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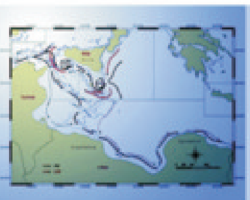
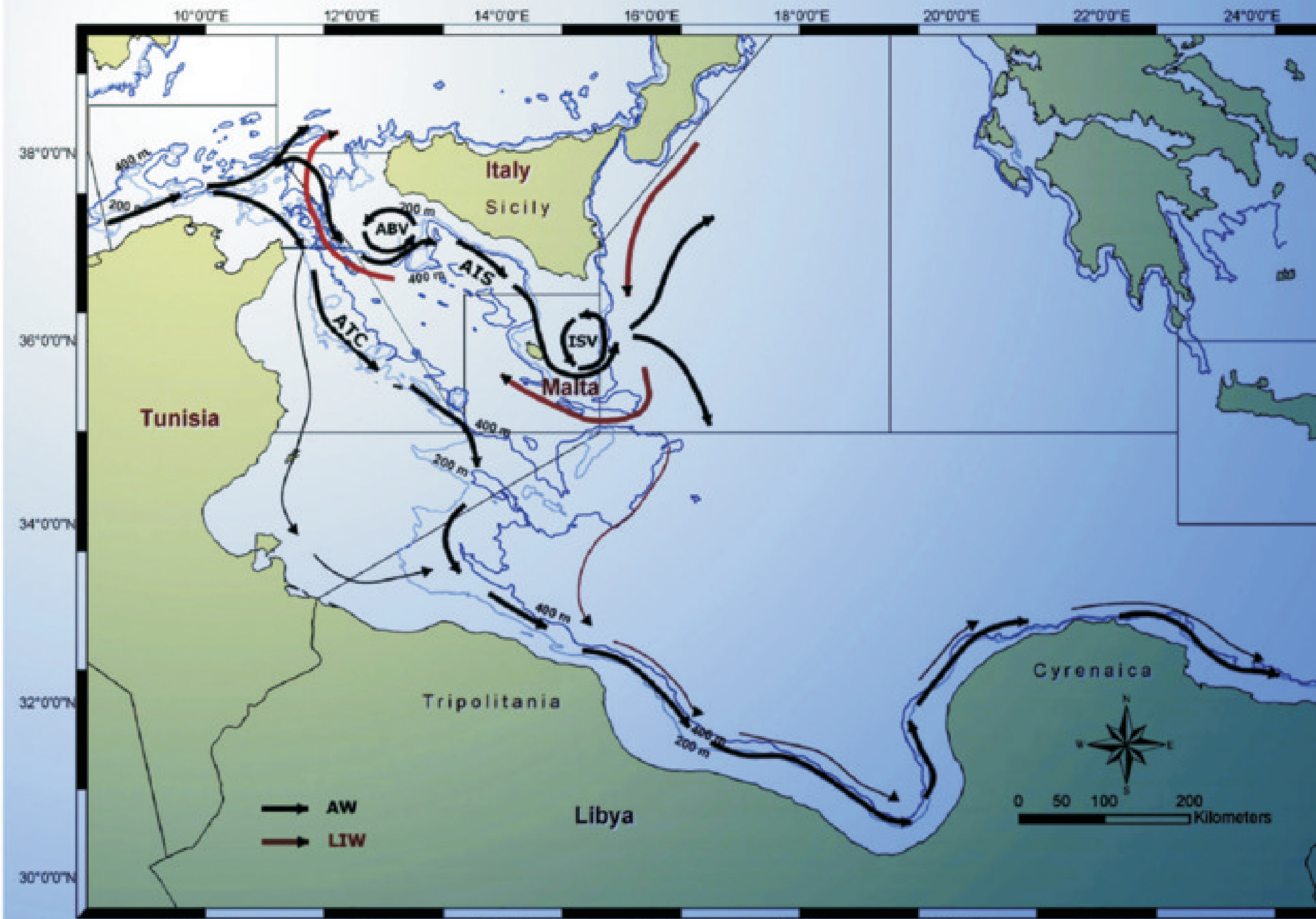


Preliminary results on spatial distribution of abundance indices, nursery and spawning areas of *Merluccius merluccius* and *Mullus barbatus* in the central Mediterranean



MEDSUDMED

ASSESSMENT AND MONITORING OF THE FISHERY RESOURCES AND ECOSYSTEMS IN THE STRAITS OF SICILY

MiPAAF

MedSudMed

GCP/RER/010/ITA

Preliminary results on spatial distribution of abundance indices, nursery and spawning areas of *Merluccius merluccius* and *Mullus barbatus* in the central Mediterranean

MedSudMed Technical Documents
GCP/RER/010/ITA/MSM-TD 19

Rome (Italy), November 2008

Preface

The Regional Project "Assessment and Monitoring of the Fishery Resources and the Ecosystems in the Straits of Sicily" (MedSudMed) is executed by the Food and Agriculture Organization of the United Nations (FAO) and funded by the Italian Ministry of Agriculture, Food and Forestry Policies (MiPAAF).

MedSudMed promotes scientific cooperation among research institutions of the four participating countries (Italy, Libyan Arab Jamahiriya, Malta and Tunisia), for the continuous and dynamic assessment and monitoring of the state of the fisheries resources and the ecosystems in this area of the Mediterranean.

Research and training are supported to increase and use knowledge on fisheries ecology and ecosystems, and to create a regional network of expertise. Particular attention is given to the technical coordination of the research among the countries, which should contribute to the implementation of the Ecosystem Approach to Fisheries. Consideration is also given to the development of an appropriate tool for the management and processing of data related to fisheries and their ecosystems.

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GCP/RER/010/ITA Publications

The MedSudMed Project publications are issued as a series of Technical Documents (GCP/RER/010/ITA/MSM-TD-00) related to meetings, missions and research organized by or conducted within the framework of the Project.

Comments on this document would be welcomed and should be sent to the Project headquarters:

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Preparation of this document

This document is the result of a cooperative work carried out by the Istituto Ambiente Marino Costiero (IAMC-CNR, Mazara del vallo, Italy), the Institut National des Sciences et Technologies de la Mer (INSTM, Sfax and Salammbô, Tunisia), the Marine Biology Research Centre (Tajura, Libya) and the Malta Centre for Fisheries Sciences (MCFS, Malta). The results compiled in the document were obtained after joint processing during the MedSudMed Working Group on joint trawl data processing (15-17 July 2005, Mazara del Vallo, Italy).

