and have a turgid consistence.	Light and dark grey	**Maturing or almost mature**	2c
M				
F	Turgid ovary extends to the whole dorsal portion, covering the organs below. Lobes and extensions well developed, in particular the abdominal extension is much evident. Oocytes well visible.	Black	**Mature**	2d
M	Petasma is perfectly visible and completely joined. Spermaticmasses in seminar ampullae. Small rostrum.			
F	resting ovary. Presence of spermatophores.	Uncoloured	**Resting adult**	2e

3 PART I. FURTHER INVESTIGATIONS ON THE GEOGRAPHICAL DISTRIBUTION AND ABUNDANCE OF THE DEEP-WATER RED SHRIMPS IN THE SARDINIAN SEAS.

3.1 INTRODUCTION

The deep-water red shrimps *Aristeus antennatus* and *Aristaeomorpha foliacea* are among the major economical resources in the whole Mediterranean Sea (Bianchini and Ragonese, 1994; Cau *et al.,* 2002). These species represent the main target of the Western and Central Mediterranean deep trawling (Sardà *et al.,* 2004). Due to their importance both species have been studied since the 70's and many research studies have been carried out all over the Western Mediterranean Sea (Cau *et al.,* 2002 and reference therein). In the easternmost sector of the Central Mediterranean basin these species were known to be a scarce resource (Thessalou-Legaki, 1994), but only in last decades have been object of a commercial fishery (Papacostantinou and Kapiris, 2001; Politou *et al.,* 2004). Nowadays many studied have been done in Greek waters where the red shrimps remain unexploited (example: Kapiris and Thessalou-Legaki, 2006; Kapiris *et al.,* 2010; Kapiris and Thessalou-Legaki, 2011) In fact Guillen *et al.,* 2012 by means of bio-economic simulation analysis, reported that the fishing effort could increase by 50-100%.

Both species are caught largely at depths between 500 and 800 m, although the distribution of *A. antennatus* is deeper than that of *A. foliacea* (Cau and Deiana, 1982; Sardà *et al.,* 2004). In the Mediterranean basin the geographical distribution and its abundance appear to be related to hydrological factors and the topography of the areas in which they live (Bianchini and 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 and Cartes *et al.,* 2011b; Orsi Relini *et al.,* 2012). In general both species coexist in large part of the

Mediterranean Sea, but *A. antennatus* being more abundant in the western basin while *A. foliacea* appears more abundant in the eastern one (Cau *et al.,* 2002; Belcari *et al.,* 2003; Politou *et al.,* 2004; Cartes *et al.,* 2011a).

In Sardinian Seas Murenu *et al.,* (1994) highlighted a more abundant presence of *A. foliacea* in the southern and eastern parts, while *A. antennatus* was more present along the northern and western coasts.

In this chapter further data on geographical distribution and abundance of *A. antennatus* and *A. foliacea* coming from the international MEDITS (1994-2012) trawl surveys were showed. In particular, the main objective was to identify the distribution patterns of the two deep-waters red shrimps using a time series data in order to give a comprehensive and homogeneous picture of the distribution in the Sardinian waters. A synoptic view of the identified areas using nineteen years of trawl surveys is presented, allowing the detection of overlapping zones which delineate areas of potentially high environmental and ecological significance.

3.2 MATERIALS AND METHODS

Biological data were gathered during bottom trawl surveys conducted from 1994 to 2012 within the framework of the EU International Project MEDITS (International bottom trawl survey in the Mediterranean). The sampling was performed according to standardized protocols: (haul) duration (i.e. the effective contact of the gear with the bottom), 60 minutes for the slope during daylight period, using a bottom trawl gear GOC 73. The horizontal net opening used to evaluate the swept area and then the abundance index was estimated based on the formula derived from trials using SCANMAR equipment (Palmas *et al.,* 2013).

The design employed was of the type random stratified by depth, with allocation of the hauls proportional to stratum area. The data covers a period of 19 years and regards 405 hauls carried out at a depth of over 200 m. For a suitable analysis and in order to evaluate the geographical variability on the distribution of the two species, the Sardinian seas were divided into seven sub-areas: two located in the eastern coast (SE-Area 1 and NE-Area 2), one in the northern (N-Area 3), three in the western (NW-Area 4, CW-Area 5 and SW-Area 6) and the last one in the southern part (S-Area 7) (Figure 3-1).

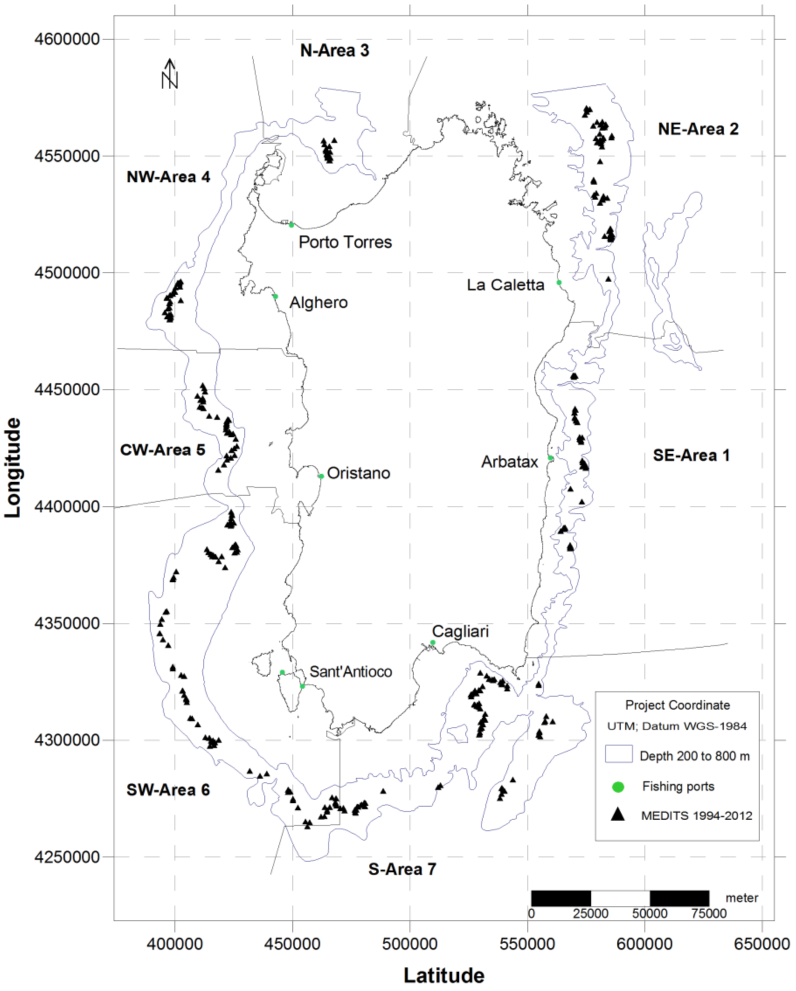


Figure 3-1. Seas around Sardinia (GFCM-Geographical Sub-Area 11), main fishing ports, location of the trawl stations surveys during the period 1994-2012 in different geographical areas. Depth from 200 to 800 m were considered.

3.2.1 *Frequency of occurrence*

In order to identify the presence in the different geographic areas the % of frequency of occurrence ($Foc = N°positive\ hauls/N°\ total\ \ hauls * 100$) were computed for each species and year. Only samplings and area extension concerning the 200–800 m depth macrostratum were considered. The relationships between *Foc* and year of sampling were evaluated with the non-parametric Spearman rank correlation test.

3.2.2 Abundance index

As well described in the above, for a suitable analysis and in order to evaluate the geographical variability on the distribution of the two species, the Sardinian seas were divided into seven Areas. The abundance indexes in number (IND/km^2, hereinafter symbolized as DI), and weight (kg/km^2, hereinafter symbolized as BI), were estimated by single and pooled stratum falling in the species area distribution (201-500 m, 501-800 m stratum and 201-800 m macrostratum) for each year according to the swept area method (Pauly, 1983). The stratum surfaces in each area were estimated (A_j in km^2, where *j* indicate the stratum) and the whole studied area (*A*) derived by simple summation of the A_j.

A statistical weight $W_j = A_j/A$ was assigned to each stratum. The formula adopted by the MEDITS protocol (Souplet, 1996) for estimating the average catch within the stratum is:

$$\bar{Y}_j = \frac{\sum_{i=1}^{i=nj} y_{i,j}}{\sum_{i=1}^{i=nj} a_{i,j}}$$

where $y_{i,j}$ denotes the capture observed in the i-*th* haul of the j-*th* stratum and $a_{i,j}$ is the area swept in the i-*th* haul of the j-*th* stratum; $n_j$is the number of hauls in the j-*th* stratum.

The variance of catch within the j-*th* stratum is:

$$\tilde{S}_j^2 = \frac{1}{n_j - 1} \sum_{i=1}^{i=nj} a_{i,j} * \left(\frac{y_{i,j}}{a_{i,j}} - \bar{Y}_j\right)^2$$

and the variance of the estimator of the average catch is:

$$Var(\bar{Y}_j) = \frac{1}{\sum_{i=1}^{i=nj} a_{i,j}} * \tilde{S}_j^2$$

The coefficient of variation is computed as:

$$CV\% = \frac{\sqrt{Var(I)}}{I} * 100$$

A total mean was calculated, for each Area, from all the yearly means for both DI and BI. Moreover, an overall total mean for all the Areas considered 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 ($CV = SD/mean * 100$) was calculated [CV%].

For each Area, the BI and DI total mean values were standardized according to the overall total mean in order to compare the geographical Areas. To analyze the general temporal trend of BI and DI of each Area, single year values were standardized according to the GSA total mean (1994-2012). A bivariate plot (total mean values *vs* years) was elaborated to highlight the general trends in all the Areas. Kendall non-parametric rank coefficient (r_k) values were calculated between standardized (according to the overall total mean) DI and BI and year.

3.2.3 Mean Weight

The mean weight ($MW = BI/DI$) values were estimated for both shrimps and different Areas in order to highlight differences in "average size" of species at geographical level.

3.2.4 Abundance Ratio

The data of BI $_{(ratio)}$, DI $_{(ratio)}$ between the species were also computed. The abundance ratios were computed as:

$$BI_{ratio} = BI_{aa}/(BI_{aa} + BI_{af})$$

$$DI_{ratio} = DI_{aa}/(DI_{aa} + DI_{af})$$

where *aa* and *af* denote *A. antennatus* and *A. foliacea,* respectively.

In addiction the one way analysis of variance (ANOVA) was applied to compare the values of means ratio and to test similarity and differences among the Areas.

The Multiple Range test was applied to determine which means were significantly different from each other. The differences between Areas were tested using the Bonferroni's multiple comparison procedure.

3.2.5 Thematic spatial maps

Thematic spatial maps were created using a georeferencing software, Surfer 8.x (Golden Software Inc.). Surfer is a contouring and 3D surface mapping program that runs under Microsoft Windows. It converts the abundance data into outstanding contour, surface, wireframe, vector, image, shaded relief and post maps.

After the georeferenced operations for every map, all the sample sites (hauls) were distributed on the studied area. Once a georeferenced base map and the corresponding spatial distribution of the hauls was obtained, it was possible to begin the spatial analysis and the maps production by means of interpolation data. Spatial structure of abundance index (variographic analysis) was not analyzed because the data were insufficient to characterize the possible autocorrelation between them. Different interpolators were tested and the most exact was chosen. Single haul data were used to generate synoptic distribution maps through the inverse distance-weighted deterministic interpolation (Isaaks and Srivastava, 1989).

The overall BI and DI were the parameter used for the maps production through interpolation data for deep water red shrimps. The values of these parameters were standardized to 1 km^2. Before producing the final map it was necessary to define an interpolation mask. The interpolation mask represents the maximum area of interest, where it was considered correct to expand the estimations of the spatial analysis. In the case of both shrimps, the interpolation mask corresponded to the total area comprised from 200 m to 800 m.

3.3 RESULTS

3.3.1 Aristeus antennatus

3.3.1.1 Foc: Frequency of occurrence

Frequency of occurrence (*Foc, %*) of the blue-and-red shrimp, considering the overall bathymetrical range (200-800 m), are reported in Table 3.1. During the time series the highest *Foc* (55%) was observed in the central western Sardinian Sea (CW-Area 5), while the lowest values were recorded in the north eastern Tyrrhenian Sea (NE-Area 2: 26%). The values were stable over time in all the Areas with the exception of the SE-Area 1 where a positive temporal trend was detected ($\rho=0.63$, $P<0.001$) (Figure 3-2).

Table 3-1. *Aristeus antennatus*. Foc % by year in each geographical area; 200-800 m.

				Frequency of Occurrence			
Year	**SE-Area 1**	**NE-Area 2**	**N-Area 3**	**NW-Area 4**	**CW-Area 5**	**SW-Area 6**	**S-Area 7**
1994	33	43	25	25	0	32	40
1995	40	14	50	25	0	42	11
1996	50	14	0	40	60	33	40
1997	33	14	67	60	60	47	50
1998	50	43	67	80	75	47	50
1999	33	14	33	60	40	40	18
2000	50	29	50	40	75	46	50
2001	50	43	50	40	25	53	60
2002	50	33	50	0	100	60	60
2003	50	17	67	25	100	38	43
2004	50	17	33	0	50	30	13
2005	40	17	33	33	100	38	38
2006	50	17	33	0	50	40	38
2007	75	0	33	33	50	40	33
2008	50	0	33	0	67	40	38
2009	50	17	33	33	100	40	29
2010	75	57	33	0	50	40	38
2011	75	67	33	33	67	40	56
2012	50	33	33	33	33	40	56
94-12	**49**	**26**	**40**	**34**	**55**	**41**	**40**

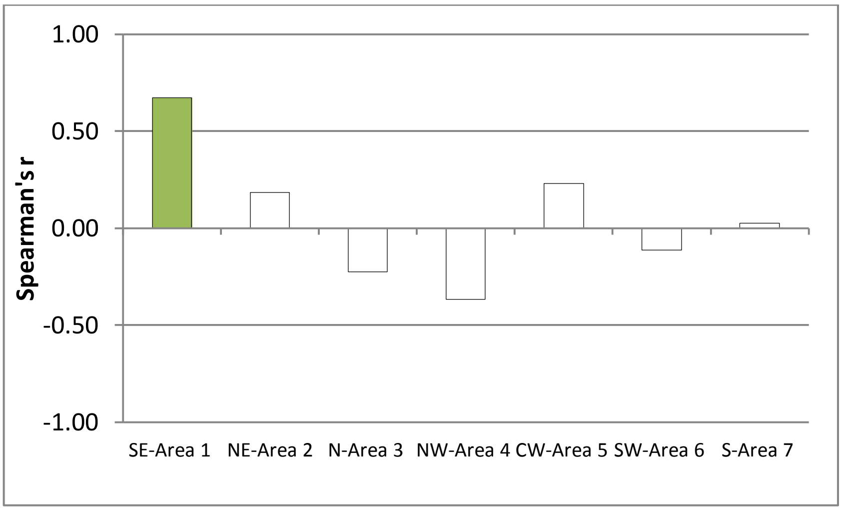


Figure 3-2. Spearman rank correlation coefficient (ρ) values for *Foc* of *Aristeus antennatus* (Green: signif. pos. trend, white: no signif. trend).

3.3.1.2 Abundance Index

The blue-and-red shrimp were poorly present in the stratum 200-500 (Table 3-2, 3-3). The most of the values were zero and the overall total mean were restricted to 0.6 kg/km^2 of BI and 26 Ind/km^2 of DI.

Table 3-2. *Aristeus antennatus.* Mean Biomass indexes (BI) and CV %, for stratum 200-500 m, by year and geographical Areas.

Biomass Index 200-500 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	BI	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	12.3	39.6	0	0	0	0	0.5	70.4	0	0
1996	0	0	0	0	0	0	0	0	0	0	3.9	98.5	0	0
1997	0	0	0	0	0.1	42.9	0	0	0.1	55	0	0	0	0
1998	3	58.6	0	0	0.3	44.4	0	43.2	0.2	44.3	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0.2	45.9	0	0	0.1	71.9
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	6.3	0	0	0	0	0
2003	0	0	0	0	6.7	22.3	0	0	2.1	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	4.1	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	4.1	41.5	0	0	0	0	0	0	0	0	0	0	0	0
2008	4.1	41.5	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0
2010	0.4	39.9	10.1	48.2	0	0	0	0	0	0	0	0	0	0
2011	0.9	44.6	2.9	49.1	0	0	0	0	6.1	39.4	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94-12	**0.7**	213	**0.7**	347	**1.0**	307	**0**	0	**1.0**	205	**0.2**	387	**0**	436
Overall Total Mean = 0.6														

Table 3-3. *Aristeus antennatus.* Mean Density indexes (DI) and and CV %, for stratum 200-500 m, by year and geographical Areas.

Density Index														
200-500 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	DI	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	733	41	0	0	0	0	98	70	0	0
1996	0	0	0	0	0	0	0	0	0	0	155	23120	0	0
1997	0	0	0	0	10	43	0	0	3	55	0	0	0	0
1998	149	59	0	0	20	44	5	43	15	44	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	10	46	0	0	7	72
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	281	0	0	0	0	0
2003	0	0	0	0	418	22	0	0	179	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	238	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	161	42	0	0	0	0	0	0	0	0	0	0	0	0
2008	161	42	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	10	0	0	0	0	0
2010	16	40	481	48	0	0	0	0	0	0	0	0	0	0
2011	49	45	155	49	0	0	0	0	370	39	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94-12	**30**	201	**35**	331	**66**	295	**0**	0	**192**	14	**299**	0	**0**	424
Overall Total Mean = 26														

The bathymetrical distribution was almost limited to the deeper stratum from 500 to 800 m in all the geographical areas considered (Table 3-4, 3-5). In this stratum the highest abundance were recorded in the northern area (N-Area 3; 24.2 kg/km^2, 1228 N/km^2) and in the central eastern area (SE-Area 1; 20.2 kg/km^2, 922 N/km^2). In the south western zone the highest values of both DI and BI denotes a high concentration of juvenile individuals (SW-Area 6; 19.4 kg/km^2, 1285 N/km^2) (Table 3-4). The lowest values were recorded in the NW-Area 4 (6.4 kg/km^2, 470 N/km^2), S-Area 7 (9.4 kg/km^2 and 538 N/km^2) and in the NE-Area 2 (10.6 kg/km^2, 428 N/km^2). The temporal analysis showed, for all the Areas, an oscillating trend for the index over the examined years reaching exceptional values in 2004 in the northern (N-Area 3; 114.5 kg/km^2 and 3655 N/km^2) and in 2001 in the central western Sardinia (CW-Area 5; 85.7 kg/km^2 and 3057 N/km^2). The analysis of abundance indexes for the macrostratum 200-800 confirms the same trend observed for the stratum 500-800 due to the low catches in the lowest depth (Table 3-6, 3-7).

Table 3-4. *Aristeus antennatus.* Mean Biomass index (BI) and CV %, for stratum 500-800 m, by year and geographical Areas.

Biomass Index

500-800 m

Year	SE-Area 1		NE-Area 2		N-Area 3		NW-Area 4		CW-Area 5		SW-Area 6		S-Area 7	
	BI	CV	BI	CV	BI	CV	BI	CV	BI	CV	BI	CV	BI	CV
1994	23.3	25.6	19.4	37.0	5.1	0.0	19.1	44.0	0.0	0.0	6.7	32.5	5.6	16.2
1995	13.9	11.1	47.2	0.0	0.0	0.0	0.3	53.3	0.0	0.0	9.1	33.8	0.5	66.0
1996	6.7	31.6	4.6	58.4	0.0	0.0	7.7	28.6	21.6	26.5	8.3	37.5	7.8	30.5
1997	22.0	19.6	2.9	59.3	14.4	0.0	16.7	5.1	11.0	12.8	20.9	17.5	3.6	42.8
1998	14.6	1.2	12.0	30.4	6.0	0.0	11.1	21.7	9.3	28.1	29.7	20.2	9.8	47.2
1999	7.9	28.1	6.8	68.7	30.6	0.0	4.4	25.7	4.2	21.0	36.2	65.2	4.6	56.8
2000	42.8	32.3	12.5	64.2	41.6	29.7	15.5	39.6	8.1	33.5	25.8	35.9	13.9	23.5
2001	15.6	18.0	13.4	46.7	27.8	0.5	11.3	40.5	85.7	0.0	44.0	26.5	8.5	15.4
2002	70.0	0.0	24.5	0.0	19.3	0.0	0.0	0.0	58.9	27.8	6.8	35.7	53.0	39.3
2003	25.2	27.3	4.1	57.7	11.2	0.0	11.3	0.0	8.9	0.0	31.5	25.3	7.9	50.2
2004	15.8	4.9	4.6	46.7	114.5	0.0	0.0	0.0	23.8	0.0	3.0	27.6	2.1	62.5
2005	21.4	22.3	10.0	53.3	9.8	0.0	3.5	0.0	2.0	0.0	21.8	10.7	8.1	38.2
2006	15.9	23.9	3.0	35.4	16.2	0.0	0.0	0.0	10.0	0.0	27.9	19.1	14.1	40.1
2007	15.6	6.8	0.0	0.0	21.4	0.0	1.0	0.0	5.4	0.0	19.6	16.7	4.9	48.4
2008	15.6	6.8	0.0	0.0	21.4	0.0	1.0	0.0	5.4	0.0	19.6	16.7	4.9	48.4
2009	27.0	20.7	4.7	65.9	62.8	0.0	6.1	0.0	5.3	0.0	10.6	31.6	5.7	27.0
2010	8.3	28.9	11.1	49.3	11.4	0.0	0.0	0.0	11.6	0.0	18.5	36.9	6.1	53.1
2011	8.9	4.2	18.2	25.0	32.8	0.0	10.2	0.0	26.4	0.0	18.4	17.9	9.9	24.6
2012	12.7	4.4	2.6	46.3	12.6	0.0	2.0	0.0	6.5	0.0	9.4	16.5	7.4	28.0
94-12	**20.2**	73.1	**10.6**	105.4	**24.2**	110.5	**6.4**	0.0	**16.0**	135.1	**19.4**	57.9	**9.4**	118.4

Overall Total Mean = 15,5

Table 3-5. *Aristeus antennatus.* Mean Density index (DI) and CV %, for stratum 500-800 m, by year and geographical Areas.

Density Index

500-800 m

Year	SE-Area 1		NE-Area 2		N-Area 3		NW-Area 4		CW-Area 5		SW-Area 6		S-Area 7	
	DI	CV	DI	CV	DI	CV	DI	CV	DI	CV	DI	CV	DI	CV
1994	1394	26	857	37	388	0	1464	44	0	0	518	31	384	18
1995	597	8	1821	0	0	0	33	53	0	0	925	34	28	66
1996	421	30	225	58	0	0	606	28	1404	25	568	37	605	31
1997	1326	26	139	59	1248	0	1566	5	890	5	1525	19	184	44
1998	683	0	406	31	430	0	1081	16	631	24	2079	21	527	44
1999	404	28	285	69	1223	0	319	28	159	25	2256	66	235	60
2000	1678	23	483	64	1780	17	1006	38	522	37	1810	37	900	25
2001	836	23	501	49	1531	7	533	35	3057	0	2620	24	503	18
2002	2470	0	750	0	1375	0	0	0	2446	23	503	38	2513	40
2003	1038	22	138	58	661	0	694	0	682	0	2042	25	361	47
2004	523	3	152	47	3655	0	0	0	951	0	140	30	131	63
2005	1273	18	474	53	460	0	190	0	348	0	1399	11	578	38
2006	635	24	141	35	991	0	0	0	689	0	2036	21	988	41
2007	671	13	0	0	1071	0	38	0	247	0	1104	19	235	47
2008	671	13	0	0	1071	0	38	0	247	0	1104	19	235	47
2009	1223	15	240	66	3692	0	414	0	277	0	724	34	348	27
2010	397	40	514	51	740	0	0	0	914	0	1258	27	374	59
2011	436	7	908	25	2243	0	841	0	1770	0	1152	16	638	24
2012	836	20	96	43	782	0	100	0	292	0	649	21	448	28
94-12	**922**	58	**428**	101	**1228**	84	**470**	0	**817**	101	**1285**	54	**538**	100

Overall Total Mean = 711

Table 3-6. *Aristeus antennatus.* Mean Biomass index (BI) and CV %, for stratum 200-800 m, by year and geographical Areas.

Biomass Index														
200-800 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	BI	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**
1994	10.7	52	10.2	57	1.7	0	7.9	102.9	0.0	0.0	2.6	39.5	3.0	22.6
1995	6.4	23	24.9	0	8.3	64	0.1	105.4	0.0	0.0	3.9	44.7	0.3	89.4
1996	3.1	55	2.4	101	0.0	0	3.2	50.3	8.4	47.1	5.6	50.8	4.2	39.3
1997	10.1	44	1.5	94	4.8	0	6.9	9.3	4.3	26.7	8.2	20.6	1.9	56.2
1998	8.3	18	6.3	46	2.2	9	4.6	39.2	3.7	61.3	11.6	24.8	5.3	61.1
1999	3.6	48	3.6	104	10.0	0	1.8	43.7	1.6	45.8	14.2	76.4	2.5	73.7
2000	19.7	57	6.6	97	13.6	65	6.4	70.1	3.3	71.8	10.1	41.2	7.5	29.9
2001	7.2	32	7.1	73	9.1	1	4.7	73.5	33.2	0.0	17.2	30.6	4.6	20.0
2002	32.2	0	12.9	0	6.3	0	0.0	0.0	26.7	54.0	2.7	65.9	28.4	88.1
2003	11.6	68	2.2	98	8.2	27	4.7	0.0	4.7	0.0	12.3	34.0	4.2	74.9
2004	7.3	11	2.4	93	37.3	0	0.0	0.0	9.2	0.0	1.2	42.2	1.1	97.6
2005	9.8	51	5.3	93	3.2	0	1.5	0.0	3.3	0.0	8.5	19.7	4.3	59.7
2006	7.3	54	1.6	79	5.3	0	0.0	0.0	3.9	0.0	10.9	30.5	7.6	61.5
2007	9.4	25	0.0	0	7.0	0	0.4	0.0	2.1	0.0	7.7	27.5	2.6	72.4
2008	9.4	25	0.0	0	7.0	0	0.4	0.0	2.1	0.0	7.7	27.5	2.6	72.4
2009	12.4	44	2.5	106	20.5	0	2.5	0.0	2.2	0.0	4.1	49.7	3.1	49.9
2010	8.3	28	11.1	49	11.4	0	0.0	0.0	11.6	0.0	18.5	36.9	6.1	53.1
2011	4.6	13	11.0	42	10.7	0	4.2	0.0	14.0	25.8	7.2	31.0	5.3	35.9
2012	5.8	10	1.4	89	4.1	0	0.8	0.0	2.5	0.0	3.7	27.3	4.0	42.1
94-12	**9.9**	66	**5.9**	102	**9.0**	93	**2.7**	0	**7.2**	123	**8.3**	59	**5.2**	114.7
Overall Total Mean = 6.9														

Table 3-7. *Aristeus antennatus.* Mean Density index (DI) and CV %, for stratum 200-800 m, by year and geographical Areas.

Density Index														
200-800 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	BI	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**
1994	641	54	452	58	127	0	608	103	0	0	203	38	206	25
1995	275	17	961	0	494	66	14	95	0	0	422	43	15	92
1996	194	52	119	102	0	0	252	50	543	44	317	46	325	40
1997	610	60	73	94	414	2	651	10	346	10	597	22	99	58
1998	395	19	214	47	154	9	452	29	253	51	813	26	283	56
1999	186	48	150	104	399	0	133	48	62	54	883	77	126	77
2000	772	42	255	98	581	37	418	67	208	79	708	42	486	31
2001	385	41	264	76	499	15	222	63	1183	0	1027	28	270	23
2002	1137	0	396	0	448	0	0	0	1119	43	197	70	1348	89
2003	478	54	73	100	497	28	288	0	374	0	799	33	194	71
2004	241	6	80	93	1192	0	0	0	368	0	55	45	70	100
2005	586	42	250	94	150	0	79	0	281	0	547	20	310	60
2006	292	55	74	79	323	0	0	0	267	0	796	33	530	63
2007	396	30	0	0	349	0	16	0	96	0	432	31	126	71
2008	396	30	0	0	349	0	16	0	96	0	432	31	126	71
2009	563	32	127	107	1204	0	172	0	113	0	283	53	187	49
2010	397	40	514	51	740	0	0	0	914	0	1258	27	374	59
2011	227	19	552	43	732	0	350	0	912	24	451	28	342	36
2012	385	48	51	83	255	0	42	0	113	0	254	35	240	42
94-12	**450**	52	**242**	100	**469**	69	**195**	0	**381**	99	**551**	58	**298**	97
Overall Total Mean = 323														

The BI and DI indexes, standardized according to overall total mean, showed very similar results. Comparing the Areas only the northern area (N-Area 3), central eastern (SE-Area 1), south west (SW-Area 6) and central western area (CW-Area 5) showed sensible positive values. The N-Area 3 recorded the highest values with respect to the overall total mean. Otherwise negative values were recorded for the others Areas for both abundance indexes (Figure 3-3, 3-4). As regards the temporal evolution of the ratios within each Area (Area yearly mean/Area total mean) no significant trends were observed (rk, p> 0.05).

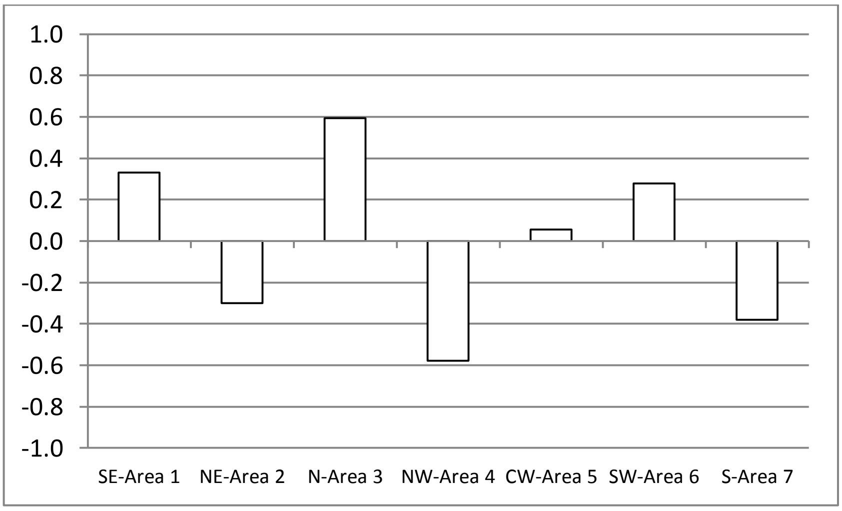


Figure 3-3. *Aristeus antennatus.* Ratio between Area total mean BI and overall total mean BI (500-800 m) (red: signif. neg. trend, Green: signif. pos. trend, white: no signif. trend).

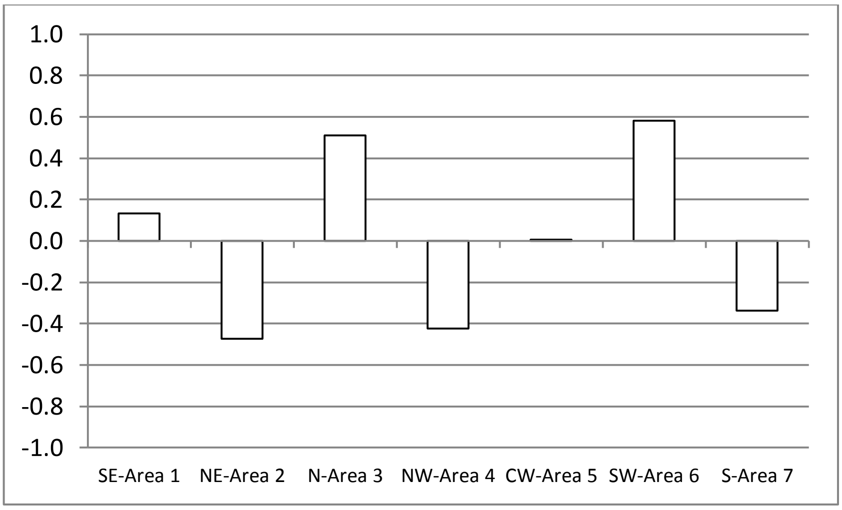


Figure 3-4. *Aristeus antennatus.* Ratio between Area total mean DI and overall total mean DI (500-800 m) (red: signif. neg. trend, Green: signif. pos. trend, white: no signif. trend).

3.3.1.3 Mean weight

The Mean Weight (MW) values obtained in each Area are reported in table 3-8. The ratio between biomass index and density index highlighted the occurrence of large “average size” in the central-eastern Tyrrhenian (SE-Area 1) as well as in the north eastern area (NE-Area 2). The other Areas showed comparable MW with the exception of central western sector (NW-Area 4) which recorded the lowest values.

For each Area the MW total mean values were standardized according to the overall total mean (calculated from all the years means) and compared with respect to this last mean (Figure 3-5). In the eastern sector of the island (SE-Areas 1 and NE-Area 2) the highest values of the standardized MW denoted the presence of bigger individual than the other Areas.

Table 3-8. *Aristeus antennatus*. Mean weight (BI/DI, g) considering the stratum 500-800 m, by year and geographical Areas.

Mean weight							
500-800 m							
Year	**SE-Area 1**	**NE-Area 2**	**N-Area 3**	**NW-Area 4**	**CW-Area 5**	**SW-Area 6**	**S-Area 7**
1994	16.71	22.64	13.14	13.05	0.00	12.93	14.58
1995	23.28	25.92	0.00	9.09	0.00	9.84	17.86
1996	15.91	20.44	0.00	12.71	15.38	14.61	12.89
1997	16.59	20.86	11.54	10.66	12.36	13.70	19.57
1998	21.38	29.56	13.95	10.27	14.74	14.29	18.60
1999	19.55	23.86	25.02	13.79	26.42	16.05	19.57
2000	25.51	25.88	23.37	15.41	15.52	14.25	15.44
2001	18.66	26.75	18.16	21.20	28.03	16.79	16.90
2002	28.34	32.67	14.04	0.00	24.08	13.52	21.09
2003	24.28	29.71	16.94	16.28	13.05	15.43	21.88
2004	30.21	30.26	31.33	0.00	25.03	21.43	16.03
2005	16.81	21.10	21.30	18.42	5.75	15.58	14.01
2006	25.04	21.28	16.35	0.00	14.51	13.70	14.27
2007	23.25	0.00	19.98	26.32	21.86	17.75	20.85
2008	23.25	0.00	19.98	26.32	21.86	17.75	20.85
2009	22.08	19.58	17.01	14.73	19.13	14.64	16.38
2010	20.97	21.49	15.38	0.00	12.74	14.74	16.36
2011	20.41	20.04	14.62	12.13	14.92	15.97	15.52
2012	15.19	27.08	16.11	20.00	22.26	14.48	16.52
94-12	**21.44**	**22.06**	**16.22**	**12.65**	**16.19**	**15.13**	**17.32**
Overall Total Mean = 17.3							

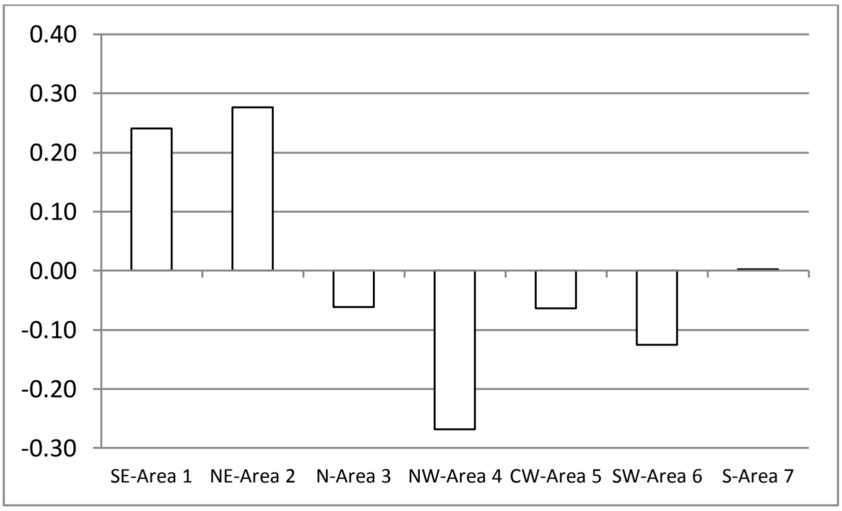


Figure 3-5. *Aristeus antennatus.* Mean Standardized Weight by Area concerning stratum 500-800 m.

3.3.2 *Aristaeomorpha foliacea*

3.3.2.1 *Foc: Frequency of occurrence*

Considering the giant red shrimp, the overall (200-800 m) highest frequency of occurrence (Table 3-9) were recorded in the central western Sardinian Sea (CW-Area 5: 57%) and in the south eastern sector (SE-Area 1: 56%), while the lowest value was recorded in north zone (N-Area 3: 38%). The Spearman rank showed significant positive trend in the SE-Area 1 ($\rho=0.583$, $P<0.001$), while in the NW-Area 4, CW-Area 5 and SW-Area 6 negative trends were observed ($\rho=-0.748$, $P<0.001$; $\rho=-0.492$, $P<0.05$ and $\rho=-0.614$, $P<0.001$) (Figure 3-6). In the other Areas the values were stable over time.

Table 3-9. *Aristaeomorpha foliacea*. Foc % by year in each geographical area; 200-800 m.

	Frequency of Occurrence						
Year	**SE-Area 1**	**NE-Area 2**	**N-Area 3**	**NW-Area 4**	**CW-Area 5**	**SW-Area 6**	**S-Area 7**
1994	50	71	25	25	33	47	27
1995	40	43	50	50	0	58	33
1996	50	57	0	60	60	47	50
1997	50	43	67	60	60	53	50
1998	67	57	67	60	75	53	60
1999	50	57	33	60	60	47	64
2000	50	43	25	40	75	54	58
2001	50	57	50	60	50	60	60
2002	50	33	50	50	100	60	33
2003	25	33	67	25	100	38	43
2004	50	50	33	33	50	40	50
2005	60	50	67	33	50	38	50
2006	75	50	33	33	50	50	50
2007	50	50	0	33	50	30	44
2008	50	33	33	33	67	30	50
2009	75	83	33	0	100	40	43
2010	75	71	33	33	50	50	38
2011	75	67	33	33	33	40	44
2012	75	33	33	33	33	30	67
94-12	**56**	**52**	**38**	**42**	**57**	**46**	**48**

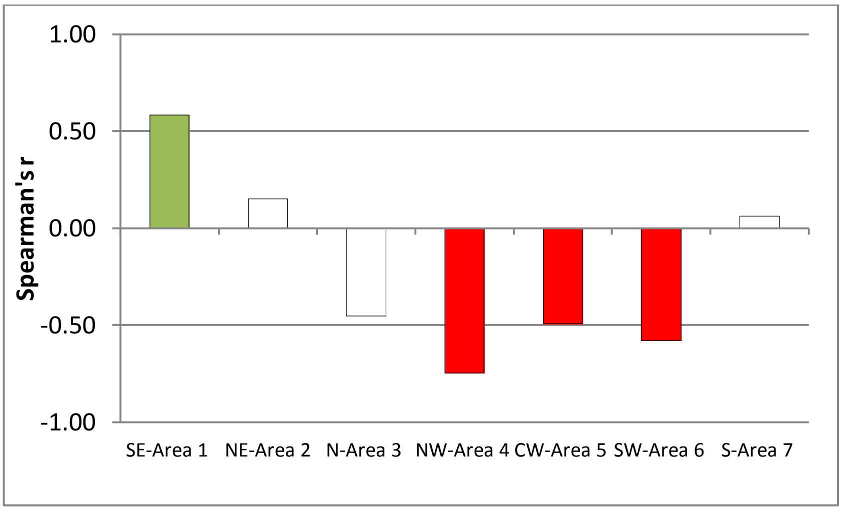


Figure 3-6. Spearman rank correlation coefficient (ρ) values for *Foc* of *Aristaeomorpha foliacea* (red: signif. neg. trend, Green: signif. pos. trend, white: no signif. trend).

3.3.2.2 Abundance index

The giant red shrimp was mostly caught in the stratum (500-800 m) in all Areas considered. The stratum 200-500 m showed in general the lowest values for both biomass and density indexes (Table 3-10, 3-11).

Table 3-10. *Aristaeomorpha foliacea.* Mean Biomass indexes (BI) and CV %, for stratum 200-500 m, by year and geographical Areas.

Biomass Index														
200-500 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	BI	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**
1994	0	0	0.5	53.6	0	0	0	0	0	54	1	78.3	0	0
1995	0	0	0.1	53.7	1.2	31.1	0	0	0	0	2.2	57	0	0
1996	0	0	0	66.2	0	0	0	0	0	0	1	75.6	0	0
1997	0.3	60.2	0	0	0.1	42.9	0	0	0.2	56	1.4	89	0	0
1998	4.6	58.4	0	0	2.5	44.4	0	0	1.3	44	7.7	85.6	0	0
1999	0	0	0	0	0	0	0	0	0.3	55	0	0	0.1	70.9
2000	0	0	0	0	0	0	0	0	45.5	46	0	0	0.9	71.9
2001	0	0	0	0	0	0	0	0	2.8	53	4.4	75.5	0	0
2002	0	0	0	0	0	0	0	0	4.7	0	0	0	0	0
2003	0	0	0	0	0.2	22.3	0	0	14.2	0	0.2	98.4	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	2.9	52.9	0	0	3.5	42.5	0	0	1.6	0	0	0	0	0
2006	6	39.5	0	61	0	0	0	0	0	0	0	83.5	0	0
2007	4.6	47.7	0.4	63.4	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0.2	42	0	0	0	0
2009	6.5	41.8	5.8	38.1	0	0	0	0	2.1	0	0	0	0	0
2010	5.1	39.9	16.7	25.2	0	0	0	0	0	0	0.5	78.2	0	0
2011	2	44.6	0.6	49.1	0	0	0	0	0.2	39	0	0	0	0
2012	18.7	40.2	0	0	0	0	0	0	0	0	0	0	0.1	60.3
94-12	**2.7**	171	**1.3**	312.15	**0.4**	246.4	**0**	0	**3.8**	276	**1**	203.5	**0.1**	356.4
Overall Total Mean = 1.3														

Table 3-11. *Aristaeomorpha foliacea.* Mean Density indexes (DI) and CV %, for stratum 200-500 m, by year and geographical Areas.

Density Index														
200-500 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	DI	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**
1994	0	0	67	54	0	0	0	0	8	54	91	82	0	0
1995	0	0	18	52	48	31	0	0	0	0	363	57	0	0
1996	0	0	2	66	0	0	0	0	0	0	66	69	0	0
1997	36	60	0	0	15	43	0	0	10	56	165	89	0	0
1998	495	58	0	0	402	44	0	0	122	44	1169	86	0	0
1999	0	0	0	0	0	0	0	0	16	55	0	0	8	71
2000	0	0	0	0	0	0	0	0	1933	46	0	0	34	72
2001	0	0	0	0	0	0	0	0	117	53	216	62	0	0
2002	0	0	0	0	0	0	0	0	188	0	0	0	0	0
2003	0	0	0	0	5	22	0	0	737	0	37	98	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	479	53	0	0	251	43	0	0	180	0	0	0	0	0
2006	859	40	3	61	0	0	0	0	0	0	2	84	0	0
2007	262	48	31	63	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	34	42	0	0	0	0
2009	927	42	960	38	0	0	0	0	104	0	0	0	0	0
2010	339	40	2287	35	0	0	0	0	0	0	92	78	0	0
2011	280	45	31	49	0	0	0	0	12	39	0	0	0	0
2012	2199	40	0	0	0	0	0	0	0	0	0	0	9	60
94-12	**309**	176	**179**	310	**38**	278	**0**	0	**182**	251	**116**	236	**3**	300
Overall Total Mean = 118														

As well observed for *A. antennatus* the species was collected almost exclusively in the stratum from 500 to 800 m (Table 3-12, 3-13). In this stratum the highest abundance were recorded in the south western Sardinian Sea (SW-Area 6; 23.5 kg/km^2, 1742 N/km^2) and in the Sardinian Channel (S-Area 7; 22.3 kg/km^2, 1509 N/km^2), while the northern area showed the lowest abundance (N-Area 3; 3.7 kg/km^2, 201 N/km^2). As reported for the blue and red shrimp, for the giant red shrimp both indexes showed very similar results. The analysis of abundance indexes for the macrostratum 200-800 m confirms the same trend observed for the stratum 500-800 due to the low catches in the lowest depth (Table 3-14, 3-15).

Table 3-12. *Aristaeomorpha foliacea.* Mean Biomass index (BI) and CV %, for stratum 500-800 m, by year and geographical Areas.

Biomass Index														
500-800 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	BI	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**
1994	10.0	23.1	4.8	26.3	4.6	0.0	24.6	44.0	0.0	0.0	5.4	40.0	12.5	39.8
1995	12.8	43.8	0.8	0.0	0.0	0.0	1.6	27.5	0.0	0.0	25.1	18.7	8.0	32.0
1996	6.1	35.1	7.1	36.1	0.0	0.0	10.3	42.6	4.1	20.2	34.2	27.5	25.1	23.2
1997	8.3	14.9	1.2	32.1	1.6	0.0	5.8	14.5	5.7	34.5	28.4	31.7	24.3	26.3
1998	14.1	18.6	4.8	9.2	11.0	0.0	3.6	13.3	15.9	39.8	20.2	23.2	48.1	34.2
1999	6.6	10.4	13.4	41.4	5.8	0.0	15.4	25.1	15.5	20.9	18.8	28.4	39.4	19.5
2000	13.5	14.5	8.5	31.0	0.7	43.4	10.7	45.8	130.3	42.9	17.8	23.0	35.0	19.9
2001	23.2	19.1	10.5	19.4	0.8	14.5	11.3	12.3	3.0	0.0	33.9	24.8	25.7	32.5
2002	1.5	0.0	11.0	0.0	0.4	0.0	0.5	0.0	22.5	41.1	90.4	15.1	13.3	6.9
2003	2.5	43.3	0.5	28.9	2.2	0.0	0.4	0.0	15.5	0.0	32.2	24.7	24.6	38.7
2004	8.2	20.2	13.6	19.1	8.2	0.0	119.6	0.0	18.4	0.0	36.4	15.8	10.0	30.4
2005	12.8	7.9	3.4	24.7	19.5	0.0	18.5	0.0	0.0	0.0	25.7	39.0	40.2	10.6
2006	23.8	4.1	16.0	34.0	0.5	0.0	1.5	0.0	1.3	0.0	20.1	31.2	12.1	27.5
2007	1.9	52.7	2.1	46.8	0.0	0.0	1.7	0.0	0.4	0.0	3.6	33.5	5.9	22.4
2008	2.5	60.3	16.7	0.0	3.4	0.0	3.9	0.0	1.2	0.0	20.8	35.6	14.5	27.6
2009	7.3	47.7	4.0	25.3	1.7	0.0	0.0	0.0	0.5	0.0	14.2	28.2	25.3	39.8
2010	11.7	30.1	16.9	20.9	2.4	0.0	0.1	0.0	2.6	0.0	1.8	39.3	31.7	48.5
2011	5.8	16.0	13.3	33.2	5.9	0.0	29.2	0.0	0.0	0.0	12.7	50.3	4.5	33.6
2012	9.0	15.5	3.6	32.1	0.7	0.0	10.7	0.0	0.3	0.0	5.4	36.5	23.1	29.6
94-12	**9.6**	66.1	**8.0**	71.5	**3.7**	134.5	**14.2**	0.0	**12.5**	236.3	**23.5**	82.5	**22.3**	56.5
Overall Total Mean = 13.4														

Table 3-13. *Aristaeomorpha foliacea.* Mean Density index (DI) and CV %, for stratum 500-800 m, by year and geographical Areas.

Density Index														
500-800 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	DI	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**
1994	564	37	191	27	153	0	869	44	0	0	192	26	467	40
1995	1255	43	66	0	0	0	163	39	0	0	2403	44	565	47
1996	336	34	207	21	0	0	409	42	196	23	1905	30	1253	27
1997	601	18	126	47	69	0	152	8	183	32	1479	33	1870	38
1998	510	7	189	13	510	0	210	31	763	41	1162	29	5935	55
1999	556	33	437	32	252	0	612	22	657	19	1030	33	2013	20
2000	1341	28	307	33	29	43	1180	55	4355	43	1194	27	2453	31
2001	951	19	283	22	51	10	477	18	143	0	1397	33	1293	40
2002	70	0	500	0	34	0	20	0	798	42	8322	16	910	9
2003	151	43	27	29	80	0	18	0	775	0	2455	29	1247	46
2004	549	20	1192	24	818	0	13291	0	680	0	3071	22	494	22
2005	818	3	153	27	885	0	1090	0	0	0	2893	46	2337	14
2006	947	12	744	33	9	0	63	0	67	0	837	33	492	30
2007	118	53	82	49	0	0	160	0	19	0	192	41	302	29
2008	131	61	467	0	97	0	478	0	73	0	2362	39	1033	35
2009	550	49	345	30	256	0	0	0	53	0	1143	39	2358	44
2010	436	28	1211	29	148	0	23	0	231	0	76	41	1560	45
2011	262	20	528	42	315	0	1364	0	0	0	518	47	211	39
2012	814	13	326	48	115	0	1540	0	45	0	458	52	1880	34
94-12	**577**	64	**388**	87	**201**	131	**1164**	0	**476**	208	**1742**	106	**1509**	86
Overall Total Mean = 865														

Table 3-14. *A. foliacea.* Mean Biomass index (BI) and CV %, for stratum 200-800 m, by year and geographical Areas.

Biomass Index														
200-800 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	BI	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**	**BI**	**CV**
1994	4.6	47.5	2.8	38.3	1.5	0.0	10.2	102.7	0.0	0.0	2.7	41.3	6.7	54.7
1995	5.9	94.3	0.5	0.0	0.8	52.7	0.7	52.3	0.0	0.0	11.2	24.7	4.3	45.2
1996	2.8	61.8	3.7	62.8	0.0	0.0	4.3	75.6	1.6	36.2	14.0	36.1	13.5	30.1
1997	4.0	32.8	0.6	52.7	0.6	0.0	2.4	26.1	2.3	70.4	12.0	35.4	13.0	34.6
1998	9.0	39.3	2.5	13.2	5.3	31.8	1.5	23.2	6.9	80.0	12.6	40.5	25.8	44.1
1999	3.0	17.9	7.1	62.6	1.9	0.0	6.4	43.4	6.2	44.8	7.4	33.3	21.2	25.1
2000	6.2	26.0	4.5	47.1	0.2	90.4	4.4	81.6	78.3	70.9	7.0	26.4	19.2	24.9
2001	10.7	34.6	5.5	30.6	0.3	39.5	4.7	22.4	2.9	56.8	15.9	27.8	13.8	42.3
2002	0.7	0.0	5.8	0.0	0.1	0.0	0.2	0.0	11.6	70.5	35.4	28.0	7.1	15.4
2003	1.2	109.5	0.3	63.2	0.9	0.0	0.2	0.0	14.7	0.0	12.7	33.0	13.2	57.9
2004	3.8	46.0	7.2	38.1	2.7	0.0	49.7	0.0	7.1	0.0	14.2	23.9	5.4	48.8
2005	7.5	26.0	1.8	42.6	8.7	26.9	7.7	0.0	1.0	0.0	10.1	71.3	21.6	16.5
2006	14.2	24.1	8.4	76.1	0.2	0.0	0.6	0.0	0.5	0.0	7.9	49.7	6.5	41.9
2007	3.4	77.9	1.3	71.4	0.0	0.0	0.7	0.0	0.2	0.0	1.4	51.2	3.2	31.3
2008	1.2	98.0	8.8	0.0	1.1	0.0	1.6	0.0	0.6	0.0	8.1	60.1	7.8	45.6
2009	6.9	70.9	4.9	54.6	0.6	0.0	0.0	0.0	1.5	0.0	5.6	44.4	13.6	73.3
2010	8.1	53.7	16.8	29.4	0.8	0.0	0.0	0.0	1.0	0.0	1.0	56.6	17.0	81.0
2011	3.7	39.0	7.3	60.1	1.9	0.0	12.1	0.0	0.1	0.0	5.0	86.6	2.4	48.2
2012	14.2	69.8	1.9	62.1	0.2	0.0	4.4	0.0	0.1	0.0	2.1	60.6	12.4	44.4
94-12	**5.8**	68.7	**4.8**	83.0	**1.5**	148.4	**5.9**	0.0	**7.2**	246.6	**9.8**	78.7	**12.0**	56.6
Overall Total Mean = 6.7														

Table 3-15. *A. foliacea* Mean Density index (DI) and CV %, for stratum 200-800 m, by year and geographical Areas.

Density Index														
200-800 m														
Year	**SE-Area 1**		**NE-Area 2**		**N-Area 3**		**NW-Area 4**		**CW-Area 5**		**SW-Area 6**		**S-Area 7**	
	DI	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**	**DI**	**CV**
1994	260	77	132	40	50	0	361	103	5	98	131	40	251	55
1995	577	93	43	13	32	50	68	70	0	0	1161	52	303	66
1996	155	59	110	36	0	0	170	74	76	41	785	39	672	35
1997	296	39	67	74	33	31	63	14	77	63	679	36	1003	50
1998	502	50	100	20	437	62	87	56	370	76	1166	61	3184	70
1999	256	56	231	48	82	0	254	39	264	41	403	38	1084	26
2000	617	49	162	51	9	94	490	98	2870	69	467	31	1332	39
2001	438	34	149	35	17	22	198	32	127	54	678	33	694	52
2002	32	0	264	0	11	0	8	0	424	69	3256	30	488	21
2003	69	108	14	51	29	6	7	0	752	0	983	38	669	68
2004	253	45	629	47	267	0	5524	0	263	0	1201	33	265	35
2005	635	42	81	47	458	37	453	0	110	0	1132	83	1254	22
2006	899	53	394	74	3	0	26	0	26	0	329	52	264	46
2007	196	76	58	69	0	0	67	0	7	0	75	62	162	40
2008	60	100	246	0	32	0	199	0	49	43	924	66	554	58
2009	754	75	635	67	83	0	0	0	84	0	447	61	1265	81
2010	384	54	1719	46	48	0	10	0	89	0	86	71	837	76
2011	272	61	293	75	103	0	567	0	7	98	203	81	113	57
2012	1562	74	172	95	38	0	640	0	17	0	179	85	1013	52
94-12	**432**	84	**290**	134	**91**	153	**484**	0	**296**	221	**752**	96	**811**	86
Overall Total Mean = 451														

Comparing the standardized values with the overall total mean for both indexes (BI, DI), calculated from all the years, the north western (NW-Area 4), south western (SW-Area 6) and the southern sector (S-Area 7) showed positive values (Figure 3-7, 3-8). The lowest values with respect to the overall total mean was recorded for the N-Areas 3. As regards the temporal evolution of the ratios within each Area (Area yearly mean/ Area total mean) no significant trends were observed (rk, p> 0.05).

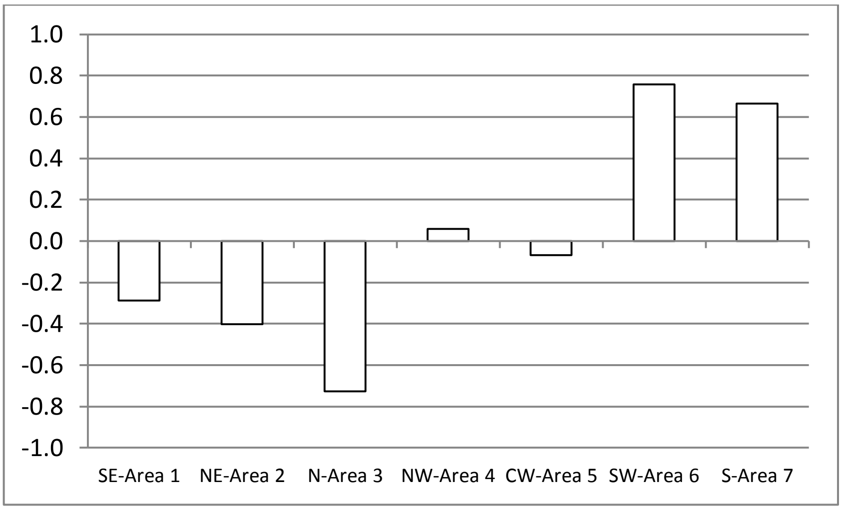


Figure 3-7. *A. foliacea* Ratio between Area total mean BI and overall total mean BI (500-800 m) (white: no signif. trend).

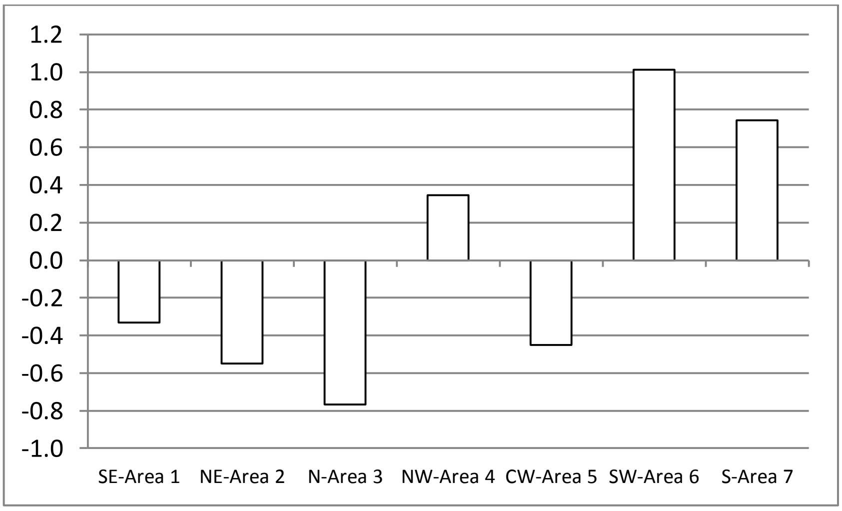


Figure 3-8. A. foliacea. Ratio between Area total mean DI and overall total mean DI (500-800 m) (white: no signif. trend).

3.3.2.3 Mean weight

The Mean weight values obtained in each Area are reported in table 3-16. The ratio between biomass index and density index highlighted the occurrence of large “average size” in the north-eastern grounds (NE-Area 2). The other Areas showed comparable ratios with the exception of central western area (CW-Area 5) which recorded the lowest values.

For each Area the MW total mean values were standardized according to the overall total mean (calculated from all the years means) and compared with this last mean (Figure 3-9).

Table 3-16 *A. foliacea*. Mean weight (BI/DI, g) considering the stratum 500-800 m, by year and geographical Areas.

Mean weight							
500-800 m							
Year	**SE-Area 1**	**NE-Area 2**	**N-Area 3**	**NW-Area 4**	**CW-Area 5**	**SW-Area 6**	**S-Area 7**
1994	17.73	25.13	30.07	28.31	0.00	28.13	26.77
1995	10.20	12.12	0.00	9.82	0.00	10.45	14.16
1996	18.15	34.30	0.00	25.18	20.92	17.95	20.03
1997	13.81	9.52	23.19	38.16	31.15	19.20	12.99
1998	27.65	25.40	21.57	17.14	20.84	17.38	8.10
1999	11.87	30.66	23.02	25.16	23.59	18.25	19.57
2000	10.07	27.69	24.14	9.07	29.92	14.91	14.27
2001	24.40	37.10	15.69	23.69	20.98	24.27	19.88
2002	21.43	22.00	11.76	25.00	28.20	10.86	14.62
2003	16.56	18.52	27.50	22.22	20.00	13.12	19.73
2004	14.94	11.41	10.02	9.00	27.06	11.85	20.24
2005	15.65	22.22	22.03	16.97	0.00	8.88	17.20
2006	25.13	21.51	55.56	23.81	19.40	24.01	24.59
2007	16.10	25.61	0.00	10.63	21.05	18.75	19.54
2008	19.08	35.76	35.05	8.16	16.44	8.81	14.04
2009	13.27	11.59	6.64	0.00	9.43	12.42	10.73
2010	26.83	13.96	16.22	4.35	11.26	23.68	20.32
2011	22.14	25.19	18.73	21.41	0.00	24.52	21.33
2012	11.06	11.04	6.09	6.95	6.67	11.79	12.29
94-12	**17.69**	**22.14**	**18.28**	**17.11**	**16.15**	**16.80**	**17.39**
Overall Total Mean = 18							

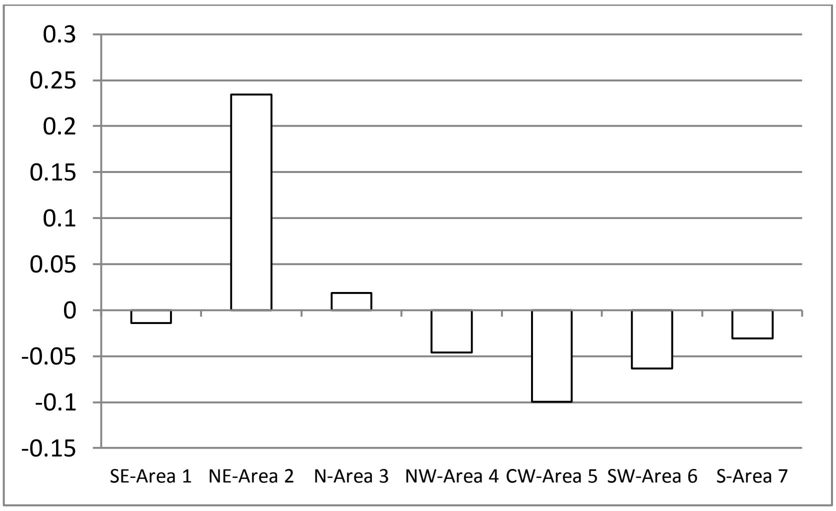


Figure 3-9 *A. foliacea.* Standardized Areas Mean weight concerning stratum 500-800 m.

3.3.3 Abundance ratio

The ratio of both indexes showed values near to 1 in the Gulf of Asinara (N-Area 3) where the bulk of the Aristeids were represented almost exclusively by *A. antennatus* in all the years with the exception of 1998 and 2005 (Table 3-17, 3-18). Differently in the S-Area 7 the ratio values showed a predominance of *A. foliacea* in the catches. A slight prevalence for *A. foliacea* were recorded in the NW-Area 4 and for *A. antennatus* in SE-Area 1 and CW-Area 5. In the other areas the ratio values indicated that the catches of the two species are more or less balanced for the yearly total mean.

Table 3-17. BI ratio between the two species (stratum 500-800).

Biomass Index Ratio							
500-800 m							
Year	**SE-Area 1**	**NE-Area 2**	**N-Area 3**	**NW-Area 4**	**CW-Area 5**	**SW-Area 6**	**S-Area 7**
1994	0.70	0.80	0.53	0.44	-	0.55	0.31
1995	0.52	0.98	-	0.16	-	0.27	0.06
1996	0.52	0.39	-	0.43	0.84	0.20	0.24
1997	0.73	0.71	0.90	0.74	0.66	0.42	0.13
1998	0.51	0.71	0.35	0.76	0.37	0.60	0.17
1999	0.54	0.34	0.84	0.22	0.21	0.66	0.10
2000	0.76	0.60	0.98	0.59	0.06	0.59	0.28
2001	0.40	0.56	0.97	0.50	0.97	0.56	0.25
2002	0.98	0.69	0.98	0.00	0.72	0.07	0.80
2003	0.91	0.89	0.84	0.97	0.36	0.49	0.24
2004	0.66	0.25	0.93	0.00	0.56	0.08	0.17
2005	0.63	0.75	0.33	0.16	1.00	0.46	0.17
2006	0.40	0.16	0.97	0.00	0.88	0.58	0.54
2007	0.89	0.00	1.00	0.37	0.93	0.84	0.45
2008	0.86	0.00	0.86	0.20	0.82	0.49	0.25
2009	0.79	0.54	0.97	1.00	0.91	0.43	0.18
2010	0.42	0.40	0.83	0.00	0.82	0.91	0.16
2011	0.61	0.58	0.85	0.26	1.00	0.59	0.69
2012	0.59	0.42	0.95	0.16	0.96	0.64	0.24
94-12	**0.65**	**0.51**	**0.78**	**0.37**	**0.67**	**0.50**	**0.29**

Table 3-18. DI ratio between the two species (stratum 500-800).

Density Index Ratio							
500-800 m							
Year	**SE-Area 1**	**NE-Area 2**	**N-Area 3**	**NW-Area 4**	**CW-Area 5**	**SW-Area 6**	**S-Area 7**
1994	0.71	0.82	0.72	0.63	-	0.73	0.45
1995	0.32	0.97	-	0.17	-	0.28	0.05
1996	0.56	0.52	-	0.60	0.88	0.23	0.33
1997	0.69	0.52	0.95	0.91	0.83	0.51	0.09
1998	0.57	0.68	0.46	0.84	0.45	0.64	0.08
1999	0.42	0.39	0.83	0.34	0.19	0.69	0.10
2000	0.56	0.61	0.98	0.46	0.11	0.60	0.27
2001	0.47	0.64	0.97	0.53	0.96	0.65	0.28
2002	0.97	0.60	0.98	0.00	0.75	0.06	0.73
2003	0.87	0.84	0.89	0.97	0.47	0.45	0.22
2004	0.49	0.11	0.82	0.00	0.58	0.04	0.21
2005	0.61	0.76	0.34	0.15	1.00	0.33	0.20
2006	0.40	0.16	0.99	0.00	0.91	0.71	0.67
2007	0.85	0.00	1.00	0.19	0.93	0.85	0.44
2008	0.84	0.00	0.92	0.07	0.77	0.32	0.19
2009	0.69	0.41	0.94	1.00	0.84	0.39	0.13
2010	0.48	0.30	0.83	0.00	0.80	0.94	0.19
2011	0.62	0.63	0.88	0.38	1.00	0.69	0.75
2012	0.51	0.23	0.87	0.06	0.87	0.59	0.19
94-12	**0.61**	**0.48**	**0.80**	**0.38**	**0.69**	**0.51**	**0.29**

The differences between the ratios were confirmed by box-plot representation which visually showed the values obtained for each Area (Figure 3-10). The differences between Areas (BI, Ratio) were confirmed by the analysis of variance (ANOVA). The model explain the 62% of the total variability and show statistically significant difference between the mean ratio from one level of Areas to another at the 95.0% confidence level (Table 3-19).

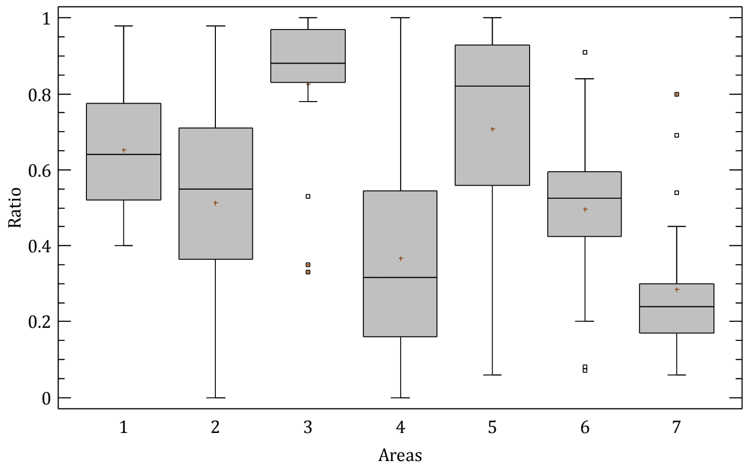


Figure 3-10. Box-Plot representation of BI ratio values.

Table 3-19. ANOVA for Ratio by geographical Areas.

ANOVA					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**
Between groups	4.174	6	0.696	***11.870**	***0.000**
Within groups	7.560	129	0.059		
Total (Corr.)	61.734	135			

* Denotes a statistically significant differences.

The Multiple Range Test showed the estimated difference between each pair of means at 95.0% of confidence level (Table 3-20). The Bonferroni procedure highlighted three homogeneous groups (Table 3-21). In general along the Sardinian coast three gradients of distribution may be noted. In the north grounds (N-Area 3) *A. antennatus* is the main species (group C), whereas *A. foliacea* predominates in the Sardinian Channel (S-Area 7) and in the central western grounds (NW-Area 4) (group A). In the other Areas the Aristeids show an irregular distribution with year of strong prevalence of one species followed by catch very low and near zero in the later year (group B). However, in the SE-Area

1 and CW-Area 5 *A. antennatus* was more abundant, instead of SW-Areas 6 and NE-Area 2 the caches of the two species were similar.

Table 3-20. Multiple range test among different Areas of Sardinian Seas.

Bonferroni Multiple Comparison procedure			
Contrast	**Significant**	**Difference**	**+/- Limits**
1 - 2		0.139	0.237
1 - 3		-0.172	0.243
1 - 4	*	**0.287**	0.237
1 - 5		-0.054	0.243
1 - 6		0.157	0.237
1 - 7	*	**0.367**	0.237
2 - 3	*	**-0.311**	0.243
2 - 4		0.147	0.237
2 - 5		-0.193	0.243
2 - 6		0.017	0.237
2 - 7		0.228	0.237
3 - 4	*	**0.459**	0.243
3 - 5		0.117	0.250
3 - 6	*	**0.329**	0.243
3 - 7	*	**0.539**	0.243
4 - 5	*	**-0.341**	0.243
4 - 6		-0.130	0.237
4 - 7		0.080	0.237
5 - 6		0.211	0.243
5 - 7	*	**0.421**	0.243
6 - 7		0.210	0.237

* Denotes a statistically significant differences.

Table 3-21. Homogenous groups between the Areas.

Areas	**Count**	**Mean**	**Homogeneous Groups**
S-Area 7	20	0.286	A
NW-Area 4	20	0.366	A
SW-Area 6	20	0.496	AB
NE-Area 2	20	0.514	AB
SE-Area 1	20	0.653	BC
CW-Area 5	18	0.707	BC
N-Area 3	18	0.825	C

3.3.4 Thematic spatial maps

The overall DI and BI maps highlighted different streaking features. Considering the spatial distribution of both species a high spatial heterogeneity and partial single correspondence between biomass and density index maps were observed. In general the species showed a mosaic pattern with no clear correlation either in time and geographic areas (Annex I and Annex II).

The synoptic view (1994-2012) of the abundance indexes indicated that a large area of the continental slope off Carloforte and Sant'Antioco island (South Sardinia-SW-Area 6), extending from the 400 m bathymetry up to 800 m, provides a fishing grounds for both shrimps (Figure 3-11, 3-12).

The blue and red shrimp was irregularly distributed with a prevalence in the south-west area (SW-Area 6) and in the northern sector (N-Area 3) (Figure 3-11). In particular in the south-west area the species is mainly cached in the fishing grounds off the island of Sant'Antioco while in the northern part of the SW-Area 6 the maps showed another hot spot. In the N-Area 3 the blue and red shrimp is more abundant in the left open slope of the Tramontana Canyon. On the other hand the distribution of *A. antennatus* is scarce in the north eastern part (NE-Area 2). In the other Areas the species show an irregular distribution with sectors of strong density surrounded by very low and near zero catches. As observed for the blue and red shrimp, the giant red shrimp was mainly abundant in the south-west coast (SW-Area 6) off the Sant'Antioco island (Figure 3-12). The other important hot spot was located in the Ichnusa seamount (also know by fisherman as Carbonara Bank-S-Area 7), extending from the 400 up to 800 m. On the contrary the lower values were detected in the northern sector (N-Area3) where the catches were near zero.

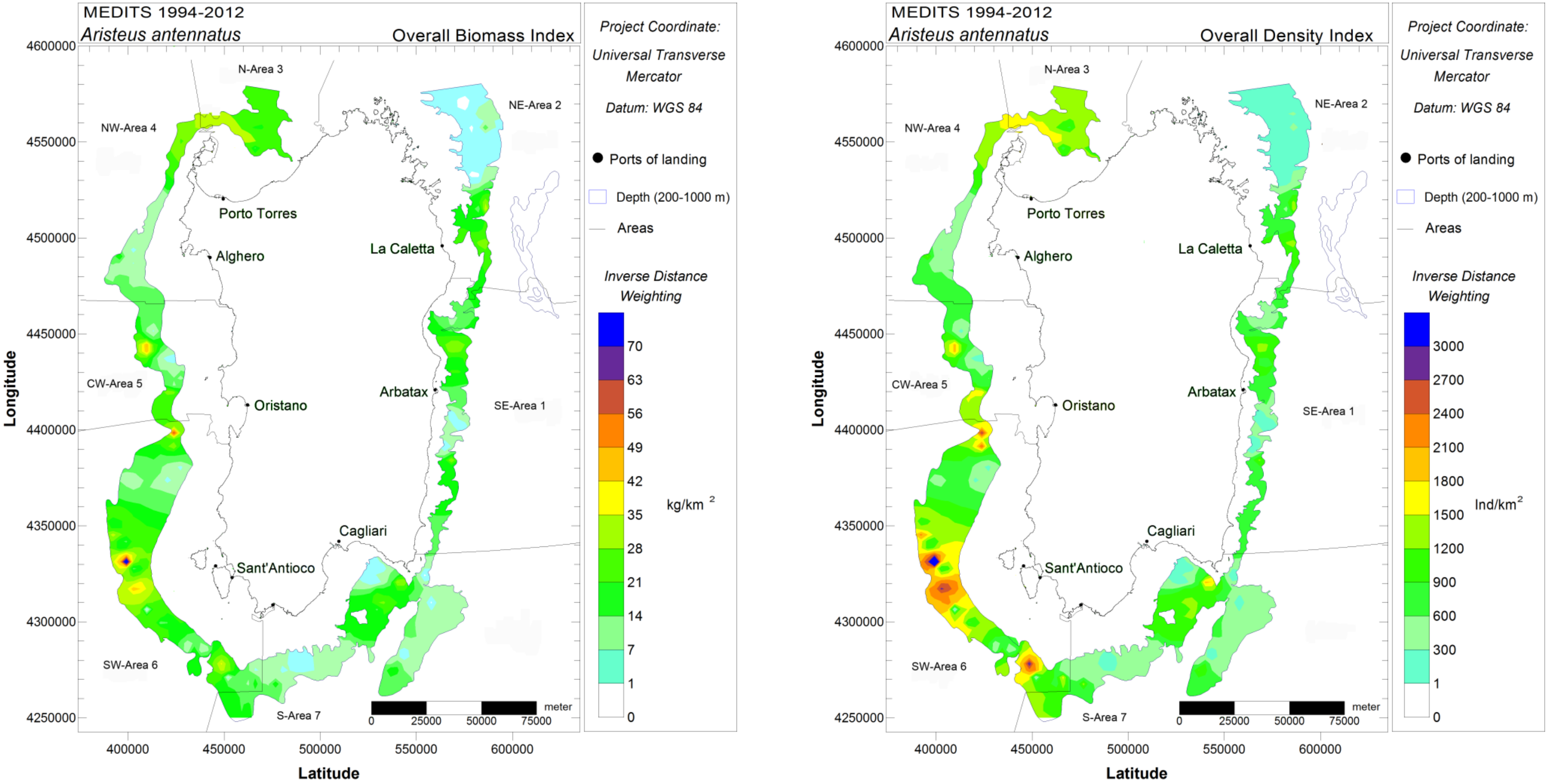


Figure 3-11. *A. antennatus*: Medits trends in biomass (a) and density (b) during the period 1994-2012 in Sardinian Seas and different geographical areas.

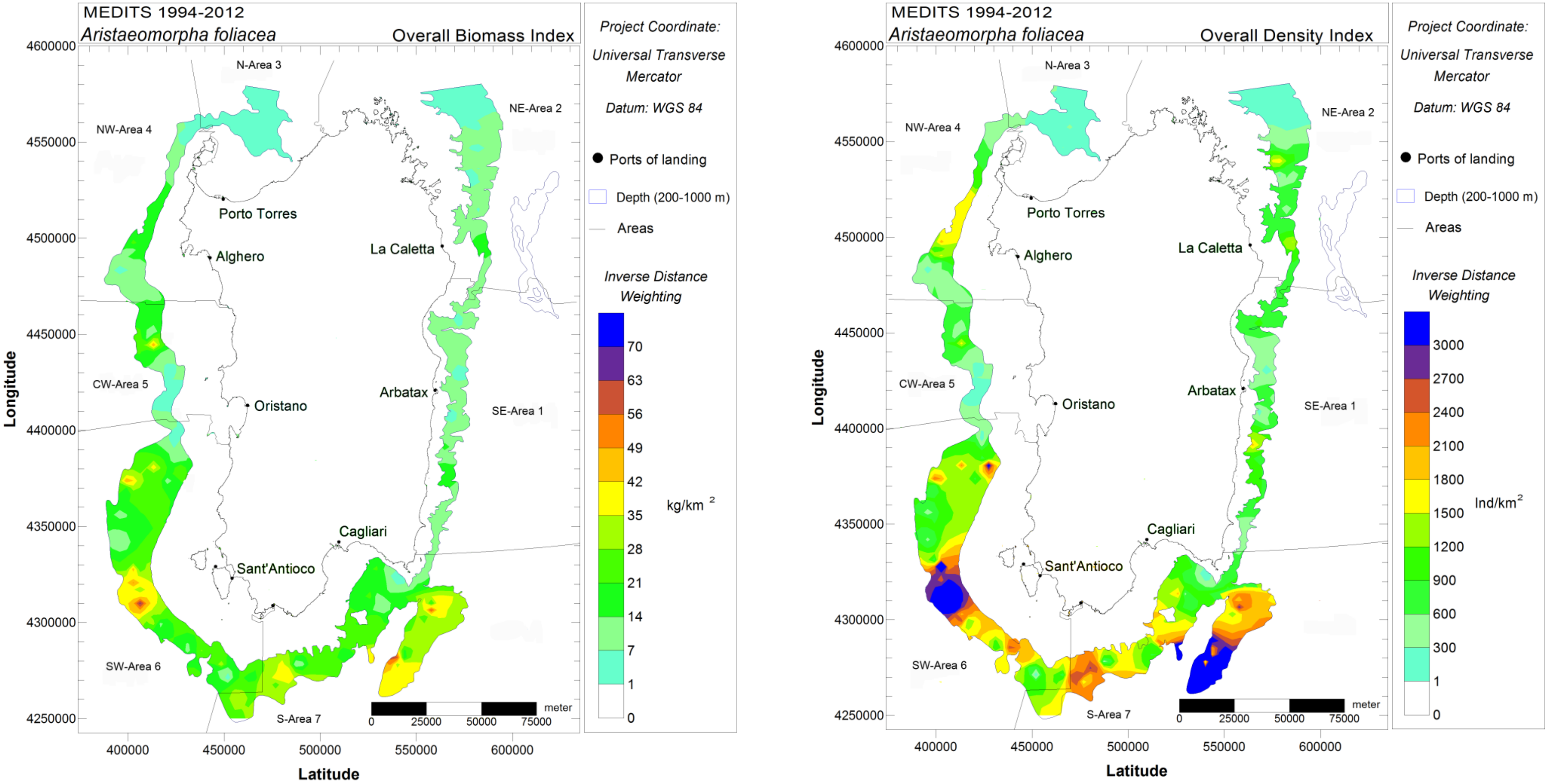


Figure 3-12. *A. foliacea*: Medits trends in density and biomass during the period 1994-2012 in Sardinian Seas and different geographical areas.

3.4 DISCUSSION

The particular geomorphology and oceanography of the Sardinian Seas determines the presence of different habitats that provide a complex system of environmental patches, reflected in the distribution and abundance of the deep-water red shrimps in this area.

The deep-sea is exposed to a strong increase in anthropogenic impact both directly through extension of the coastal fisheries to the slope (Rochet *et al.,* 2010; Sabatini *et al.,* 2013), and indirectly due to the impact of general global climatic change (Danovaro *et al.,* 2001; Coll *et al.,* 2010). As a consequence, apart from areas where habitats and resources are naturally protected (example: irregular trawl bottoms near submarine canyons), the red shrimps living on the slope have also been subject to high trawl fishing pressure in recent decades in the Sardinian slope region (Sabatini *et al.,* 2013). The MEDITS surveys carried out systematically in the last 19 years on the demersal resources of this area have provided a large amount of standardized data useful for detecting the current status of these marine resources and investigating, over a wide time scale, any changes in their availability, as well as in the geographical pattern.

Based on the frequency of occurrence, the data reflect a higher presence of *A. foliacea* (48%) compared to that of *A. antennatus* (41%). The data collected in different part of Sardinia Seas allowed a global comparative study of the distribution and abundance of deep water red shrimps *A. antennatus* and *A. foliacea.* In general the largest catches for both species were made at 500-800 m, though *A. foliacea* was often found also at shallower depth (200-500 m). In fact, the blue-and-red shrimp showed in the 200-500 m stratum a total mean biomass of 0.6 kg/km^2 and density values 26 N/km^2 while, *A. foliacea* showed higher values (1.3 kg/km^2, 118 N/km^2). These result are in good agreement with previous studies suggesting that *A. foliacea* is the main species at shallower depths, while *A. antennatus* is more abundant at greater depths (Sardà *et al.*

2004) and that the two species overlap at a depth of around 650 m (Cau and Deiana, 1982).

In general the abundance indexes showed an extreme interannual variability in the catches and any significant trend was observed for both species in the analyzed period (1994-2012). A peak of catches in both species occurred in 2002, while highest abundance were recorded in 2010 and 2004 for *A. antennatus* and *A. foliacea*, respectively.

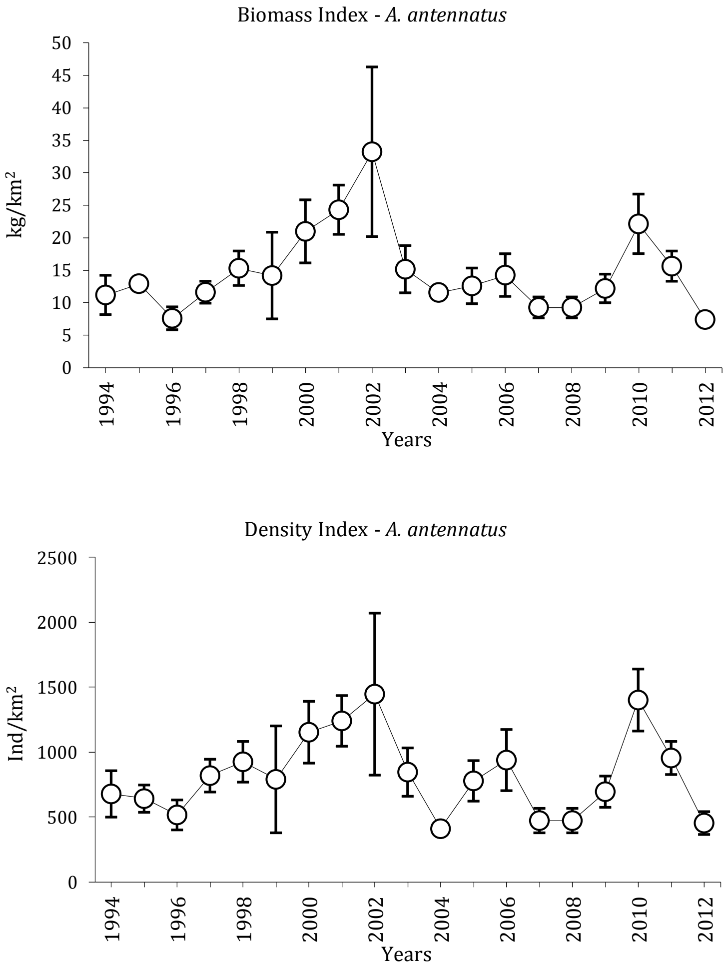
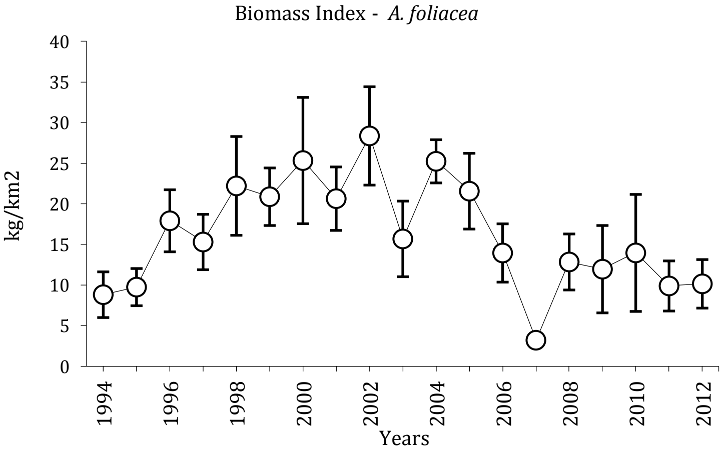


Figure 3-13. Biomass and Density (±S.d) Index per year for *A. antennatus* in the Sardinian Seas from 1994 to 2012.



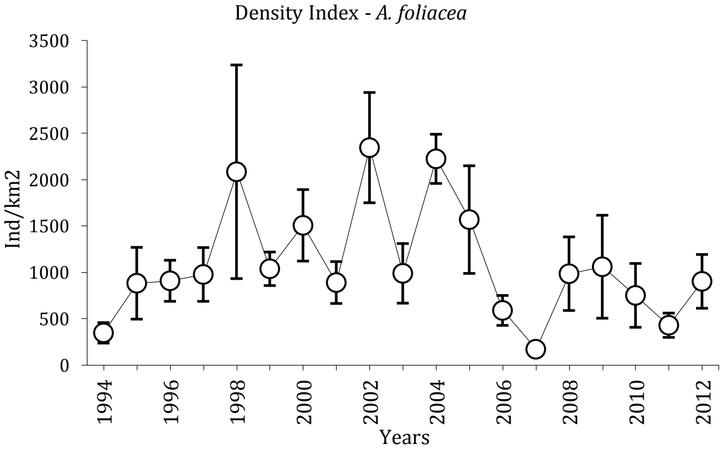


Figure 3-14. Biomass and Density (±S.d) Index per year for *A. foliacea* in the Sardinian Seas from 1994 to 2012.

The extreme variability of the data can also be observed comparing the mean weight (MW). The yearly mean values for *A. antennatus* highlighted the presence of smaller individuals in all the northern and western coast. In the same way, for *A. foliacea* the occurrence of small "average size" values were recorded in the western coast as well as in south eastern and south zones.

The geographical distribution of *A. foliacea* and *A. antennatus* observed in this study partially confirms small-scale geographical differences of the two species, already detected by the literature for the Sardinian waters (Murenu *et al.,* 1994; Cau *et al.,* 2002). The spatial maps, generate using single hauls data, evidenced local higher abundances (hotspots) where the blue and red shrimp and the giant red shrimp are mainly concentrated. The south west area (SW-Area 6) showed the highest abundance values for both species. Concerning the blue and red shrimp, “hotspots” were observed in the central eastern sector of Sardinia (SE-Area 1), in western Sardinia (CW-Area 5) and in the northern sector (N-Area 3) where the specie was more consistent. Otherwise the giant red shrimp show two “hotspots”, located in southern Sardinia, where the species was more abundant in the grounds from the Ichnusa seamount to Sant’Antioco Island fishing grounds (S-Area 7 and SW-Area 6).

The variation in the catches which are evident for both abundance indexes, suggest some relation with some biotic and abiotic factors. Many authors have correlated various environmental variables trying 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). Given that higher occurrences and abundances were detected in different areas of Sardinian Seas, and therefore likely subject to different conditions, the overall distribution and abundance patterns of these species might reflect several intermingling factors such as natural noise, oceanographic features, food availability or recruitment success (Cau *et al.,* 2002; Carbonell *et al.,* 2008; Cartes *et al.,* 2011a). 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.

4 PART II. HYDROGRAPHIC CONDITIONS OF THE SARDINIAN SHELF-SLOPE REGION.

4.1 INTRODUCTION

During the last three decades a large number of works has been focused on the description of the hydrographic conditions of the Sardinian slope region. Most of these have been made using both, *in situ* data sets (e.g. Bouzinac *et al.,* 1999; Sammari *et al.,* 1999; Santinelli *et al.,* 2002; Ribotti *et al.,* 2004) and numerical models (e.g. Testor *et al.,* 2005; Sorgente *et al.,* 2011; Olita *et al.,* 2013a; Olita *et al.,* 2013b). Sea water temperature and salinity are two of the most important components in the oceanographic and biological investigations and represent the basic elements for any ecological and/or ecosystem modeling attempt. Together the two variables control the sea-water density, which is the major factor, together with wind forcing, governing the vertical and horizontal movement of sea waters.

One goal in the studies on the distribution of marine species is to make and test generalizations about spatial variations in patterns of environmental causes. In the case of deep water red shrimps, such models are useful for generating hypotheses about the specific environmental stimuli (Company *et al.,* 2008; Maynou, 2008; Sardà *et al.,* 2009; Cartes *et al.,* 2011a) that are responsible for making predictions about spatial distribution and/or the temporal fluctuations.

Mediterranean Seawater Surface Temperature (SST, hereafter) nowadays can be easily and continuously investigated by remote sensing. The satellite imagery, and especially the thermal imagery, provides since the late 1970s a climatological view of the basin at a spatio-temporal scales (e.g. NOAA/AVHRR). Despite that, the hydrographic conditions on the shelf-slope are difficult to monitor by remote sensing given the high complex bottom topography, local mixing of different layers and mesoscale signals (Sardà *et al.,* 2004). Further, circulation cannot be directly inferred by SST, that on the other hand, together with Ocean Color imagery, can provide useful hints about mesoscale features. Other tools used to study open-sea oceanographic processes, like scatterometers (winds) or altimeters (sea level) are not still well suited to investigate coastal areas, whose study on the contrary needs a combination of high-resolution modeling and *in situ* observations.

Such is the case of the shelf/slope area of the seas surrounding Sardinia. Sardinian Seas a large area between the Algerian-Provençal (Western Mediterranean Sea), the Tyrrhenian basins and Sardinian Channel characterized by non homogeneous fishing grounds (Cau *et al.,* 1994; Sabatini *et al.,* 2013), both from the geomorphological (Palomba and Ulzega, 1980) and oceanographic point-of-view (Ribotti *et al.,* 2004; Olita *et al.,* 2011; Olita *et al.,* 2013a).

Water masses occurring on the continental shelf-slope areas, where the deep water red shrimps are fished, are mainly the Modified Atlantic Water (MAW) and Levantine Intermediate water (LIW). Red shrimps, anyway, are batimetrically located with LIW and with even heavier and deeper waters (TDW, Tyrrhenian Deep Water). MAW, usually flowing in surface and subsurface layers, can be hypothesized to have just a marginal influence on the layers (400-800) where red shrimps live, for example in case of deepening of the isopycnal due to the convergence occurring in the interior of anticyclones. The LIW and a branch of the Eastern Mediterranean Deep-water (EMDW) enter in the Tyrrhenian Sea through the Sicilian Channel. Some this waters flow along the Corsica and Sardinia, mixing with the Tyrrhenian deep water (TDW) (Millot, 1999). Along the South-Western coasts of Sardinia, LIW and TDW flow northward, showing a change in path due to the interaction with the Algerian eddies and with topography.

In addition to the above mentioned methodologies used to investigate such processes and water masses on shelf-slope areas, an effective alternative (particularly suited to investigate water masses in correspondence to biological samples) was the one adopted in the present study, i.e. the sampling of oceanographic profiles in coincidence with the experimental bottom trawl hauls (MEDITS; Bertrand *et al.,* 2002). The research protocol of the MEDITS survey include the sampling of temperature and bathymetric profiles by applying a Minilog device onto the head rope of the gear. The device was used to help monitoring of the gear performance and to get real time measure of sea water temperature in order to highlight any possible catch level relationship (Bertrand *et al.,* 2002). In spite of the easy use of Minilog, the device shows lower precision and accuracy of data if compared to other devices. To improve the accuracy of the temperature data and collect others parameters, as well salinity, we put in the otter a CTD (SBE 37-IM Microcat) for collecting data during the bottom trawling.

In this context the aim of this chapter was to identify the seasonal (spring-summer) pattern of water masses from investigation of the physic-chemical properties of seawater in the shelf-slope areas around the Island of Sardinia. In particular this chapter focuses on the study of the horizontal and vertical oceanographic features in the Sardinian shelf-slope areas because of the actual (Cartes et al. 2011a,b) and potential impact of such water masses in relation to the distribution of the deep water red shrimps.

4.2 MATERIAL AND METHODS

Hydrological data have been collected with a CTD (SBE 37-IM Microcat Conductivity–Temperature–Depth measurements) at 361 stations during four MEDITS surveys (spring-summer) between 2009 and 2012 (Figure 5-1, 5-2) . In order to study the water mass structure in the basin, we divided the Western Mediterranean in sectors: Tyrrhenian Sea (sector 1), Sardinia Channel (sector 2); central Algerian/Provençal basin (i.e Sardinian Sea, sector 3). Surveys time scheduled and specification are present in Table 5-1. Samplings were performed according to standardized protocol. To emphasize the typical water structure in the Sardinian shelf-slope during the four years of investigation we performed representative stations profile between 0 m and 800 m.

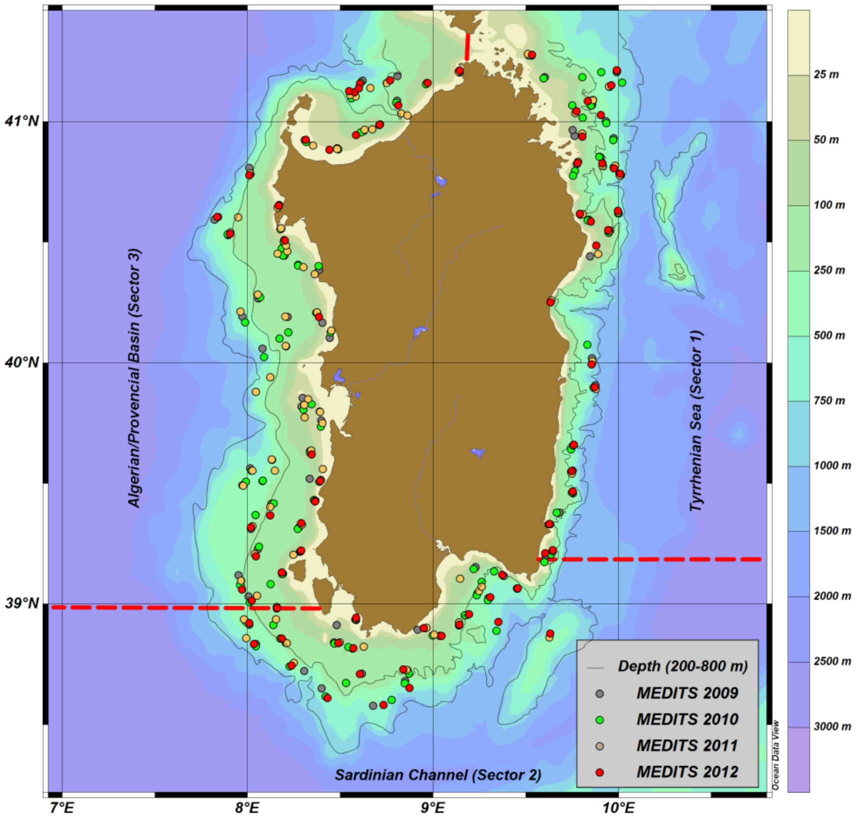


Figure 4-1. Station map. Dots indicate the sampling site, corresponding to the CTD stations, in the Tyrrhenian Sea, Sardinian Channel and Algero/Provençal Basin.