Acknowledgements

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ABSTRACT

Preliminary results on spatial distribution of some key variables (abundance indices, recruits and spawner density indices) of *Merluccius merluccius* and *Mullus barbatus* populations in central Mediterranean are presented at regional level for the first time. Data were collected during trawl surveys carried out under national programmes (Italy, Libya, Malta and Tunisia) in the MedSudMed Project area (GFCM GSAs 12, 13, 14, 15, 16 and 21). An effort to standardize the data collection and processing was made with the support of the MedSudMed Project. About 290 hauls were made within the depth range 10–800 m in May–August 2003, covering an area of about 150,000 km^2. For each haul, spawners were identified as female fish whose total length was greater than the length at 50% maturity (the established common value of 30 cm TL and 15 cm TL for hake and red mullet, respectively). Also for each haul, the proportion of recruits, expressed in terms of young of the year, was estimated by analysis of the length–frequency distribution. In the case of hake, a species that reaches maturity at the age of one year, the spatial distribution of the young fish with a length lower than $L_{50\%}$ (juveniles) was also considered. Spawning and nursery areas were identified as areas showing the highest values of spawner and recruit indices, respectively. To avoid bias due to the different sampling gears, all the indices were standardized to the maximum value, keeping separate the areas sampled with different nets. Qualitative comparison of hake and red mullet stocks among the Italian–Maltese, the Tunisian and the Libyan sub-regions, revealed that large differences exist in abundance indices and the demographic structure implicit in these indices. Though differences in the small size-classes may result from differences in gear selectivity and survey season, the contrasting distribution observed in the large size-classes is likely to result from an actual paucity of large specimens in the Italian–Maltese sub-region. Analysis of spatial distribution by life-phase showed that both species are distributed, or migrate, across the boundary of two adjacent GSAs or the boundary of a zone of national maritime jurisdiction and the adjacent high seas. Proposals for future research were made to better understand occurrence of stock units and the effect of environmental factors on them.

Table of Contents

1. Background information

This document is the outcome of the activities of the Working Group on Abundance, Spawning/Nursery Areas and Fish Assemblages (WG1) established in the framework of the MedSudMed component *Spatial Distribution of Demersal Resources in the Strait of Sicily and the Influence of Environmental Factors and Fishery Characteristics*. The Working Group met in Salammbô (Tunisia) from 8 to 10 February 2005 and in Mazara del Vallo (Italy) from 12 to 14 July 2005. The Working Group comprised GIS experts and fisheries biologists from research institutes of all four countries (Italy, Malta, Tunisia, Libya) participating in the MedSudMed Project. The objective of WG1 was to agree on a methodology to be adopted at the regional level for the study of the spatial distribution of demersal resources in the MedSudMed Project area. The main issues addressed included: choice of species, selection of relevant biological parameters to be mapped, criteria to be applied in the identification of nursery/spawning areas, tools and mapping methods.

The Working Group produced several maps depicting the spatial distribution of some key variables (abundance indices, recruits and spawner density indices) of *Merluccius merluccius* and *Mullus barbatu* stocks in the MedSudMed Project area. These results represent the first assessment of the geographical distribution of the stocks in the region within a harmonized analytical framework and were presented during the 7th meeting of the Sub-committee on Stock Assessment of the General Fishery Commission of the Mediterranean (Tirana, Albania, 26-30 September 2005; GFCM-SCSA, 2005).

2. Introduction

The south-central Mediterranean is a highly productive area of utmost importance for fishing. In particular, one of the most important fishing fleets in the Mediterranean region, the trawler fleet based at Mazara del Vallo on the south-west coast of Sicily (232 vessels; 25,959 GT; 76,104 kW), operates in a great part of the area (Fiorentino et al., 2004).

The south-central Mediterranean encompasses the General Fisheries Commission for the Mediterranean (GFCM) Geographical Sub-Areas (GSAs) 12, 13, 14, 15, 16 and the western part of GSA 21 (GFCM, 2001), which differ greatly with respect to bio-geographical, historical, and current fishery characteristics.

Some groundfish species' stocks in the area are thought to be shared or straddling stocks (Caddy, 1998), but despite the strong management demand for prioritizing these considerations (FAO, 1995; FAO-GFCM, 2008), scientific evidence is still fragmentary and insufficient. Very little information is currently available about the most relevant spatial aspects of commercial stocks, such as geographic distribution of local stock(s), location of nursery, spawning and feeding areas, migration patterns, possible connections between stocks sub-units. It is likely that several stocks are distributed, or migrate, across the boundaries of two GSAs (or national maritime jurisdictions), or across the boundary of a national maritime jurisdiction and the adjacent high seas. The important consequence of this scenario is that the natural spatial scale of resources might not match the scale of assessment and management. As many demersal stocks in the Strait of Sicily seem to be heavily exploited (Gharbi 1985; Levi and Andreoli, 1989; Levi et al., 1993; Levi et al., 1995a; Ragonese and Bianchini, 1996; Ben Mariem et al. 1995; Ben Mariem and Gharbi, 1996; Levi et al., 1998; IRMA–CNR, 1999; Gharbi et al. 2004), it becomes critical to obtain evidence of the distribution of independent stocks and the rate of exchange across the whole region.

Most recent research suggests that understanding spatial distribution in stock fractions and their dynamics, and implementing consistent spatially explicit management measures, such as networks of marine protected areas, are fundamental conditions to ensure long-term sustainable management of fishery resources (Caddy, 2000; Jennings et al., 2001; Smedbol and Wroblewski, 2002; Kritzer and Sale, 2004; Berkeley et al., 2004).

Especially relevant to this aim is information on the features of the stocks and the persistence of their spatial distribution, as well as relative abundance and concentration areas of vulnerable life stages of fishery target species. Indeed, temporary or permanent restriction of fishing on spawning grounds is believed to constitute the most effective management measure for preserving reproductive potential of exploited resources and enhancing recruitment (Berkeley et al., 2004). On the other hand, reducing fishing effort on juvenile stages is of utmost importance when small and young individuals are a primary target of unselective fishing gears (Caddy, 2000).

Scientific trawl surveys constitute the fundamental source of information on spatial distribution and abundance of relevant life-history stages of groundfish. They are routinely carried out in most of the south-central Mediterranean, with the primary aim of monitoring and assessing the state of the fishery resources (Levi et al. 1998; Bertrand et al., 2002; Lamboeuf et. al., 1995). However, different sampling designs and protocols have been used to date in the countries of the MedSudMed Project area (MedSudMed, 2006).