Table 4-1. Time scheduled: survey code, year and time range of MEDITS surveys carried out in the Sardinian Seas. Start and end refer to the beginning and end of the survey. Nominal time refers to the median day of given survey period.

Survey Code	Years	Start	End	Nominal date	N° of Station
MEDITS09	2009	08-Jun	10-Jul	24-Jun	98
MEDITS10	2010	17-May	16-Jun	01-Jun	100
MEDITS11	2011	01-Jun	05-Jul	18-Jun	87
MEDITS12	2012	05-Jun	12-Jul	23-Jun	76

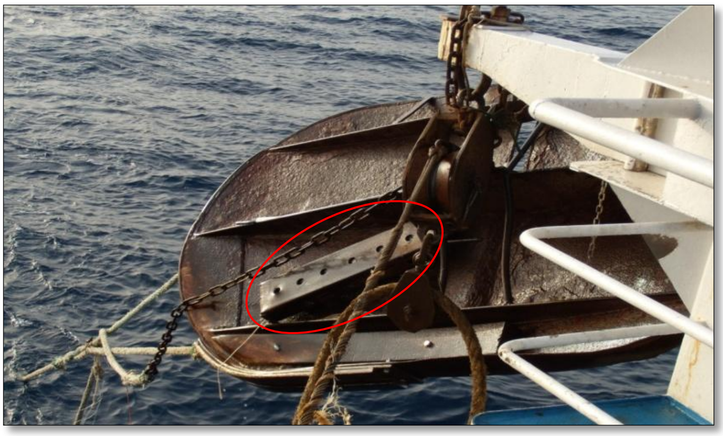


Figure 4-2. CTD position in the otter of the gear.

From all the CTD stations considered, we found the subsurface salinity (S_{max}) and the related temperature (T_{max}) and pressure values. The properties of each layer both in terms of salinity and temperature were analyzed.

The data processing and contour plot visualization was created using Ocean Data View software (Schilitzer, 2007). Different interpolators were tested and the most exact interpolator (VG gridding) was chosen. These algorithms, appropriate for poor or heterogeneous data coverage, analyzes the distribution of the data points and constructs a variable resolution, rectangular grid, where grid spacing along the X and Y axes vary according to data density. High resolution (small grid spacing) is provided in regions with good data coverage, whereas in areas of sparse sampling the grid is coarse and resolution is limited.

4.3 RESULTS AND DISCUSSION

The hydrological data set, collected in the Sardinian Seas during the spring-summer surveys from 2009 to 2012, revealed the principal characteristics of the water masses present in the Sardinian continental slope. The potential temperature vs. salinity (T/S) diagram for each year are shown in Figure 4-3. The three major typical water masses of the western Mediterranean Sea were evidenced: the surface water MAW (Modified Atlantic Water) (S~37.7-37.8) with marked variations at a several month/year scale, the LIW (Levantine

Intermediate Water) (T_{max}~13.82-13.92 and S~38.60–38.67 psu), and a mixed MAW and LIW flow layers (37.9-38.5 psu).

The surface water (MAW), which extended to a depth of about 200 m, is constituted by the inflowing of Atlantic waters which are largely modified by local environmental constraints during their transit (Millot, 1999). Its temperature was highly variable during the years, from 12.95 in the 2009 to >26°C for the extreme surface in summer 2012 (Figure 4-3). The salinity was also very variable during the time-series in the range from 36.78 (in the surface layer) to 38.4 psu (200 m) due to the presence of a mixed MAW and LIW flow layers. This situation was conforming to what was described in literature (Millot, 1999; Olita *et al.,* 2011). The MAW is considered as mostly affected by local climatic conditions (Schroeder *et al.,* 2006) and subject to strong seasonal and annual influences of atmospheric forcing as showed by Olita *et al.,* 2013a for the western Sardinian shelf-slope area.

The LIW is formed in the Rhodes gyre and sinks to a depth of 200-500 m. Its hydrographical signature decreases from east to west (Millot, 1999). In the Sardinian shelf-slope areas the LIW was extending approximately between 400 and 600 m. It was characterized by a maximum of salinity and temperature 13.82–13.92 °C in the range 38.60–38.67 psu, generally found at 400-450 m (Figure 4-3).

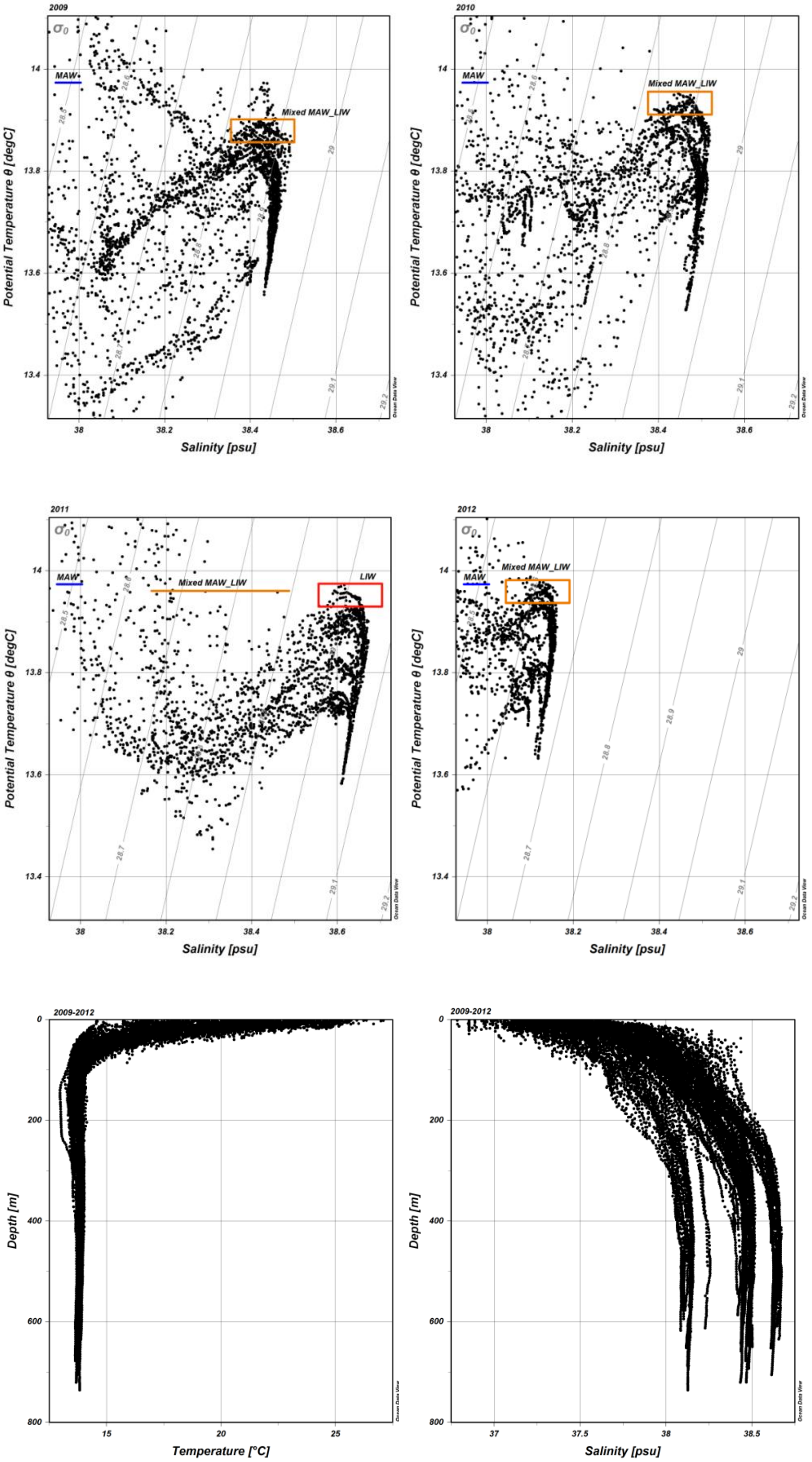


Figure 4-3. Hydrological characteristics for the 2009–2012 dataset. Potential temperature vs. salinity (TS) diagram year by year. Potential temperature profiles and Salinity profiles 2009-2012.

In Figure 4-4, 4-5, 4-6 sections for temperature and salinity up to 700 m are presented for the different years. The stratification in the mixed layer depth (about 100 m) for all the sectors and years showed large variability due to an intense mesoscale activity. In the northern part of the Sector 1 (between ~9 and ~10° E) the vertical sections indicate the presence of mixed upper layer between 50 and 100 m for all the years considered. In these depth layers the temperature varied form a minimum of 14 to a maximum of 14.3 °C while the relative minimum salinity of 37.8 psu indicating the presence of MAW (Ribotti *et al.,* 2004). This area is influenced by the steady mistral wind which blowing through the Bonifacio Strait (Artale *et al.,* 1994) induced the formation of cyclonic eddies. In summer, the dynamic of this area is dominated by a well-known dipole located to the east of the Bonifacio Strait (Lo Iacono *et al.,* 2013).

In the Sector 2 and Sector 3, as well registered in the north-eastern section (sector 1), the mixed upper layer involved the shallower water up to 150. The south-eastern corner of Sardinia (Sector 2) is characterized by the presence of mesoscale structures (South Eastern Sardinian cyclonic Gyre, SESG) with high spatial and temporal variability (Sorgente *et al.,* 2011), while in the Algero-Provençal Basin (Sector 3) the mean surface circulation is characterized by a southward current flow getting closer to the coast in correspondence of the southern corner of the Island (Olita *et al.,* 2013a). Considering the depth of ~ 200 m the characteristics of the water masses are ascribable to the lower part of the MAW (37.8 psu), while up to ~350 m we found a marked influence of MAW and LIW mixing (37.9-38.5 psu).

Intermediate temperature and salinity maxima are found in all the sectors, even if with different values for depth and years.

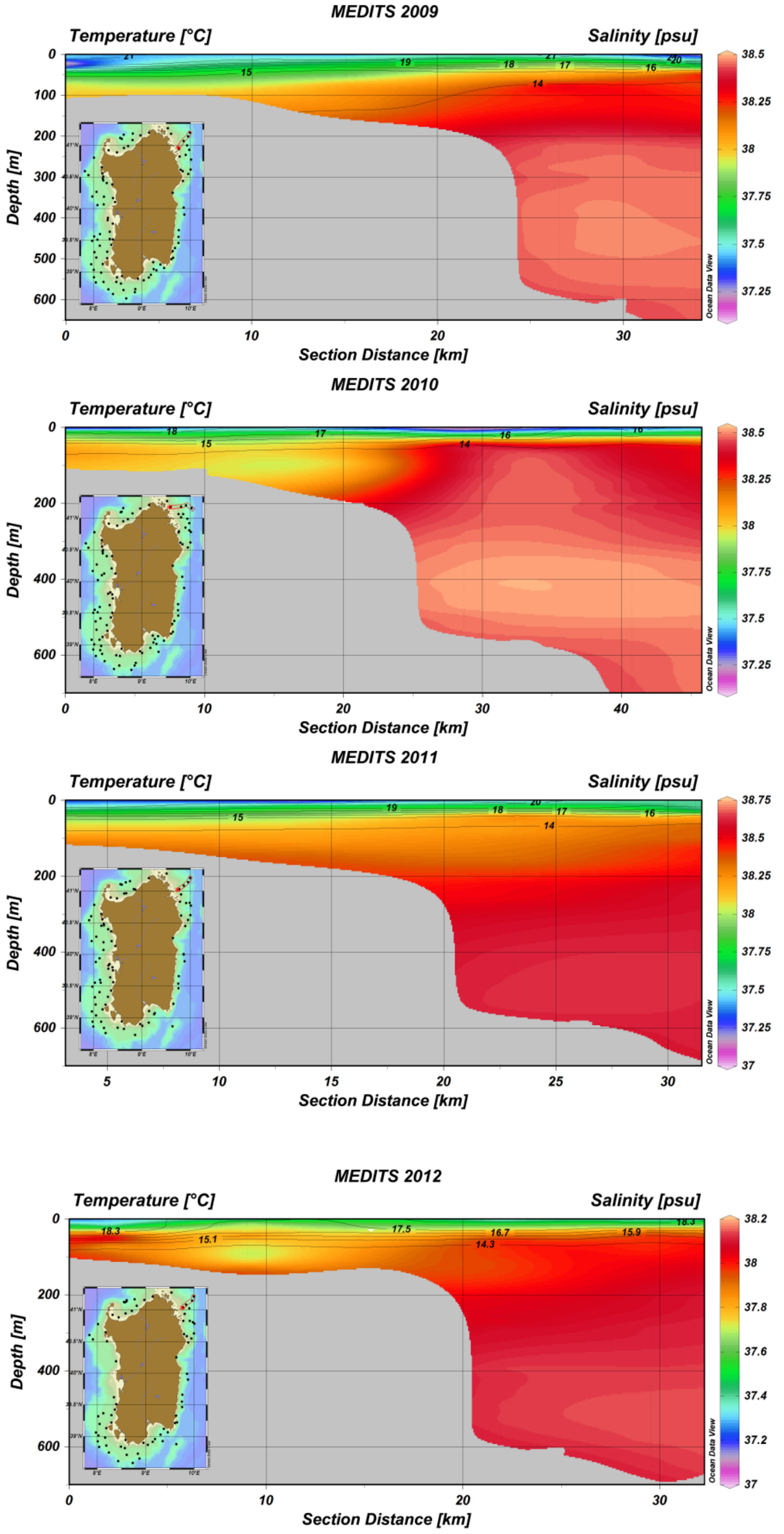


Figure 4-4. Salinity, temperature profiles along the section in the Tyrrhenian Sea (Sector 1) in four years (2009-2012).

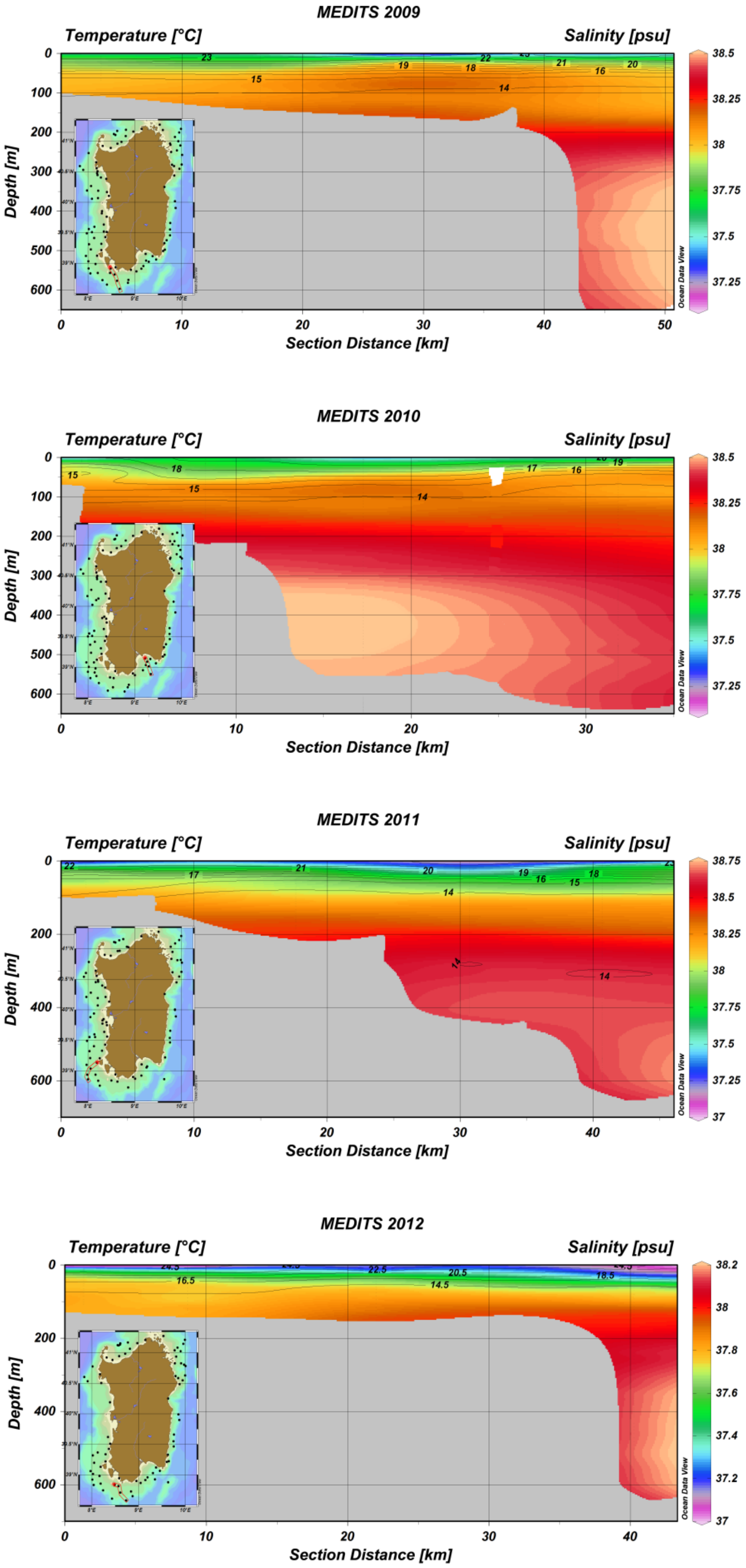


Figure 4-5. Salinity, temperature profiles along the section in the Sardinian Channel (Sector 2) in four years (2009-2012).

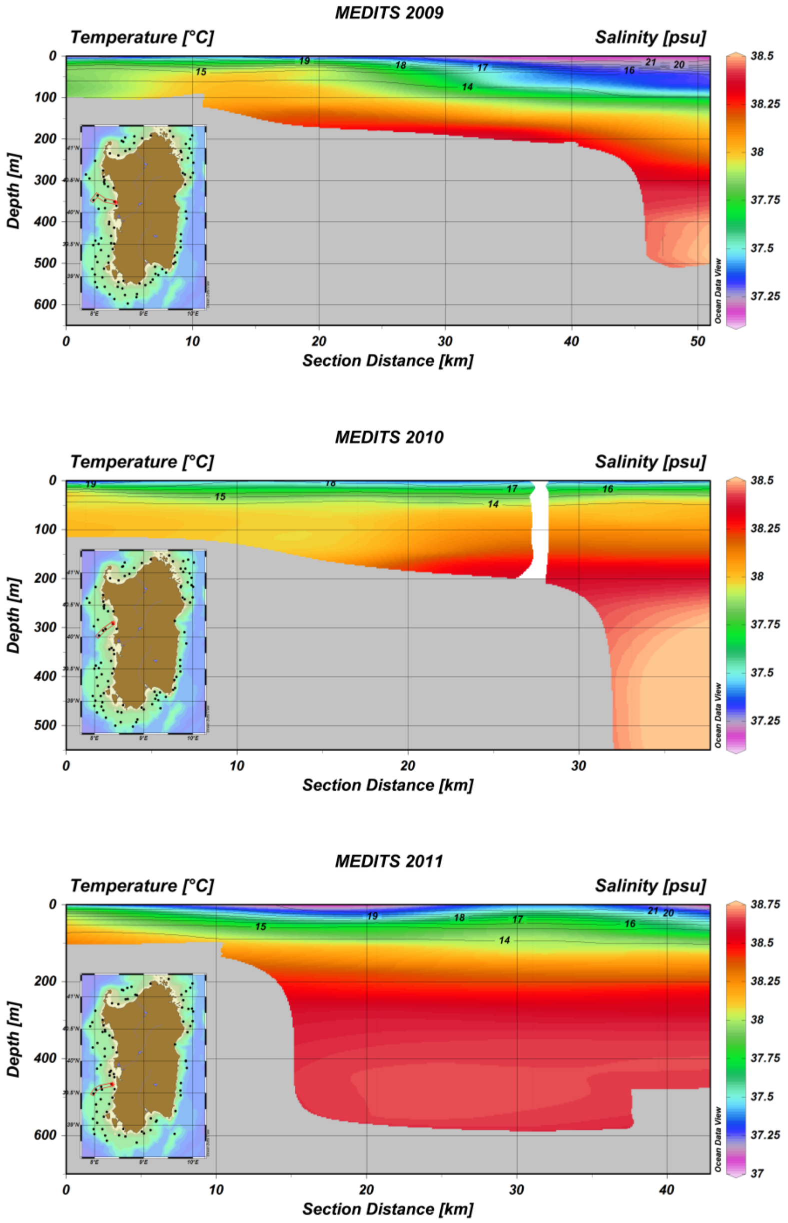


Figure 4-6. Salinity, temperature profiles along the section in the Sardinian Channel (Sector 3) in four years (2009-2012).

The horizontal mapping of 400 m salinity field is showed in Figure 4-7 for the four years. In 2011 the salinity maximum of LIW was found at 400 m with S_{max} between 38.6-38.69 in all the sectors. Lower values of salinity were found in the year 2009 and 2010 due to the interaction with the MAW layer. The lowest values of salinity were registered in the 2012 at 400 with S_{max} between 38.00 and 38.2 psu. I can note that two variable branches (400 m) of subsurface salinity and temperature maximum appear. The maximum values of salinity were observed at 400-500 m along the western Sardinian shelf-slope area (also called Sardinian branch, Perilli *et al.,* 1997). Another branch of LIW were found southern in the Sardinian channel starting from Capo Carbonara to Carloforte Island. We highlighted also the lower temperature in the northern part of the sector 3, because it is influenced by the steady mistral came from the Gulf of Lions (Artale *et al.,* 1994; Lo Iacono *et al.,* 2013).

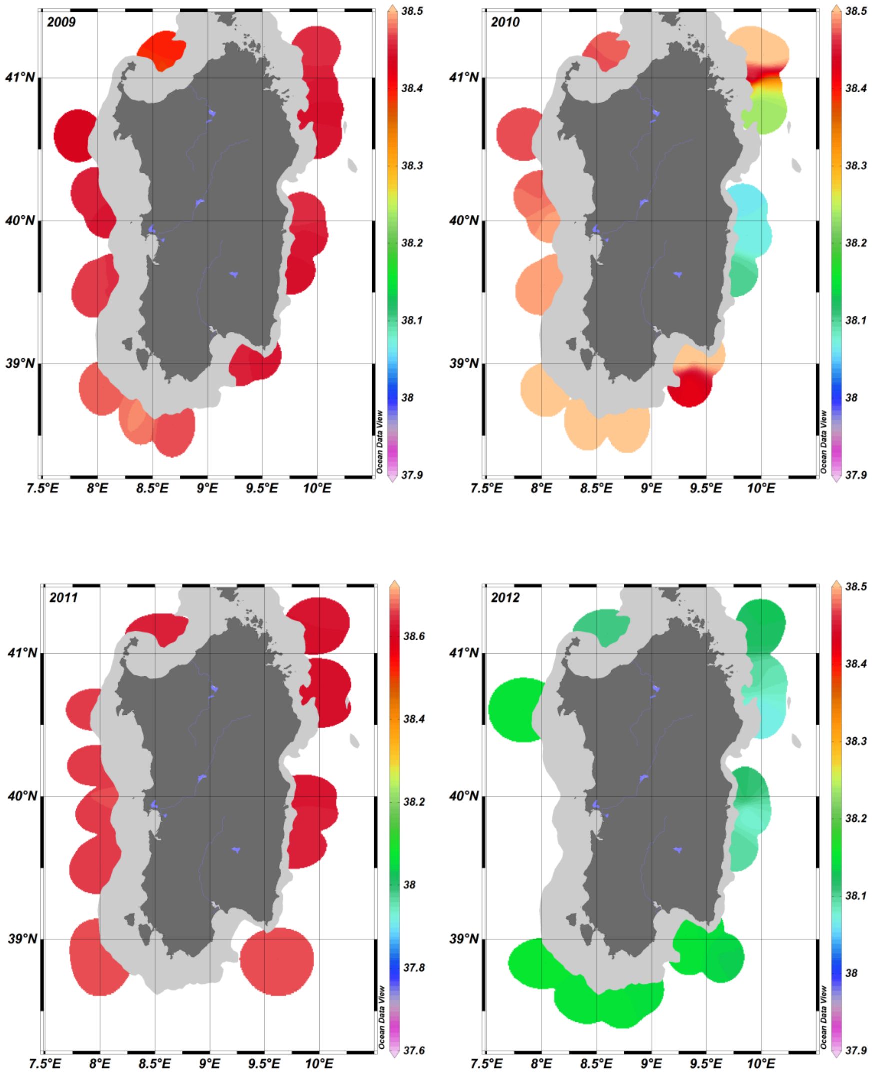


Figure 4-7. Four years of salinity field at 400 m.

4.4 CONCLUSION AND PROSPECT

This chapter analyzes the hydrographic conditions on the Sardinian shelf-slope region. The information collected by CTD "SBE 37-IM Microcat" during four years of trawl survey (MEDITS) have significantly increased the number of in situ observations required for the study of possible impact on the distribution of deep water red shrimps.

Only the MAW and LIW, with the corresponding transitional layer, play a relevant role in the hydrological characterization studied in the present case, considering the depth interval explored by trawl surveys (10-800m). These masses of waters overlap and even partially mix each other during their displacement across the Mediterranean basin, according to the general topography of the lands and the bottoms (Figure 4-8).

In the surface layer, data allowed to recognize the MAW located between 10-150 m. It is clear that, as showed from previous studies on the Algerian current, the MAW flow is highly variable at mesoscale. The Algerian Current, is relatively narrow (30-50 km) and deep (200-400 m) in the west, but becomes wider and thinner while progressing eastwards along the Algerian slope until the Channel of Sardinia (Robinson *et al.,* 2001). Anticyclonic Eddies are generated from the Algerian Current by its baroclinic instabilities (i.e. instabilities generated by flows occurring along strong horizontal/vertical density gradients) and can last for long time (even years) between Balearic and Sardinian Islands, once separated from the Algerian coast (Testor *et al.,* 2005). Another part of the MAW flows in the Southern Tyrrhenian Sea and flows cyclonically along the Northern Sicilian Slope. Southern Tyrrhenian Sea, mainly the Sardinian-Sicilian part, constitutes a key area in the hydrologic dynamics between West and East Mediterranean Sea.

At intermediate layer (mainly originates in the Levantine basin), data bring evidence of large heterogeneity, clearly associated with waters of very different origin that follow converging routes and mix in the study area. The Intermediate Levantine Water (LIW) enter in the Tyrrhenian Sea through the Sicilian Channel

(Millot. 1999). Part of this intermediate water mass flows southward along the eastern coast of Corsica and Sardinia, mixing with the deep Tyrrhenian water (TDW) (Millot. 1999). Along the South-Western coast of Sardinia, LIW shows a change in its path due to the interaction with the Algerian eddies and with topography (Olita *et al.,* 2013 and references therein).

Although limited in time and space and affected by precision and accuracy constraints, present data support the classic basic layers structure of the investigated area. Bottom trawl surveys may allow to record millions of easy to use and relatively cheap CTD data and the production of continuous or synthetic values for thousands of hauls. These data represents invaluable information, after a proper elaboration, in order to investigate the relationships with fishery data. This is particularly true in such highly variable systems, where not accurate and time-space related oceanographic data, such those obtained by numerical models can negatively affect the analysis of bio-physical relationships.

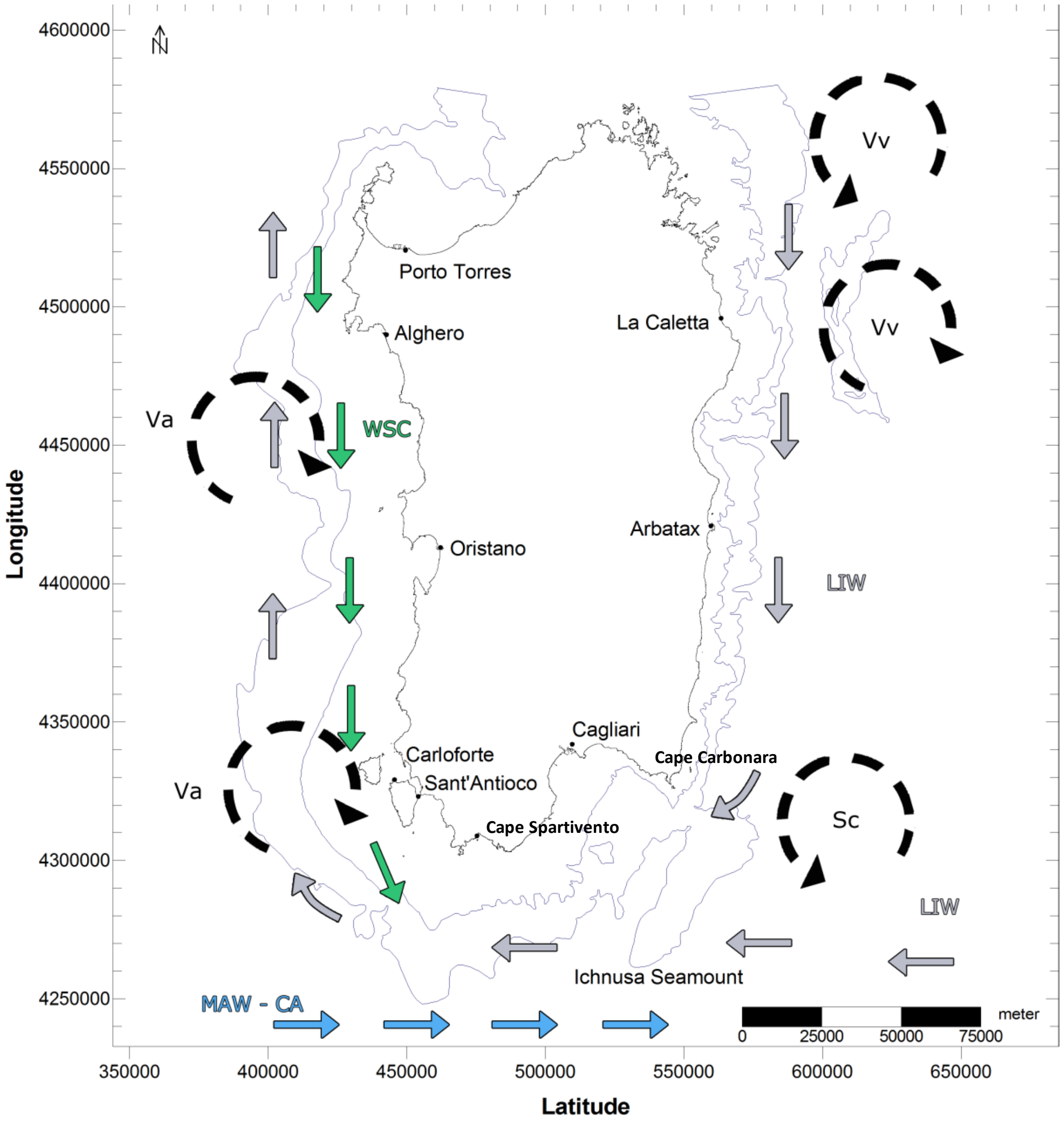


Figure 4-8. Surface (MAW, light blue), (WSC, green) and Intermediate (LIW, grey) water mass circulation in Sardinian shelf-slope region. Mesoscale structures (Black) have high temporal and spatial variability. Va: anticyclonic eddies of Atlantic origin and generated from the Algerian Current. Vv: eddies influenced by the steady mistral wind which blowing through the Bonifacio Strait. Sc: Eastern Sardinian cyclonic Gyre. MAW-CA: Algerian Current carrying on Atlantic Waters. WS: Western Sardinian Current flows southward getting closer to the coast.

5 PART III: INFLUENCES OF GEOMORPHOLOGICAL FEATURES ON THE DISTRIBUTION OF DEEP–WATER RED SHRIMPS IN SARDINIAN SEA

Biological rhythms are widely reported for resources of the continental shelf and margins of all oceans (Naylor, 2005). Species display behavioural responses to fluctuations in light intensity that result in the movement of thousands of individuals through different depth strata of the water column, seabed depths, or in and out of the sediment (Review in Aguzzi and Company, 2010).

The quantification of animal movement in time and space is fundamental to the study of animal ecology and to the design of effective strategies for resource conservation and management (Pittman and McAlpine, 2001). The time of day, and the depth are important determinants of the capture rate and the size composition of catches (Naylor, 2005; Bahamon *et al.,* 2009). In Mediterranean Sea the knowledge on the abundance of fish stocks and exploited ecosystems is obtained primarily by analyzing commercial catch data and from research vessel surveys that provides a wider scope of biological data (reviewed by Bertrand *et al.,* 2002). Bottom trawl survey represents one of the most reliable methods of population sampling in areas where depth makes more direct observations technically and economically unfeasible (Raffaelli *et al.,* 2003).

Nowadays, three major types of displacement are recognized in relation to behavioral rhythms: vertical, in the water column as pelagic or benthopelagic (when animals touch the bottom); nektobenthic, across a depth gradient along the seabed; and finally, endobenthic, a metric for burrowers and buriers, with phases of emergence from the substrate and retraction in it (Aguzzi and Company, 2010). The blue and red shrimp *A. antennatus* (Risso, 1816) and the giant red shrimp *A. foliacea* (Risso, 1827) are able to adapt their normal cycles near particular topographic structures such as submarine canyons and seamounts and can make some vertical migrations within these structures (Cartes *et al.,* 1993; Tudela *et al.,* 2003; Sabatini *et al.,* 2007).

These geomorphological features are very rich in nutrients with strong turbidity currents (Shepard *et al.,* 1974). They are complex environments and the species living there are usually more mobile than those of typical deep-sea assemblages (Rowe, 1971). Submarine canyons can also affect general and local scale circulation patterns by deflecting the in-coming and out-coming flows (Flexas *et al.,* 2008). Several key factors play a role by enhancing or reducing the canyon effect, i.e. the canyon's relative position (distance) from the coast, its size and morphology and general circulation and local currents. The result is a great variety of situations and effects which can occur for each single canyon (or each canyon system) set along the continental margin of the Mediterranean, and which are, in some cases, very different from what could be expected through oceanographic process modelling (Würtz, 2012 and references therein).

The Sardinian margin is characterized by the presence of a complex system of 29 canyons incised in the continental slopes of the Island of Sardinia and two seamounts. Canyon density is higher in the eastern and southern coast unlike the western margin where only seven canyons are present (see paragraph 2.3). Submarine canyons, however, are not the only geomorphological structures interesting the seabed topography. Two seamounts far from the coast of Sardinian island are present (Baronie and Ichnusa). Many of these canyons and seamounts have been studied in terms of geomorphology processes (Palomba and Ulzega, 1980; Ulzega, 1988; Chioggi *et al.,* 2011) but only a few studies have focused on the mobility in day-night cycle of these species.

The influence of submarine canyon on the distribution of deep water red shrimps in Sardinian Seas is of interest, given their high biomass and economic value (up to 15–20% of total biomass; IREPA, 2005–2010, Sabatini *et al.,* 2013). In this context a case of study is reported: the demersal assemblages found at different times of the day in the Baronie Seamount (Sabatini et al., 2011).

5.1 DEMERSAL ASSEMBLAGES IN TWO TRAWL FISHING LANES LOCATED IN BARONIE SEAMOUNT (CENTRAL WESTERN MEDITERRANEAN.

A. Sabatini, M.C. Follesa, I. Locci, G. Matta, **F. Palmas**, A.A. Pendugiu, P. Pesci and A. Cau. (2011) Journal of the Marine Biological Association of the United Kingdom, 91, 65-75.

5.1.1 Abstract

This work focuses on the species associations of the Baronie Seamount (north-eastern Sardinia, Italy), according to variations in depth and time of day. The aim was to highlight the potential vertical movements of the species and to compare these results to existing data from a submarine canyon. Twenty-two samples were taken at different depths and times along two trawl lines over the seamount. A total of 94 species were caught; among these, 48 bony fish, 9 cartilaginous fish, 13 molluscs and 24 crustaceans were selected for analysis. Cluster analysis showed 3 groups in which both depth and time of day play an important role in grouping. Nine species showed some daily and nocturnal movement, probably linked to trophic requirements. The daily movements according to size and sex of the shrimps Aristaeomorpha foliacea and Aristeus antennatus were also studied. For these two populations, the analysis showed an uneven distribution and the diel cycle appears to involve only the females. These species seem to adapt their life cycle to the geomorphology of the sea bottom. The diurnal movements from the base of the seamount to the edge of the continental shelf increase the range of the species distribution. In fact, the seamount, due to its geomorphological conformation, offers these species the opportunity to very quickly span a considerable range of depths. These movements are known to occur in the continental shelf and slope, but in the seamount they are broadened and can be studied more easily.

Keywords: seamount, fish and shellfish assemblages, bathymetric distribution, multivariate analysis, Tyrrhenian Sea

5.1.2 Introduction

The spatial distribution of demersal species has been widely studied (Cartes *et al.,* 1994; Cartes and Sardà, 1993; Moranta *et al.,* 1998; Blanchard, 2001; Abello *et al.,* 2002; Cartes *et al.,* 2004; Company *et al.,* 2004; D'Onghia *et al.,* 2004; Massutı *et al.,* 2004; Moranta *et al.,* 2008). In a broad sense, it refers to the dispersion of individuals within their area of distribution. Spatial distribution is usually considered to vary according to environmental features (e.g. depth, bathymetric boundaries, bottom type: Abello *et al.,* 2002), oceanographic conditions (e.g. characteristics of water masses: Carney, 2005; Company *et al.,* 2008; Canals *et al.,* 2009), biological factors (e.g. competition among species: Blanchard, 2001, and references therein) and human influence (e.g. impact fisheries: Blanchard, 2001). Among these, the depth gradient is generally considered to be the main factor affecting species associations (D'Onghia *et al.,* 2004; Massutı *et al.,* 2004).

Bottom geomorphology can determine local hydrographic and substrate flows or facilitate species movements, thus con- tributing to the often unique spatial distributions observed, for example in submarine canyons (Orru and Ulzega, 1988; Tobar and Sarda, 1992; Sabatini *et al.,* 2007). The varying mobility of particular animals can be very important in determining the spatial distribution of species, and can occasionally be an important cause of both seasonal and nycthemeral cycles (Cartes *et al.,* 1993; Sabatini *et al.,* 2007). In this context, sea bottoms with a particular geomorphological structure, such as canyons and seamounts, can be of ecological interest regarding the vertical migration of marine species. Submarine canyons are areas very rich in nutrients with strong turbidity currents (Shepard *et al.,* 1974). They are complex environments and the species living there are usually more mobile than those of typical deep-sea assemblages (Rowe, 1971). The environmental influence on the movements of marine species has been studied (Sarda *et al.,* 1997; Tudela *et al.,* 2003) as have the diurnal movements of the species living in these environments (Sabatini *et al.,* 2007).

Submarine canyons, however, are not the only ecologically interesting seabed topographic feature influencing species' vertical migrations. Some seamounts far from the coast are characterized by a rising of the continental shelf leading to a decrease in water depth. Seamounts can be defined as isolated underwater features (mountains, terraces, ridges, banks, plateaux and shelves) less than 1000 m above the sea floor and peaking below sea level (WWF/IUCN, 2004). These features are often characterized by significant levels of endemism and relatively high primary production that could support productive fisheries (Rogers, 1994; Koslow *et al.,* 2001). Seamounts can potentially enable vertical migration far from the coast and have been identified as diversity hot- spots (Koslow, 1997). Given its distance from the coast, the first fishermen to fish close to the Baronie Seamount found many species, and more importantly they found economically important species such as the shrimps *Aristaeomorpha foliacea* (Risso, 1827) and *Aristeus antennatus* (Risso, 1816). According to local fishermen, this area has a higher biomass of commercial species than adjacent regions and hence represents a site of particular biological and economic interest.

We studied the Baronie Seamount located 25 miles off the north-eastern coast of Sardinia (Italy), called also 'K' bank by local fishermen. This is the first study concerning the demersal assemblages of this area, which started to be economically exploited only few years ago. The aim of this paper is to study the different species assemblages found at different times of the day, and to highlight the potential vertical movements of these species, as observed in another Sardinian area, the Quirra Canyon (Sabatini *et al.,* 2007). Juveniles and adults of some very important species such as the shrimps, showed variations in diet, bathymetric distribution and, even, daily migratory behaviour (Cartes *et al.,* 2004, 2008). In addition, the daily timing of changes in depth occurrence and size composition of the giant red shrimp, A. foliacea and the blue and red shrimp A. antennatus was studied.

5.1.3 Material and methods

5.1.3.1 Study area

The data analysed in this work were collected on the Baronie Seamount, which is located off the north-eastern coast of Sardinia (in the western part of the central Tyrrhenian Sea) (Figure 5-1). It is characterized by a rise in the continental shelf, which results in a decrease in sea depth. The seamount rises from the sea bottom to two levels lying at 162 m and 168 m characterized by a flat morphology and a thin sedimentary cover (Bellagamba *et al.,* 1979). It has an elongate shape, running from north to south, parallel to the coast line. Samples were taken on the eastern side of the seamount, where a substantial variation in depth occurs. Depth varies from 180 m to over 1000 m in only 2 nautical miles. This is one of the few areas in the Baronie Seamount that can be exploited by bottom fishing trawl.

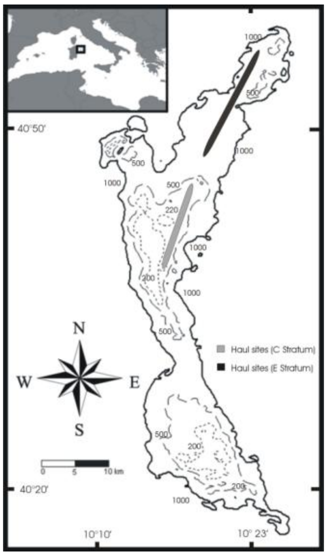


Figure 5-1. Map of the study area. Continuous lines, 1000 m depth; hatched lines, 500 m; dotted lines, 200 m. In the upper left rectangle, the geographical position of the Baronie Seamount is indicated.

5.1.3.2 Data collection

Data were collected between January and April 2003. The survey vessel (80 tons and 338 kw) was equipped with a gear commonly used by local fishermen (trawl net, 40 mm stretched mesh size in the cod end). The trawl samples were collected throughout the entire 24-hour period and categorized as to time of day and depth, as reported in Sabatini *et al.,* (2007). A total of 22 samples were collected from depths ranging between 176 m and 745 m and from 110 to 334 minutes in duration. Samples coded ‘C’ were for hauls made above 350 m (14 hauls) and ‘E’ for hauls deeper than 500 m (8 hauls). The geomorphological features of the Baronie Seamount’s bottom prevent trawling at intermediate depths (350–500 m).

Thirteen of the 22 hauls were performed during daylight (‘L’, from 1 hour before sunrise to 1 hour after sunset), 5 during the first part of the night (‘N1’, from 1 hour after sunset to 01:00 a.m.) and 4 during the second part (‘N2’, from 01:00 a.m. to 1 hour before sunrise). The night was divided into two time intervals to distinguish the different species caught during the first and the second part (Table 5-1). We noted the yield in weight and the catch in number of individuals of fish and shellfish for each sample. These data were used to generate biomass indexes which were standardized per 1 hour of trawl (kg/h). For the red shrimps *A. antennatus* and *A. foliacea* only, the carapace length (CL) was measured by sex to the nearest millimetre, from the posterior margin of the eyestalk to the posterior mid-dorsal edge of the carapace, in order to obtain length–frequency distributions.

Table 5-1. Code, date, season, start and end time (solar time), duration and depth for each haul studied.

Code	Date	Season	Start sampling	End sampling	Duration (minutes)	Depth (m)	Group	
L-C-1	15/01/2003	Winter	7.43	10	133	186	L	C
L-C-2	15/01/2003	Winter	10.3	12.4	130	176	L	C
L-C-3	15/01/2003	Winter	13.18	16.2	182	199	L	C
N1-C-4	15/01/2003	Winter	16.58	19.42	164	209	N1	C
N1-C-5	15/01/2003	Winter	20.25	23.06	161	227	N1	C
N2-C-6	15/01/2003	Winter	23.45	2.3	175	222	N2	C
N1-C-7	26/03/2003	Spring	20.07	22.56	169	225	N1	C
N2-C-8	26/03/2003	Spring	23.4	2.15	155	221	N2	C
N2-C-9	27/03/2003	Spring	3.3	5.2	110	222	N2	C
L-C-10	27/03/2003	Spring	6.4	8.45	125	183	L	C
L-E-11	28/03/2003	Spring	5.58	10.24	266	740	L	E
L-E-12	28/03/2003	Spring	10.46	16.15	334	703	L	E
L-C-13	28/03/2003	Spring	18	20.25	145	206	L	C
N1-C-14	28/03/2003	Spring	21.07	23.5	163	219	N1	C
L-E-15	29/03/2003	Spring	5.3	10.35	305	723	L	E
L-E-16	29/03/2003	Spring	12	16.25	334	745	L	E
L-C-17	28/04/2003	Spring	8.16	11	164	209	L	C
L-E-18	28/04/2003	Spring	11.45	16	255	731	L	E
L-C-19	28/04/2003	Spring	17.32	19.27	115	211	L	C
N1-E-20	28/04/2003	Spring	20.4	23	140	745	N1	E
N2-E-21	28/04/2003	Spring	23.55	2	267	716	N2	E
L-E-22	29/04/2003	Spring	6.18	10.45	125	704	L	E

5.1.3.3 Statistical analysis

Cluster analysis was used to study the species assemblages, carried out using the biomass data, standardized per hour of trawling. Data were analysed in relation to depth (C and E depth levels) and the time of day (L, N1 and N2). The data were root-root transformed to reduce the influence of the dominant species and to support the importance of the rare ones (Somerfield and Clarke, 1997).

The similarity among hauls was calculated using the Bray–Curtis index (Bray and Curtis, 1957; Field *et al.,* 1982). This is generally considered an excellent similarity measure since it preserves the ecological distance among the studied communities (Clarke and Warwick 1994).

Samples were then classified by hierarchical agglomerative cluster analysis, using the group average linking method. A SIMPER (SIMilarity PERcentage) analysis was performed (Clarke, 1993; Clarke and Warwick 1994) in order to quantify the percentage contribution of each species to the average similarity/dissimilarity between samples. Statistical analyses were all performed using the PRIMER package (release 6.0) (Clarke and Gorley 2006). The Kolmogorov–Smirnov test

(KS) was performed on pairs of size–frequency distributions for depth, time and sex to detect significant differences (P = 0.05) (Conover 1980).

5.1.4 Results

On the Baronie Seamount, a total of 94 species were collected, including 57 fish (48 bony fish, 9 cartilaginous), 13 molluscs and 24 crustaceans (Table 5-2). Most of them were mainly found at their typical depth-range (as reported in the literature). It was therefore possible to subdivide the species into four groups according to their depth habits (Table 5-2).

The first two groups represent the species found during the entire 24-hours period at their typical depth-range (C species or E species). They were never found at different depth levels, indicating that they do not move up and down the water column.

The third group is represented by the ubiquitous species, found within a wide depth-range (Tortonese, 1970, 1975; Relini *et al.,*1999). Some species, such as *Phycis blennoides* (Brunnich, 1758), were found in both depth levels, during the entire day. Others, such as *Helicolenus dactylopterus* (Delaroche, 1809), were found at all times in the C depth level, while only during daylight hours in the E depth level. They were put into the third group on the basis of their ecologically known depth-range from the literature (Tortonese, 1970, 1975; Relini *et al.,* 1999; Serena, 2005; www.fishbase.org; www.sealifebase.org).

The fourth group includes all the species that typically live at the E depth level, but which were put into a separate group since they were also found at depths of less than 350 m, but only during the night. Their typical depth-range, according to published information and experience, is deeper than 400–500 m but they are known to make some migrations to shallower depths (Cartes *et al.,* 1993) like the shrimp *A. antennatus* or the bony fish *Mora moro* (Risso, 1810). These species appear to rise up the seamount during the night, reaching 350 m and less. During daylight hours, they stay at deeper levels. In fact, they were never found at the shallower depth level (C) during daylight hours (L) (Table 5-2).

Table 5-2. Sampled species by depth level (C, 350 m, E .500 m) and time period (L, daylight; N1, first part of the night; N2, second part of the night) with the corresponding standardized abundance (ind/h) and iomass (kg/h) estimates. The depth-range (m) found in the literature is also indicated: outside parentheses, the referential depth-range at which the species is more abundant; within parentheses, the depth-range at which the species can be found in the Mediterranean Sea (Tortonese, 1970, 1975; Relini *et al.,* 1999; Serena, 2005; www.fishbase.org, www.sealifebase.org).

	Species	**Stratum**						**Ind/h**	**Kg/h**	**Typical depth range (m)**	
		C			**E**						
		L	**N1**	**N2**	**L**	**N1**	**N2**				
C species	*Ancistroteuthis lichtensteini* (Frussac, 1839)		X					0	0.02		(0-250)
	Anthias anthias (Linnaeus, 1758)	X	X	X				14	0.4	130-200	(15-300)
	Argentina sphyraena Linnaeus, 1758		X					26	0.61	70-450	(50-700)
	Arnoglossus laterna (Walbaum, 1792)	X	X					182	0.95	10-200	(10-550)
	Aspitrigla cuculus (Linnaeus, 1758)	X	X	X				141	9.12	100-200	(15-400)
	Calappa granulata (Linneaus, 1767)	X						3	1.31	30-150	(13-400)
	Centracanthus cirrus Rafinesque, 1810	X	X					107	0.32	200-350	(200-464)
	Diaphanus metopoclampus (Cocco, 1829)	X						4	0.03	90-850	(90-1085)
	Dipturus oxyrinchus (Linnaeus, 1758)	X	X	X				6	2.42		(15-900)
	Eledone cirrhosa (Lamarck, 1798)	X	X	X				22	4.6	50-300	(5-660)
	Eledone moschata (Lamarck, 1798)	X	X					1	0.17		(10-300)
	Glossanodon leioglossus (Valenciennes, 1848)	X	X	X				465	36.86	100-400	
	Gnathophis mystax (Delaroche, 1809)		X	X				6	0.17		(80-800)
	Gymnammodytes cicerelus (Rafinesque 1810)		X					175	1.64	0-120	
	Lepidopus caudatus (Euphrasen, 1788)	X	X	X				10	13.44	100-300	(42-620)
	Lepidorhombus boscii (Risso, 1810)	X						21	0.51	200-400	(50-700)
	Lepidorhombus whiffiagonis (Walbaum, 1792)	X	X	X				106	19.29	200-400	(200-700)
	Loligo forbesi Steenstrup, 1856	X	X	X				177	80.92	100-400	(20-560)
	Loligo vulgaris Lamarck, 1798	X						399	66.46	20-250	(0-550)
	Lophius budegassa (Spinola, 1807)	X						0	0.84		(300-1013)
	Macrorhamphosus scolopax (Linneaus, 1758)	X	X	X				187	1.69	50-200	(0-400)
	Mullus surmuletus (Linnaeus, 1758)	X	X					7	0.82		(5-409)
	Neorossia caroli (Jouben, 1902)	X	X					2	0.12	300-400	(300-1000)
	Parthenope macrochelos (Herbst, 1790)		X	X				12	0.35		(20-750)
	Physiculus dalwigki (Kaup, 1858)			X				1	0.01		(100-738)
	Plesionika antigai Zariquiey Alvarez, 1955		X	X				672	42.19	330-370	(120-800)
	Plesionika edwardsii (Brandt, 1851)	X	X	X				796	56.88	250-380	(110-680)
	Raja miraletus (Linnaeus, 1758)	X						5	0.82	50-150	(17-462)
	Raja polystigma Regan, 1923	X	X	X				20	4.61	100-400	

	Sepia orbignyana Férussac, 1826	X	X					105	2.45	50-250	(15-570)
	Sepietta oweniana (Pfeffer, 1908)		X					0	0.01		(50-600)
	Serranus cabrilla (Linnaeus, 1758)		X					4	0.11		(5-500)
	Solea elongata (Day, 1877)	X	X					0	1.95		(8-280)
	Squalus blainville (Risso, 1827)	X	X					3	1.95	16-440	(16-780)
	Trachurus mediterraneus (Steindachner, 1868)	X						3	0.01	5-250	(0-500)
	Trigla lyra (Linnaeus, 1758)	X	X					8	1.19	150-400	(100-700)
	Trisopterus minutus (Linnaeus, 1758)	X	X					3	0.13	15-200	(1-440)
	Zeus faber (Linnaeus, 1758)	X						0	0.14	50-150	(5-400)
E species	*Cepola rubescens* (Linnaeus, 1758)				X			4	0.11		(15-400)
	Epigonus telescopus (Risso, 1810)				X	X		4	1.69	300-800	(75-1200)
	Haplostetus mediterraneus (Cuvier, 1829)				X	X		2	0.4		(100-1175)
	Hexhancus griseus (Bonnaterre, 1788)						X	0	4.13	180-1100	(1-2550)
	Histioteuthis reversa (Verrill, 1880)				X			6	1.52		(0-2000)
	Hymenocephalus italicus Giglioni, 1884				X	X	X	289	1.47	300-800	(100-1400)
	Lampanyctus crocodilus (Risso, 1810)				X	X	X	239	3.49	400-800	(100-1000)
	Lepidion lepidion (Risso, 1810)				X	X	X	41	0.73	750-1000	(500-2230)
	Maya squinado (Herbst, 1788)				X			0	0.06	0-150	(0-600)
	Molva dypterygia (Pennant, 1784)				X			0	0.18		(150-1000)
	Nephrops norvegicus (Linnaeus, 1758)				X			11	0.46	20-600	(200-800)
	Nettastoma melanurum Rafinesque, 1810				X	X	X	10	0.42	400-1000	(37-1647)
	Nezumia sp.				X	X	X	164	1.64	500-3200	(130-3200)
	Notolepis rissoi (Bonaparte, 1840)				X			1	0.01		(0-2200)
	Pagellus bogaraveo (Brunnich, 1768)				X			1	1.93	150-300	(0-700)
	Parapenaeus longirostris (Lucas, 1846)				X			7	0.01		(20-700)
	Pasiphaea sivado (Risso, 1816)				X	X	X	19	0.17	200-300	(200-700)
	Plesionika giglioli (Senna, 1903)						X	3	0.02	330-370	(120-800)
	Plesionika martia (A. M. Edwards, 1883)				X	X		140	0.7	200-700	(180-1200)
	Polycheles typhlops Heller, 1862				X	X	X	60	0.24	300-600	
	Schedophilus ovalis (Cuvier, 1833)				X			3	0.45	80-240	(70-700)
	Sergia robusta (Smith, 1882)				X			2	0.01		(250-1000)
	Stomias boa boa (Risso, 1810)				X		X	2	0.09		(200-1500)
	Trachurus trachurus (Linnaeus, 1758)				X			7	0.02	100-200	(0-1050)
Ubiquitous species	*Capros aper* (Linnaeus, 1758)	X	X	X	X			541	107.46	100-400	(40-700)
	Conger conger (Linnaeus, 1758)	X			X			9	13.9		(0-1171)
	Epigonus denticulatus Dieuzeide, 1950		X		X			11	0.04	250-400	(130-830)
	Gadiculus argenteus argenteus (Guichenot, 1850)	X					X	7	0.29		(100-1000)
	Geryon longipes Milne Edwards, 1881	X			X			13	0.25		(300-1370)
	Helicolenus dactylopterus (Delaroche, 1809)	X	X	X	X			433	29.57	100-800	(50-1100)
	Illex coindetii (Verany, 1839)	X	X	X	X			32	2.04	0-700	(50-1100)
	Lophius piscatorius (Linnaeus, 1758)	X	X		X	X	X	3	24.83	20-500	(20-1000)

	Macropipus tuberculatus (Roux, 1830)	X	X		X	X	X	84	1.4	300-400	(30-840)
	Merluccius merluccius (Linnaeus, 1758)	X	X	X	X			22	4.72	50-700	(20-1000)
	Micromesistius poutassou (Risso, 1827)	X			X	X		2	0.46	300-400	(150-3000)
	Nemichthys scolopaceus Richardson, 1848		X		X			10	0.39		(91-2000)
	Notacanthus bonaparte (Risso, 1840)	X			X		X	5	0.3		(487-2000)
	Paramola cuvieri (Risso, 1816)	X				X		1	0.16	80-350	(50-1000)
	Phycis blennoides (Brünnich, 1768)	X	X	X	X	X	X	54	3.56	100-300	(10-1200)
	Raja clavata Linnaeus,1758	X	X	X		X		15	7.89	80-200	(0-700)
	Rossia macrosoma (Delle Chiaie, 1830)	X				X		1	0.04	50-500	(100-500)
	Scaeurgus unicirrhus (Orbigny, 1840)	X	X	X	X			97	9.31	100-350	(6-800)
	Scyliorhinus canicula (Linnaeus, 1758)	X	X	X	X			28	1.89	150-300	(10-780)
	Synchiropus phaeton (Günther, 1861)	X			X			12	0.09	80-650	(80-848)
	Todarodes sagittatus (Lamarck, 1798)	X		X	X			2	0.26		(0-800)
	Todaropsis eblanae (Ball, 1841)	X	X	X	X			13	1.67	100-500	(30-700)
E species moving to C	*Aristeus antennatus* (Risso, 1816)		X	X	X	X	X	117	32.07	500-800	(80-1500)
	Aristaeomorpha foliacea (Risso, 1827)		X	X	X	X	X	241	80.42	450-750	(120-1300)
	Centrophorus granulosus (Bloch, 1801)		X	X	X			12	41.45	150-500	(50-1440)
	Chlorophthalmus agassizi Bonaparte, 1840		X	X	X	X	X	246	34.47	50-1000	
	Etmopterus spinax (Linnaeus, 1758)		X		X	X	X	47	1.87	300-500	(70-1000)
	Galeus melastomus Rafinesque, 1809		X	X	X	X	X	454	35.61	200-500	(55-1000)
	Mora moro (Risso, 1810)		X	X	X	X	X	127	4.76	500-800	(300-2500)
	Pasiphaea multidentata Esmark, 1866		X	X	X	X	X	13	0.2	500-700	(200-2000)
	Trachyrhynchus scabrus (Rafinesque, 1810)		X		X	X	X	13	0.36	395-1700	

Cluster analysis describes the relationship between depth and time of the day, in the various samples (Figure 2). We found three groups: the first (●) consists of all hauls made at depths below 500 m, both during daylight and during the night. The second (■) comprises the hauls made in the C depth level, but only during the night (N1 and N2), while the third (▲) is composed of hauls made in the C depth level as well, but only during daylight hours (L). Each group contains some indicator species which typify and characterizes it. For example, deep species (E depth level, clustering group 1) such as *A. foliacea* were clearly separated from shallow ones (C depth level, clustering groups 2 and 3) such as *C. agassizii* or *H. dactylopterus*.

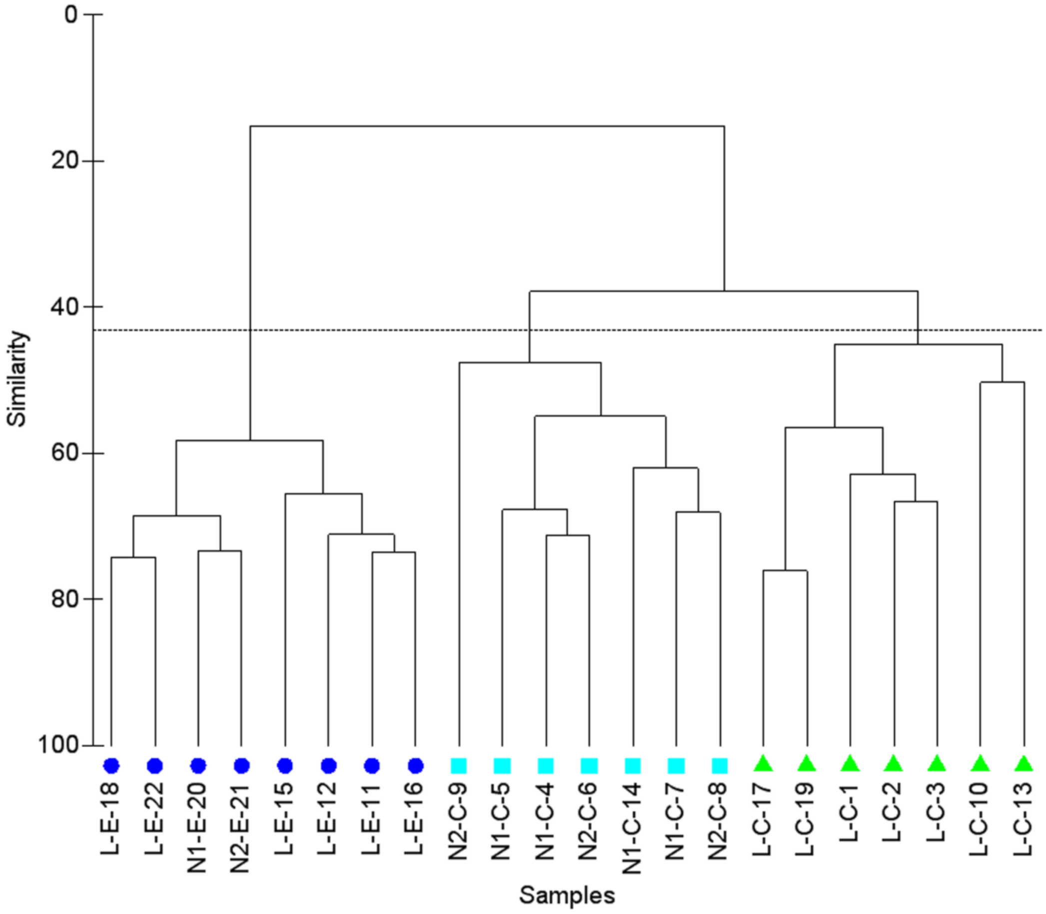


Figure 5-2. Classification (cluster analysis) of species assemblages in the Baronie Seamount. Clusters at 43% similarity are indicated by the dashed line. ●, 1st group; ■, 2nd group; ▲, 3rd group.

The SIMPER analyses (Table 5-3) showed the species with the highest contribution to the similarity between the three groups. The main indicator species of the first group was *A. foliacea* (14.6%), while for the second group, it was *Loligo forbesi* (Steenstrup, 1856) (11.5%) and for the third one, it was *Capros aper* (Linnaeus, 1758) (10.5%). This analysis also showed that the first and third groups are the most diverse (average dissimilarity 91.5%), indicating that the species caught at the C depth level during daylight hours (3rd group) are very different from those caught in the E depth level (1st group). The most species which most discriminates between these two groups is *A. foliacea* (5.2%), never being found at a depth of less than 350 m during day- light hours. The 2nd and the 3rd group are the least diverse (average dissimilarity 62.1%). The discriminating species between them is *L. vulgaris* (5.4%). The dissimilarity between the 1st and the 2nd group is 78.1%, which is inter- mediate compared to the previously observed dissimilarities. The species that most discriminates between these two groups was found to be *L. forbesi* (4.7%). The length–frequency distribution of both red shrimps in the catches varied according to time, depth and sex (Figure 5-4). The above analysis indicated that their bathymetric distribution is correlated to the size and sex of the individuals. For each temporal and spatial set of hauls analysed, the percentage of females was greater than that of males. Regarding *A. foliacea*, the KS test showed significant statistical differences ($P<0.05$) between the females caught at different depths (C and E depth levels) and periods of time. On the contrary, no significant differences were found between N1-E and N2-E samples indicating a similar size composition within the population both for females ($D=0.188$ $P= 0.243$) and for males ($D = 0.170$ $P= 0.596$). The analysis of N1-C samples showed the exclusive presence of females which were statistically smaller than those caught at greater depths (L-E, N1-E, N2-E). The analysis of *A. antennatus* catches showed a similar predominance of females, like *A. foliacea*. In contrast however, the mean of the CL increased progressively during hauls N1-C and N2-C, and decreased during the day samplings (Figure 3). In fact, for *A. antennatus* females, the KS test showed significant differences in the composition of the population between samples caught at different depths (C, E), while no significant differences were found between the hauls L-E and N2-E ($D=0.095$ $P=0.423$) and N1-C versus N2-C ($D=0.119$ $P=0.246$). For males, no significant differences were found between the hauls carried out at shallower depths and those below 500 m during the day or night.

Figure 5-3. Results of the SIMPER analysis; species are listed in order of their contribution to the average similarity within their own group, with a cut-off when the cumulative percentage contribution reaches 90%.

Group 1

Average similarity: 62,98

Species	Av.Abund	Av.Sim	Sim/SD	Contrib.%	Cum.%
A. foliacea	1.73	9.17	6.91	14.57	14.57
G. melastomus	1.33	6.7	5.06	10.64	25.21
A. antennatus	1.07	5.98	9.15	9.49	34.7
M. moro	0.82	4.22	6.33	6.7	41.4
L. crocodilus	0.78	4.16	4.91	6.6	48.01
C. conger	0.79	4.02	4.73	6.39	54.39
P. blennoides	0.71	3.67	6.17	5.83	60.23
Nezumia sp	0.65	3.36	4.96	5.33	65.55
H. italicus	0.63	3.31	7.07	5.26	70.81
E. spinax	0.61	2.85	1.68	4.52	75.33
P. typhlops	0.41	2.26	11.59	3.6	78.92
L. piscatorius	0.69	1.91	0.73	3.04	81.96
P. martia	0.42	1.49	1.03	2.37	84.33
H. mediterraneus	0.32	0.96	0.73	1.53	85.86
N. melanurum	0.32	0.93	0.72	1.48	87.33
P. sivado	0.27	0.88	0.98	1.39	88.73
T. scabrus	0.28	0.82	0.71	1.3	90.03

Group 2

Average similarity: 56.04

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
L. forbesi	1.41	6.43	4.83	11.47	11.47
C. agassizii	1.3	4.75	2.52	8.48	19.95
H. dactylopterus	1.16	4.62	4.84	8.25	28.2
L. whiffiagonis	1.04	4.15	4.4	7.41	35.61
C. granulosus	1.26	4.12	1.47	7.36	42.97
A. antennatus	1.14	3.77	1.47	6.72	49.69
C. aper	1.02	3.34	3.51	5.96	55.65
S. unicirrhus	0.69	2.96	5.98	5.28	60.92
G. leioglossus	0.69	2.72	4.55	4.86	65.78
P. edwardsii	1.1	2.39	0.6	4.26	70.04
A. cuculus	0.58	2.01	1.34	3.58	73.62
E. cirrhosa	0.44	1.45	1.49	2.59	76.21
P. antigai	0.83	1.39	0.4	2.48	78.68
R. clavata	0.52	1.33	0.89	2.38	81.07
R. polystigma	0.5	1.21	0.91	2.16	83.22
M. scolopax	0.39	1.07	0.9	1.91	85.13
M. moro	0.35	0.89	0.91	1.59	86.72
D. oxyrinchus	0.46	0.85	0.58	1.52	88.24
A. foliacea	0.37	0.76	0.9	1.35	89.59
S. canicula	0.36	0.71	0.59	1.27	90.86

Group 3

Average similarity: 52.72

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
C. aper	1.53	5.54	2.04	10.5	10.5
L. whiffiagonis	1.03	4.94	7.77	9.37	19.88
A. cuculus	0.98	4.86	6.93	9.22	29.1
S. unicirrhus	0.95	4.28	4.3	8.12	37.21
L. vulgaris	1.3	4.12	0.87	7.81	45.02
H. dactylopterus	0.95	4.04	5	7.67	52.69
L. caudatus	0.88	2.85	0.88	5.41	58.09
I. coindetii	0.6	2.42	1.5	4.58	62.67
E. cirrhosa	0.67	2.17	1.4	4.11	66.78
M. merluccius	0.63	2.13	1.47	4.04	70.83
R. clavata	0.66	1.95	0.89	3.71	74.53
M. scolopax	0.51	1.8	1.49	3.41	77.94
G. leioglossus	0.88	1.62	0.56	3.07	81.01
T. lyra	0.48	1.5	0.91	2.84	83.85
T. eblanae	0.45	1.36	0.91	2.58	86.44
P. blennoides	0.41	1.22	0.91	2.32	88.76
R. polystigma	0.5	1.09	0.62	2.07	90.82

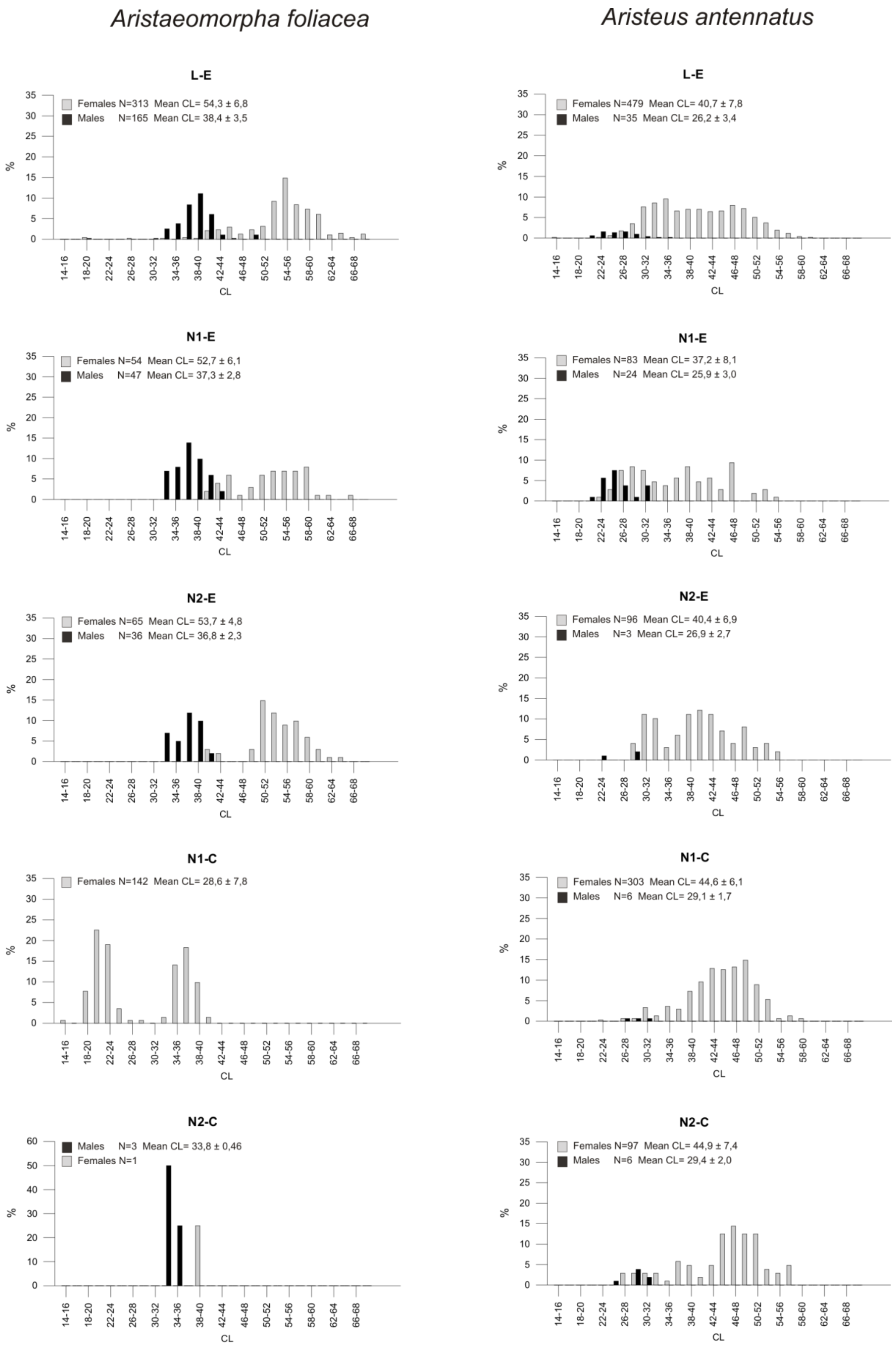


Figure 5-4. Length–frequency distributions by time, depth and sex in Aristaeomorpha foliacea and Aristeus antennatus sampled in the Baronie Seamount

5.1.5 Discussion

These analyses allowed a first overview of the species distribution on the Baronie Seamount and to study the species assemblages found there. The results strongly suggest that the spatial distribution patterns of the demersal species of the Baronie Seamount vary according to both depth and time of day. Most of the species seem to be sedentary or limited to a particular depth-range and it was possible to clearly distinguish the fauna of the deeper waters from those living at shallower depths. Groups 2 and 3, both related to the C depth level, had many species in common, all typical of shallow waters. However, some species were found in both groups 1 and 2 as well. These are the typically deep water species found between 500 and 800 m. This work clearly shows that both red shrimps, A. foliacea and A. antennatus, adapt their life cycle to the geomorphology of the seamount. Their daily and nocturnal movements from the base of the seamount to the edge of the continental shelf increase the range of their distribution. These two populations of crustacean decapods exhibit an uneven distribution and their diurnal movements appear to involve only the females. In fact, the presence of males in shallower waters (depth level C) was minimal when compared to those fished at the same time of day at the E depth level. Particularly for the red shrimp A. foliacea, the smallest individuals were usually found at a depth of less than 350 m (depth level C) compared to those of larger size, which showed a lesser migratory tendency. The smallest individuals reach the first upper edge of the seamount immediately after sunset (N1-C) and then disappear completely during the second part of the night (N2-C). The smallest females seem to rise to shallower depths than those where they usually live and then, during the last hours of the night, they descend again to greater depth. Moreover in the N2-C samples only four individuals were caught and the KS test was not applied to these samples. We can suppose that the individuals with a greater size do not reach depths lower than 350 m during the night, but we cannot confirm this because we were not able to sample the intermediate depth levels (350–500 m).

Regarding the blue and red shrimp A. antennatus, the data showed a greater presence of smaller individuals at the E depth level. The population does not have a uniform distribution, and during the migration individuals of different sizes behave differently. The largest individuals were found at the C depth level during the first part of the night (N1-C) and the small individuals were only found during the second part of the night (N2-C). In the Baronie Seamount 7 other species were found performing this migration pattern in addition to the two red shrimps: *C. granulosus*, *C. agassizii*, *E. spinax*, *G. melastomus*, *M. moro*, *P. multidentata* and *T. scabrus*.

Some species are able to adapt their normal cycles near topographic structures such as submarine canyons and can make some vertical migrations within these structures (Cartes *et al.,* 1993; Tudela *et al.,* 2003; Sabatini *et al.,* 2007). The seamounts that can occasionally be found far from the coast are so proven to allow movements as submarine canyons do. Quirra Canyon is one example of these. It is located in central-eastern Sardinia where day–night cycle migrations were also observed (Sabatini *et al.,* 2007). Comparison of the two sites, the Baronie Seamount and the Quirra Canyon, demonstrates some interesting differences. Firstly, the number of species found in the two areas was different. In Quirra Canyon, a great number of species were typically coastal, such as *Mullus barbatus* (Linnaeus, 1758), *Mullus surmuletus* (Linnaeus, 1758) and *Boops boops* (Linnaeus, 1758). The Quirra Canyon is in fact closer to the coast (2 nautical miles) than the Baronie Seamount (25 nautical miles from the north-eastern Sardinian coast). Both in Quirra Canyon and on the Baronie Seamount, vertical diurnal migrations were recorded for the species living there. These are probably linked to trophic requirements, as suggested for benthopelagic decapods (Cartes *et al.,* 1993) and for demersal fish (Blaber and Bulman, 1987 and references therein; Madurell *et al.,* 2004 and references therein; Cartes *et al.,* 2008; Preciado *et al.,* 2008). However, some differences in migration patterns were observed between the two sites. Mobile species were noted in the C depth level both during N1 and N2 on the Baronie Seamount, while only during N1 in the Quirra Canyon. The different patterns of migration can probably be linked to the geomorphological and bottom features of the two sites. In the Quirra Canyon the horizontal distance that migrating species have to cover between the depth levels C and E, where the species have their usual haunts, is about three times greater than that on the Baronie Seamount. On the seamount, species can cover the shorter distances in 1/3 of the time compared to the canyon. The differ- ent bottom features probably allow migrating species on the Baronie Seamount to stop for longer times (N1 and N2) at shallower depths compared to those in the Quirra Canyon, which should move toward depths of 500 m during the latter part of the night (N2), before the first hours of the day. Nycthemeral movements have been investigated in Sardinian seas by Cau and Deiana (1982) who highlighted daily and nocturnal movements of red shrimps which were strictly linked to the substratum. In the same way, Maurin (1960), Bombace (1975) and Matarrese *et al.,* (1995) observed similar situations in the Corsican, Sicilian and Ionian Seas, respectively. The size and sex frequency distributions described in these studies, seem to follow similar trends to the crustacean populations that we studied. In fact, the larger individuals are found at greater depths, while smaller ones are captured at lower depths. In addition, at greater depths we found a greater number of females larger than males. The pattern of diurnal movements is protracted on the seamount and can be studied more easily than in the generally surrounding continental shelf and the same is true for the submarine canyon. Areas such as submarine canyons, or seamounts far from the coast, make it possible to study phenomena such as the diurnal movements of the species found there which cannot be so easily observed in other areas with different geomorphological conformations.

6 PART IV. DISTRIBUTION OF SPAWNING AND NURSERY GROUNDS FOR DEEP-WATER RED SHRIMPS IN THE SARDINIAN SEAS

6.1 INTRODUCTION

To implement management measures with a view to reducing the effects of fishing on spawners and juveniles, we need to identify their spawning grounds and nurseries (FAO-SGMED, 2009). Describing the spatial and temporal patterns of important commercial species is fundamental to our understanding of the stock dynamics of fish populations (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 a higher juvenile density and a 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 and 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; Carbonell *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 are dynamically very different, as 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 (see chapter 4-Part II). 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 these shrimps' distribution (Cau *et al.,* 2002; Company *et al.*, 2004) and biology (Mura *et al.,* 1997; Kapiris and Thessalou-Legaki, 2009;), 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 (Carbonell *et al.,* 2008; D'Onghia *et al.,* 2008; Orsi Relini *et al.,* 2012, Sardà and Company, 2012).

The aims of this chapter was consequently to document the location of spawning and nursery grounds of both shrimps using georeferenced information on their abundance, to contribute to our understanding of their distribution in 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.

6.2 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 (1994-2005). The study only considered samplings in which red shrimps were caught, which amounted to 405 obtained between depths of 345 and 730 m in the spring-summer surveys, and 207 obtained at depths of 236 to 681 m in the autumn surveys (Figure 6-1).

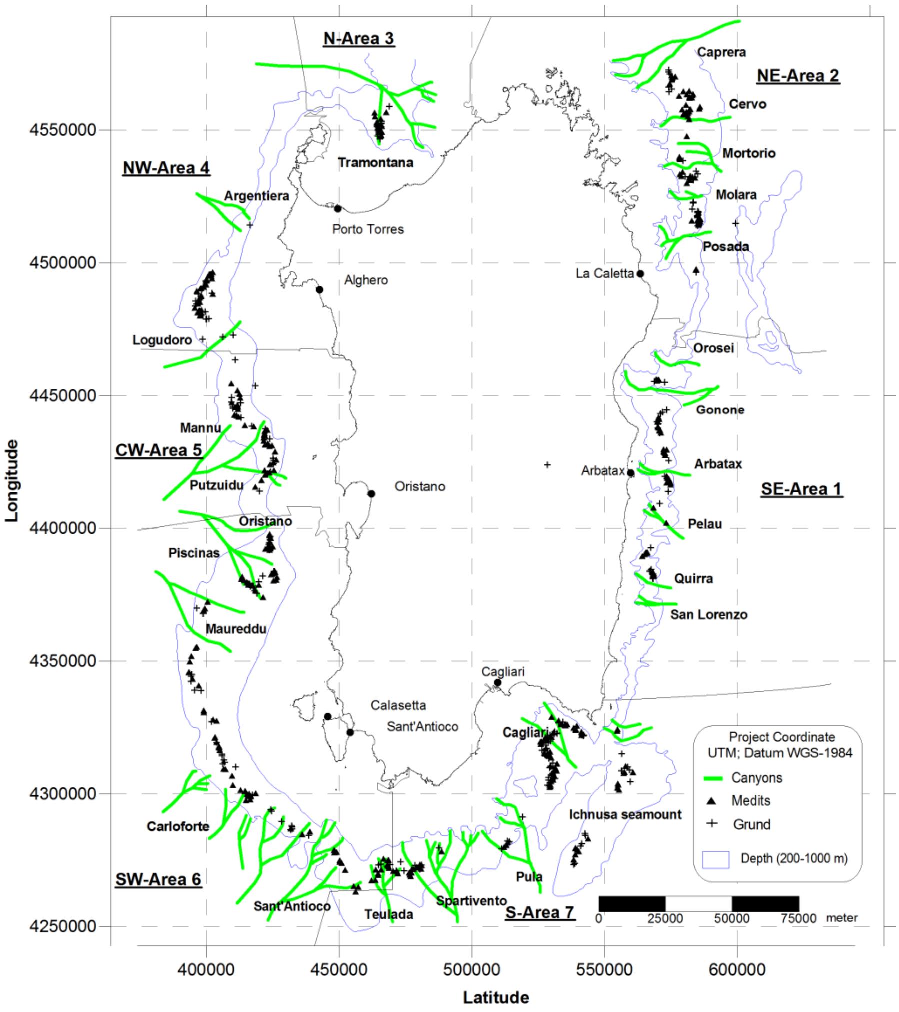


Figure 6-1. Hauls position for the MEDITS and GRUND project and shape of the canyons.

Catch data (number of specimens per sample) were processed using the swept-area method (Sparre and Venema, 1998), 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).

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. 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). Due to difficulties in separating the cohorts by LFD, the mean sizes per annual age group of the *A. antennatus* were calculated using the von Bertalanffy growth function for both and females (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 together.

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 (MEDITS Handbook, 2013). Females' maturity was established from the presence of turgid ovary extending to the whole dorsal portion, well-developed lobes and abdominal extension, and clearly visible oocytes (MEDITS Handbook, 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 and 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 d_{ij}=1 if the same haul *i* is within the third quartile in the year *j*, and d_{ij}=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.

6.3 RESULTS

6.3.1 Spawning areas

6.3.1.1 Aristaeomorpha foliacea spawning areas

The MEDITS surveys indicated a patchy distribution of *A. foliacea*, which were located mainly off the southern and western coasts of Sardinia. The most persistent spawning grounds for giant red shrimp are shown in Figure 6-2. 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), between 545 and 573 m deep, and on the slope between Spartivento and the Teulada canyon, at depths between 461-719 m. 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 (Figure 6-2).

6.3.1.2 *Aristeus antennatus spawning areas*

The spawner distribution maps for *A. antennatus* in the Sardinian sea (MEDITS) revealed a clear pattern characterized by a few dense patches, or hot spots. The highest concentrations most frequently recorded during the time series, with two important areas of spawner concentration at PI≥06 (Figure 6-4). 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, 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 (Figure 6-4). 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 summer. Spawning grounds were also recognized (PI≥04) on the slope in the Gulf of Cagliari at 595-673 m (S-Area 7) and on the northern open edge of the Posada canyon at 504-635 m (NE-Area 2).

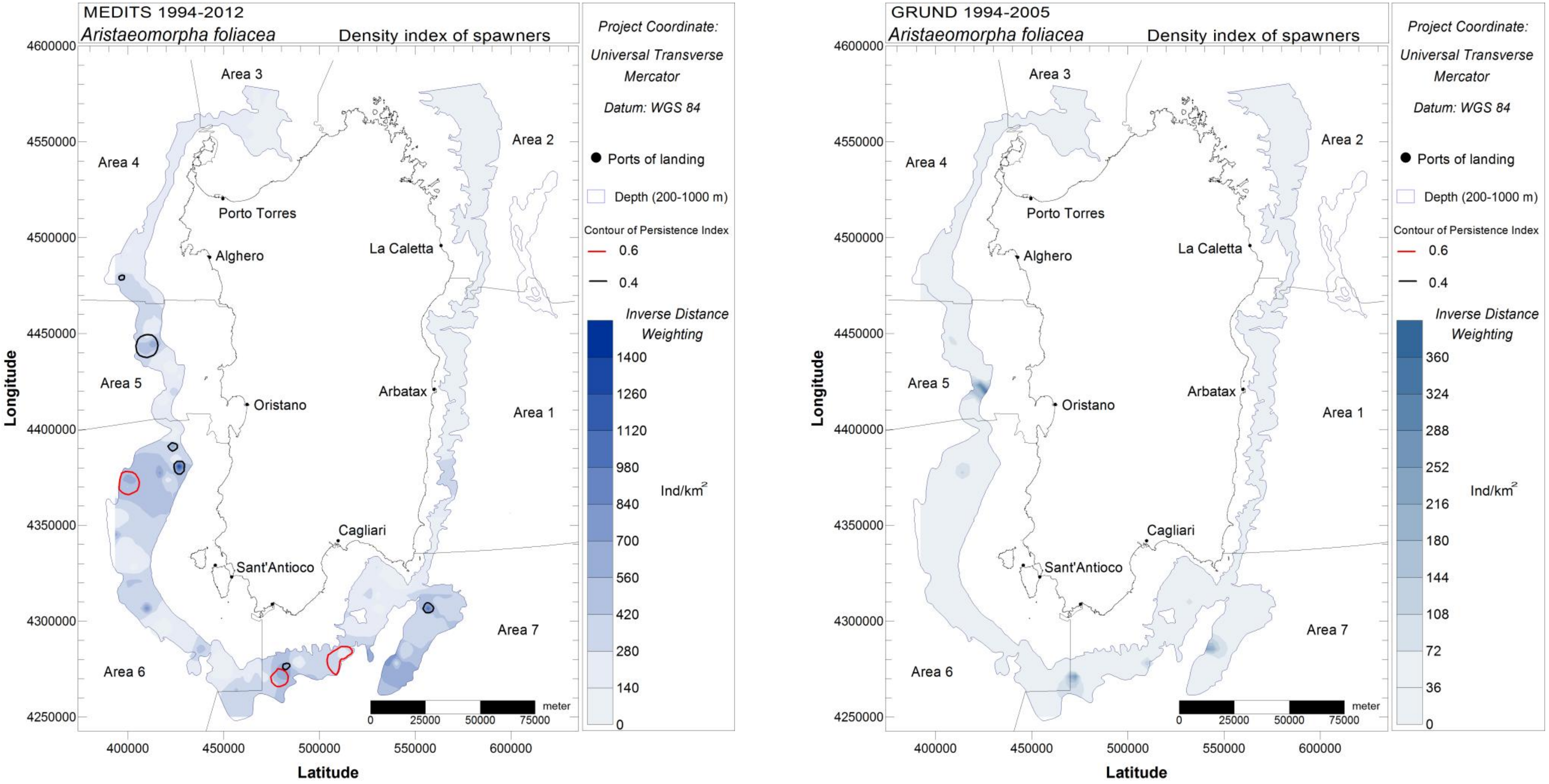


Figure 6-2. Temporal persistence of giant red shrimps spawning ground calculated from MEDITS and GRUND time-series density maps.

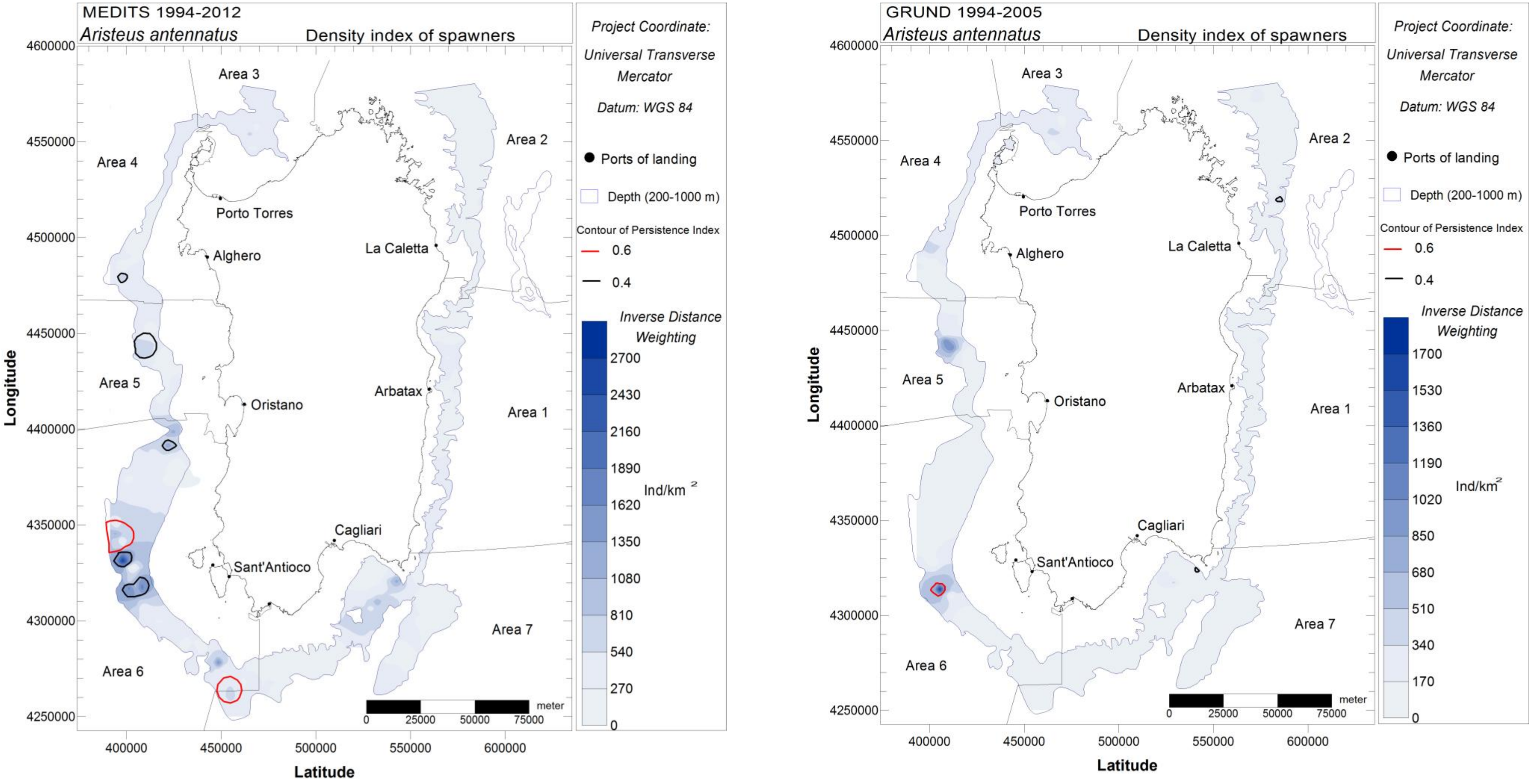


Figure 6-3. Temporal persistence of the blue and red shrimps spawning ground calculated from MEDITS and GRUND time-series density maps.

6.3.2 Nursery areas

6.3.2.1 Aristaeomorpha foliacea nursery areas

The fishing recruitment of giant red shrimp takes place in spring (Mura *et al.,* 1997), making it easy to identify the first modal component in the LFD for each survey. For the spring-summer datasets, the mean cut-off length (CL) was 25 and 30 mm for males and females, respectively. In autumn, the CL was longer, and varied on average between 35 and 40 mm for males and females, respectively. In general the chosen CLs were 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 (Figure 6-3). 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 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), though the PI was only 0.5. This could be because the seabed's shape 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 530-615 m (SE–Area 1), to the south-west of the Island of Sant'Antioco at 478-600 m (SW-Area 6), and on the slope between the two main tributaries of the Mortorio canyon at 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). In southern Sardinia (S-Area 7) two persistent nurseries were identified in the southern and northern sectors of the Ichnusa seamount, between 590-623 m and 468-628 m, respectively. The fourth 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 density nursery density hot spots were identified in a large portion of the slope off the Carloforte Island, 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).

6.3.2.2 Aristeus antennatus nursery areas

In Sardinia 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 the females have 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. 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 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 (Figure 6-2). 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 hot spots distributed on the slope along the Sardinian coast, consistently with the spring-summer survey. The

DI of recruits showed a higher abundance in autumn when the juveniles had been fully recruited (Figure 6-2). 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 the 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 juveniles, 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.

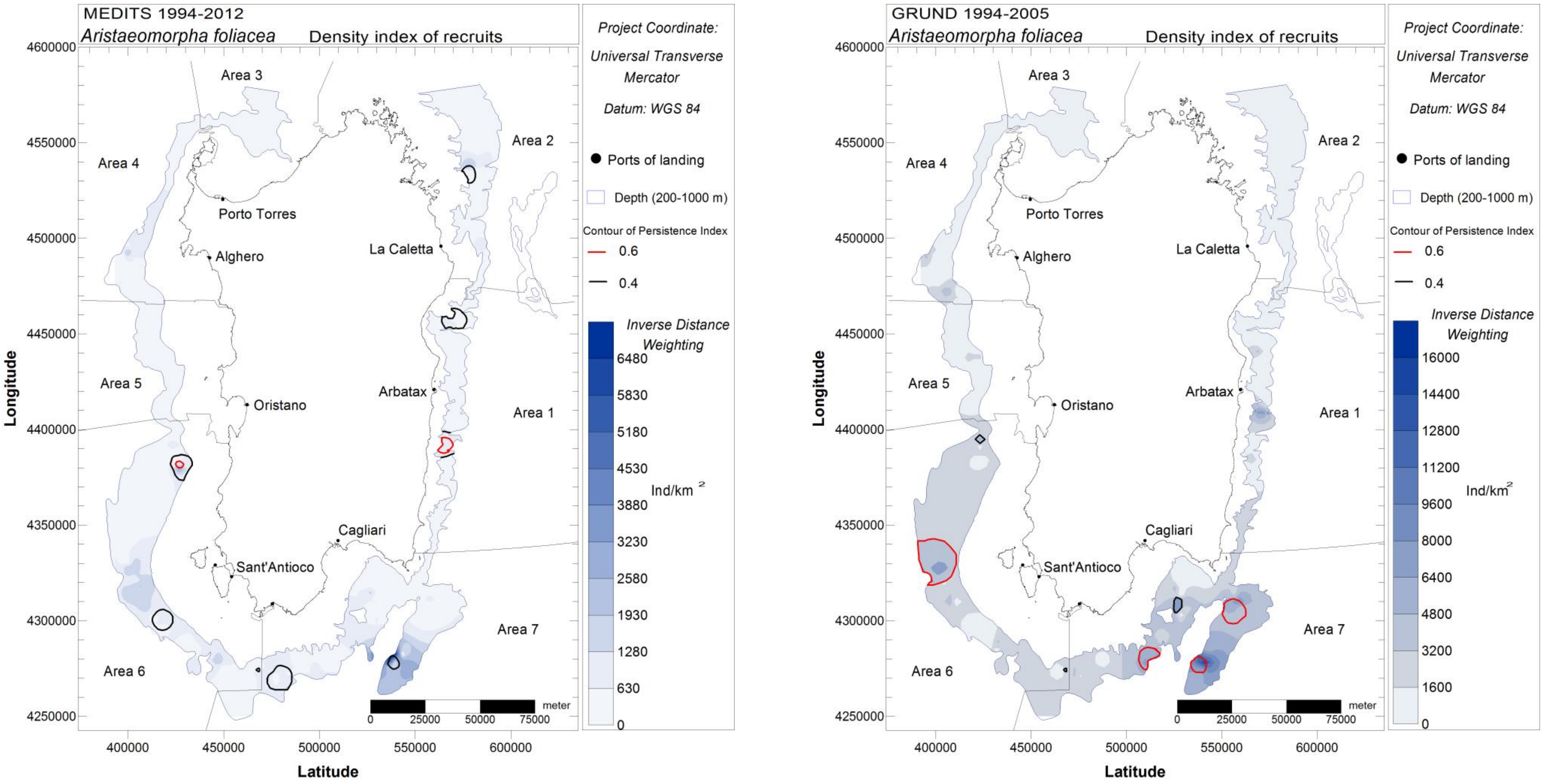


Figure 6-4. Temporal persistence of giant red shrimps nurseries calculated from MEDITS and GRUND time-series density maps of recruits.