In the present study an attempt is made to establish a harmonized framework of common objectives, tasks and methods, so as to take advantage from the existing data series and use them to investigate the spatial distribution of exploitable demersal fish stocks in the south-central Mediterranean. European hake (*Merluccius merluccius,* L., 1758) and red mullet (*Mullus barbatus*, L., 1758) are the target species, selected because of their major commercial importance in the central Mediterranean (Andreoli et al., 1995; Ben Mariem and Gharbi, 1996; Fiorentini et al., 1997; Gharbi et al., 2004; Fiorentino et al., 2005) and because the two species have different bathymetric distributions and biological characteristics.

Hake is a necto-benthonic species, characterized by a long reproductive period, inhabiting a wide range of bottom depths (10–1000 m: Colloca, 1999). Red mullet is a benthic species, characterized by a discrete spawning event, frequently found on muddy bottoms at depths between 5 and 250 m (Voliani, 1999). Although aspects of the biology and ecology of both species have been investigated (Fiorentino, 2007a, b), few studies have addressed the issue of spatial distribution of stock fractions and their dynamics (Lembo et al. 2000; Fiorentino et al. 2003; Garofalo et al., 2004; Fiorentino et al. 2006; Abella et al., 2008).

The main objective of this study is to describe the spatial distribution of the two species in the south-central Mediterranean, with special emphasis on their key life phases, young of the year/juveniles and adult/spawners. The information reported in this study (localizing nurseries and spawning areas) could serve as a basis to suggest hypotheses on the structure of stocks in the region to be developed. In addition, considering this baseline, linkages between the spatial distribution of different stock fractions and the main topographical and hydrodynamical features of the Strait of Sicily could be explored. Specifically, patterns of connection among local stock sub units through larval dispersal and migration could be hypothesized in the future. Moreover, gaps in data and scientific knowledge could be identified and future research priorities highlighted.

The present study was implemented within the cooperative framework of the FAO Regional Project "Assessment and Monitoring of the Fishery Resources and the Ecosystems in the Straits of Sicily" (MedSudMed) (MedSudMed, 2003).

3. Bottom topography and hydrodynamical characteristics of the Strait of Sicily

The south-central Mediterranean area is characterized by complex bottom topography (Fig. 1) and by important hydrodynamical processes, which determines the water-mass exchanges between the western and eastern Mediterranean basins (Fig. 2) (Béranger et al., 2004).

Along the southern coast of Sicily, the shelf is characterized by two wide and shallow (100 m depth) banks in the western (Adventure Bank) and eastern sectors (Malta Bank), separated by a narrow shelf in the middle part (Fig. 1). The North African shelf is very wide, especially along the Tunisian coasts. In the Gulf of Gabès, the continental shelf, with depths less than 30 m, extends far offshore (Fig. 1). The topography of the sea bed below the 200 m depth between Sicily and Tunisia is extremely irregular, incised by many canyons, deep trenches and steep slopes, whereas it is very gentle (average depth of less than 300 m) between Malta and Libya. East of the Malta Bank, the shelf break is very steep (Malta Escarpment).

The general circulation is characterized by an inflow of fresh modified Atlantic Water (AW) flowing eastward near the surface (above 200 m depth) and an outflow of deeper salty water (in the 200–500 m depth range), the Levantine Intermediate Water (LIW), flowing westward along the Sicilian slope (Fig. 2). The AW entering the region across the Strait of Sicily splits into two main streams: the Atlantic Ionian Stream (AIS) and the Atlantic Tunisian Current (ATC) (Béranger et al., 2004).

The AIS follows the Sicilian shelf edge along the Adventure Bank, comes close to the middle coast, and moves away from the coast again when it encounters the Malta Bank, drifting northwards into the Ionian Sea (Sorgente et al. 2003; Pinardi et al., 2006). Along this path, the AIS meanders around semi-permanent features: the cyclonic Adventure Bank Vortex (ABV) and, east of Malta, the cyclonic Ionian Shelf Break Vortex (ISV) (Fig. 2). East of Malta, the AW encounters the warmer Ionian Sea water determining a sharp thermal front extending along the Malta Escarpment (Sorgente et al. 2003).

The ATC flows eastwards along the edge of the Tunisian shelf (another stream flowing close to the coast in the Gulf of Gabès) and forms a strong coastal stream close to the Libyan shelf edge (Alhammoud et al., 2005; Millot and Taupier-Letage, 2005).

The path, spatial extent and volume transport of each of the two streams just described present strong seasonal variability, with the AIS being more intense during summer and the ATC being more pronounced during late autumn (Sorgente et al. 2003). During winter, south-east of Malta, the AIS branches and flows mainly south-southeastwards, where it eventually joins the stream moving along the African coast (Sorgente et al. 2003; Millot and Taupier-Letage, 2005).

The LIW stream, strongly controlled by the topography, circulates in the 200–400 m depth range. It enters the region south of Malta and spreads when it reaches the edge of the Adventure Bank, flowing over the Tunisian sill (Sorgente et al. 2003).

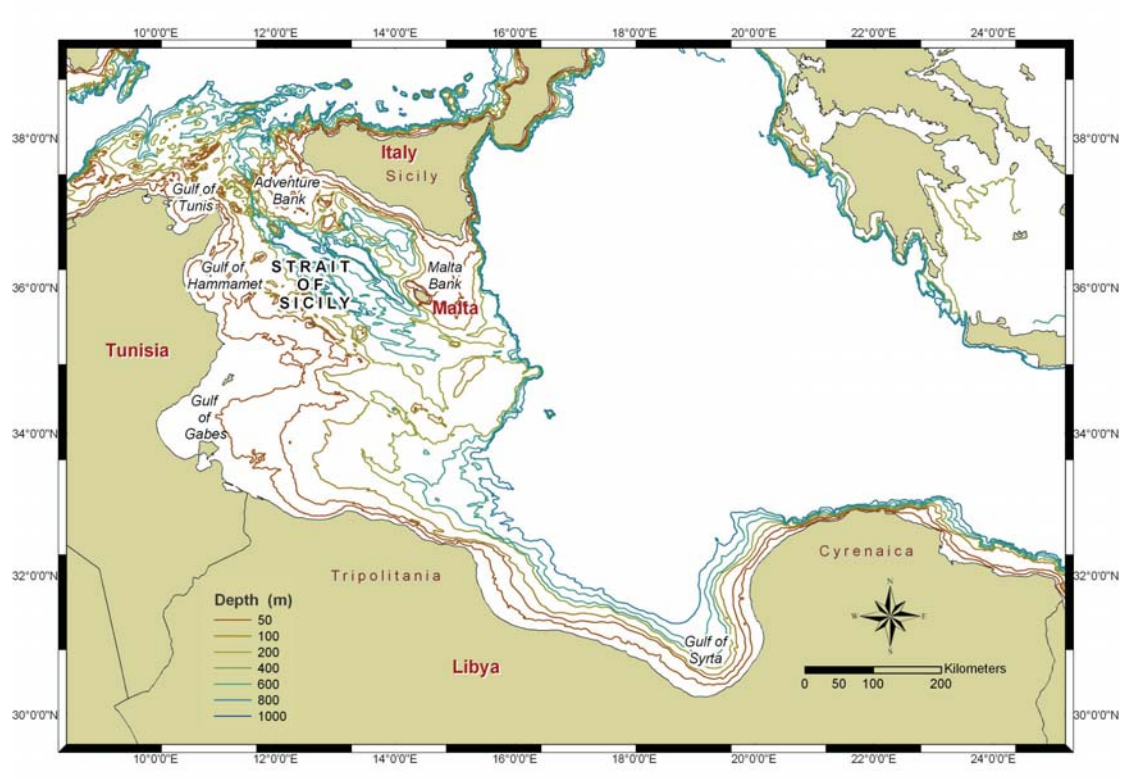


Fig. 1. Bathymetric map of the Strait of Sicily and the Libyan coast

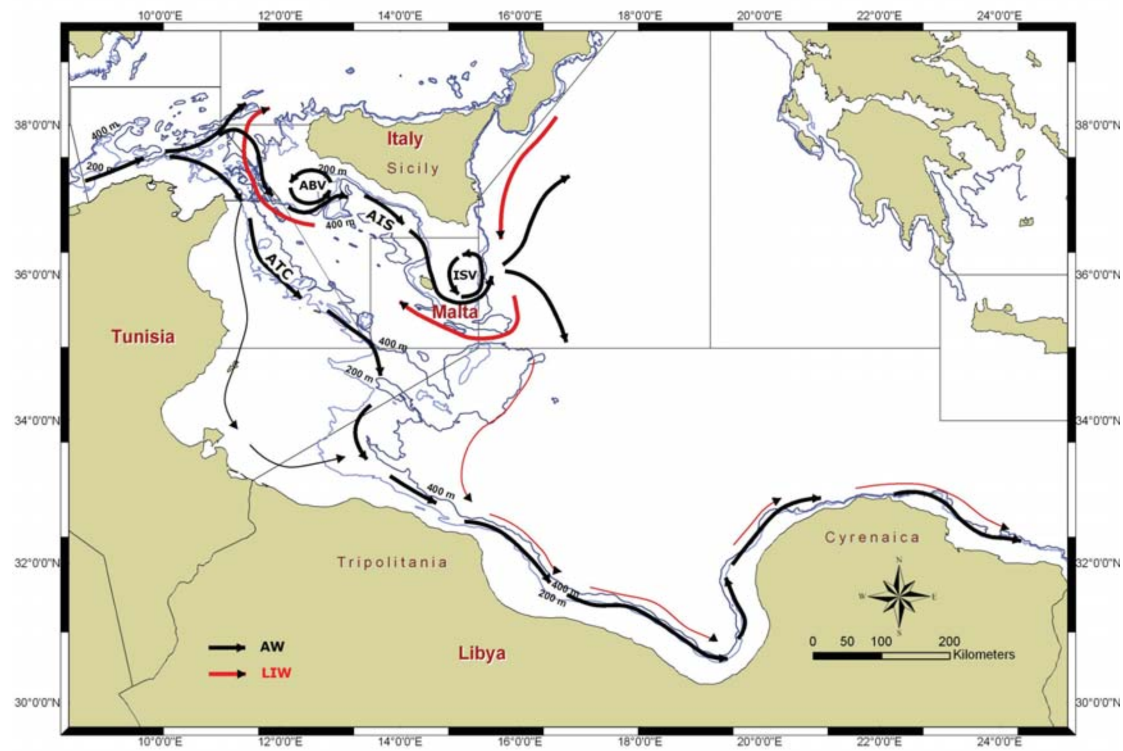


Fig. 2. Main circulation and hydrographical features in the Strait of Sicily according to Millot and Taupier-Letage (2005) and Pinardi et al. (2006). Dominant paths of AW (*black*) and LIW (*red*) are represented by *thick lines*, whereas secondary or intermittent paths are represented by *thin lines*. The depth contours represent the 200-m (*pale blue*) and the 400-m (*lavender blue*) isobaths.

4. Material and methods

4.1. Data sources

The data were collected either within the framework of national and international programmes for the evaluation of demersal resources (MEDITS in GSAs 15 and 16; Bertrand et al., 2002 **DEMSUD5** in GSAs 12, 13 and 14), or during occasional trawl surveys (GSA 21). However, the selected data set includes samples that were all collected during spring–summer 2003 (Table 1).

Three different vessels were used: RV *Hannibal* (INSTM, Tunisia), CV *St Anna* (IAMC, Italy and MCFS, Malta) and RV *Cilia* (MBRC, Libya). The investigated areas correspond to six GFCM geographical sub-areas (GSAs): 12, 13, 14, 15, 16 and 21 (Fig. 3), covering about 150,000 km^2.