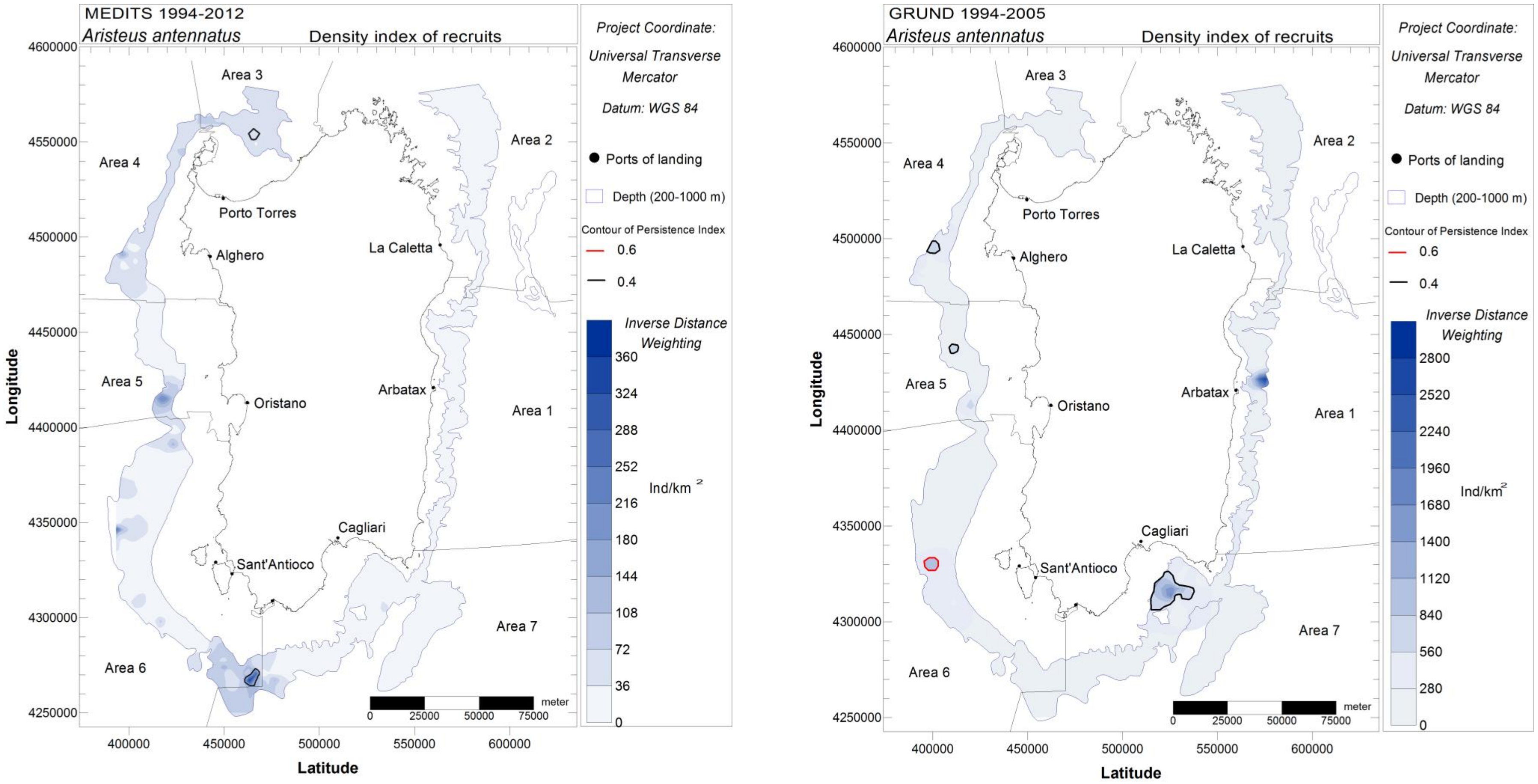


Figure 6-5. Temporal persistence of the blue and red shrimps nurseries calculated from MEDITS and GRUND time-series density maps of recruits.

6.4 DISCUSSION

Studying time-series data from the MEDITS and GRUND surveys revealed important, persistent and stable spawning grounds and nurseries in the Sardinian slope region for the giant red shrimp, and for 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 the MEDITS and the GRUND 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 the mature females (Sardà *et al.*, 2004). During the autumn surveys, the density of mature females dropped and only one persistent spawning ground was identified. Several authors have said that the blue and red shrimps' reproductive period starts in spring, peaks in summer (when most of the 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 their length and the stock's reproductive potential depends largely on the biggest mature females (Orsi Relini and Semeria, 1983; Kapiris and 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 (PI≥06) 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; Carbonell *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 and Company, 2012). Blue and red shrimp recruitment to the fishery occurs mainly during the spring when individuals of both sexes are more than a year old (from 18 to 20 mm CL) (Mura *et al.,* 1997; AAVV, 2008). Several authors have suggested that *A. antennatus* recruitment is a process exclusive to deep waters (Sardà *et al.,* 2004; Cartes et al. 2008; Sardà and Company, 2012), with full recruitment during the following autumn (Mura *et al.,* 1997). This is confirmed by their higher abundance during the GRUND survey (autumn). The only area of persistence at PI≥06 was found at depths between 575 and 601 m, while the others (PI≥04) were from 500 to 681 m in depth.

As seen for *A. antennatus*, the *A. foliacea* spawner distribution maps 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 the central-western slope of Sardinia (Maureddu canyon, SW-Area 6), at depths from 461 to 719 m. 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 and Bianchini, 1995; Papacostantinou and Kapiris, 2003).

Analyzing the spring-summer data for giant red shrimp, the distribution of recruits showed two areas of persistence at depths between 377 and 450 m, 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 at depths of 468-628 m (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 types of shrimp 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 and Thessalou-Legaki 2009), and in the Catalan Sea at depths mainly between 500 and 800 m (Cartes and Sardà, 1993). The most notable difference between the two types of shrimp lay in the more pronounced seasonality of *A. antennatus* reproductive activity 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), juveniles of *A. foliacea* were fished in the upper parts of the continental slope (at 377-450 m), while the same age cohort reached greater depths (between 468 and 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. Although both these factors may help to justify our results, the latter hypothesis seems more likely. Sardà and Company (2012) documented an ontogenic migration of juvenile individuals from deep-sea grounds to the upper slope, and these movements bear out our observation of recruitment taking place at deeper depths in summer, with a subsequent migration of juveniles to shallower waters (575-681 m) in autumn (Figure 6-6).

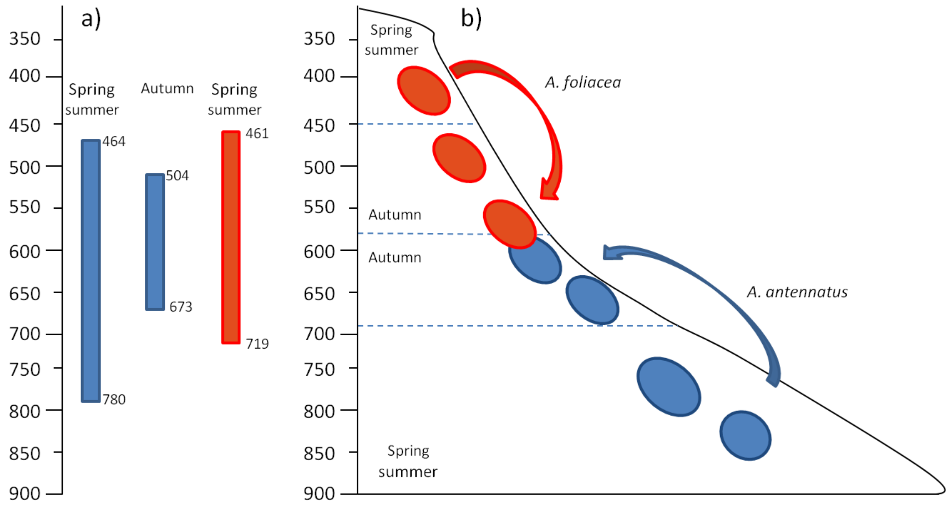


Figure 6-6. Depth and seasonal distribution of the spawning (a) and nursery (b) grounds for *A. foliacea* (Red) and *A. antennatus* (Blue).

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) (Figure 6-7). 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 correlate strongly with the spatial pattern of the main persistent oceanographic processes identified in the Sardinian Sea (Ribotti et *al.,* 2004; Chapter IV-Part II), such as enrichment due to upwelling events, described for the first time in the shelf-slope area by Olita *et al.,* (2013a). These authors found the area characterized by the presence of the Western Sardinian Current (WSC) that 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), that is actually triggered by mistral winds 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 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 LIW's path changes due to interaction with the Algerian eddies and topographical features (Olita *et al.,* 2013b, and references therein). The interaction between the LIW and Algerian eddies gives rise to two different environmental conditions: the south-eastern part becomes favorable 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 refuges' for the deep water red shrimps habitats unsuitable for trawling and providing some renewal of the stock (Caddy 1990). Concerning the management of the deep water resources, there is no specific regulation at basin level. In 2005, the General Fisheries Commission for the Mediterranean (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 (European Council Regulation n. 1967/2006). In this context this study provide relevant information on spatial and temporal distribution of seasonal or persistent aggregations of spawners and juveniles and provide 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.

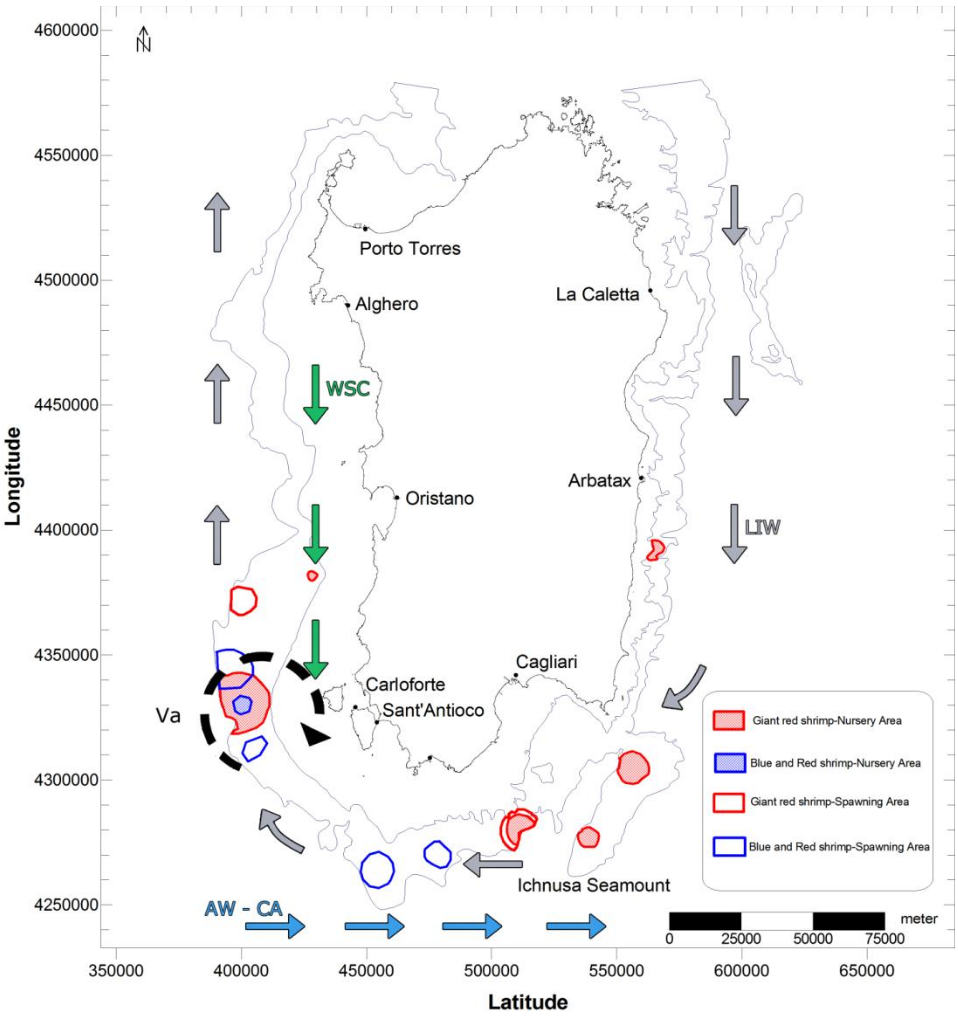


Figure 6-7. Synoptic view of the persistence nursery and spawning Areas identified for both MEDITS and GRUND surveys. Surface (AW-CA; Algerian Current carrying on Atlantic Waters, blue) intermediate water mass circulation (LIW; Levantine Intermediate Water, Grey) and Western Sardinian Current (green). Mesoscale structures (black): Va anticyclonic eddies.

7 PART V. RELATIONSHIP BETWEEN HYDROGRAPHIC CONDITIONS OF THE SARDINIAN SHELF-SLOPE REGION AND DISTRIBUTION OF DEEP WATER RED SHRIMPS.

7.1 INTRODUCTION

Geographical and bathymetric distribution of demersal communities have been investigated in order to identify species allocation (e.g. Bombace, 1975; Biagi et al., 2002; Massutì and Renones, 2005; Moranta *et al.,* 2008; Follesa *et al.,* 2011). Red shrimps *A. foliacea* (Risso, 1827) and *A. antennatus* (Risso, 1816) are mainly captured at depths between 400 and 800 m (Matarrese *et al.,* 1995; Cau *et al.,* 2002). From previous studies we know that *A. foliacea* is the main species at shallower depths (above 600 m), while *A. antennatus* is more abundant at greater depths (Sardá et al., 2004), below 700 m and that they overlap at a depth of around 650 m (Cau and Deiana, 1982). In the Mediterranean the abundance of these species showed marked fluctuations in all the basin, with strong declines of catches in some areas (Relini and Orsi-Relini, 1987; Cau *et al.,* 2002; Cartes *et al.,* 2011a; Rinelli *et al.,* 2013). The spatial and temporal variability in the catches of these two species seems to be associated with many abiotic factors, such as the topography of the continental slope, presence of geomorphological structures (Bianchini and Ragonese, 1994; Sabatini *et al.,* 2007; Sabatini *et al.,* 2011), fishing pressure (Relini and Orsi-Relini, 1987; D'Onghia *et al.,* 2005; Sabatini *et al.,* 2013) and lastly but not less important oceanographic and climatological factors (Ghidalia and Bourgois, 1961; Maynou, 2008; Cartes *et al.,* 2011a; Cartes *et al.,* 2011b). Due to this set of conditions, the spatial distribution of these two species is different among Mediterranean basins. In fact, *A. antennatus* is the only species in the western and northern Mediterranean (Spain, North-Western Africa and Ligurian Sea), while *A. foliacea* predominates in the central part (Sicily Channel) (Ragonese and Bianchini, 1995) and in the eastern Mediterranean Sea

(Papacostantinou and Kapiris 2001; Papacostantinou and Kapiris, 2003). This allocation seems to follow an east-west distribution gradient (Cau *et al.,* 2002; Cartes *et al.,* 2011b; Politou *et al.,* 2004). In this gradient, the Ionian Sea is an exception, since here *A. foliacea* was less abundant than *A. antennatus* (AAVV, 2008; D'Onghia *et al.,* 2012). In Sardinia, the ratios in the catches are more or less balanced, although with some local differences (Chapter 3-Part I).

The island of Sardinia, which is located in a central position of the western Mediterranean, is conditioned by several water masses and different types of meteorological conditions (Chapter 3-Part II). Furthermore, its meridian displacement (about four degrees latitude) may have a certain climatic relevance, while geographically it separates very different basins (Algerian-Provencal basin, the Tyrrhenian Sea and the Sardinian Channel), in their dynamics and biochemical characteristics (Santinelli *et al.,* 2002). In our study area the water masses occurring on the continental shelf-slope areas, where the deep water red shrimps are fished, are mainly the Modified Atlantic water (MAW) and intermediate Levantine water (LIW). Red shrimps, anyway, are batimetrically collocated with LIW and with even heavier and deeper waters (TDW, Tyrrhenian Deep water). But only the MAW and LIW, with the corresponding transitional layer, play a relevant role in the hydrological characterization studied in the present case (Chapter 4-Part II). These waters masses overlap and even partially mix each other during their displacement across the Mediterranean basin, according to the general topography of the lands and the bottoms.

In this context we have sought to identify those environmental factors having the greatest influence in the spatio-temporal distribution of deep water red shrimps on the slope of the Sardinian region. To investigate the spatio-temporal variability of abundance and to generate standardized information about environmental variables that took into account likely sources of variation, we assumed a General Linear Modeling approach to conduct the analysis of variance.

7.2 MATERIAL AND METHODS

7.2.1 Trawl and environmental data

Analyzed data, biological and environmental variables, were collected simultaneously for 4 years (2009-2012) (Chapter 4-Part II). Fishery-independent data was obtained from experimental bottom trawl surveys carried out in the Sardinia island, during late spring and early summer, following the international MEDITS bottom trawl surveys protocol (Bertrand *et al.,* 2002). Samples were collected using a stratified random strategy by means of a local trawler of 168 GT. From an initial number of 403 stations sampled, 77 were considered for this study (from 12 to 23 stations by year), which correspond to those carried out in the slope (between 200 and 800 m depth where the Aristeids were sampled). The fishing gear used was the GOC 73 bottom trawl (Fiorentini *et al.,* 1999), which was designed for scientific experimental fishing. It had a cod-end mesh size of 20 mm (stretched mesh) (Bertrand *et al.,* 2002). The horizontal net opening was used to evaluate the swept area and then the abundance index (Palmas *et al.,* 2013). Abundance data for both *A. antennatus* and *A. foliacea* were standardized (Ind/km^2) in order to obtain comparable samplings. Given the great geographical variability of the area of study we subdivided the seas around Sardinia into in to seven areas: two located in the eastern coast (SE-Area 1, NE-Area 2), one in the northern (N-Area 3), three in the western (NW-Area 4, CW-Area 5, SW-Area 6) and the last one in the southern part S-Area 7 (Figure 7-1).

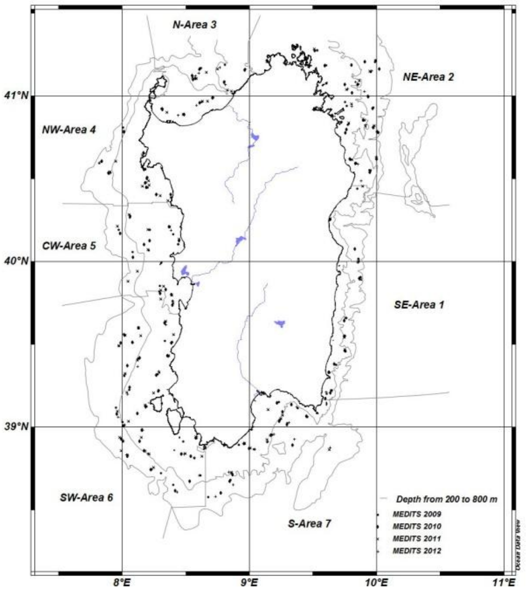


Figure 7-1. Hauls position for the MEDITS from 2009 to 2012.

Conductivity-Temperature-Depth data (CTD) were recorded at each station using a multi-parameters probe (SBE 37-IM Microcat) mounted on the otter of GOC73 net. Depth, temperature and salinity were recorded with a frequency of 10 seconds when the fishing net was being lowered and while it was being dragged (vertical and longitudinal profiles respectively).

To investigate the effect of hydrological conditions on abundances, a suite of environmental factors was selected that could have an important influence on the spatio-temporal distribution. For the longitudinal profiles an average measure of temperature and salinity on the bottom (TBot; SBot) during the fishing activity was obtained. For each vertical profile we compiled the recorder T and S at LIW core (the maxima of T and S found between 300-500 m) (TLIW; SLIW). The haul depth (DHaul) was also considered.

7.2.2 Statistics

Principal component analysis (PCA) was performed on the correlation matrix of the environmental variables. The PCA was performed in order to ordinate Areas with regarding their abiotic environmental. The resulting loadings provided a measure of association between each original variable and the resultant principal components (Zar, 1999). Environmental variables were normalized before analyses.

GLMs were carried out considering the abundance (Overall Density Index) of both deep water red shrimps separately. The generalised linear model (GLM) is a flexible generalisation of ordinary least squares regression. The GLM generalises linear regression by allowing the linear model to be related to the response variable via a link function and by allowing the magnitude of the variance of each measurement to be a function of its predicted value (Guisan *et al.,* 2002).

Before the analysis, a draftsman plot (i.e. scatter plots of all pairwise combinations of variables) (Clarke and Warwick, 2001) was applied to environmental variables to identify whether any were strongly correlated and thus provided redundant information. Redundant variables ($\rho > 0.60$) were discarded, simplifying the matrix.

We combined quantitative and categorical variables in a several modeling framework, allowing the determination of the relative importance of the variables affecting catch rates in a multiplicative model.

The general linear model used was:

$$DI = \mu + \beta_i x_i + \beta_j x_j + \beta_k x_{k\dots} + \varepsilon_{ijk}$$

Where μ is the intercept; β is the parameter set relating the dependent variables to the response and ε the error term assumed to be distributed normally. The goodness of fit of the models was assessed by comparing their relative contribution to total deviance explained. Temporal (Year) and spatial (Areas) density indexes were obtained from least squares mean estimates adjusted for the GLM statistically significant terms. Contour fit plot was used to construct the predicted surface overlaid of the observed data. All the above statistics were applied using PRIMER6 and STATGRAPHICS Centurion XVI.

7.3 RESULTS

Results from PCA summarized the regional environmental variability of seven examined Areas and four year of samplings. Environmental variables interrelationships among the component loadings of the PCA are presented in Table 7-1. The first principal component (PC1), explaining 42.7% of the variance, relates to the salinity at LIW core (SLIW) and bottom salinity (SBot) (as shown by the high factor loadings); the PC2 explaining 26,4% of the variance, relates to the average depth haul (DHaul) and bottom temperature (TBot).

Table 7-1. Relationships between environmental variables using principal component analysis.

	Principal components	
	PC1	**PC2**
Eigenvalues	2.13	1.32
% Variation	42.7	26.4
Cum. %Variation	42.7	69.1
DHaul	-0.337	0.657
TBot	0.369	-0.558
SBot	0.599	0.378
TLIW	-0.124	0.038
SLIW	0.613	0.335

In PCA biplot, considering the years as factor, we can identify a yearly gradients linked to the different conditions of water masses (Figure 7-2a, 7-2b). Most of the data belonging to 2011 had a positive value in the PCI, suggesting that this year was characterized by the higher values of salinity both at bottom and depth at LIW core levels (Figure 7-2a). In 2011 the salinity maximum of LIW was found at 400 m with S_{max} between 38.6-38.69 in all the areas examined (Chapter 4-Part II). On the contrary the 2012 showed negative values for both PCs, suggesting the presence of lower values for both Bottom and LIW core salinity (TBot; TLIW). These data was also confirmed by T/S profiles that identify lowest values of salinity in the 2012 at 400 with S_{max} between 38.00 and 38.2 psu. On the other hand, considering the Areas as factor, no clear patterns were found due to the main differences recorded in the years (Figure 7-2a, Figure 7-2b).

The exploratory analysis using the Draftsman plot correlation showed that the environmental variable SLIW *vs* SBot were highly correlated (ρ = 0.90) (Figure 7-

3). Due to the fact that these variables were at ρ>0.6, we conducted the analysis on several models including one environmental factor at a time with the aim to determining which factors best explained the observed variability in density indexes.

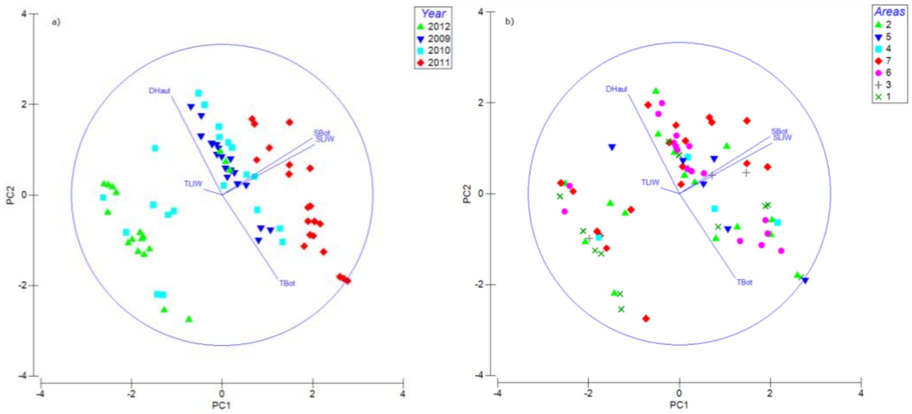


Figure 7-2. Principal component analysis (PCA) ordination for environmental variables recorder. a) biplot from the PCA showing the grouping of years, b) biplot from the PCA showing the grouping of Areas.

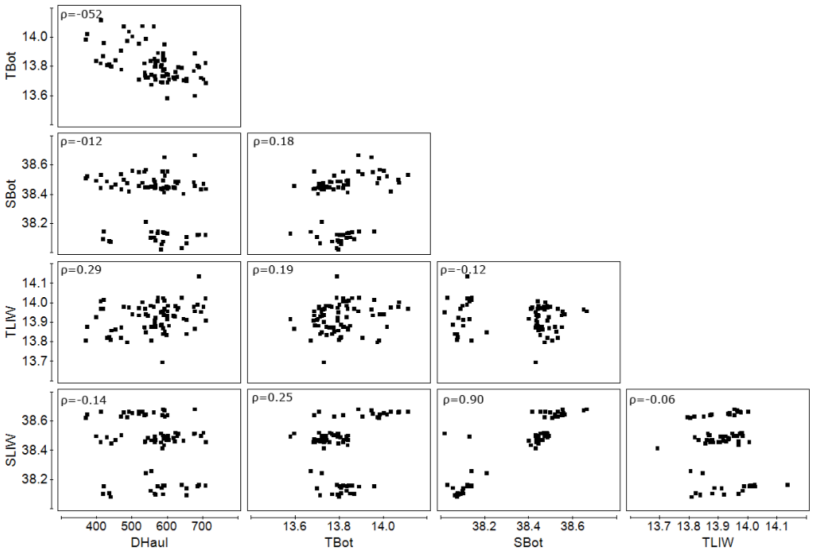


Figure 7-3. Draftsman plot correlation between the environmental variables.

For *A. antennatus* abundance, the best model in terms of explained variability (56,88%) was GLM3 where the total deviance was explained by 4 variables (Areas, Year, TBot and DHaul) explaining the variability (Table 7-2). The most significant effects on the overall total density of *A. antennatus* were explained by the categorical factors: geographical areas (Area; P<0.001) and year of sampling (Year; P<0.01). Among the quantitative variables the most significant were the negative linear bottom temperature and the positive linear average haul depth (TBot, DHaul; P<0.05).

Table 7-2. Analysis of deviance results for GLM fitted to *A. antennatus* overall density index. For each model, values of sum of squares of each factor, degrees of freedom (Df), mean square, F-Ratio, percentage of the total deviance as well as values of F and probability (P), are shown.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	% Dev expl.
(GLM1)						
Year	3.34E+06	3	1.11E+06	4.81	0.005	58,65%
Areas	7.76E+06	6	1.29E+06	5.59	0.000	
DHaul	669077	1	669077	2.89	0.946	
TBot	1.14E+06	1	1.14E+06	4.92	0.032	
SBot	12036.9	1	12036.9	0.05	0.821	
TLIW	402907	1	402907	1.74	0.193	
Residual	1.04E+07	45	231120			
Total (corrected)	2.52E+07	58				
(GLM2)						
Year	2.54E+06	3	8.47E+05	3.67	0.019	58.69%
Areas	7.66E+06	6	1.28E+06	5.53	0.000	
DHaul	682499	1	682499	2.96	0.093	
TBot	1.09E+06	1	1.09E+06	4.74	0.035	
SLIW	21181.9	1	21181.9	0.09	0.763	
TLIW	322914	1	322914	1.4	0.243	
Residual	1.04E+07	45	230917			
Total (corrected)	2.52E+07	58				
(GLM3)						
Year	3.30E+06	3	1.10E+06	4.77	0.0055	56,88%
Areas	7.41E+06	6	1.23E+06	5.35	0.0003	
DHaul	1.01E+06	1	1.01E+06	4.39	0.0478	
TBot	872769	1	872769	3.78	0.0416	
Residual	1.08E+07	47	230802			
Total (corrected)	2.52E+07	58				

The analysis of *A. antennatus* abundance, explained by the model, revealed an oscillating signal in the data with an increasing trend in catches from 2009 until 2011 followed by a sharp decrease occurred in 2012. Considering the distribution between the different areas we observed a peak in the catches in the northern part of Sardinian Island (N-Area 3). On the other hand the lowest catches were observed in the S-Area 7, NW-NW-Area 4 and NE-Area 2.

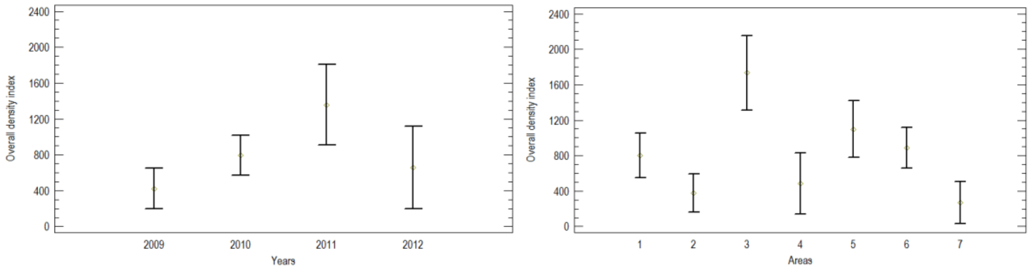


Figure 7-4. Result of the main effect model. Each plot represents the contribution of the corresponding variable to be fitted linear predictor for Year and Areas of samplings.

For *A. foliacea* abundance, several combination of predictor variables were tested in GLMs and the best model were selected according to best explained variability (Table 7-3). The bottom temperature and Salinity (TBot; SBot) were rejected from the GLMs because not significant. The reduced final model (51.73%) for *A. foliacea* ODI (GLM3) included year and areas of sampling (Year, Areas), haul depth (DHaul), temperature and salinity at LIW core (TLIW, SLIW). The most significant effects on the overall total density of *A. foliacea* were explained by the year of sampling (Year; P=0.0023) and temperature at the LIW core (TLIW; P=0.0030).

As well registered for the blue and red shrimp, the analysis of *A. foliacea* abundance revealed an oscillating signal in the data, with a decreasing trend in catches from 2009 until 2012 (Figure 7-5). Considering the distribution between the different areas we observed an increase in the catches in the southern and south western part of Sardinian Island (S-Area 7 and SW-Area 6). On the other hand the lowest catches were observed in the N-Area 3.

Table 7-3. Analysis of deviance results for GLM fitted to *A. foliacea* overall density index. For each model, values of sum of squares of each factor, degrees of freedom (Df), mean square, F-Ratio, percentage of the total deviance as well as values of F and probability (P), are shown.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	% Dev expl.
(GLM1) ODI *A. foliacea*						
Year	1.01E+06	3	338070	2.39	0.0826	48.75
Areas	2.59E+06	6	432116	3.06	0.0147	
DHaul	1.27E+06	1	1266750	8.97	0.0047	
TBot	9.27E+04	1	92673.7	0.66	0.4226	
SBot	5.72E+05	1	572062	4.05	0.0509	
TLIW	1.00E+06	1	1002060	7.1	0.0111	
Residual	5.65E+06	40	141198			
Total (corrected)	1.10E+07	53				
(GLM2) ODI *A. foliacea*						
Year	1.50E+06	3	499617	3.91	0.0154	53.6
Areas	2.18E+06	6	363450	2.84	0.0212	
DHaul	1.29E+06	1	1286020	10.06	0.0029	
TBot	2.07E+05	1	206538	1.62	0.2110	
SLIW	1.11E+06	1	1107090	8.66	0.0054	
TLIW	1.43E+06	1	1426910	11.16	0.0018	
Residual	5.11E+06	40	127823			
Total (corrected)	1.10E+07	53				
(GLM3) ODI *A. foliacea*						
Year	2.22E+06	3	739301	5.7	0.0023	51.73
Areas	2.22E+06	6	370253	2.85	0.0205	
DHaul	1.25E+06	1	1249430	9.63	0.0035	
SLIW	1.05E+06	1	1052050	8.11	0.0069	
TLIW	1.30E+06	1	1295890	9.99	0.0030	
Residual	5.32E+06	41	129743			
Total (corrected)	1.10E+07	53				

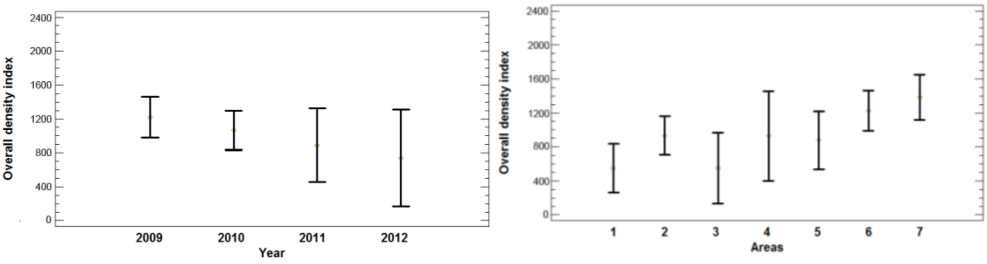


Figure 7-5. Result of the main effect model. Each plot represents the contribution of the corresponding variables to be fitted linear predictor for Year and Areas of samplings.

7.4 DISCUSSION

Several authors have examined the variability in catches of deep-water red shrimps, including the causal roles of a number of environmental variables

(D'Onghia *et al.,* 2003; Maynou, 2008; Cartes *et al.,* 2011a; Cartes *et al.,* 2011b). Some authors have suggested that hydrological conditions could determine the distribution and abundance of this species in the Mediterranean and Atlantic waters (Ghidalia and Bourgois, 1961; Bombace, 1975; Politou *et al.,* 2004), while others have also been proposed as a possible explanation for the decline of *A. foliacea* stocks in the Balearic Sea during early 1960s (Cartes *et al.,* 2011a, 2011b). Ghidalia and Bourgois (1961) proposed a probably association between the presence of the deep-water red shrimp populations and the temperatures and salinity of specific water masses. *A. antennatus* have been associated to Western Mediterranean Dense Water (WMDW) characterized by temperature of ≈ 12.8 °C and salinity of 38.4 psu. *A. foliacea* have been considered to be linked to warmer and more saline LIW (T≈ 13.5 °C and S≈38.5). In a comparative study Politou *et al.,* 2004 observed that, the striking abundance differences of the species between the western and eastern locations may be related to the increase in salinity from east to west (from 38.8 psu in the Balearic basin to 38.82 psu the eastern Ionian). Furthermore, the eastern Mediterranean deep water transient may play a role in the geographical pattern, since this event is associated with a significant upward nutrient transport, which is most pronounced in the eastern Ionian Sea, and may result in greater biological productivity (Politou *et al.,* 2004). On the other hand, the increase of temperature and salinity in the LIW core (Cartes *et al.,* 2011a), due to the Nile damming (Cartes *et al.,* 2011b) have been correlated with their extinction in the Balearic basin. However, there are still few studies analyzing the influence of in situ environmental variables on the spatio-temporal distribution of Aristeids (Sardà *et al.,* 2009). Their results indicated a significant relationship between *A. antennatus*, salinity (>38.5 psu) and temperature (13.1-13.2 °C) of the water.

In the same way our multidisciplinary approach helped to clarify the role played by some key environmental process on deep water red shrimps dynamic in the central Mediterranean Sea. The GLMs seems to suggested that mainly depth and bottom temperature, at small regional scale, could be responsible for increasing and decreasing of *A. antennatus* abundance, but that other factors (yearly variability in catches) accounted for local pattern too. *A. foliacea* density shared some different response to the considered predictors. The variability in the overall density index seems to be explained by the temperature and salinity at LIW core. The particular variability in the hydrographic conditions of the Sardinian seas determine the presence of different habitats that provide a complex system of environmental patches, reflected in the distribution and abundance of the deep-water red shrimps in Sardinian slope region. The abundance indexes explained by the model showed an extreme local and interannual variability in the catches.

Two hot spot of distribution may be noted: in the northern coasts, *A. antennatus* is the main species, whereas *A. foliacea* predominates in the southern and eastern sides. For *A. antennatus* the highest values were recorder in 2011 in the northern sector (N-Area 3), while for *A. foliacea* the highest values were observed in 2009 in the S-Area 7. The comparison between hydrographic and biological data evidences that both *A. antennatus* and *A. foliacea* seem to be connected to the peculiar features and fate of the LIW. The Sardinian slope region is influenced by the same water types, which first cross the Tyrrhenian and then the Algerian basin, through the Sardinian channel (Chapter 4-Part II). However, during their journey, the water masses significantly modify their properties due to the different dynamics present in different areas of Sardinian slope region. In fact, in the southern part (S-Area 7), LIW properties predominate and *A. foliacea* is the main species. In the northern sides of Sardinia, on the other hand, LIW properties lose intensity in favor of *A. antennatus* which prefers colder temperatures. The comparative study of the two species indicated that the depth was the main factor structuring the Aristeids abundance in the present study. However, depth is in fact a proxy for a combination of several environmental variables affecting deep-sea organisms. For example, temperature and salinity are correlated with depth and they may have a more direct influence on species distribution (e.g. in the case of the shrimp *A. foliacea*:

Cartes *et al.,* 2011a) than depth *per se*. Both, the geographical and the depth distribution ranges of marine species are related with the physiological limits that they can tolerate (Pauly *et al.,* 1980).

In conclusion, changes in the density of Aristeids are related over Sardinian slopes with water mass conditions, basically defined by changes in salinity and temperature, that are generally linked to food inputs prey. Besides the environmental factor influencing the distribution of Aristeid, the high catch rates observed in different year could be related to important biological phenomena including reproduction and recruitment, which occur mainly in particular areas of concentration (Chapter 6-Part IV).

8 GENERAL CONCLUSIONS

Ecosystem based management of renewable marine resources is currently replacing the more simplistic concepts based on the traditional population dynamics (Massutì *et al.,* 2008). The new holistic approach suggests that the strategy of exploitation and conservation should take into account the functioning of the ecosystems, their natural variation and the factors that control these changes. One of the main purpose of this approach is to make hypothesis about the spatial variation and on the temporal fluctuations of fishery resources in response to the environmental causes. In this context, the main question that motivated the study developed in this thesis was to understand how the abiotic factors could influences the spatio temporal distribution of *A. antennatus* and *A. foliacea* in the Central Western Mediterranean (Sardinian seas). To reach this goal a multidisciplinary study was performed considering different sources of variation, such as the presence of particular geomorphological and oceanographic structures.

From the results obtained, the following conclusion can be extracted:

Part I: The MEDITS surveys carried out systematically in the last 19 years on the demersal resources of this area have provided a global comparative study of the distribution and abundance of deep water red shrimps in Sardinian seas. Both red shrimps species occur almost exclusively on the “meso-bathyal” stratum (500-800 m), though *A. foliacea* has been catched also at shallower depths (stratum 200-500 m). The distribution pattern appears quite different for the two species, and any significant trends in density and biomass indexes (neither at geographical nor at temporal level) may be detected. The abundance indexes as well the spatial maps, evidenced local higher abundances (hotspots) where the blue and red shrimp and the giant red shrimp are mainly concentrated. In general, a very high interannual variability was detected in all areas. The south western area showed the highest abundance values for both species. In the northern fishing grounds, *A. antennatus* is the main species, whereas *A. foliacea* predominates in the Sardinian Channel (south) and in the north western zones. In the other areas, the species showed an irregular distribution with years of strong prevalence of one species followed by very low catches in the further years. The variation in the catches, which is evident for both species and areas of samplings, seems to be linked with some environmental factors.

Part II: The hydrological characteristics of water masses and circulation in the Sardinian slope region have been estimated by using in situ observation gathered simultaneously with the biological data. A CTD SBE-37 was placed in the otter of the net in order to record water temperature and salinity. The hydrological fields have been calculated as yearly seasonal averages over a period of four years (MEDITS 2009-2012). In our study area the water masses occurring on the continental shelf-slope zones, where the deep water red shrimps are catched, are mainly the Modified Atlantic Water (MAW) and Levantine Intermediate Water (LIW). These water masses overlap and even partially mix each other during their displacement across the Sardinian shelf-slope area according to the general topography of the lands and the bottoms. Results showed that the distribution of the main water masses is comparable to the literature, moreover, the results confirmed that the great variability between basins and year of sampling is clearly associated with waters of very different origin that follow converging routes and mix together in the study area. These data represents an invaluable information in order to investigate relationships or event causal correlations with fishery data. This is particularly true in such highly variable systems, where not accurate and time-space related oceanographic data, such those obtained by numerical models, can negatively affect the analysis of bio-physical relationships.

Part III: The analysis carried out in this part underlined the influence of peculiar areas, such as seamounts, on the structure of the middle-slope assemblages as well as the behavioural rhythms of the deep water red shrimps. In particular, distinctions can be made between the fauna of the deeper waters (>500 m) and those living at shallower depths (<350 m). Groups 2 and 3, both related to the shallow waters had many species in common (example: red gurnard *A. cuculus* and boarfish *C. aper*). However, some species were found in both groups 1 and 2 as well. These are the typically deep water species found between 500 and 800 m even if these species move toward the upper level along the seamount wall's during the night (example: blackmouth catshark *G. melastomus*, the giant red shrimp *A. foliacea* and the blue and red shrimp *A. antennatus*). Their daily and nocturnal movements from the base of the seamount to the edge of the continental shelf increase the range of their distribution. This results highlights the fact that shrimps and other species in the Baronie seamount, move during a day-night cycle, probably influenced by some parameter indirectly related to their activity. These nektobenthic displacements are known to occur also in the continental shelf and slope, but in the canyon and seamounts they are broadened and can be studied more easily. These displacements could produce a bias in trawl survey data according to the time of day with effects on population assessment and demographic evaluation.

Part IV: The presence of spawning and nursery grounds, and their relationship to major, persistent oceanographic processes in the central western Mediterranean Sea were investigated using fishery-independent data (trawl surveys, 1994-2012). The spatial distributions were generated for mature animals and juveniles, 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 *A. foliacea* and *A. antennatus*. The analysis highlighted that a broad area of overlap between recruits and spawners of the two species is located in the south west coast of Sardinia. The location of the area appears to be correlated with the spatial pattern of the main persistent oceanographic processes, identified in the Sardinia Sea, such as enrichment due the upwelling present in the south west shelf-slope area. Other important areas of aggregation for both juveniles and mature females were found over the bathyal zones in canyon and seamounts environments, where productivity is reported higher than elsewhere. These privileged areas for recruitment, rich in nutrients thanks to the effect of different currents, would seem to guarantee the regeneration of the resource. Finally, the analysis also suggested the existence of a seasonal bathymetric distribution of the nursery areas. The juveniles of *A. foliacea* are located in the upper part of the continental slope in spring-summer and reach greater depths in autumn. For *A. antennatus*, for which nursery areas appear only in autumn, an opposite ontogenic migration from deep sea to upper slope, has been noted during the summer.

Part V: In this part the influences of in situ hydrographic variables on the distribution of the Aristeid stocks on the fishing grounds of Sardinia were analysed. To investigate the effect of hydrological conditions on abundances, a combination of environmental factors were considered using a General Linear Model. In general, the significance of the various predictors reveals effects on the distribution of both species, due to the geographic area and year of fishing. The particular variability in the hydrographic conditions of the Sardinian seas seems to determine the presence of different habitats that produce a complex system of environmental patches. Among the quantitative factors, the GLM suggests that the increase in the density index of *A. antennatus* is positively correlated with depth and negatively related to bottom temperature. For *A. foliacea*, the registered variability in the density index values seems to be explained by the temperature and salinity registered at LIW core. The comparison between hydrographic and biological data evidenced that both species seem to be connected to the peculiar features and fate of the LIW (Levantine Intermediate Water) between 400 and 600 m. In fact, in the south-eastern part, the LIW properties predominate and *A. foliacea* is the main species, while in the western and northern areas of Sardinia the LIW loses intensity in favor of *A. antennatus,* which prefers colder temperatures. Besides the oceanographic features influencing the distribution pattern of these species, the variation left unexplained by the model may be attributed to different sources of variation such as the presence of geomorphological structures or reproduction and recruitment phenomena already discussed in the above parts of the thesis.

In conclusion, following a multidisciplinary approach, this thesis tries to give a substantial contribution to the knowledge of the spatio-temporal dynamics of the two Mediterranean deep-water red shrimps. The results highlight how these patterns of distribution strongly correlated not only with the main oceanographic process (LIW properties) but also with local hydrographic conditions. Among these conditions, upwelling events and the particular geomorphology that characterized the Sardinian shelf-slope region seem to be the most important factors. In addition life history traits of these two species linked to a heavy prolonged fisheries exploitation, could determine a masking effect that makes difficult to interpret the whole picture of the distribution of the two species. For this reason, these results should take in to account for the assessment and management of these important resources.

9 REFERENCES

AAVV 2008. Status of deep-sea Red Shrimps in Central and Eastern Mediterranean Sea, Final Report. Project Ref FISH/2004/03-32.

Abello´ P., Carbonell A. and Torres P. (2002). Biogeography of epibenthic crustaceans on the shelf and upper slope off the Iberian Peninsula Mediterranean coasts: implications for the establishment of natural management areas. *Scientia Marina,* 66: 183–198.

Aguzzi J. and Company J.B. (2010). Chronobiology of deep-water decapod crustaceans on continental margins. *Advanced in Marine Biology,* 58, 155–225.

Ardizzone G.D., Belluscio A., Schintu P. (1994). Considerazioni sullo stato di sfruttamento delle risorse demersali (Isola di Giannutri–Foce di Garigliano). *Biologia Marina Mediterranea*, 1(2): 43-46.

Artale V., Astraldi M., Buffoni G., Gasparini G.P. (1994). Seasonal variability of gyre-scale circulation in the northern Tyrrhenian Sea. *Journal of Geophysical Research*, 99: 14127-14137.

Bahamon N., Aguzzi J. and Sardà F. (2009). Fuzzy diel pattern in commercial catchability of deep water continental margin species. ICES Journal of Marine Science, 66: 2211-2218.

Bartolino V., Colloca F., Sartor P., Ardizzone G. (2008). Modelling recruitment dynamics of hake, *Merluccius merluccius*, in the central Mediterranean in relation to key environmental variables. *Fisheries Research*, 92: 277-288.

Bas C. and Sardà F. (1998). Long-term morphometric variations in a population of the deep-sea shrimp *Aristeus antennatus* (Risso, 1816) (decapoda, Aristeidae) with implications for resource conservation. *Crustaceana*, 71(4): 369-377.

Belcari P., Viva C., Mori M., De Ranieri S. (2003). Fishery and Biology of *Aristaeomorpha foliacea* (Risso, 1827) (Crustacea: Decapoda) in the Northern Tyrrhenian Sea (Western Mediterranean). *Journal of Northwestern Atlantic Fishery Science*, 31: 195-204.