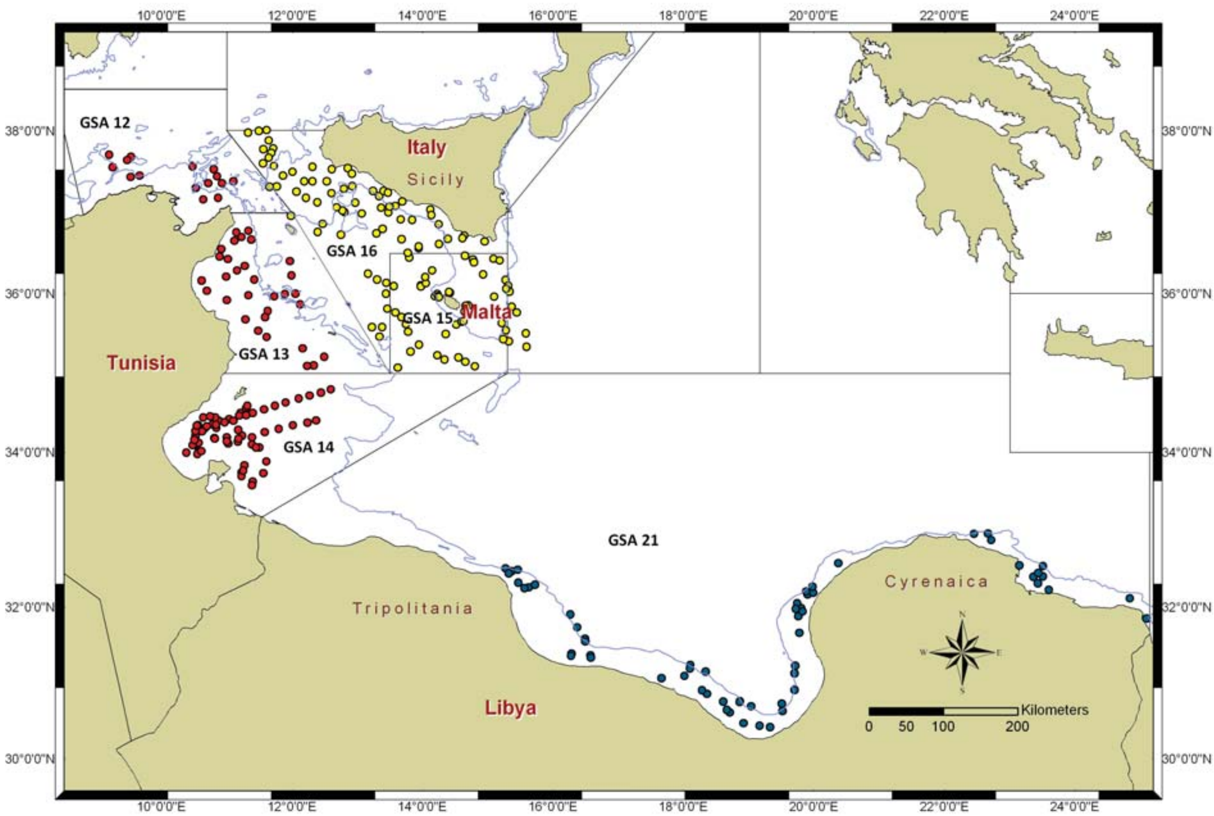


Fig. 3. GSAs included in the MedSudMed Project area and position of hauls carried out during trawl surveys in spring–summer 2003. The Italian–Maltese and the North African platforms (200-m depth contour) are shown (*pale blue*).

Table 1. Sampling period and hauls by GSA.

GSA	Sub-region	Sampling period	No. of hauls
12	Tunisian	July 2003	15
13		June 2003	31
14		May 2003	66
15	Italian	July-August 2003	76
16	Maltese	July-August 2003	44
21	Libyan	June 2003	60

The catches were obtained using two different experimental "high vertical opening bottom trawl". In GSAs 12, 13 and 14, the net used was a GOV: 42/55 type. A "shrimp bottom trawl" was also used in shallow waters (<50 m) of GSA 14.

In GSAs 15, 16 and 21, samples were collected with the Standard MEDITS GOC 73:36/40 net. The main characteristics of the gears are given in Table 2.

Table 2. Vertical and horizontal openings of the types of trawl net adopted by the countries participating in MedSudMed.

Trawl type	Codend mesh size (mm; opening)	Vertical opening (m)	Horizontal opening (m)
GOC 73:36/40 (MEDITS)	20	2.4–2.9	12–18
Shrimp bottom trawl (45/56)	40	2–2.5	16–18
GOV:42/55	40	4.5–6	15–18

The prospected depths differed from one zone to another and consequently the depth stratification varied from one GSA to another (see Table 3). The data were collected using a protocol for random sampling with stratification.

Table 3. Number and depth range of strata by GSA.

GSA	No. of strata	Depth ranges
12	4	50–100, 101–300, 301–500, >500
13	4	50–100, 101–200, 201–400, >400
14	4	30–50, 51–100, 101–200, >200
15	5	10–50, 51–100,101–200, 201–500, >500
16	5	10–50, 51–100,101–200, 201–500, >500
21	5	25–50, 51–75,76–100,101–150, 151–400

Most hauls were performed during daylight. Some night hauls were carried out in specific zones, such as the Gulf of Gabès (GSA 14, Tunisia) and Gulf of Sidra (Gulf of Syrta, GSA 21, Libya).

Trawling was performed at a nominal standard speed of 3 knots. The nominal (effective) haul time was set from the winch stop to the beginning of warp retrieval. The haul duration was different, depending on the teams involved, therefore catches were standardized to 1 km^2 using the swept area. The haul validity was usually established subjectively by the chief scientist on board, on the basis of such criteria as gear damage, anomalies in the overall performance, presence of some big objects (stones), etc.

For each haul, commercial species were sorted out, weighed and analysed separately. The total length (TL) of each fish was measured to the nearest 0.5 cm below.

4.2. Parameter estimation

According to the suggestion reported in MedSudMed (2006), abundance indices and length–frequency distributions (LFD) were elaborated using the swept-area method (Sparre and Venema, 1998) to obtain values per square kilometre. Therefore, biomass index (BI) and density index (DI) were calculated as kg km^{-2} and N km^{-2}, respectively. LFDs were used to estimate indices describing the occurrence of juveniles and spawning adults by haul, with the final aim of localizing the nursery and spawning areas.

Areas showing the highest concentration of juveniles were defined as nursery areas. Two different approaches may be adopted to identify juveniles, depending on the biological traits of the species. In the first approach the age is used as a discerning criterion and all the individuals less than one year old are considered young; these specimens belong to the first age group (group 0+) and are called "young of the year" (YOY). The second approach entails a more conservative choice and applies to species that mature only after several years; in this case individuals that have not reached sexual maturity are considered juveniles. With this criterion, all the age groups of immature specimens are considered juveniles (JUV).

As regards hake, since the species in the MedSudMed area matures at about 3 years of age for males and 4 years of age for females (Fiorentino et al., 2006), individuals are considered as not exploitable until this age. Therefore two maps were drawn and compared: distribution of group 0+ (YOY); and distribution of juveniles (JUV).

As regards red mullet, since females mature within the first year of life, the young fish (JUV) correspond to the young of the year (group 0+) (YOY).