Bellagamba M., Napoleone G. and Tramontana M. (1979). Batimetria e morfologia delle aree settentrionale e centro-meridionale del bacino della Sardegna (Mar Tirreno). Atti del convegno scientifico nazionale, Progetto Finalizzato Oceanografia e Fondi marini, Roma. Volume 2, pp. 739–751.

Bello G. and Pipitone C. (2002). Predation on cephalopods by the giant red shrimp *Aristaeomorpha foliacea*. *Journal of Marine Biological Association of United Kingdom*, 82: 213-218.

Bensch A., Gianni M., Gréboval D., Sanders JS., Hjort A. (2008). Worldwide review of bottom fisheries in the high seas. FAO Fisheries and Aquaculture Technical Paper. No. 522. Rome, FAO 145pp.

Benzohra M. and Millot C. (1995). Characteristics and circulation of the surface and intermediate water masses of Algeria. *Deep-Sea Research*, 42(10): 1803-1830.

Bertrand J.A., Gil De Sola L., Papaconstantinou C., Relini G., Souplet A. (2002). The general specifications of the Medits surveys. *Scientia Marina*, 66: 9-17.

Biagi F., Sartor P., Ardizzone G.D., Belcari P., Belluscio A., Serena F. (2002). Analysis of demersal assemblages off the Tuscany and Latium coasts (north-western Mediterranean). *Scientia Marina,* 66: 233–242.

Bianchini M.L. and Ragonese S. (1994) Proceedings of the International Workshop on 'Life Cycles and Fisheries of the Deep Water Red Shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus*'. *N.T.R. I.T.P.P.* Special Publication, 3: 87 pp.

Blaber S.J.M. and Bulman C.M. (1987). Diets of fishes of the upper continental slope of eastern Tasmania: content, calorific values, dietary overlap and trophic relationships. *Marine Biology,* 95: 345-357.

Blanchard F. (2001). The effect of fishing on demersal fish community dynamics: an hypothesis. *ICES Journal of Marine Science,* 58: 711-718.

Bombace G. (1975). Considerazioni sulla distribuzione delle popolazioni di livello batiale con particolare riferimento a quelle bento-nectoniche. *Pubblicazioni Stazione Zoologica Napoli,* 21: 7-21.

Botsford L.W., Castilla J.C., Peterson C.H., (1997). The Management of Fisheries and Marine Ecosystems. *Science*, 277: 509-515.

Bouzinac C., Font J. and Millot C. (1999). Hydrology and currents observed in the channel of Sardinia during the PRIMO-1 experiment from November 1993 to October 1994. *Journal of Marine System,* 20: 333-355.

Bray J.R. and Curtis J.T. (1957). An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs,* 27: 325–349.

Caddy J.F. (1990). Options for the regulation of Mediterranean demersal fisheries. *Natural Resource Modeling*, 4: 427-475.

Campillo A. (1994). Bio-ecology of *Aristeus antennatus* in the French Mediterranean. In: M.L. Bianchini and S. Ragonese (eds.), Life cycles and fisheries of the deep-water red shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus*. N.T.R.-I.T.P.P. Spec. Publ., 3: 25-26.

Canals M., Danovaro R., Heussner S., Lykousis V., Puig P., Trincardi F., Calafat A.M., Durrieu de Madron X., Palanques A. and Sanchez-Vidal A. (2009). Cascades in Mediterranean submarine grand canyon. *Oceanography,* 22: 26-43.

Cannas R., Sacco F., Follesa M.C., Sabatini A., Arculeo M., Lo Brutto S., Maggio T., Deiana A.M. and Cau A. (2011). Genetic variability of the blue and red shrimp *Aristeus antennatus* in the Western Mediterranean Sea inferred by DNA microsatellite loci. *Marine Ecology,*33(3): 350-363.

Carbonell A., Lloret J., Demestre M. (2008). Relationship between condition and recruitment success of red shrimp (Aristeus antennatus) in the Balearic Sea (Northwestern Mediterranean). *Journal of Marine System*, 71: 403-412.

Carbonell A., Dos Santos A., Alemany F. and Vélez-Belchi P. (2010). Larvae of the red shrimp *Aristeus antennatus* (Decapoda: Dendrobranchiata: Aristeidae) in the Balearic Sea: new occurrences fifty years later. *Marine Biodiversity Record*, 3: 1-4.

Carlucci R., D'Onghia G., Sion L., Maiorano P., Tursi A. (2006). Selectivity parameters and size at first maturity in deep-water shrimps, *Aristaeomorpha foliacea* (Risso, 1827) and *Aristeus antennatus* (Risso, 1816), from the North-Western Ionian Sea (Mediterranean Sea). *Hydrobiologia*, 557(1): 145-154.

Carney R.S. (2005). Zonation of deep biota on continental margins. *Oceanography and Marine Biology: an Annual Review*, 43: 211-278.

Cartes J.E. and Sarda F. (1989). Feeding ecology of the deep-water Aristeid crustacean *Aristeus antennatus*. *Marine Ecology Progress Series*, 54: 229-238.

Cartes J.E. and Sardà F. (1993). Zonation of deep-sea decapod fauna in the Catalan Sea (Western Mediterranean). *Marine Ecology Progress Series*, 94: 27-34.

Cartes J.E. (1994). Influence of depth and season on the diet of the deep-water Aristeid *Aristeus antennatus* along the continental slope (400 to 2300 m) in the Catalan Sea (western Mediterranean). *Marine Biology*, 120: 639-648.

Cartes J.E. (1995). Diets of, trophic resources exploited by, bathyal Penaeoidean shrimps from the Western Mediterranean. *Marine and Freshwater Research*, 46: 889-896.

Cartes J., Company J.B. and Maynou F. (1994). Deep-water decapod crustacean communities in the north-western Mediterranean: influence of submarine canyons and season. *Marine Biology Berlin*, 120: 221-229.

Cartes J.E., Maynou F., Moranta J., Massutı E., Lloris D. and Morales-Nin B. (2004). Pattern of bathymetric distribution among deep-sea fauna at local spatial scale: comparison of minland vs. insular areas. *Progress in Oceanography,* 60: 29-45.

Cartes J., Papiol V. and Guijarro B. (2008). The feeding and diet of the deep-sea shrimp *Aristeus antennatus* off the Balearic Islands (Western Mediterranean): Influence of environmental factors and relationship with the biological cycle. *Progress in Oceanography*, 79: 37–54.

Cartes J.E., Maynou F., Abelló P., Emelianov M., Gil de Sola L., Solé M., (2011a). Long-term changes in the abundance and deepening of the deep-sea shrimp *Aristaeomorpha foliacea* in the Balearic Basin: Relationships with hydrographic changes at the Levantine Intermediate Water. *Journal of Marine System*, 88(4): 516-525.

Cartes J.E., Maynou F. and Fanelli E. (2011b). Nile damming as plausible cause of extinction and drop in abundance of deep-sea shrimp in the western Mediterranean over broad spatial scales. *Progress in Oceanography,* 91: 286-294.

Cartes J.E., LoIacono C., Mamouridis V., López-Pérez C. and Rodríguez P. (2013).Geomorphological, trophic and human influences on the bamboo coral *Isidella elongata* assemblages in the deep Mediterranean: To what extent does Isidella form habitat for fish and invertebrates? *Deep Sea Research Part I*, 76: 52-65.

Cau A. and Deiana A.M. (1982). Sulle variazioni di cattura del gambero rosso "*Aristaeomorpha foliacea*" in relazione alla sua eco-etologia. *Bollettino dei Musei e degli Istituti Biologici dell'Università di Genova* 50: 145-150.

Cau A., Sabatini A., Murenu M., Follesa M. C., Cuccu D. (1994). Considerazioni sullo stato di sfruttamento delle risorse demersali (Mari di Sardegna). *Biologia Marina Mediterranea*, 1(2): 67-76.

Cau A., Carbonell A., Follesa M.C., Mannini A., Norrito G., Orsi-Relini L., Politou C.Y., Ragonese S. Rinelli P. (2002). MEDITS-based information on the deep-water red shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus* (Crustacea: Decapoda: Aristeidae). *Scientia Marina*, 66(2): 103-124.

Chartosia N., Tzomos T.H., Kitsos M.S., Karani. I., Tselepides A., Koukouras A. (2005). Diet comparison of the bathyal shrimps, *Aristeus antennatus* (Risso, 1816) and *Aristaeomorpha foliacea* (Risso 1827) (Decapoda, Aristeidae) in the Eastern Mediterranean. *Crustaceana*, 78(3): 273-284.

Clarke K.R. (1993). Non-parametric multivariate analyses of change in community structure. *Australian Journal of Ecology*, 18, 117–143.

Clarke K.R. and Warwick R.M. (1994). Change in marine communities: an approach to statistical analysis and interpretation. Plymouth, UK: Plymouth Marine Laboratory.

Clarke K.R. and Warwick R.M. (2001). Change in Marine Communities: An Approach to Statistical Analysis and Interpretation (2nd ed.). Primer-E Ltd, Plymouth.

Clarke K.R. and Gorley N.R. (2006). Primer v6: user manual/tutorial. Plymouth, UK: Primer-E.

Coll, M. *et al.,* (2010). The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. *PLoS One* 5(8): e11842.

Colloca F., Bartolino V., Lasinio G.J., Maiorano L., Sartor P., Ardizzone G. (2009). Identifying fish nurseries using density and persistence measures. *Marine Ecology Progress Series*, 381: 287-296.

Company J.B., Maiorano P., Tselepides A., Politou C-Y., Plaity W., Rotllant G. and Sardà F. (2004). Deep-sea decapod crustaceans in the western and central Mediterranean Sea: preliminary aspects of species distribution, biomass and population structure. *Scientia Marina,* 68: 73–86.

Company J.B., Puig P., Sardà F., Palanques A., Latasa M., Scharek R. (2008). Climate influence on deep sea populations. *PLoS One,* 1 e1431.

Conover W.J. (1980). Practical nonparametric statistics. New York: John Wiley & Sons.

D'Onghia G., Tursi A., Maiorano P., Panza M., (1998). Distribution, biology, and population dynamics of *Aristaeomorpha foliacea* (Risso, 1827) (Decapoda, Natantia, Aristeidae) in the north-western Ionian Sea (Mediterranean Sea). *Crustaceana*, 71 (5): 518–544.

D'Onghia G., Mastrototaro F., Matarrese A., Politou C.Y., Mytilineou Ch. (2003). Biodiversity of the Upper Slope Demersal Community in the Eastern Mediterranean: preliminary comparison between two areas with and without trawl fishing. *Northwestern Atlantic Fishery Sciencie*, 31: 263-273.

D'Onghia G., Politou C-Y., Bozzano A., Lloris D., Rotllant G., Sion L. and Mastrotaro F. (2004). Deep-water fish assemblages in the Mediterranean Sea. *Scientia Marina,* 68: 87-99.

D'Onghia G., Capezzuto F., Mytilineou Ch., Maioranoa P., Kapiris K., Carlucci R., Siona L., Tursi A. (2005). Comparison of the population structure and dynamics of (Risso, 1816) between exploited and unexploited areas in the Mediterranean Sea. *Fisheries Research,* 76: 22-38.

D'Onghia G., Giove A., Maiorano P., Carlucci R., Minerva M., Capezzuto F., Sion L., Tursi A. (2012). Exploring relationships between demersal resources and environmental factors in the Ionian Sea (CentralMediterranean). *Journal of Marine Biology*,12 pp.

Danovaro R., Anno A. D., Fabiano M. & Pusceddu A. (2001). Deep-sea ecosystem response to climate changes : the eastern Mediterranean case study. *Trends in Ecology and Evolution*, 16: 505-510.

Demestre M. and Fotuno J.M. (1992). Reproduction of the deep-water shrimp Aristeus. *Marine Ecoogy Progress Series*,1: 41-51.

FAO-GFCM. 2011. Capture Production 1970-2008 database (Re- lease date: December 2010) and FAO, 2000. FishStat Plus. Universal software for fisheries statistical time series. Version 2.3. FAO, Rome.

FAO-SGMED (2009). Working Group on the Mediterranean. Part I. Scientific and technical research series. Publications Office of the European Union, Luxembourg.

FAO 2012. The State of World Fisheries and Aquaculture 2012. Rome. 209 pp.

Field J.G., Clarke K.R. and Warwick R.M. (1982). A practical strategy for analyzing multispecies distribution patterns. *Marine Ecology Progress Series,* 8: 37-52.

Fiorentini L., Dremiere P.Y., Leonori I., Sala A., Palumbo V. (1999). Efficiency of the bottom trawl used for the Mediterranean international trawl survey (MEDITS). *Aquatic Living Resourches*, 12(3): 187-205.

Fiorentino F., Orsi Relini L., Zamboni A., Relini G. (1998). Remarks about the optimal harvest strategy for red shrimps (*Aristeus antennatus*, Risso 1816) on the basis of the Ligurian experience. In: Lleonart J. (Ed.), Cahiers Options Mediterraneennes, vol. 35. Dynamique des populations marines, 323–333.

Fiorentino F., Garofalo G., De Santi A., Bono G., Giusto G.B., Norrito G. (2003). Spatio-Temporal Distribution of Recruits (0 group) of Merluccius merluccius and Phycis blennoides (Pisces; Gadiformes) in the Strait of Sicily (Central Mediterranean). *Hydrobiologia*, 503: 223–236.

Flexas M.M., Boyer D.L., Espino M., Puigdefàbregas J., Rubio A. and Company J.B. (2008). Circulation over a submarine canyon in the NW Mediterranean. *Journal of Geophysical Research*, 113: 1-18.

Follesa M.C., Cuccu D., Murenu M., Sabatini A. and Cau A. (1998). Aspetti riproduttivi negli Aristeidi, *Aristaemorpha foliacea* (Risso, 1827) e *Aristeus antennatus* (Risso, 1816), della classe di età 0+ e 1+. *Biologia Marina Mediterranea*, (5)2: 232–238.

Follesa M.C., Porcu C., Cabiddu S., Mulas A., Deiana A.M. and Cau A. (2011). Deep-water fish assemblages in the central-western Mediterranean (south Sardinian deep-waters). *Journal of Applied Ichthyology,* 27: 129–135.

García-Rodriguez M. and Esteban, A. (1999). On the biology and fishery of *Aristeus antennatus* (Risso, 1816), (Decapoda, Dendrobranchiata) in the Ibiza Channel (Balearic Islands, Spain). *Scientia Marina,* 63: 27–37.

Garofalo G., Fortibuoni T., Gristina M., Sinopoli M. and Fiorentino F. (2011). Persistence and co-occurrence of demersal nurseries in the Strait of Sicily (central Mediterranean): Implications for fishery management. *Journal of Sea Research*, 66: 29-38.

Gayanilo F.C., Sparre, P., Pauly D. (2006). The FAO-ICLARM Stock Assessment Tools (FiSAT) User's Guide. FAO Computerized Information Series, Fisheries 8, 168 pp.

Gennesseaux M. G., Stanley D. J. (1983). Neogene to recent displacement and contact of Sardinian and Tunisian margins, Central Mediterranean. *Smithsonian Contribution to the Marine Science*, 23: 1-24.

GFCM (2002). Report of the fifth session of the SAC. Rome,1-4 July 2002. FAO Fish Rep 684.

GFCM (2004). Report of the seventh session of the SAC. Rome, 19-22 October 2004. FAO Fish Rep 763.

GFCM (2010). Report of the twelfth session of the SAC. Budva, Montenegro, 25-29 January. FAO Fish Rep 936.

GFCM-SAC (2007). Report of the workshop on trawl survey based monitoring fishery system in the Mediterranean. Rome, Italy, 26-28 March.FAO Fish Rep.

GFCM-SAC. (2008) Report of the tenth session of the SAC. Nicosia, Cyprus, 22-26 October 2007. FAO Fish Rep 856.

Ghidalia W. and Bourgois F. (1961). Influence de la témperature et de l'éclairement sur la distribution des crevettes des moyennes et grandes profondeurs. Studes et Revues. General Fishereis Council of Mediterranean, Rome. FAO 16: 1-53.

Green R. H. (1979). Sampling design and statistical methods for biologists. John Wiley & Sons, 257 pp.

Gristina M.F., Badalamenti F., Barbera G., D’Anna G., Pipitone C. (1992). Preliminary data on the feeding habits of *Aristaemorpha foliacea* (Risso) in the Sicilian Channel. *Oebalia*, 17: 143-144.

Guijarro B., Massutí E., Moranta J. and Díaz P. (2008). Population dynamics of the red shrimp *Aristeus antennatus* in the Balearic Islands (western Mediterranean): Short spatio-temporal differences and influence of environmental factors. *Journal of Marine System,* 71: 385-402.

Guillen J., Maynou F., Floros C., Sampsom D., Conidex A., Kapiris K. (2012). A bio-economic evaluation of the potential for establishing a commercial fishery on two newly developed stocks: The Ionian red shrimp fishery. *Scientia Marina,* 76: 597–605.

Guisan A., Edwards T.C. and Hastie T. (2002). Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecological Modelling*, 157: 89-100.

Harris P.T. and T. Whiteway (2011). Global distribution of large submarine canyons: Geomorphic differences between active and passive continental margins. *Marine Geology*, 285: 69-86.

Hilborn R. and Walters C.J. (1992). Quantitative Fisheries Stock Assessment: Choice, Dynamics Uncertainty. Chapman & Hall: 570 pp.

Hinckley S., Hermann AJ., Mier KL., Megrey BA. (2001). Importance of spawning location and timing to successful transport to nursery areas: a simulation study of Gulf of Alaska walleye pollock. *ICES Journal of Marine Science*, 58(5): 1042.

Holthuis L.B. (1980). FAO species catalogue. Vol. 1. Shrimps and lobsters of the world. An annotated catalogue of species of interest to fisheries. *FAO Fisheries Synopsis,* 125: 1-271.

IREPA (2010). Osservatorio economico sulle strutture produttive della pesca marittima in Italia 2010. Edizioni Scientifiche Italiane, Napoli. ISBN 978-88-495-2235-8.

Isaaks E.H. and Srivastava R.M. (1989). An introduction to applied geostatistics. Oxford Univ. Press. New York.

Kapiris K., Tursi A., Mytilineou Ch., Kavadas S., D' Onghia G., Spedicato M.T. (2001). Geographical and bathymetrical distribution of *Aristaeomorpha foliacea* and *Aristeus antennatus* (Decapoda, Aristeidae) in the Hellenic Ionian Sea. 36th CIESM, 24-28 October 2001, Monte Carlo, Congress Proceedings, 36: 280.

Kapiris K. and Thessalou-Legaki M. (2006). Comparative fecundity and oocyte size of *Aristaeomorpha foliacea* and *Aristeus antennatus* in the Greek Ionian Sea (E. Mediterranean) (Decapoda: Aristeidae). *Acta Zoologica*, 245: 239-245.

Kapiris K. and Thessalou-Legaki M. (2009). Comparative reproduction aspects of the deep-water shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus* (Decapoda, Aristeidae) in the Greek Ionian Sea (Eastern Mediterranean). *International Journal of Zoology*, ID 979512, 9 pp.

Kapiris K., Thessalou-Legaki M., Petrakis G., Conides A. (2010). Ontogenetic shifts and temporal changes the trophic patterns of deep-sea red shrimp *Aristaeomorpha foliacea* (Decapods, Aristeidae) in the Eastern Ionian Sea (Eeastern Mediterranean). *Marine Ecology*, 31(2): 341-354.

Kapiris K. and Thessalou-Legaki M. (2011). Feeding ecology of the deep-water blue red shrimp *Aristeus antennatus* (Decapoda: Aristeidae) in the Greek Ionian Sea (Eastern Mediterranean). *Journal of Sea Research,* 65: 151-160.

Koslow J.A. (1997). Seamounts and the ecology of deep-sea fisheries. *American Scientist,* 85: 168-176.

Koslow J.A., Gowlett-Holmes K., Lowry J., O'Hara T., Poore G. and Williams A. (2001). The seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Marine Ecology Progress Series,* 213: 111-125.

Leonardi E. Ardizzone G.D. (1994) Biology of *Aristeomorpha foliacea* along the Latium coast (Central Tyrrhenian Sea). In: M.L. Bianchini and S. Ragonese (eds.), Life cycles and fisheries of the deep-water red shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus*. N.T.R.-I.T.P.P. Spec. Publ., 3: 33-34.

Lloret J., Lleonart J., Solé I. (2001). Fluctuations of landings and environmental conditions in the north-western Mediterranean Sea. *Fisheries Oceanography*, 10: 33-50.

Lo Iacono R. Napolitano E., Marullo S., Artale V., Vetrano A. (2013). Seasonal Variability of the Tyrrhenian Sea Surface Geostrophic Circulation as Assessed by Altimeter Data. *Journal of Physical Oceanography,* 43(8): 1710-1732.

Madurell T., Cartes J.E. and Labropoulou M. (2004). Changes in the structure of fish assemblages in a bathyal site of the Ionian Sea (eastern Mediterranean). *Fishery Research*, 66: 245-260.

Massutì E., Gordon J.D.M., Moranta J., Swan S.C., Stefanescu C. and Merrett N.R. (2004). Mediterranean and Atlantic deep-sea fish assem- blages: differences in biomass composition and size-related structure. *Scientia Marina,* 68: 101-115.

Massutì E. and Renones O. (2005). Demersal resource assemblages in the trawl fishing grounds off the Balearic Islands (western Mediterranean). *Scientia Marina,* 69: 167-181.

Massuti E., Monserrat S., Oliver P., Moranta J., López-Jurado J.J., Marcos M., Hidalgo M., Guijarro B., Carbonell A., Peleda P. (2008). The influence of oceanographic scenarios on the population dynamics of demersal resources in the western Mediterranean: Hypothesis for hake and red shrimp off Balearic Islands. *Journal Marine System,* 71: 421-438.

Matarrese A., D'Onghia G., Deflorio M., Panza M. and Costantino G. (1995). Recenti acquisizioni sulla distribuzione batimetrica di *Aristaemorpha foliacea* e *Aristeus antennatus* (Crustacea, Decapoda) nel Mar Ionio. *Biologia Marina Mediterranea*, 2: 299-300.

Maurin C. (1960). Les crevettes profondes du littoral francais de la Mediterranere partition selon la profondeur. Notes Biome triques. Rapports et Proces-Verbaux des Reunions CIESM, 15: 147-154.

Maynou F. (2008). Environmental causes of the fluctuations of red shrimp (*Aristeus antennatus*) landings in the Catalan Sea. *Journal of Marine System,* 71: 294–302.

Maynou F. and Cartes J. (1997). Field estimation of daily ration in deep-sea shrimp *Aristeus antennatus* (Crustacea : Decapoda) in the western Mediterranean. *Marine Ecology Progress Series,* 153: 191-196.

Maynou F., Sardà F., Tudela S. and Demestre M. (2006). Management strategies for red shrimp (*Aristeus antennatus*) fisheries in the Catalan sea (NW Mediterranean) based on bioeconomic simulation analysis. *Aquatic Living Resourches,* 19: 161-171.

Maynou F. and Cartes J.E. (2012). Effects of trawling on fishes and invertebrates from deep-sea coral facies of *Isidella elongata* in the western Mediterranean. *Journal of the Marine Biological Association of United Kingdom,* 92 (7): 1501-1507.

Medits Handbook (2013). Version n. 7, MEDITS Working Group: 120 pp.

Millot, C. (1999). Circulation in the Western Mediterranean Sea. *Journal of Marine System,* 20: 423-442.

Moranta J., Stefanescu C., Massutì E., Morales-Nin B. and Lloris D. (1998). Fish community structure and depth-related trends on the continental slope of the Balearic Islands (Algerian basin, western Mediterranean). *Marine Ecology Progress Series,* 171: 247-259.

Moranta J., Quetglas A., Massutì E., Guijarro B., Hidalgo M., Diaz P. (2008). Spatio-temporal variations in deep-sea demersal communities off the Balearic Islands (western Mediterranean). *Journal of Marine System,* 71: 346-366.

Mori M., Biagi F., De Ranieri S. (1994). Reproductive biology of *Aristaeomorpha foliacea* in the Southern Tuscany archipelago (Central Tyrrhenian Sea). In: M.L. Bianchini and S. Ragonese (eds.), Life cycles and fisheries of the deep-water red shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus*. N.T.R.-I.T.P.P. Spec. Publ., 3: 31-32.

Mura M. (1987). Crostacei Decapodi batiali della Sardegna meridionale. *Rendiconti Seminario Facoltà Scienze Università Cagliari*, 2: 1-11.

Mura M., Campisi S. and Cau A. (1992). Osservazioni sulla biologia riproduttiva negli Aristeidi demersali del Mediterraneo centro occidentale. *Oebalia*, 17: 75-80.

Mura M., F. Orrù and Cau A. (1997). Osservazioni sull'accrescimento di individui in fase pre-riproduttiva di *Aristeus antennatus* e *Aristaeomorpha foliacea*. *Biologia Marina Mediterranea*, 4(1): 254-261.

Murenu M., Cuccu D., Follesa C., Sabatini A. and Cau A. (1994). The occurrence of *Aristaeomorpha foliacea* in Sardinian waters. In: M.L. Bianchini and S. Ragonese (eds.), Life cycles and fisheries of the deep-water red shrimps

Aristaeomorpha foliacea and *Aristeus antennatus*. N.T.R.-I.T.P.P. Spec. Publ., 3: 49-50.

Naylor E. 2005. Chronobiology: implications for marine resources exploitation and management. *Scientia Marina*, 69: 157-167.

Nouar A., Kennouche H., Ainoucheand N. and Cartes J.E. (2011). Temporal changes in the diet of deep-water Penaeoidean shrimp (*Parapenaeus longirostris* and *Aristeus antennatus*) off Algeria (south western Mediterranean). *Scientia Marina,* 75: 279-288.

Olita A., Sorgente R., Ribotti A., Fazioli L. and Perilli A. (2011). Pelagic primary production in the Algero-Provençal Basin by means of multisensor satellite data: focus on interannual variability and its drivers. *Ocean Dynamic,* 61: 1005-1016.

Olita A., Ribotti A., Fazioli L., Perilli A. and Sorgente R. (2013a). Surface circulation and upwelling in the Western Sardinia sea: A numerical study. *Continental Shelf Research,* 71: 95-108.

Olita A., Sparnocchia S., Cusí S., Fazioli L., Sorgente R., Tintoré J. and Ribotti A. (2013b). Observations of phytoplankton spring bloom onset triggered by a density front in NW Mediterranean. *Ocean Science Discussion,* 10: 1559-1580.

Orrù P. and Ulzega A. (1988). Ricerche geomorfologiche sul canyon Gonone (Sardegna Orientale). Bulletin de la Societé Royale des Sciences de Liege 57: 415-427.

Orsi Relini L. and Semeria M. (1983). Oogenesis and fecundity in bathyal penaeid prawns, *Aristeus antennatus* and *Aristaeomorpha foliacea*. Rapport de la Commission Internationale pour la Exploration Scientifique de la Mer Mediterranée.

Orsi Relini L., Mannini A. and Relini G. (2012). Updating knowledge on growth, population dynamics, and ecology of the blue and red shrimp, *Aristeus antennatus* (Risso, 1816), on the basis of the study of its instars. *Marine Ecology,* 34(1): 90-102.

Palmas F., Pesci P., Buttu S., Atzori G., Secci M., Sabatini A. (2013). Estimated impact of the horizontal net opening in the calculation of abundance indeces in the trawl survey. *Biologia Marina Mediterranea*, 20(1): 200-201.

Palomba M. and Ulzega A. (1984). Geomorfologia dei depositi quaternari del Rio Quirra e della piattaforma continentale antistante (Sardegna Orientale). *Rendiconti del Seminario della Facoltà di Scienze,* 54: 109-121.

Papacostantinou C. and Kapiris K. (2001). Distribution and population structure of the red shrimp (*Aristeus antennatus*) on an unexploited fishing ground in the Greek Ionian Sea. *Aquatic Living Resources,* 14: 303-312.

Papacostantinou C. and Kapiris K. (2003). The biology of the giant red shrimp (*Aristaeomorpha foliacea*) at an unexploited fishing ground in the Greek Ionian Sea. *Fisheries Research*, 62: 37-51.

Pauly D. (1980). On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks.

Journal du Conseil Permanent International pour Exploration de le Mer, 39: 175-192.

Pauly D. (1983). Some simple methods for the assessment of tropical fish stocks. FAO Fish Tech. Pap. 234: 52 pp.

Pérès J.M. (1982). Major benthic assemblages. *Marine ecology*, 5: 373-508.

Perilli A., Pinardi N., Ribotti A., Sorgente R. and Calise L. (1997). Seasonal variability of the Levantine Intermediate Waters in the Western Mediterranean-Algerian Provengal basin. Journal of *Operation Oceanography,* 576-583.

Pittman S.J. and McAlpine C.A. 2001. Movements of marine fish and decapods crustaceans: Process, theory and application. *Advanced Marine Biology An Annual Review*, 44: 206-295.

Politou C.Y., Kapiris K., Maiorano P., Capezzuto F., Dokos J. (2004). Deep-sea Mediterranean biology: the case of *Aristaeomorpha foliacea* (Risso, 1827) (Crustacea: Decapoda: Aristeidae). *Scientia Marina*, 68(3): 117-127.

Preciado I., Velasco F. and Olaso I. (2008). The role of pelagic fish as forage for the demersal fish community in the Southern Bay of Biscay. *Journal of Marine Systems,* 72: 407-417.

Raffaelli D., Bell E., Weithoff G., Matsumoto A., Cruz-Motta J.J., Kershaw P., Parker R., Parry D., Jones M. (2003). The ups and downs of benthic ecology: considerations of scale, heterogeneity and surveillance for benthic-pelagic coupling. *Journal of Experimental Marine Biology and Ecology*, 285-286.

Ragonese S., Bianchini L., Gallucci V.F. (1994). Growth and mortality of the red shrimp Aristaeomorpha foliacea in the Sicilian channel (Mediterranean Sea). *Crustaceana*, 67: 348-361.

Ragonese S. and Bianchini M.L. (1995). Size at sexual maturity in red shrimp females, *Aristaeomorpha foliacea*, from the Sicilian channel (Mediterranean Sea). *Crustaceana*, 68: 73-82.

Ragonese S., Bertolino F., Bianchini M. L. (1997). Biometric relationships of the red shrimp, *Aristaeomorpha foliacea* Risso 1827, in the Strait of Sicily (Mediterranean Sea). *Scientia Marina*, 61(3): 367-377.

Ragonese S., Vitale S., Dimech M., and De Santi A. (2012). Growth discontinuity in males of the deep-water giant red shrimp *Aristaeomorpha foliacea* in the Mediterranean Sea. *Marine Ecology*, 33(3): 386-392.

Relini G. and Orsi Relini L. (1987). The decline of red shrimps stocks in the Gulf of Genova. *Investigation Pesquera*, 51(1): 254-260.

Relini G. (1998). Valutazione delle risorse demersali. *Biologia Marina Mediterranea*, 5: 3-19.

Relini G., Bertrand J. and Zamboni A. (1999). Synthesis of the knowledge on bottom fishery resources in central Mediterranean (Italy and Corsica). *Biologia Marina Mediterranea*, 6 (Supplement 1) 868 pp.

Relini G. (2000). La ricerca sulla pesca: le risorse demersali. *Biologia Marina Mediterranea*, 7(4): 13-45.

Ribotti A., Puillat I., Sorgente R., Natale S. (2004). Mesoscale circulation in the surface layer off the southern and western Sardinia island in 2000-2002. *Chemistry and Ecology*, 20(5): 345-363.

Righini P., Abella A. (1994). Life cycle of *Aristeus antennatus* and *Aristaeomorpha foliacea* in the Northern Tyrrhenian Sea. In: M.L. Bianchini and S. Ragonese (eds.), Life cycles and fisheries of the deep-water red shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus*. N.T.R.-I.T.P.P. Spec. Publ., 3: 29-30.

Rinelli P., Bianchini M. L., Casciaro L., Giove A., Mannini A., Profeta A., Politou C.Y., Ragonese S., Sabatini A. (2013). Occurrence and abundance of the deep-water red shrimps *Aristeus antennatus* (Risso, 1816) and *Aristaeomorpha foliacea* (Risso, 1827) in the Mediterranenan Sea. *Cahiers de Biologie Marine*, 54: 335-347.

Robinson A.R. and Leslie W.G. (2001). Mediterranean Sea Circulation. *Ocean Current,* 1-19.

Rochet M.J., Trenkel V.M., Carpentier A., Coppin F., De Sola L.G., Léauté J.P., Mahé J.C., Maiorano P., Mannini A., Murenu M., Piet G., Politou C.Y., Reale B.k., Spedicato M.T., Tserpes G., Bertrand J. (2010). Do changes in environmental and fishing pressures impact marine communities? An empirical assessment. *Journal of Applied Ecology*, 47(4): 741-750.

Rogers A.D. (1994). The biology of seamounts. *Advances in Marine Biology,* 30: 305-350.

Rowe G.T. (1971). Observations in bottom currents and epibenthic populations in Hatteras Submarine Canyon. *Deep-Sea Research,* 18: 569-581.

Sabatini A., Follesa M. C., Locci I., Pendugiu A. A., Pesci P., Cau A. (2007). Assemblages in a submarine canyon: influence of depth and time. *Hydrobiologia*, 580: 265-271.

Sabatini A., Follesa M. C., Locci I., Matta G., Palmas F., Pendugiu A.A., Pesci P. and Cau A. (2011). Demersal assemblages in two trawl fishing lanes located on the Baronie Seamount (Central Western Mediterranean). *Journal of the Marine Biological Association of the United Kingdom*, 91(1): 65-75.

Sabatini A., Locci I., Deiana A.M., Follesa M.C., Gastoni A., Pendugiu A.A., Pesci P., Cau A. (2013). Temporal trends in biodiversity of the middle-slope assemblages in Sardinian seas (Central-Western Mediterranean). *Journal of the Marine Biological Association of the United Kingdom* 1-14.

Sammari C., Millot C., Stefani A. and Brahim M. (1999). Hydrological characteristics in the Tunisia, Sardinia and Sicily area during spring 1995. *Deep Sea Research Part,* 46: 1671-1703.

Santinelli C., Gasparini G.P., Nannicini L. and Seritti A. (2002). Vertical distribution of dissolved organic carbon (DOC) in the Western Mediterranean Sea in relation to the hydrological characteristics. *Deep-Sea Research I,* 49: 2203-2219.

Sardà F. and Demestre M. (1987). Estudio bioecologico della gamba *Aristeus antennatus*, Risso 1816, en nel mar Catalan. Investigation Pesquera, 51(1): 213-232.

Sardà F., Maynou F. and Tallo L.I. (1997). Seasonal and spatial mobility patterns of rose shrimp (Aristeus antennatus, Risso, 1816) in the western Mediterranean: result of a long-term study. *Marine Ecology Progress Series,* 159: 133-141.

Sardà F., Company J.B., Maynou F. (2002). Deep-sea shrimp *Aristeus antennatus* (Risso, 1816) in the Catalan Sea, a review and perspectives. *Journal of Northwestern Atlantic Fishery Science*, 31: 1-10.

Sardà F., Calafat A., Mar Flexas M., Tselepides A., Canals M., Espino M. and Tursi A. (2004). An introduction to Mediterranean deep-sea biology. *Scientia Marina*, 68: 7-38.

Sardà F., Company J.B., Bahamónb N., Rotllant G., Flexas M.M., Sánchez J.D., Zúñiga D., Coenjaerts J., Orellana D., Jordà G., Puigdefábregas J., Sánchez-Vidal A., Calafat A., Martín D., Espino M. (2009). Relationship between environment and the occurrence of the deep-water rose shrimp *Aristeus antennatus* (Risso, 1816) in the Blanes submarine canyon (NW Mediterranean). *Progress in Oceanography,* 82: 227-238.

Sardà F., Roldán M.I., Heras S., Maltagliati F. (2010). Influence of the genetic structure of the red and blue shrimp, *Aristeus antennatus* (Risso, 1816), on the sustainability of a deep-sea population along a depth gradient in the Western Mediterranean. *Scientia Marina*, 74: 569-575.

Sardà F. and Company J.B. (2012). The deep-sea recruitment of *Aristeus antennatus* (Risso, 1816) (Crustacea: Decapoda) in the Mediterranean Sea. *Journal of Marine System*, 105(108): 145-151.

Schlitzer R. (2002). Interactive analysis and visualization of geoscience data with Ocean Data View. *Computer Geoscience,* 28: 1211-1218.

Schröder K., Gasparini G.P., Tangherlini M. and Astraldi M. (2006). Deep and intermediate water in the western Mediterranean under the influence of the Eastern Mediterranean Transient. *Geophysical Research Letter,* 33: 1-6.

Serena F. (2005). Field identification guide to the sharks and rays of the Mediterranean and Black Sea. FAO Species Identification Guide for Fishery Purposes. Rome: FAO, 97 pp.

Sheppard, F.P., Marshall N.F., McLoughlin P.A. (1974). Current in submarine canyons. *Deep-Sea Research,* 21: 691-706.

Somerfield P.J. and Clarke K.R. (1997). A comparison of some methods commonly used for the collection of sublittoral sediments and their associated fauna. *Marine Environmental Research*, 43: 145-156.

Sorgente R., Olita A., Oddo P., Fazioli L. and Ribotti A. (2011). Numerical simulation and decomposition of kinetic energy in the Central Mediterranean: insight on mesoscale circulation and energy conversion. *Ocean Science,* 7: 503-519.

Souplet A. 1996. Calculation of abundance and length frequencies in the MEDITS survey. In: Bertrand J. (ed), Campagne internationale de chalutage demersal en Méditerranée (MEDITS). Campagne 1995, Vol. III. Rapport final de contract CEE - IFREMER - IEO - SIBM - NCMR (MED/93/020, 0, 18, 006, 004).

Sparre P. and Venema S.C. (1998). Introduction to tropical fish stock assessment Part 1. Manual. FAO Fisheries Technical Papers 306.1 (Rev. 2): 1-407.

Spedicato M.T., Lembo G., Carbonara P., Silecchia T. (1994). Biological parameters and dynamics of *Aristaeomorpha foliacea* in Southern Tyrrhenian Sea. In: M.L. Bianchini and S. Ragonese (eds.), Life cycles and fisheries of the deep-water red shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus*. N.T.R.-I.T.P.P. Spec. Publ., 3: 35-36.

Testor PB., Eranger K., Mortier L. (2005). Modeling the deep eddy field in the southwestern Mediterranean: The life cycle of Sardinian eddies. *Geophysical Research Letters,* 32: 13602.

Thessalou-Legaki M. (1994). Distribution of *Aristeus antennatus* and *Aristaeomorpha foliacea* in the eastern Mediterranean Sea. In: M.L. Bianchini and S. Ragonese (eds.), Life cycles and fisheries of the deep-water red shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus*. N.T.R.-I.T.P.P. Spec. Publ., 3: 61.

Tobar R. and Sardà` F. (1992). Annual and diel light intensity cycle as a predictive factor in deep-water fisheries for the prawn Aristeus antennatus, Risso 1816. *Fisheries Research*, 15: 179-196.

Tortonese E. (1970). Osteichthyes. (Pesci ossei). Volume X. Bologna: Calderini, 565 pp.

Tortonese E. (1975) Osteichthyes. (Pesci ossei). Volume XI. Bologna: Calderini, 636 pp.

Tudela S., Sardà F., Maynou F. and Demestre M. (2003). Influence of submarine canyons on the distribution of the deep-water shrimp, *Aristeus antennatus* (Risso, 1816) in the NW Mediterranean. *Crustaceana,* 76: 217-225.

Tudela S. (2004). Ecosystem effects of fishing in the Mediterranean: an analysis of the major threats of fishing gear and practices to biodiversity and marine habitats. Rome: FAO, GFCM Studies and Reviews, 74.

Ulzega A. (1988). Carta geomorfologica della Sardegna marina e continentale: Progetto finalizzato Oceanografia e Fondi marini.

Ungaro N., C.A. Marano R. Marsan M. Martino M.C. Marzano G. Strippoli and A. Vlora (1999). Analysis of demersal species assemblages from trawl surveys in the South Adriatic Sea. *Aquatic Living Resourches*, 13: 177-185.

Vaccarella R., Marano G., Petruzzi T. (1986). Pesca a strascico nel basso Adriatico: Crostacei. *Nova Thalassia*, 8(3): 663-667.

Würtz M. (2012). Mediterranean Submarine Canyons: Ecology and Governance, Glang, Switzerland and Malaga, Spain: IUCN, 216 pp.

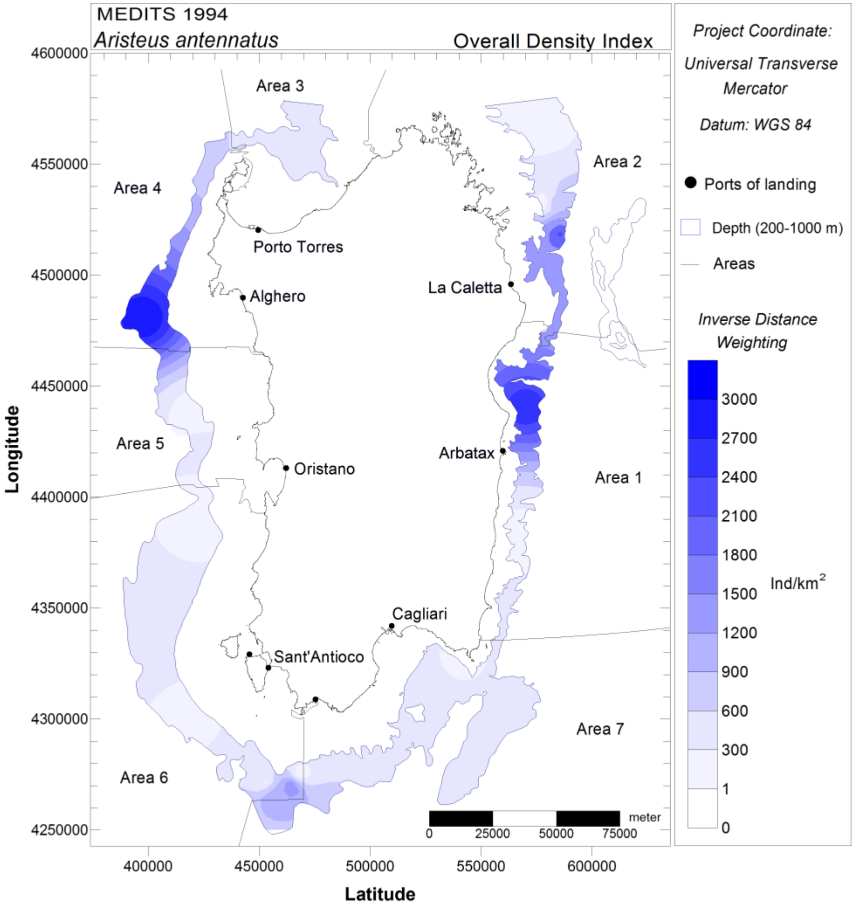
WWF/IUCN (2004). The Mediterranean deep-sea ecosystems: an overview of their diversity, structure, functioning and anthropogenic impacts, with a proposal for conservation. IUCN, Malaga and WWF, Rome.

Zar J.H. (1999). Biostatistical Analysis, 3rd edn. Prentice Hall, Englewood Cliffs, NJ, 662 pp.

10 APPENDIXE I – THEMATIC SPATIAL MAPS

INVERSE DISTANCE WEIGHTING

Aristeus antennatus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Aristeus antennatus
Overall Density Index
Project Coordinate:
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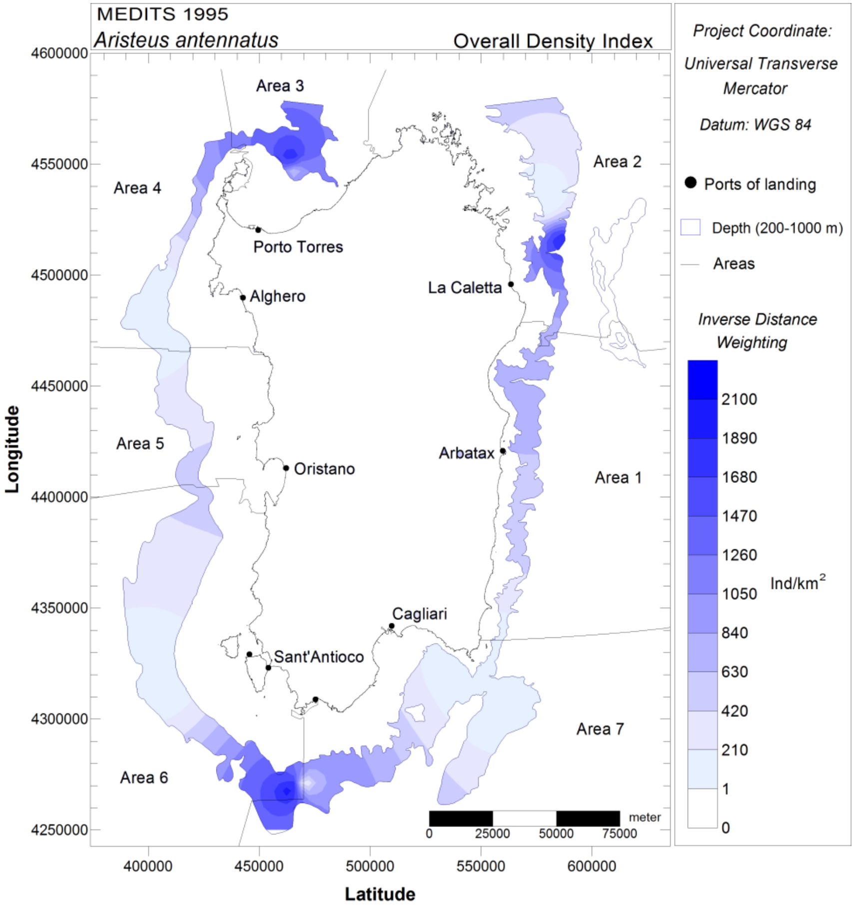
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
3000
2700
2400
2100
1800
1500
1200
900
600
300
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Arbatax
Oristano
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude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Overall Density Index
Project Coordinate:
Universal Transverse Mercator
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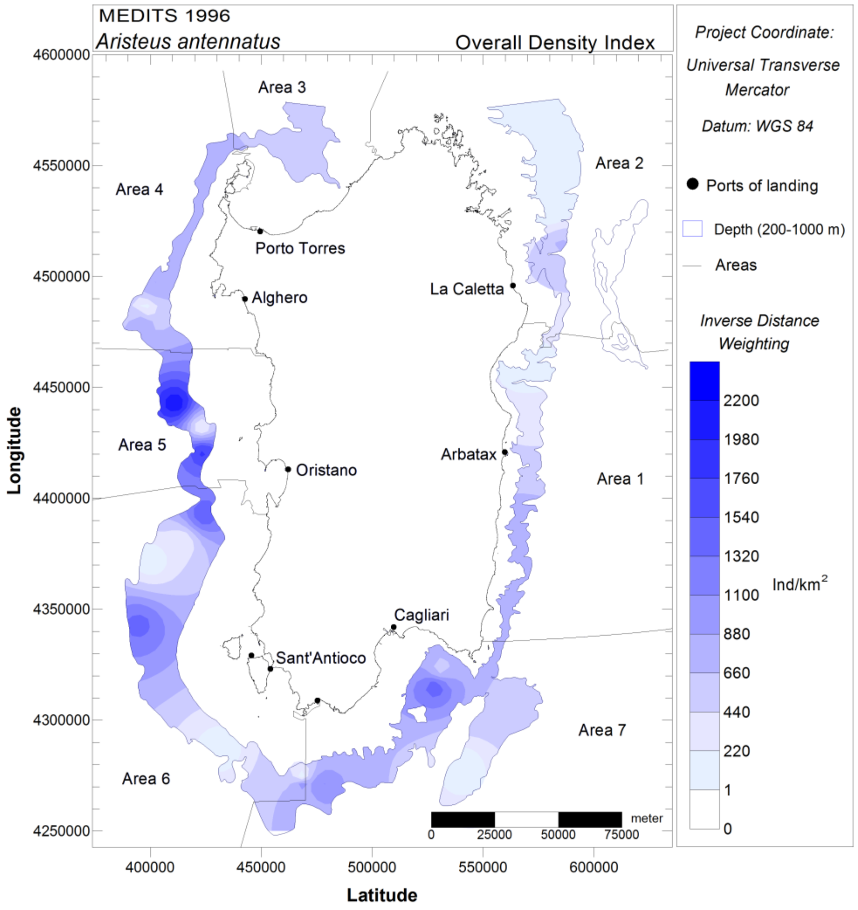
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
2100
1890
1680
1470
1260
1050
840
630
420
210
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Arbatax
Oristano
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude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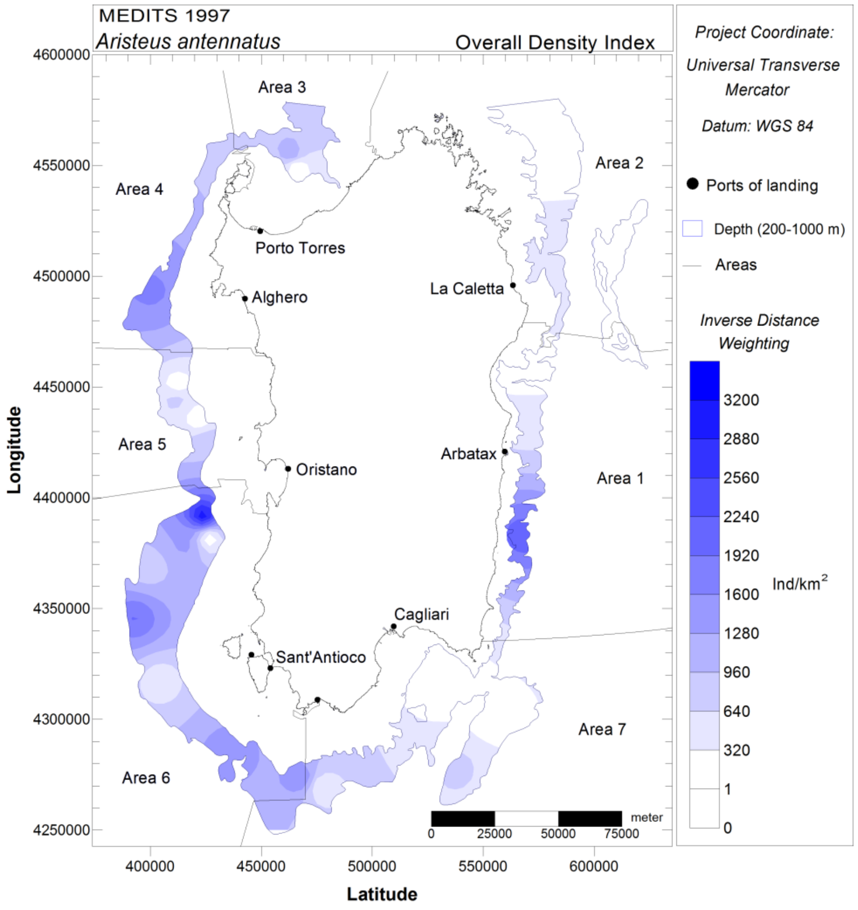
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
2200
1980
1760
1540
1320
1100
880
660
440
220
1
0
Ind/km^2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Longitude
400000
450000
500000
550000
600000
Latitude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Overall Density Index
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Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
3200
2880
2560
2240
1920
1600
1280
960
640
320
1
0
Ind/km^2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
4600000
4550000
4500000
4450000
4400000
4350000
4300000
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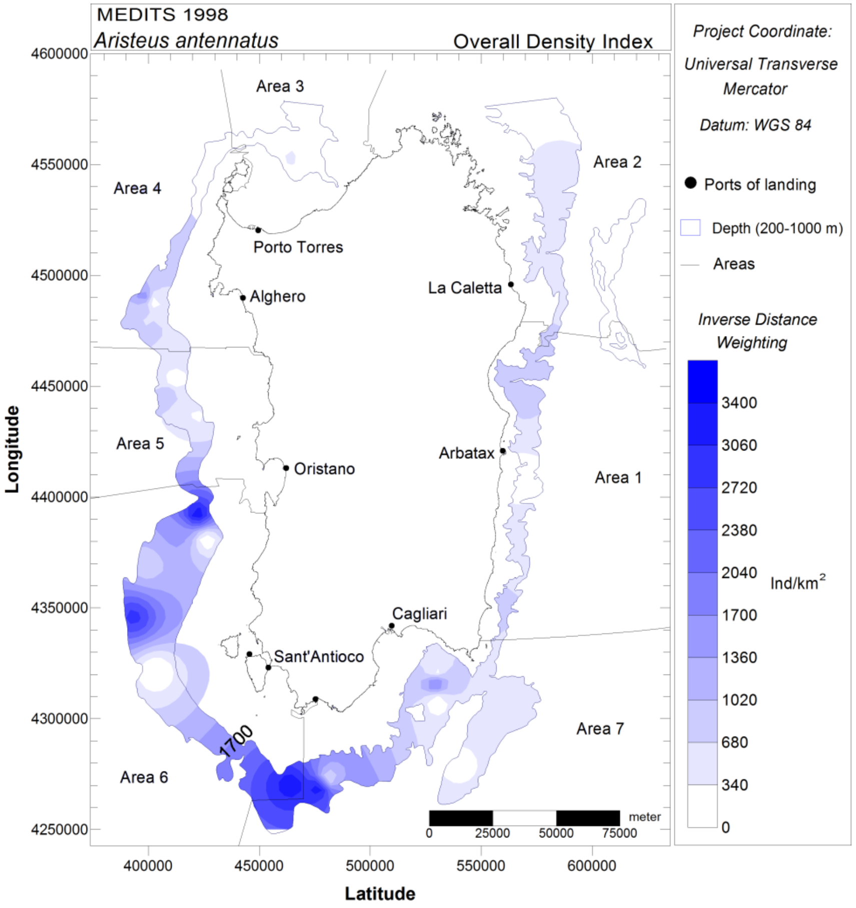
Longitude
400000
450000
500000
550000
600000
Latitude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Aristeus antennatus
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
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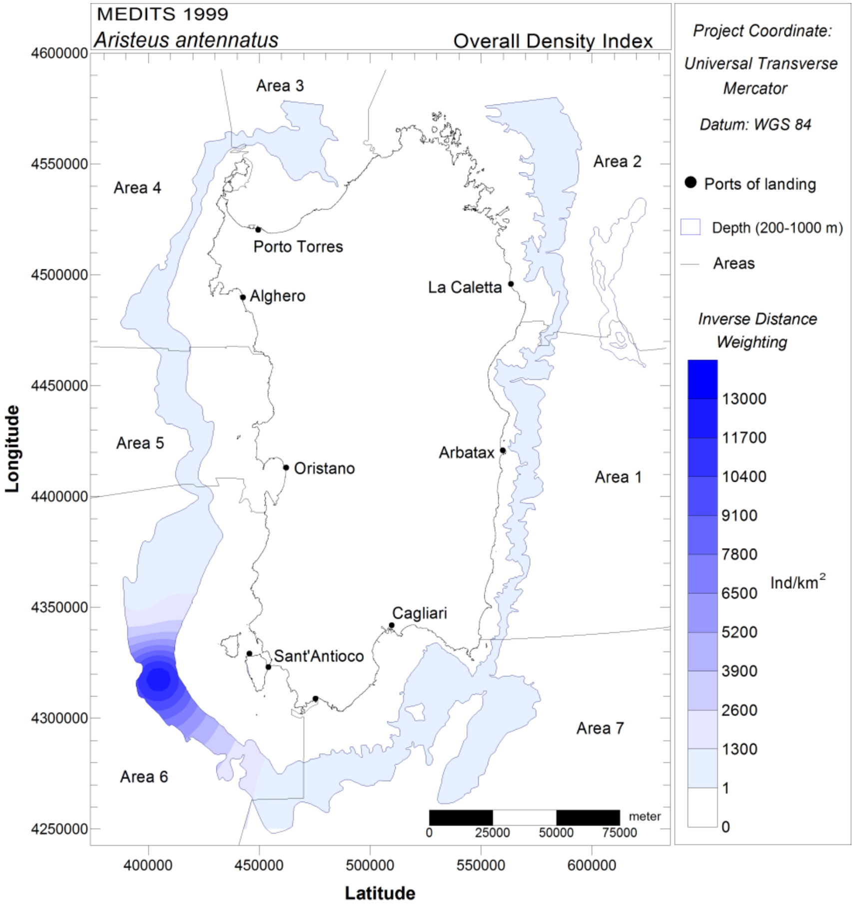
Depth (200-1000 m)
Areas
Inverse Distance Weighting
3400
3060
2720
2380
2040
1700
1360
1020
680
340
0
Ind/km^2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
1700
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Longitude
400000
450000
500000
550000
600000
Latitude
meter
0
25000
50000
75000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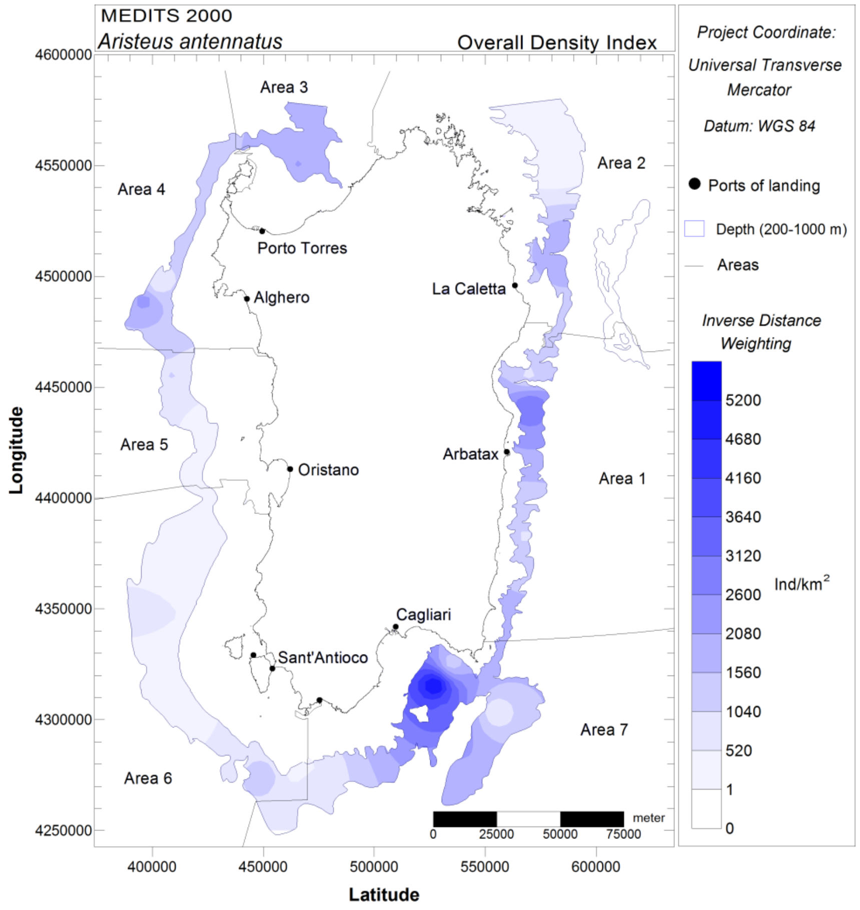
Depth (200-1000 m)
Areas
Inverse Distance Weighting
13000
11700
10400
9100
7800
6500
5200
3900
2600
1300
1
0
Ind/km^2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Longitude
400000
450000
500000
550000
600000
Latitude
meter
0
25000
50000
75000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Overall Density Index
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Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
5200
4680
4160
3640
3120
2600
2080
1560
1040
520
1
0
Ind/km^2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
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450000
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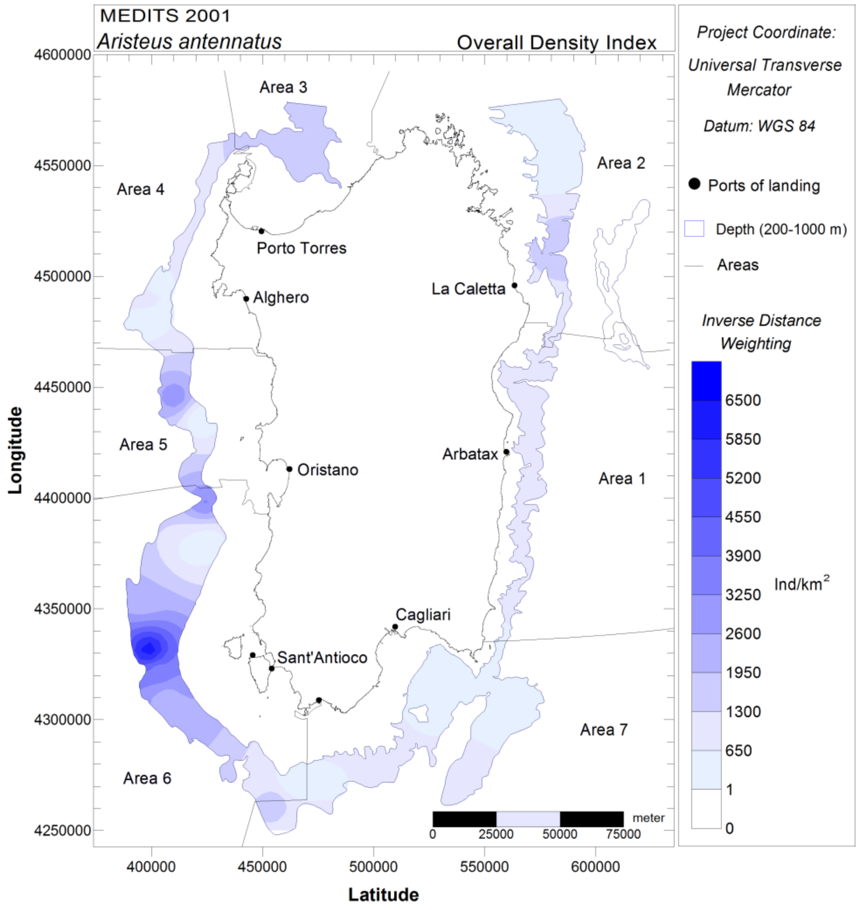
Longitude
Latitude
0
25000
50000
75000
meter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Overall Density Index
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Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
6500
5850
5200
4550
3900
3250
2600
1950
1300
650
1
0
Ind/km^2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
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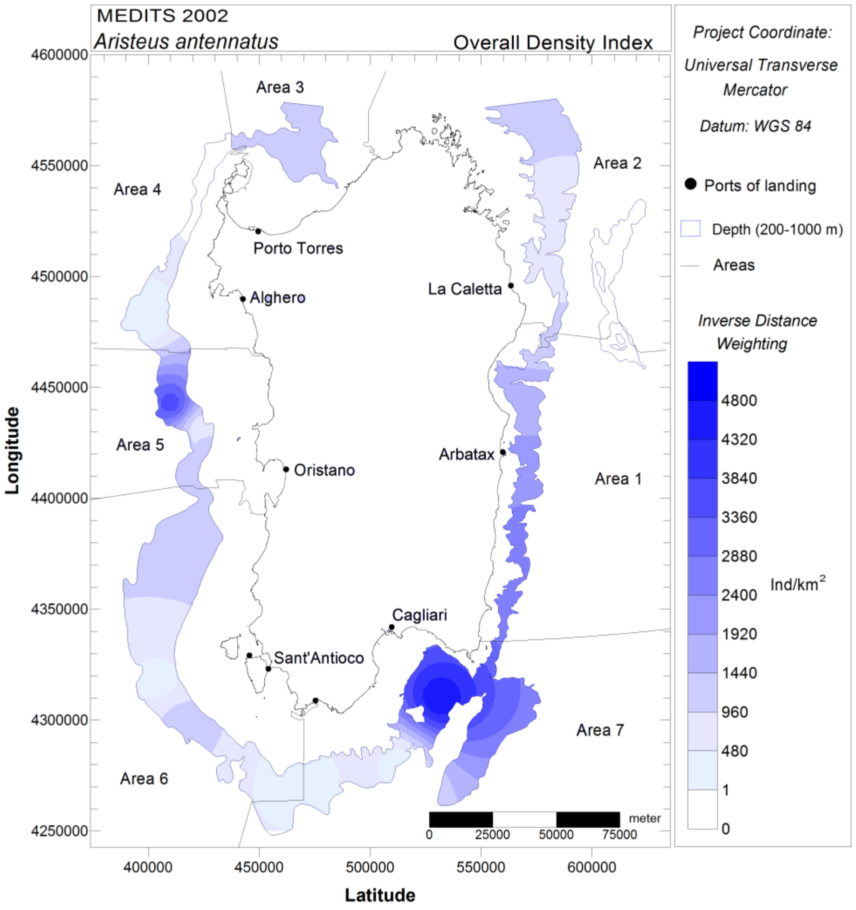
Longitude
Latitude
0
25000
50000
75000
meter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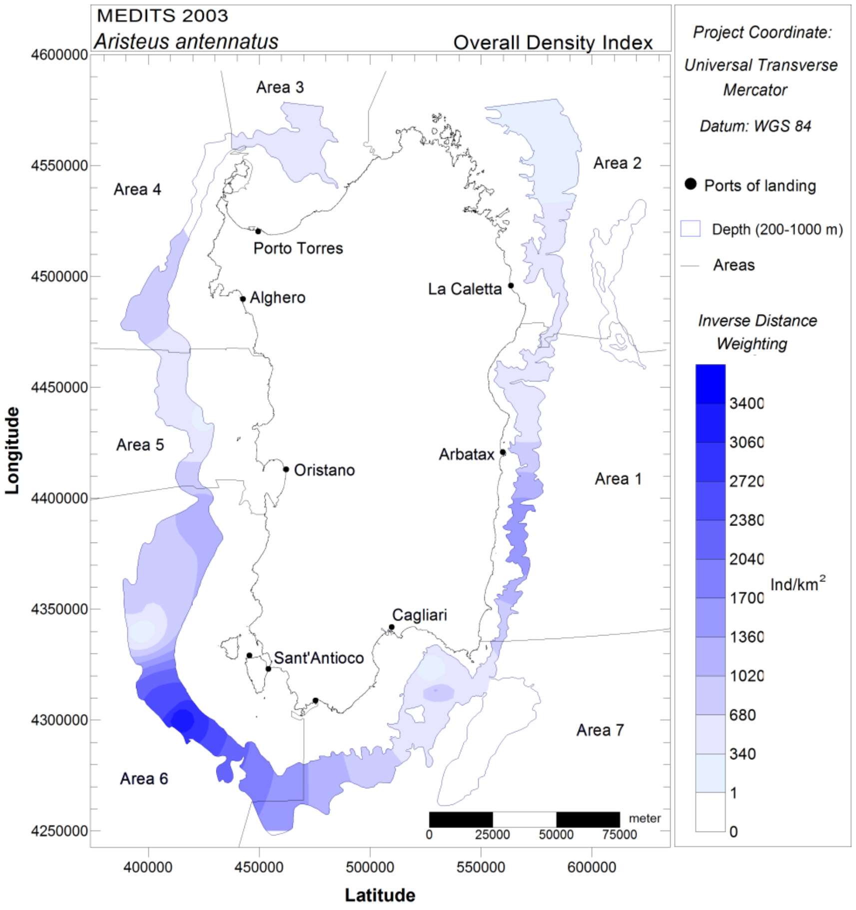
Overall Density Index
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude
0
25000
50000
75000
meter
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
4800
4320
3840
3360
2880
2400
1920
1440
960
480
1
0
Ind/km²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Overall Density Index
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude
0
25000
50000
75000
meter
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
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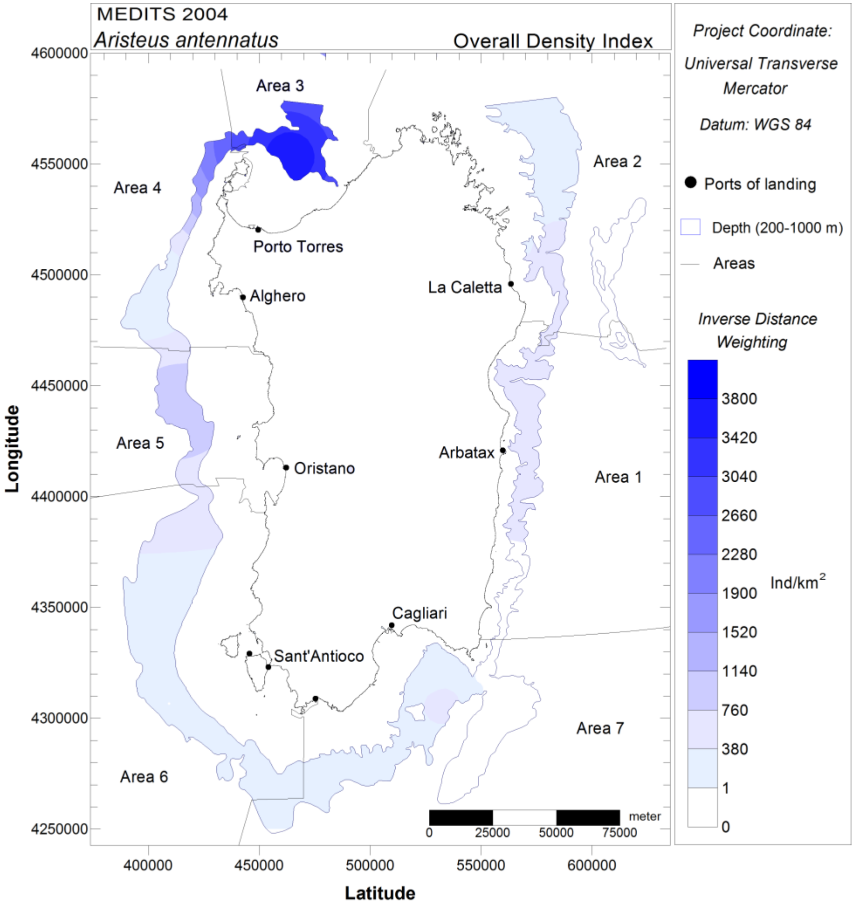
3060
2720
2380
2040
1700
1360
1020
680
340
1
0
Ind/km²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Overall Density Index
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Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
3800
3420
3040
2660
2280
1900
1520
1140
760
380
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
Longitude
Latitude
4600000
4550000
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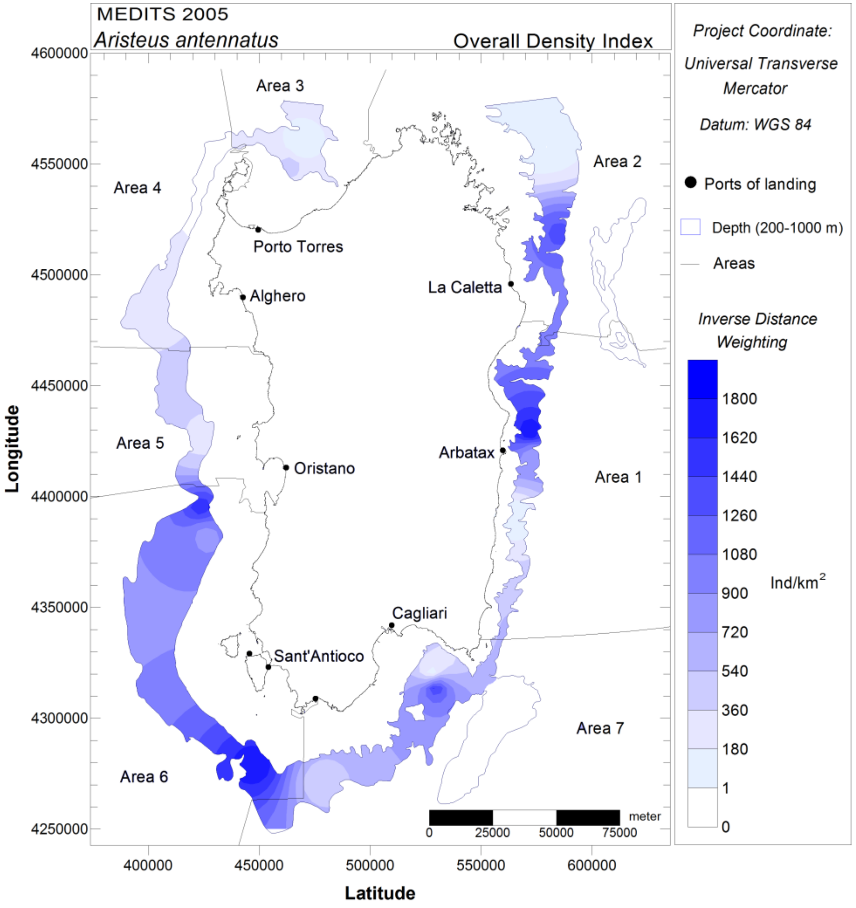
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Overall Density Index
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Depth (200-1000 m)
Areas
Inverse Distance Weighting
1800
1620
1440
1260
1080
900
720
540
360
180
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
Longitude
Latitude
4600000
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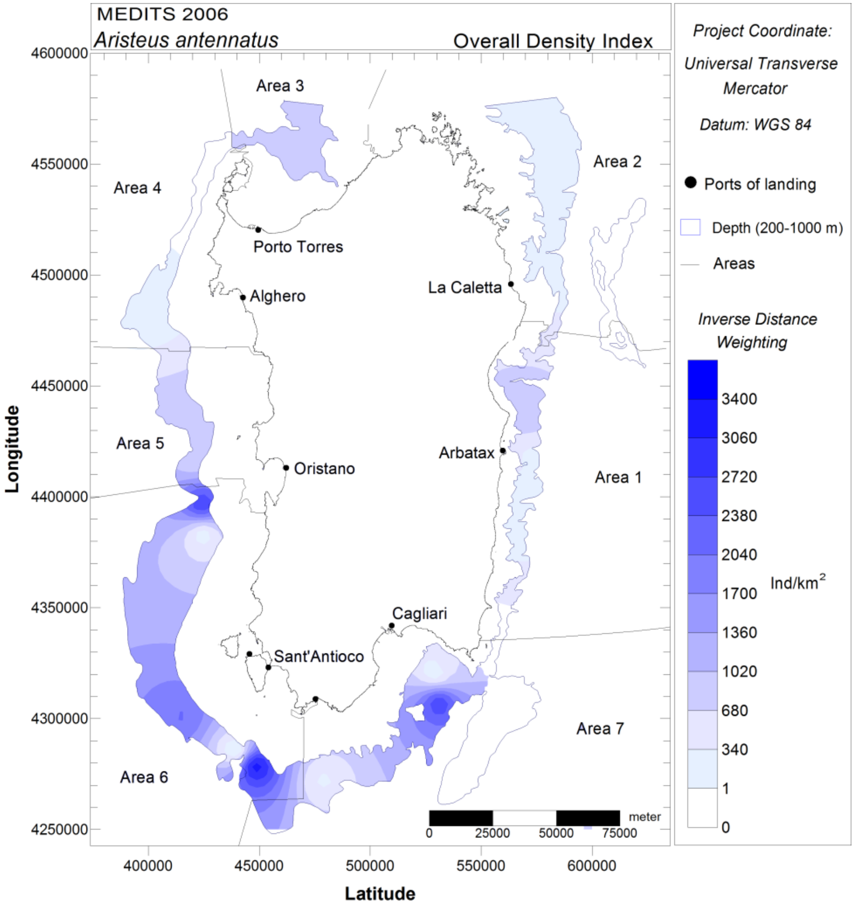
75000
meter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Areas
Inverse Distance Weighting
3400
3060
2720
2380
2040
1700
1360
1020
680
340
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
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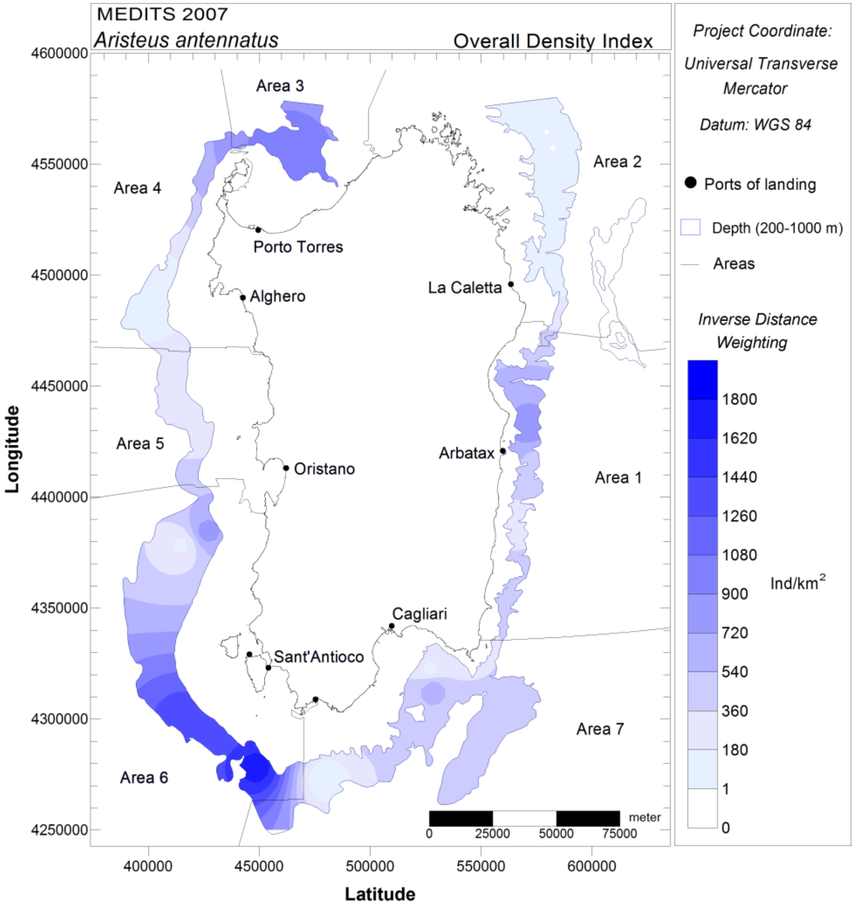
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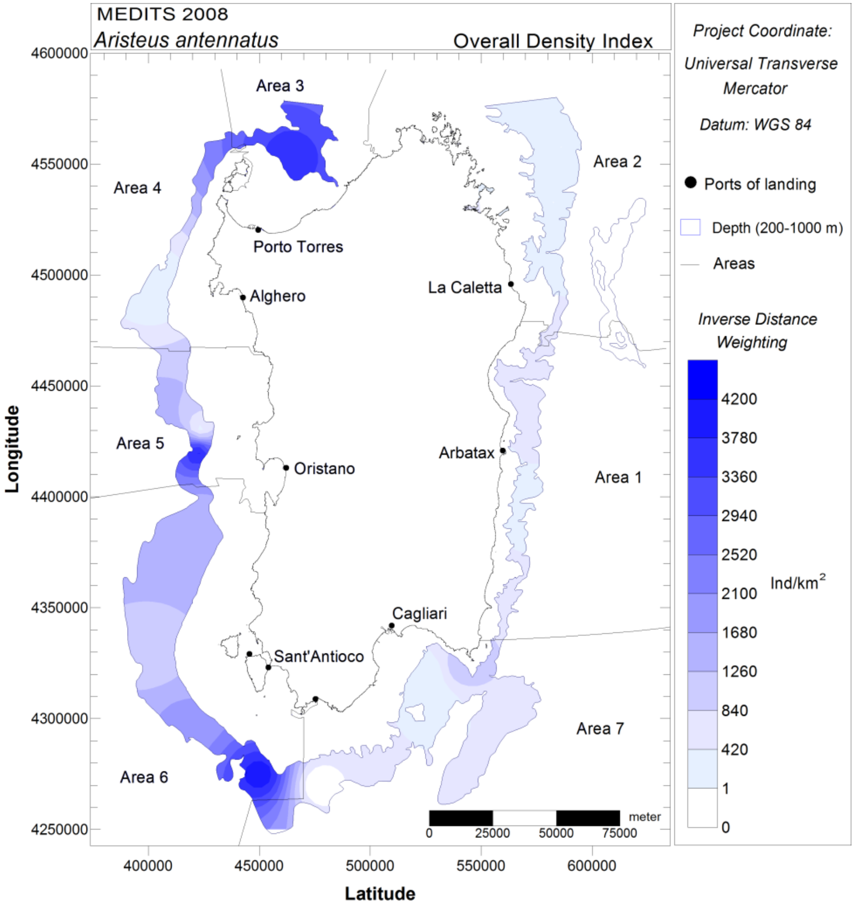
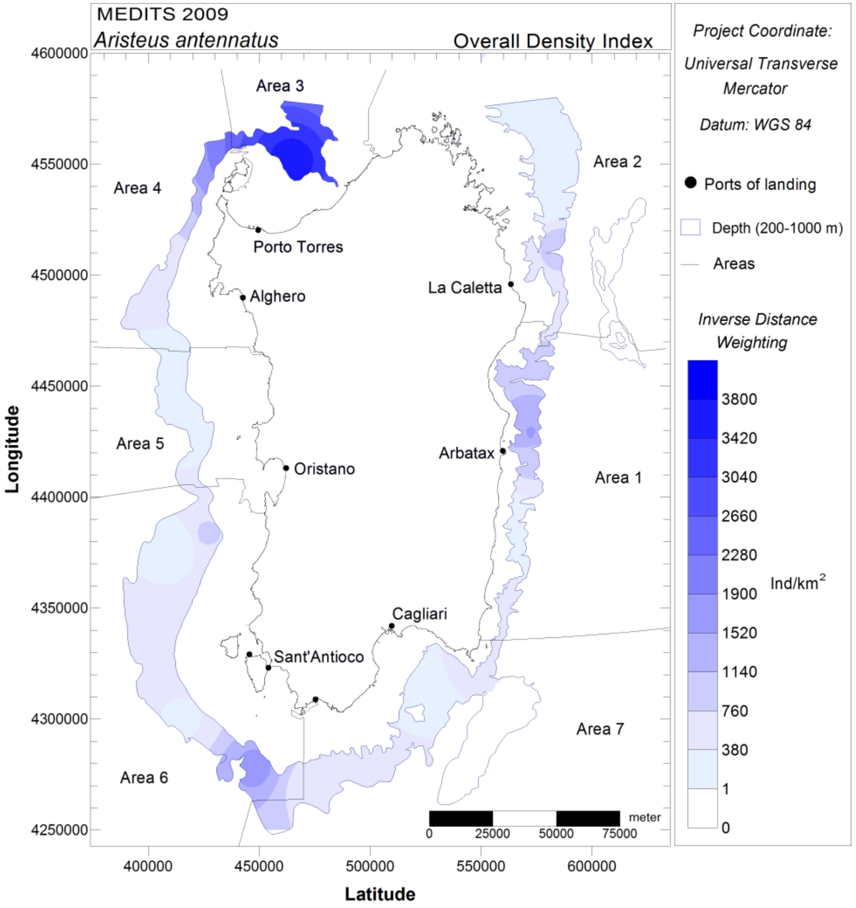
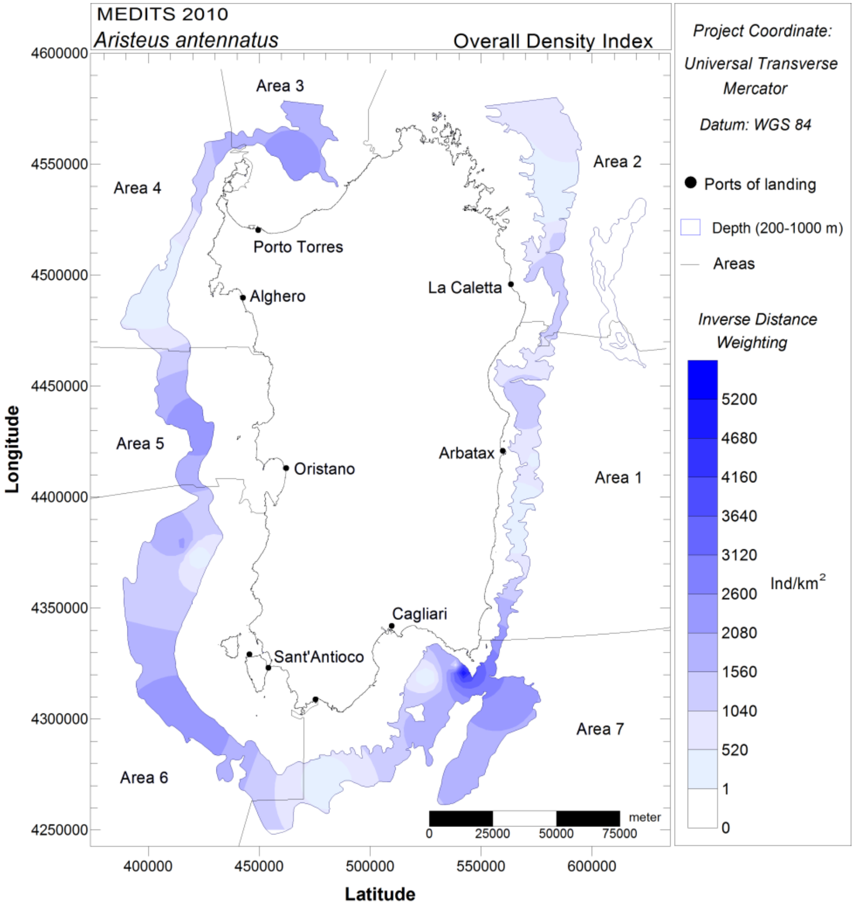
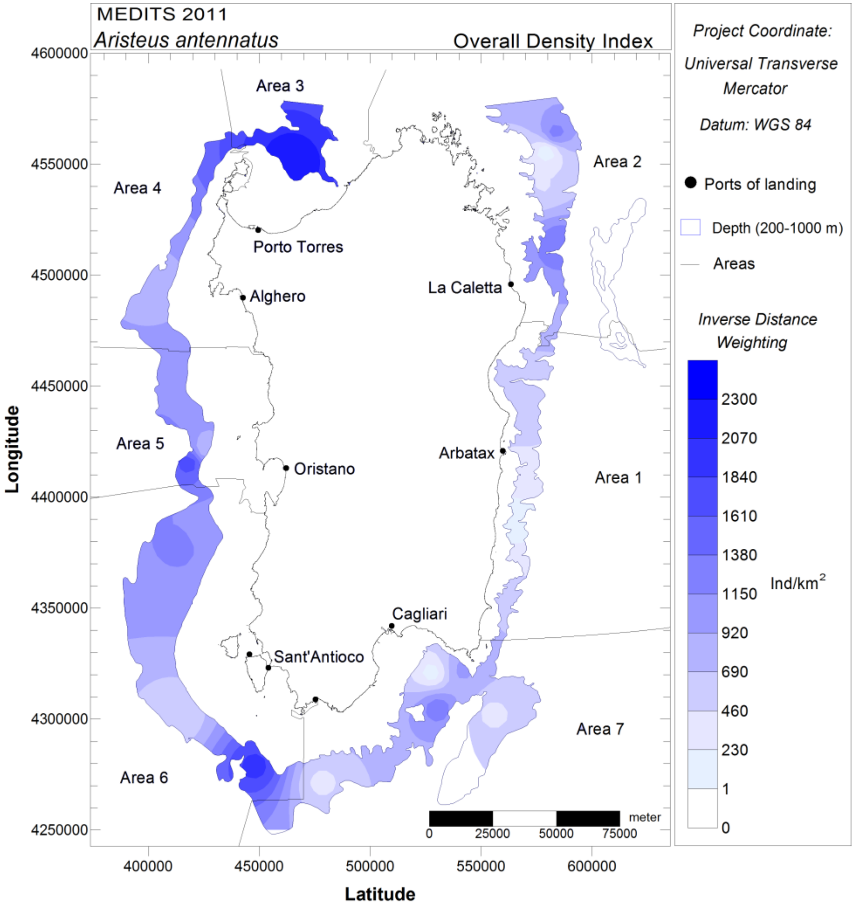
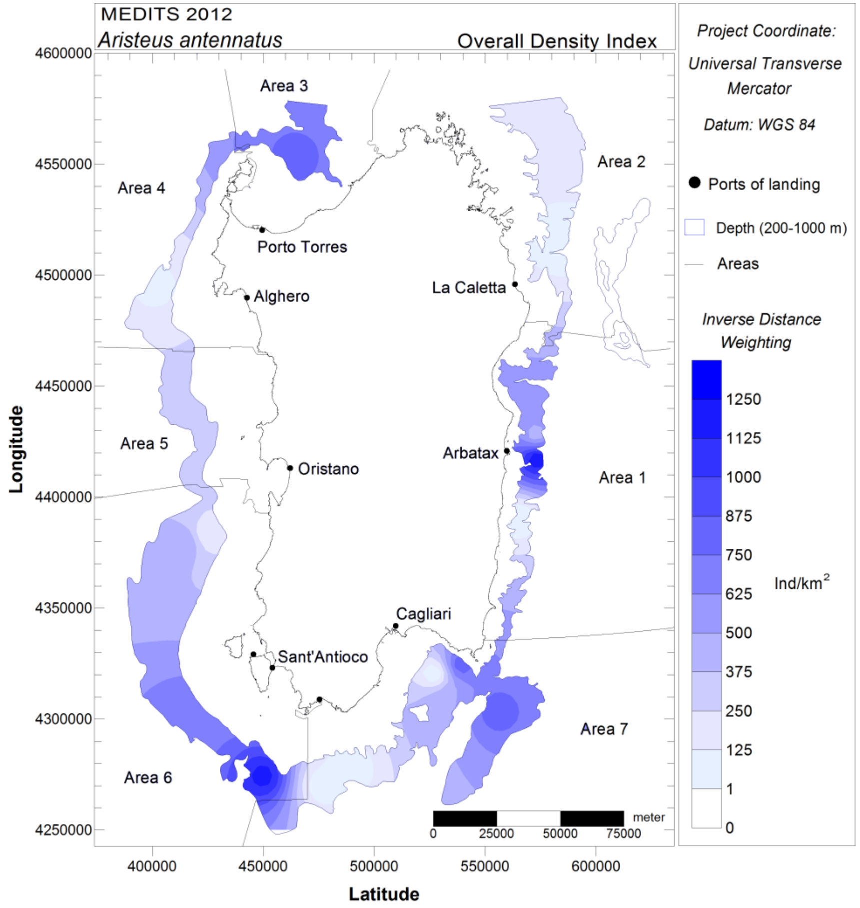
Depth (200-1000 m)
Areas
Inverse Distance Weighting
1800
1620
1440
1260
1080
900
720
540
360
180
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Longitude
400000
450000
500000
550000
600000
Latitude
0
25000
50000
75000
meter


MEDITS 2008
Aristeus antennatus
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
4200
3780
3360
2940
2520
2100
1680
1260
840
420
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude


MEDITS 2009
Aristeus antennatus
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
3800
3420
3040
2660
2280
1900
1520
1140
760
380
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude


MEDITS 2010
Aristeus antennatus
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
5200
4680
4160
3640
3120
2600
2080
1560
1040
520
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
0
25000
50000
75000
meter
Longitude
Latitude

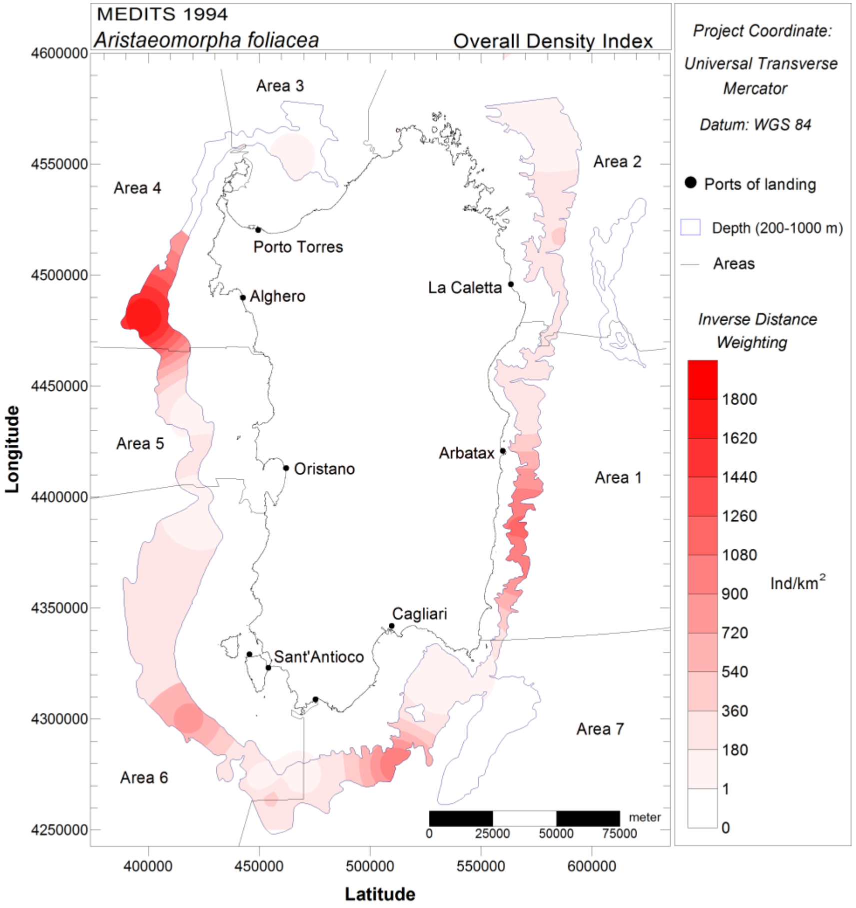

MEDITS 2011
Aristeus antennatus
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
2300
2070
1840
1610
1380
1150
920
690
460
230
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
0
25000
50000
75000
meter
Longitude
Latitude

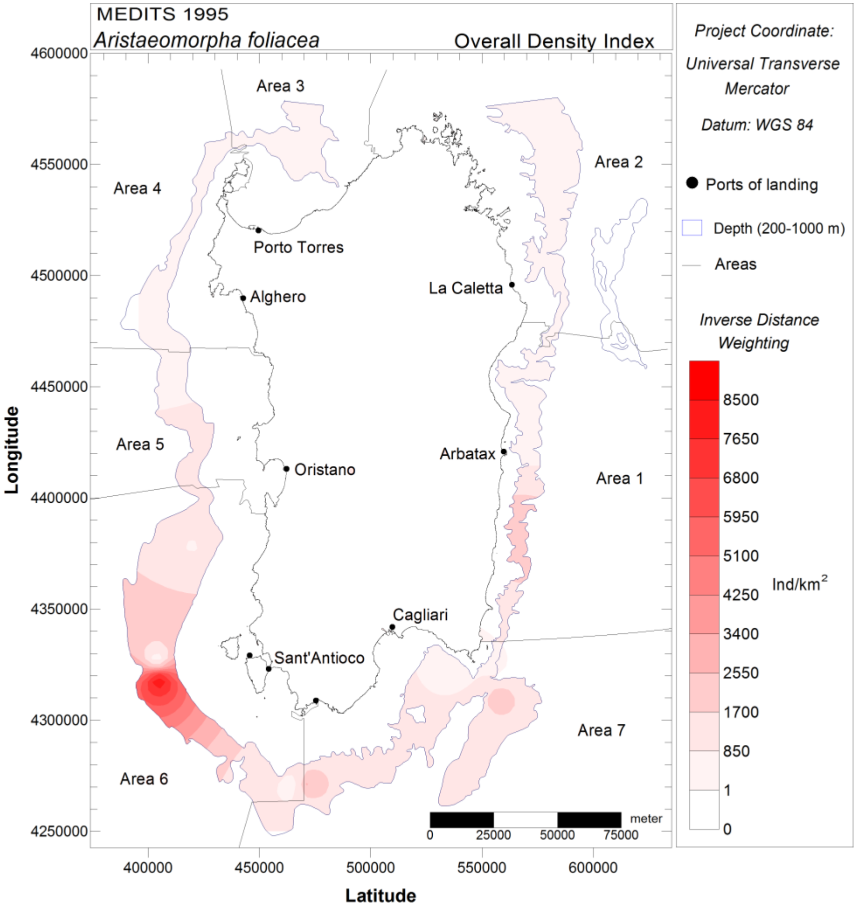

MEDITS 2012
Aristeus antennatus
Overall Density Index
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Arbatax
Oristano
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude
0
25000
50000
75000
meter
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
1250
1125
1000
875
750
625
500
375
250
125
1
0
Ind/km^2