The approaches used to estimate the two variables, YOY and JUV, were:

1. YOY (Fiorentino et al., 2003) – the overall standardized LFD, by survey, was prepared and the mean length ($\bar{l}$) of the first component and its corresponding standard deviation (*sd*) were estimated. Hence, the density index of the YOY by haul is calculated as all specimens whose length is below $\bar{l}$ + *1 sd* of the first component. This arbitrary threshold is chosen so as to limit the inclusion among the youngest of the year of those small specimens belonging to the second component (likely from the previous cohort), mainly for hake.
2. JUV (Fiorentino et al., 2002) – density indices by hauls were estimated as all specimens whose length is below the length of females at first maturity (L_{50}). Females were chosen because their L_{50} is usually larger than the L_{50} of males. This choice allows considering a greater fraction of immature individuals and hence following a more precautionary approach.

As regards spawning areas, the abundance of spawning females (i.e., at maturity stage 3 and above) should ideally be calculated directly when the maturity stage is identified for each individual during the survey. When information on the maturity of individuals is lacking, the length at sexual maturity L_{50}, from available maturity ogive(s), can be used to discriminate the individuals to be taken into account (length $\geq L_{50}$).

Table 4 reports the values of L_{50} available for the two species in the region on the basis of the literature and unpublished data. The length of females at sexual maturity was used to calculate the density index of adult females (MFI Mature Female Index) as a standardized number of females whose length was equal to or exceeded the L_{50}. Since there were no estimates of L_{50} for both species in the GSA 21, the values used for the immediately adjacent GSA 14, along the African continental shelf, were assumed to be valid. However it is worth noting that the differences in L_{50} among GSAs were negligible.

Table 4. Length at sexual maturity, by sex, of hake and red mullet available in the region.

Hake

Sex	INSTM GSA 12, 13, 14	IRMA/MCFS GSA 15, 16	MBRC GSA 21
Males	21.5 cm	22 cm (proxy of L_{50})	
Females	29 cm	30 cm (proxy of L_{50})	29 cm*

Red mullet

Sex	INSTM GSA 12, 13, 14	IRMA/MCFS GSA 15, 16	MBRC GSA 21
Males	14 cm	13 cm	
Females	15 cm	15 cm	15 cm*

* For GSA 21, where estimates of L_{50} for both species were not available, the same values as those of the adjacent GSA 14 were used.

4.3. Mapping method

All parameters to be mapped (BI, DI, YOY, JUV and MFI) were normalized in order to allow the comparison of data that were collected with different fishing gears and the representation on the same map. Specifically, a ratio score, which scales the data between the observed maximum and minimum values, was used for each of the three data sets (GSA 12, 13, 14; GSA 15, 16; GSA 21), as follows:

$$N_{ij} = (C_{ij}-a)/(b-a)$$

where N_{ij} is the normalized value for species i (or species fraction) and haul j

C_{ij} is the catch of species i (or species fraction) in haul j, in N km^{-2} or kg km^{-2}

a is the minimum catch of a species among all hauls of the survey, in N km^{-2} or kg km^{-2}

b is the maximum catch of a species among all hauls of the survey, in N km^{-2} or kg km^{-2}

Since the observed minimum was always a zero catch, the normalization consisted in dividing each value by the highest density index found in each data set. The parameters were then geo-referenced using the location of the sampling stations, calculated as the central point of the segment that connects the start and end points of the haul.

The ArcGIS 8 (ESRI, 2001) package, with its extensions for spatial and geostatistical analysis, was used to manage, analyse, and display the spatially referenced layers of information. The digital bathymetry and coastline of the first edition of the International Bathymetric Chart of the Mediterranean (IBCM) was chosen as basic cartography. It is at the scale of 1:1,000,000 and is incorporated into the GEBCO Digital Atlas.

The spatial distribution of available samples (Fig. 3) and the sea-bed topography of the area (Fig. 1) were preliminarily examined with a view of identifying homogeneous "macro-areas" where to perform interpolation. Five macro-areas were discriminated, after excluding sectors with no sampling points at all and outlining areas where the spatial coverage of the samples was reasonably uniform: GSA16+GSA15; GSA 12; GSA13+GSA14; GSA21 west; GSA21 east.

Inside each macro-area, the spatial distribution of all parameters was produced by interpolation. The inverse distance weighting (IDW) algorithm was chosen, as it is a moving average interpolator usually applied to highly variable data (Isaaks and Srivastava, 1989). It is based on the assumption that the nearby points have more influence than the more distant points on the interpolating surface. The chosen model used a value of 2 for the distance exponent. The output maps were produced as grids of 1x1-km cell size and were clipped with the minimum convex polygon of the sample points.

5. Results

5.1. Standardized abundance indices and length–frequency distributions

The biomass indices observed in the various sub-regions were not directly comparable in magnitude, given the use of different gears. However, an analysis of the standardized biomass distributions of both species (Figs. 4 and 5) showed a wide range of catch rates, and the highest values were found off the African coasts.

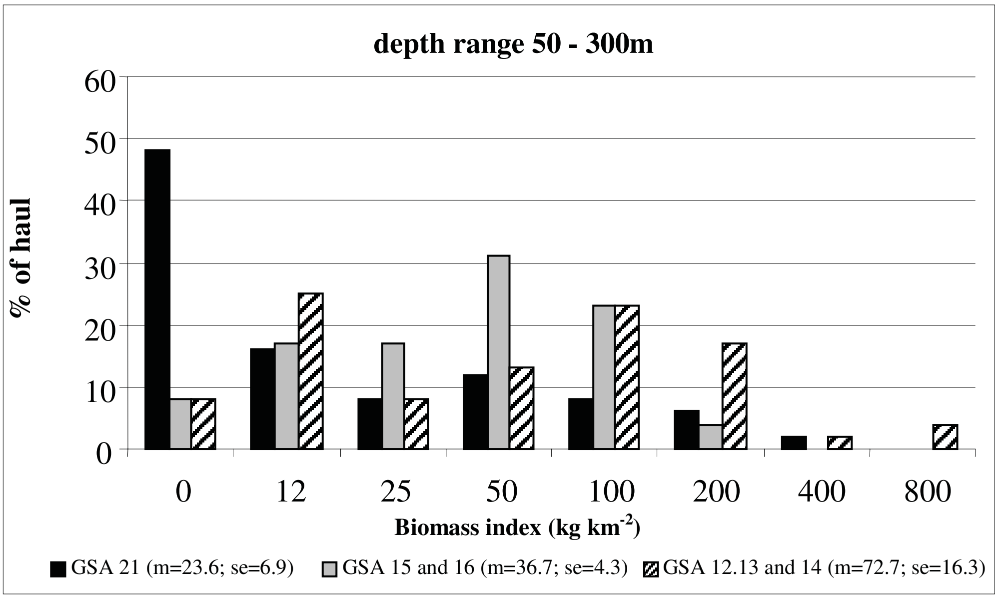


Fig. 4. Standardized biomass distribution of hake (*M. merluccius*). Mean value (*m*) and standard error (*se*) are calculated for each sub-region.