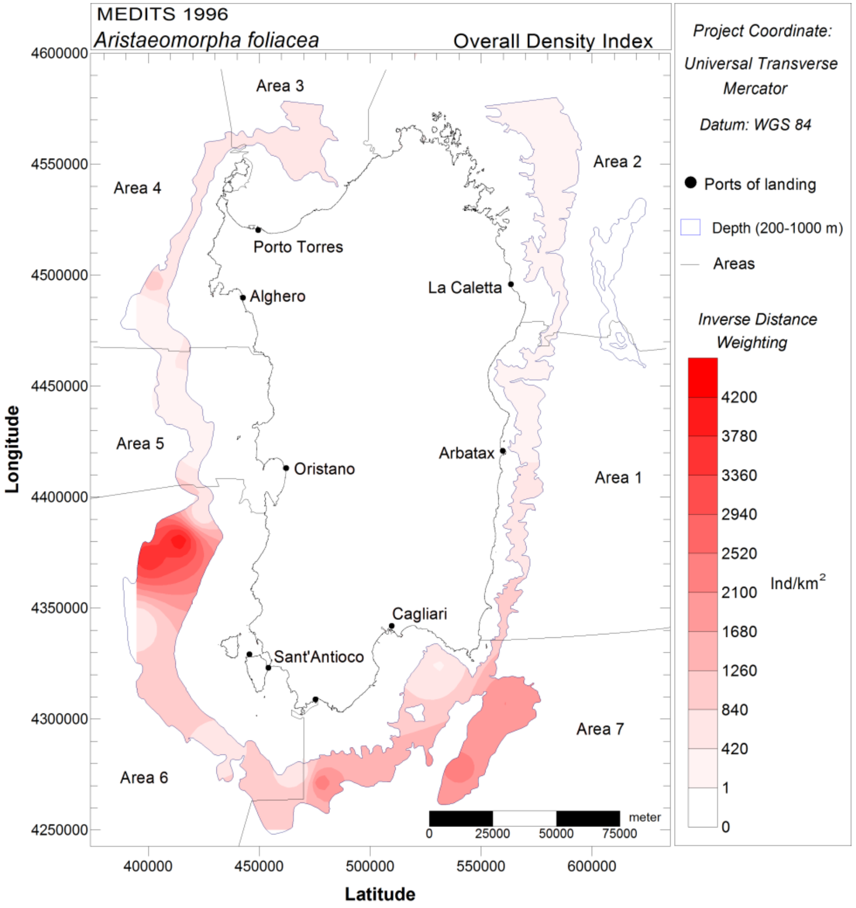
11 APPENDIXE II – THEMATIC SPATIAL MAPS

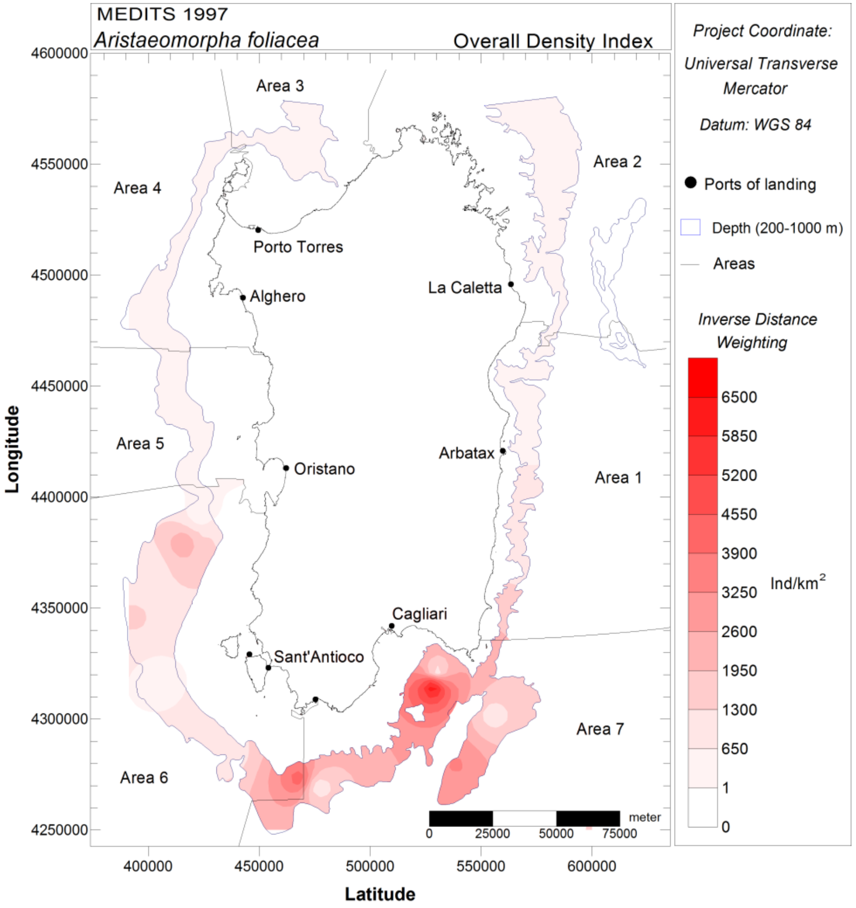
INVERSE DISTANCE WEIGHTING

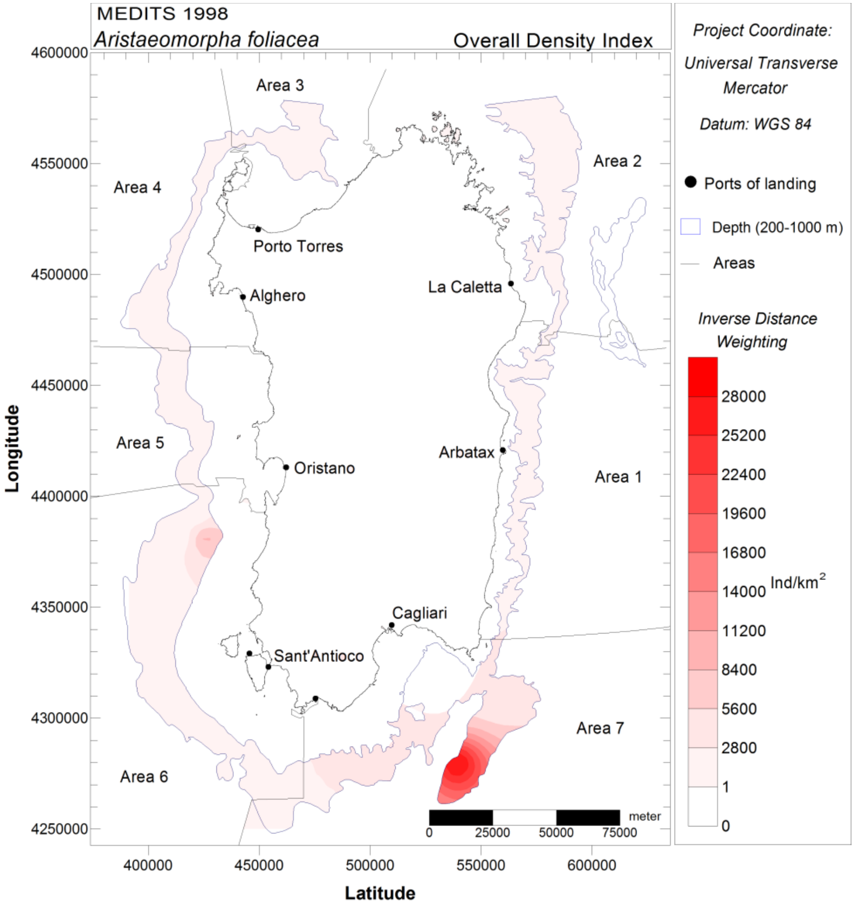
Aristaeomorpha foliacea

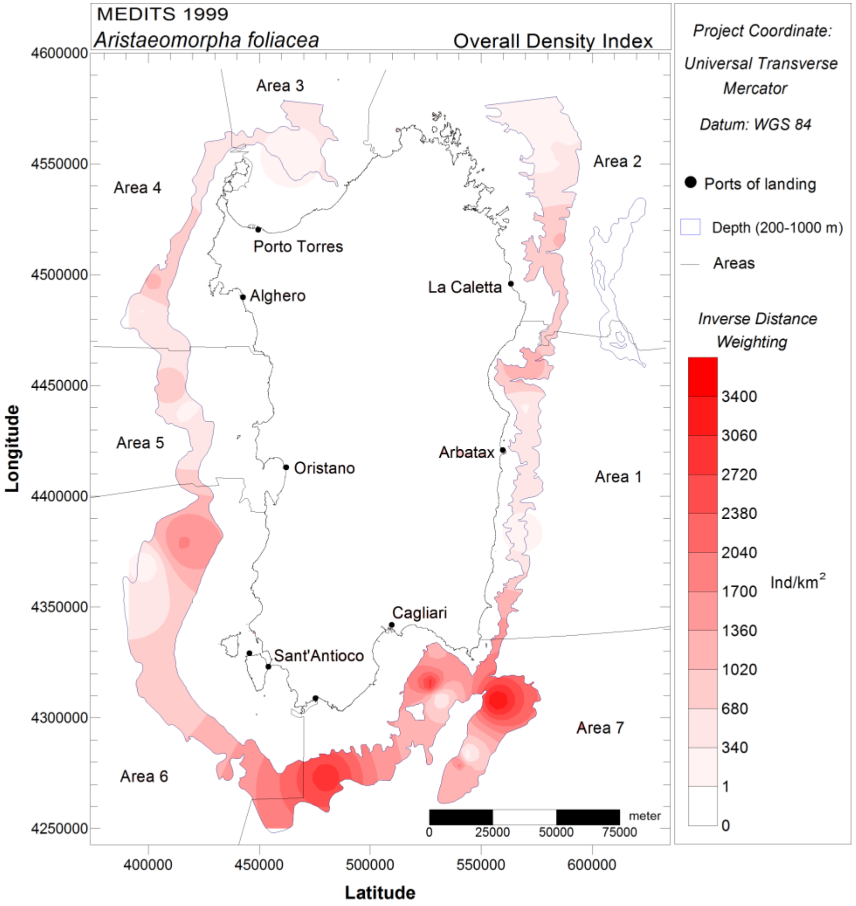

MEDITS 1994
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
1800
1620
1440
1260
1080
900
720
540
360
180
1
0
Ind/km^2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude
0
25000
50000
75000
meter

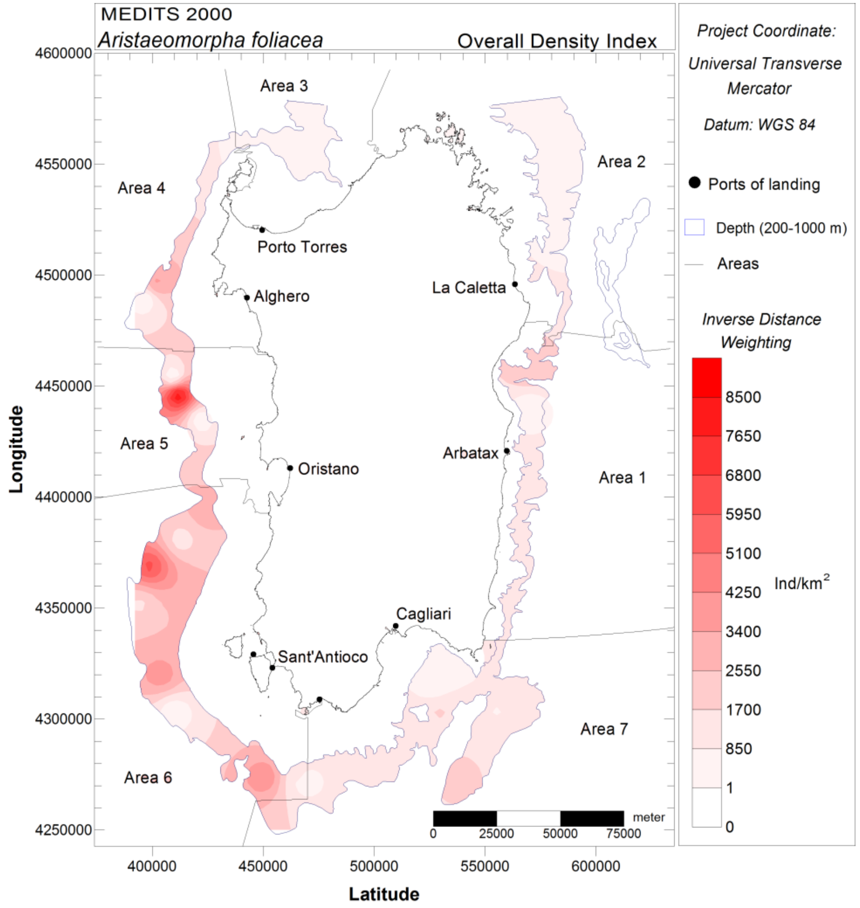

MEDITS 1995
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
8500
7650
6800
5950
5100
4250
3400
2550
1700
850
1
0
Ind/km^2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude
0
25000
50000
75000
meter

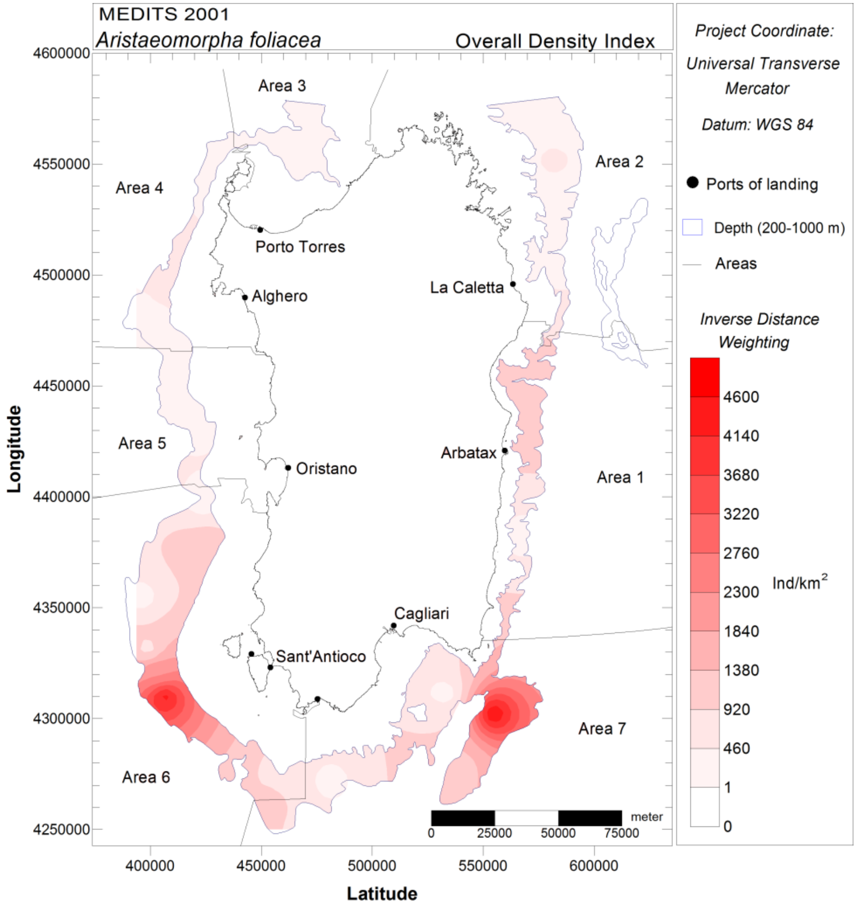

MEDITS 1996
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
4200
3780
3360
2940
2520
2100
1680
1260
840
420
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Longitude
400000
450000
500000
550000
600000
Latitude
0
25000
50000
75000
meter


MEDITS 1997
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
6500
5850
5200
4550
3900
3250
2600
1950
1300
650
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Longitude
400000
450000
500000
550000
600000
Latitude
0
25000
50000
75000
meter


MEDITS 1998
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
28000
25200
22400
19600
16800
14000
11200
8400
5600
2800
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude
0
25000
50000
75000
meter


MEDITS 1999
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
3400
3060
2720
2380
2040
1700
1360
1020
680
340
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Longitude
Latitude
0
25000
50000
75000
meter


MEDITS 2000
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
8500
7650
6800
5950
5100
4250
3400
2550
1700
850
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
Longitude
Latitude
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000


MEDITS 2001
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
4600
4140
3680
3220
2760
2300
1840
1380
920
460
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
Longitude
Latitude
4600000
4550000
4500000
4450000
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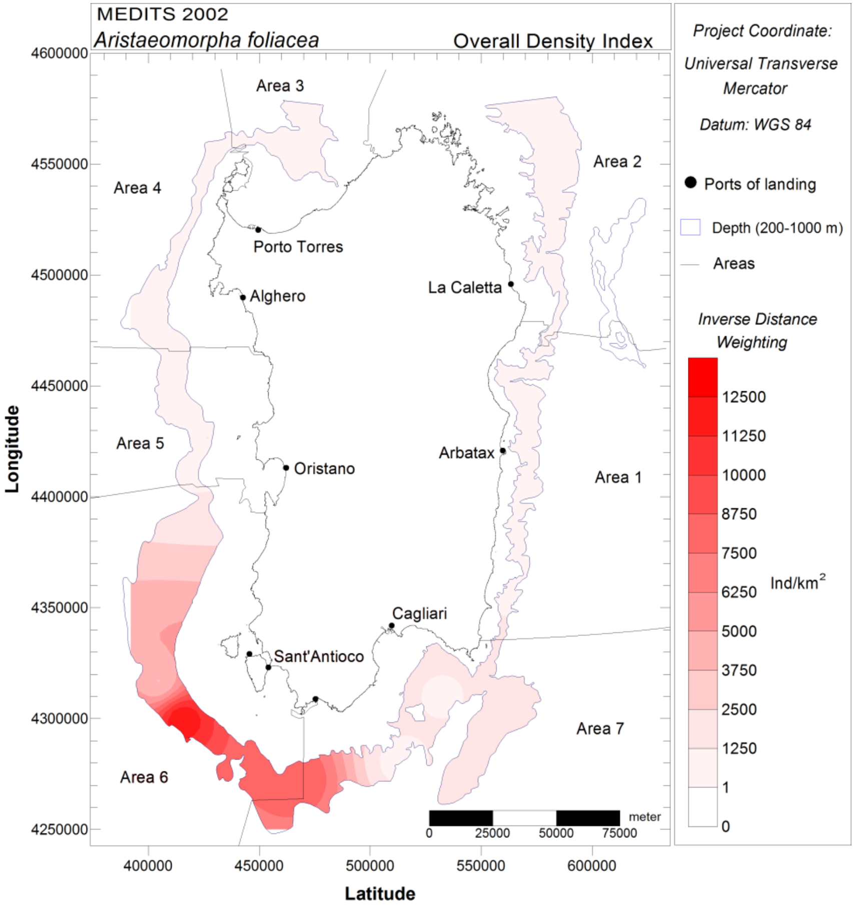
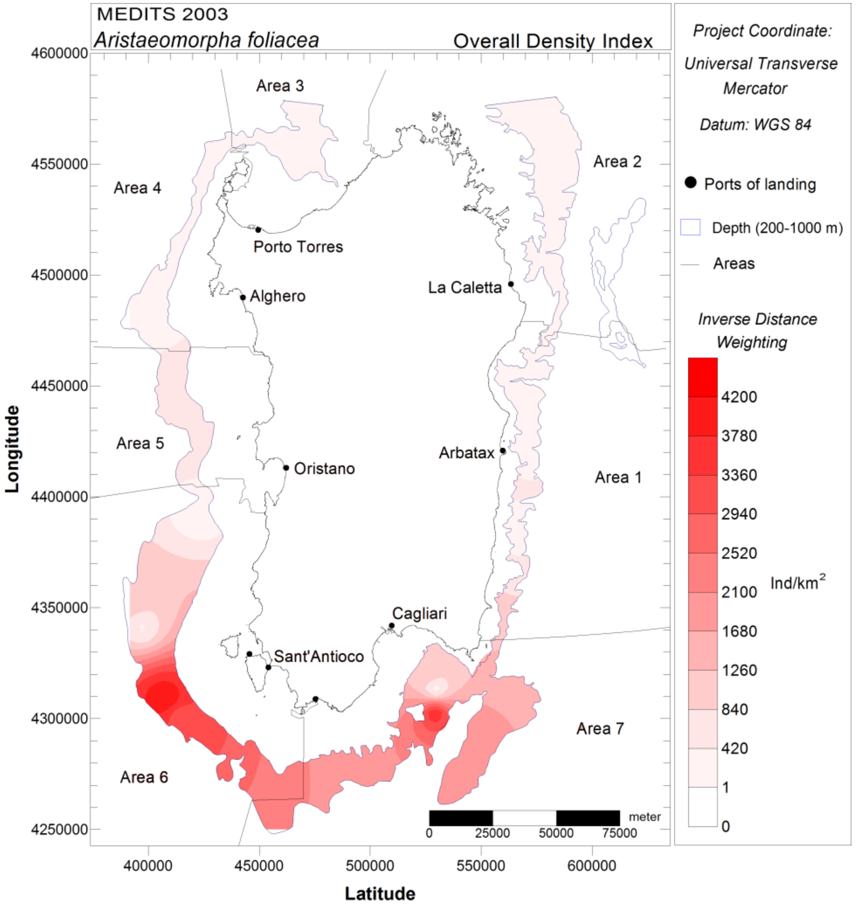
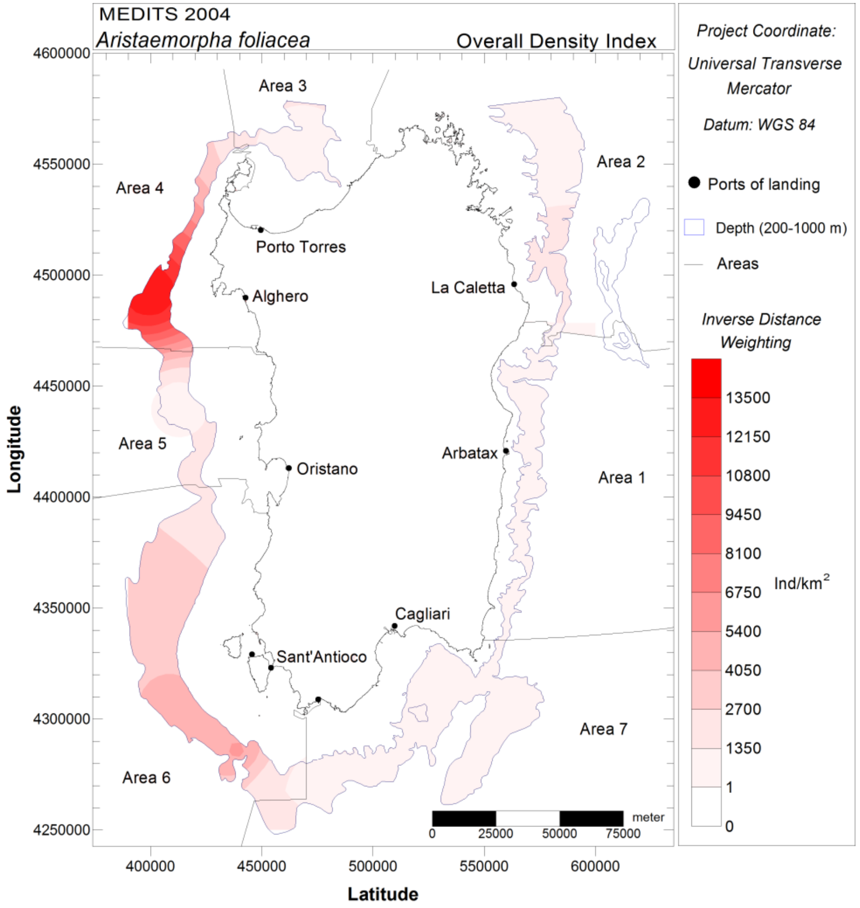
4350000
4300000
4250000
400000
450000
500000
550000
600000

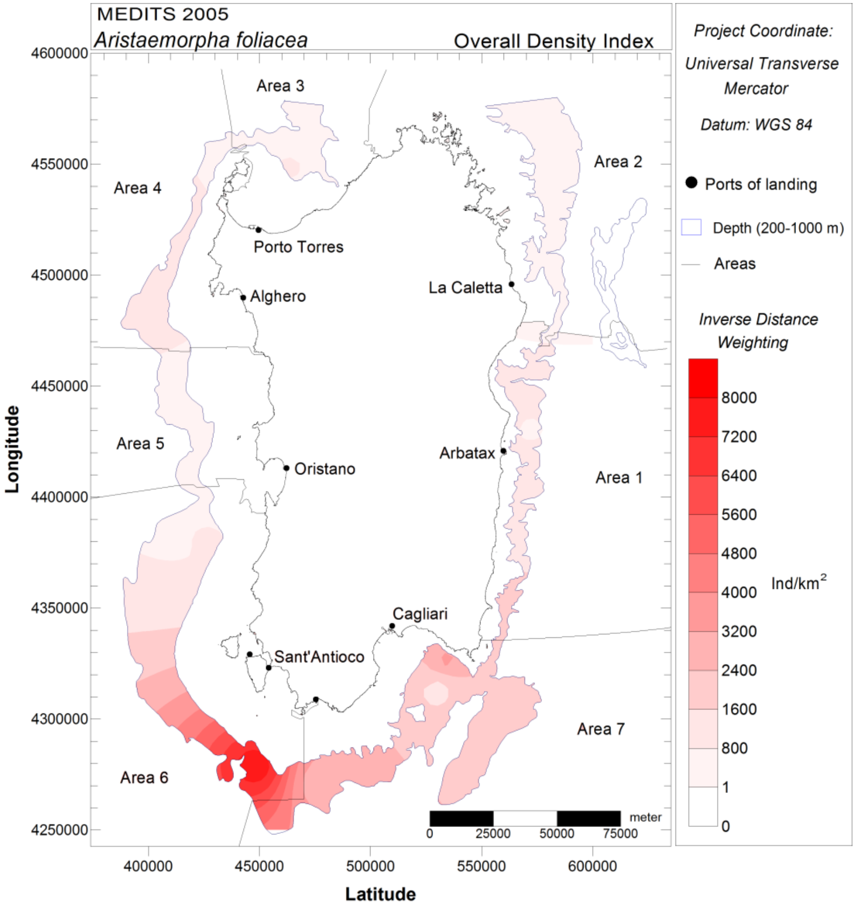


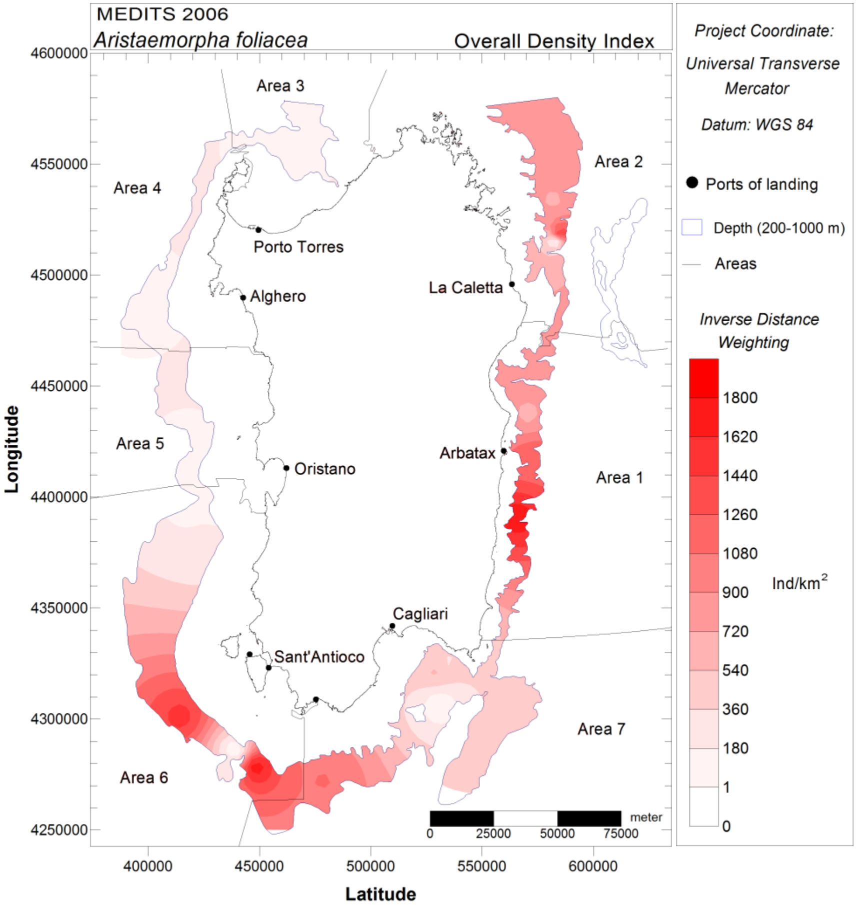
MEDITS 2002
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
12500
11250
10000
8750
7500
6250
5000
3750
2500
1250
1
0
Ind/km2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
0
25000
50000
75000
meter
Longitude
Latitude

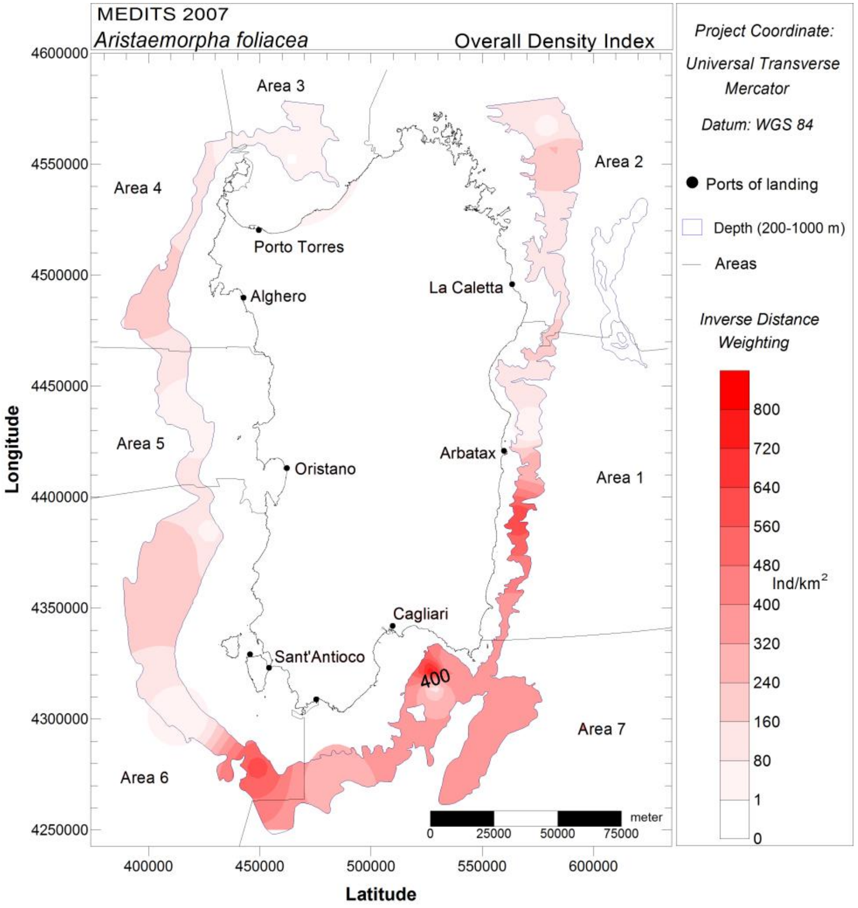


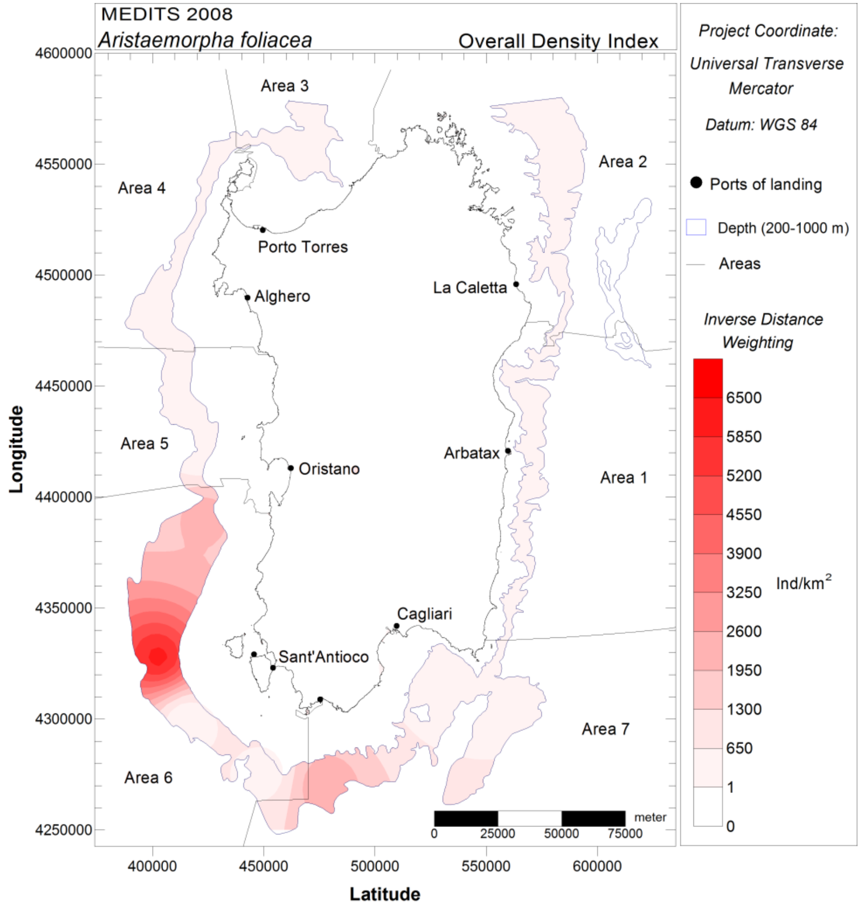
MEDITS 2003
Aristaeomorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
4200
3780
3360
2940
2520
2100
1680
1260
840
420
1
0
Ind/km2
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
0
25000
50000
75000
meter
Longitude
Latitude

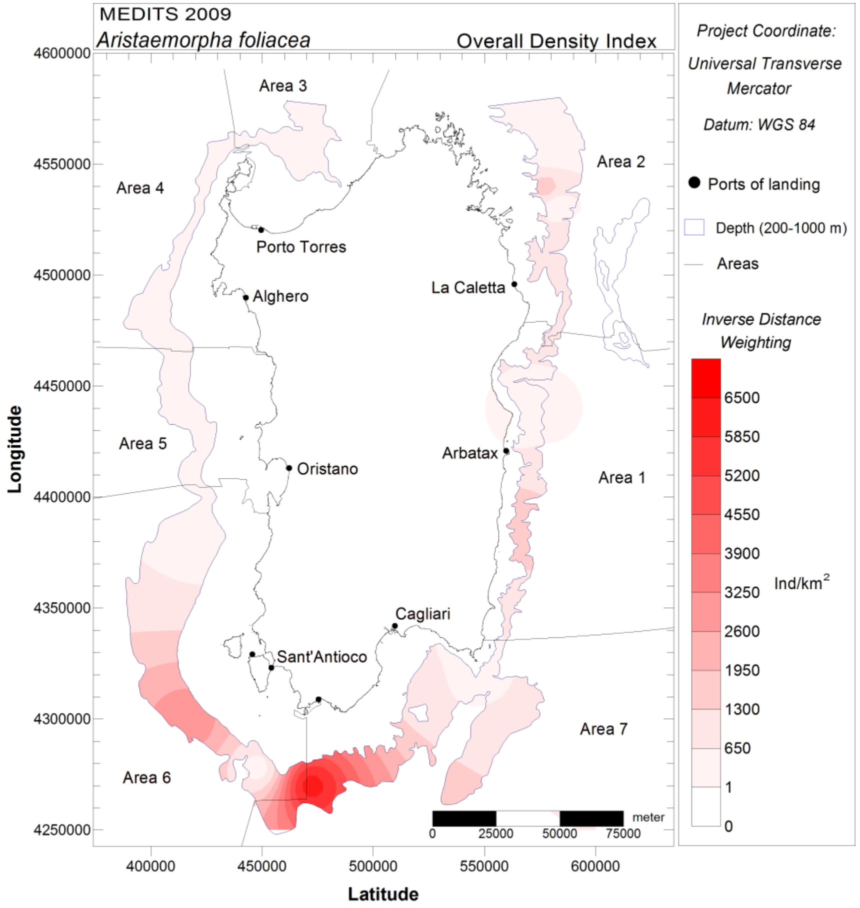

MEDITS 2004
Aristaemorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
13500
12150
10800
9450
8100
6750
5400
4050
2700
1350
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Arbatax
Oristano
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Longitude
400000
450000
500000
550000
600000
Latitude
0
25000
50000
75000
meter

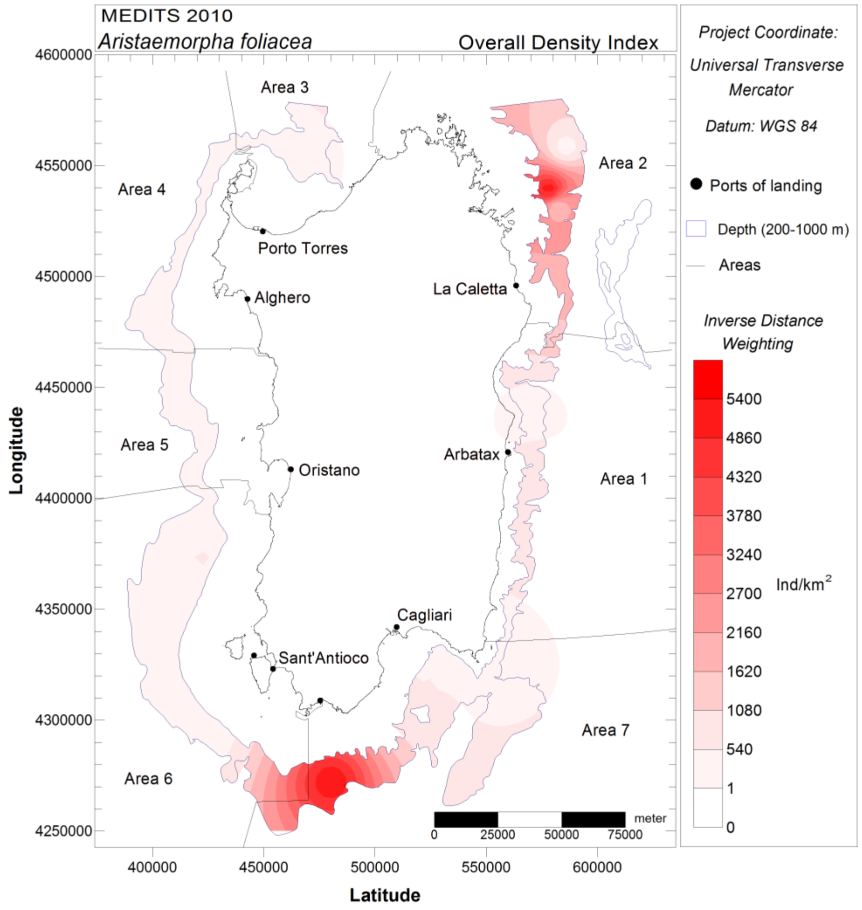

MEDITS 2005
Aristaemorpha foliacea
Overall Density Index
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
8000
7200
6400
5600
4800
4000
3200
2400
1600
800
1
0
Ind/km²
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Arbatax
Oristano
Cagliari
Sant'Antioco
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Longitude
400000
450000
500000
550000
600000
Latitude
0
25000
50000
75000
meter

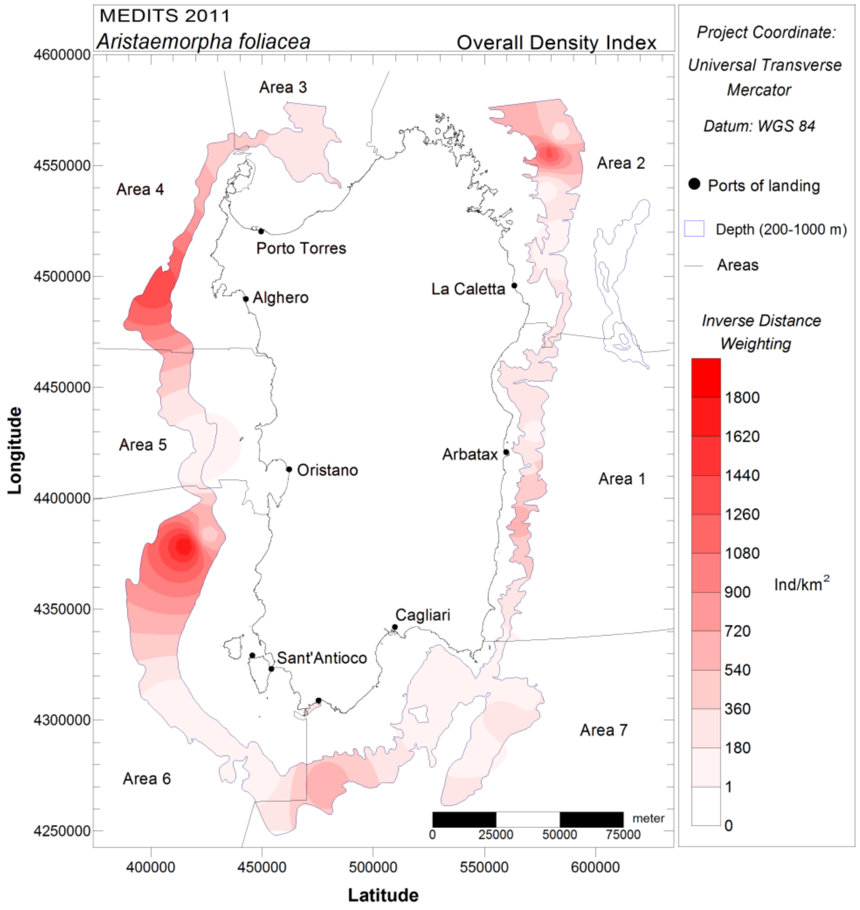

MEDITS 2006
Aristaemorpha foliacea
Overall Density Index
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
Longitude
Latitude
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
0 25000 50000 75000 meter
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
1800
1620
1440
1260
1080
900
720
540
360
180
1
0
Ind/km2

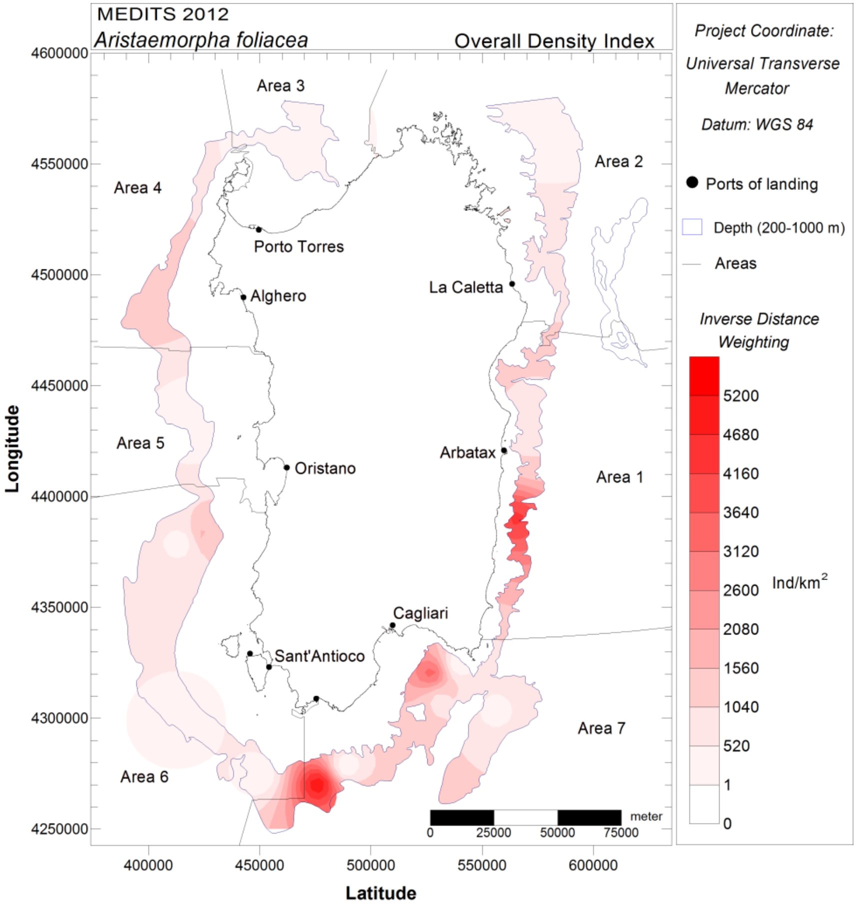

MEDITS 2007
Aristaemorpha foliacea
Overall Density Index
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
400
Longitude
Latitude
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
0 25000 50000 75000 meter
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
800
720
640
560
480
400
320
240
160
80
1
0
Ind/km2


MEDITS 2008
Aristaemorpha foliacea
Overall Density Index
Longitude
Latitude
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
6500
5850
5200
4550
3900
3250
2600
1950
1300
650
1
0
Ind/km²


MEDITS 2009
Aristaemorpha foliacea
Overall Density Index
Longitude
Latitude
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
400000
450000
500000
550000
600000
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
6500
5850
5200
4550
3900
3250
2600
1950
1300
650
1
0
Ind/km²


MEDITS 2010
Aristaemorpha foliacea
Overall Density Index
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
5400
4860
4320
3780
3240
2700
2160
1620
1080
540
1
0
Ind/km2
meter
0
25000
50000
75000
Longitude
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Latitude
400000
450000
500000
550000
600000


MEDITS 2011
Aristaemorpha foliacea
Overall Density Index
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
Ports of landing
Depth (200-1000 m)
Areas
Inverse Distance Weighting
1800
1620
1440
1260
1080
900
720
540
360
180
1
0
Ind/km2
meter
0
25000
50000
75000
Longitude
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Latitude
400000
450000
500000
550000
600000


MEDITS 2012
Aristaemorpha foliacea
Overall Density Index
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
Longitude
400000
450000
500000
550000
600000
Latitude
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 7
Porto Torres
Alghero
La Caletta
Oristano
Arbatax
Cagliari
Sant'Antioco
0
25000
50000
75000
meter
Project Coordinate:
Universal Transverse Mercator
Datum: WGS 84
● Ports of landing
☐ Depth (200-1000 m)
— Areas
Inverse Distance Weighting
5200
4680
4160
3640
3120
2600
2080
1560
1040
520
1
0
Ind/km²