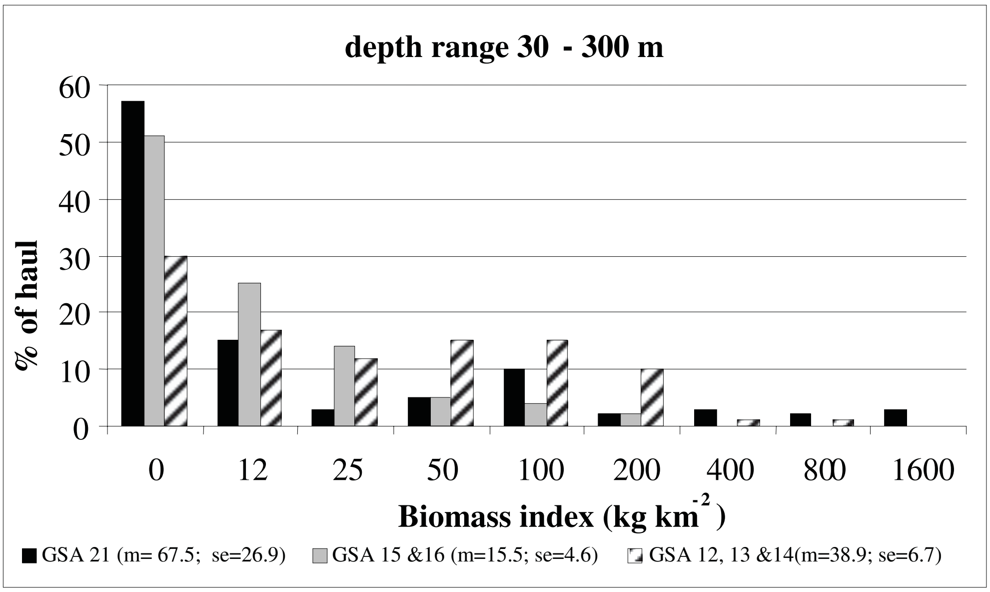


Fig. 5. Standardized biomass distribution of red mullet (*M. barbatus*). Mean value (*m*) and standard error (*se*) are calculated for each sub-region.

As regards length–frequency distributions, strong differences among sub-regions were observed for both species (Figs. 6 and 7).

The LFD of hake in GSA 21 (Fig. 6) was characterized by a wide size range that encompassed both small-sized (length range 40–160 mm TL) and large-sized (length range 180–400 mm TL) fish. The presence of relatively abundant large size-classes (200–280 mm TL) was particularly evident. The LFDs for GSAs 15 and 16 also presented both small-size and large-size components, but larger size-classes were much less relatively abundant than they were in GSA 21. On the other hand, the LFDs in GSAs 12, 13, 14 appeared mainly constituted by large-size fish (modal length 220–260 mm TL), whereas the small-size component (<100 mm TL) was not present. It is worth noting the presence of a few records showing very large-size fish (between 400 and 500 mm TL).

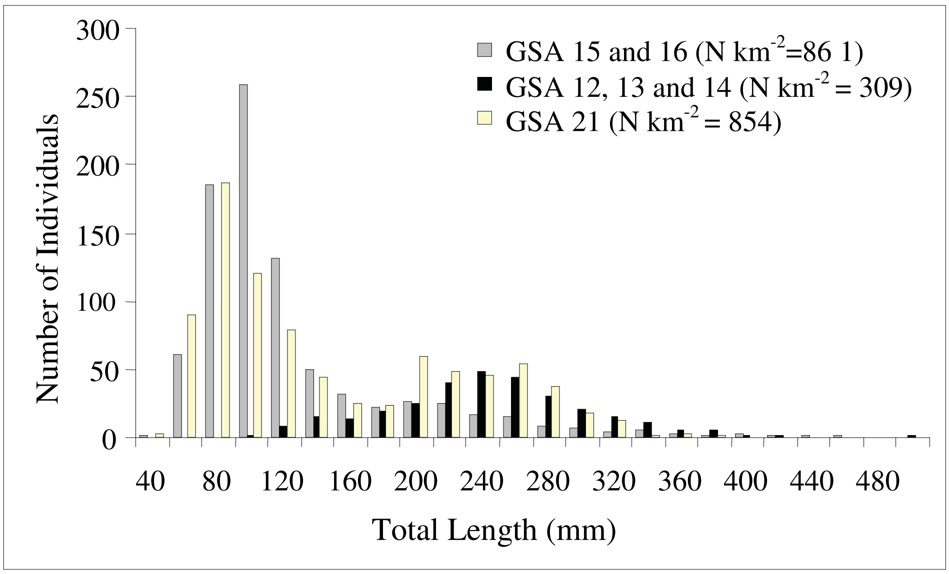


Fig. 6. Standardized (to square kilometres) length–frequency distributions of hake (*M. merluccius*).

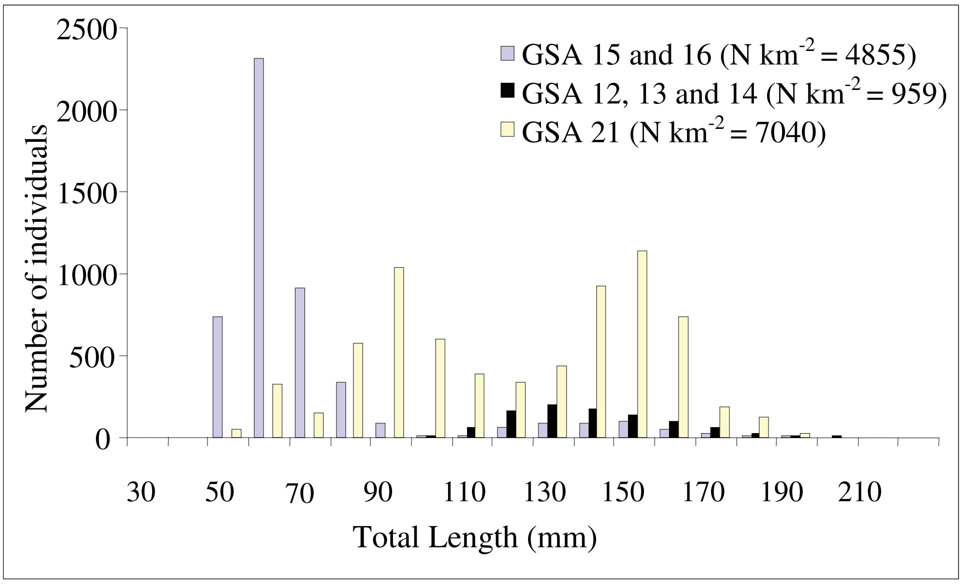


Fig. 7. Standardized (to square kilometres) length–frequency distributions of red mullet (*M. barbatus*).

Differences among sub-regions in the red mullet LFDs (Fig. 7) were comparable to those described for hake. Specifically, a wide range of size-classes (length range 40–190 mm TL) was present in the LFD for GSA 21 (Libyan sub-region): at least three modal components may be distinguished, with the larger size-classes being the most abundant. The small-size component (length range 40-90 mm TL) was clearly predominant in the LFD for GSA 15+16 (Italian and Maltese waters), whereas the large size-classes were relatively under-represented. Finally, only the large-size component (length range 100-200 mm TL) of the LFD was observed in GSA 12+13+14 (Tunisian waters).

5.2. Spatial distribution of biomass and density indices, nursery and spawning areas

Figure 8 shows the areas where the highest hake biomass indices occurred. In the Italian–Maltese sub-region, the resource was preferentially located over the offshore banks, the Adventure Bank in GSA 16 and the Malta Bank in GSA 15, and their south-eastern border. Off the Tunisian coasts, two large concentration areas were found in GSA 12 and GSA 13, whereas low abundances were observed in the Gulf of Gabès (GSA 14). Along the Libyan coast, significant abundances were found in the Gulf of Sidra (Gulf of Syrta, western part of GSA 21), whereas the resource was very scanty along the Cyrenaica coast (GSA 21 east).

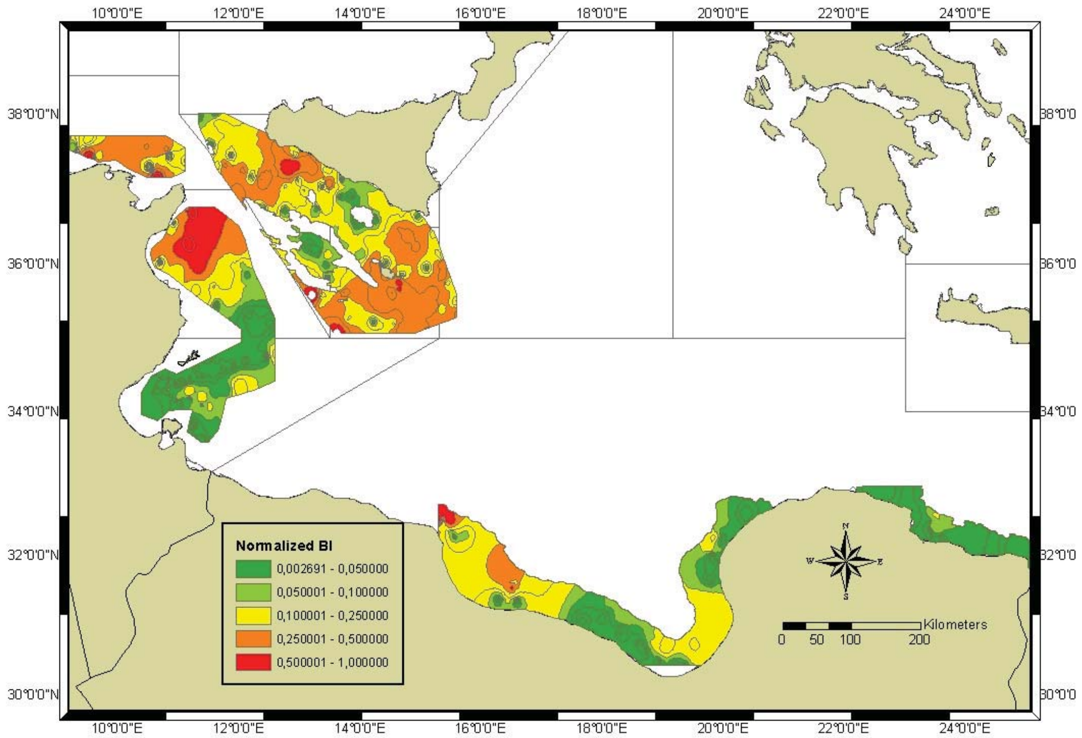


Fig. 8. Spatial distribution of normalized biomass index (BI) of hake (spring–summer 2003).

Figures 9–11 show how the different fractions of the population contribute to the general distribution just described.

In the northern part of the Strait of Sicily, female adult hake were mainly located over the Adventure Bank (GSA 16) and south of the Island of Malta (GSA 15) (Fig. 9). Their distribution appeared rather spread, probably due to the criterion used for their identification. Conversely, the distribution of recruits (YOY) was highly aggregated and presented two well defined high-density patches (Fig. 10). The YOY were located along the eastern border of the Adventure and the Malta Banks at about 200 m depth and were situated east of the distribution of spawners. Figure 11 shows a spread of the juvenile stages from the nurseries, sensu stricto, to the grounds occupied by adults.

Concerning the Tunisian waters, an important hake spawning area was identified in the Gulf of Hammamet (GSA 13), whereas only a minor one was found in the Gulf of Tunis (GSA 12) (Fig. 9). The maps of YOY (Fig. 10) and JUV (Fig. 11) distribution show very low numbers of individuals in this area.

In the GSA 21, female adult hake had a wide distribution, with three cores of high abundance in the Gulf of Sidra (Gulf of Syrta, western part of GSA 21), whereas they occurred in low abundances along the Cirenaica coast (GSA 21 east) (Fig. 9). The YOY were quite uniformly distributed along the continental shelf from the western to the inner part of the Sidra (Syrta) Gulf (Fig. 10). Unlike the pattern observed in GSAs 15 and 16, the distributions of spawners and recruits partially overlapped. Juveniles showed a more widespread distribution compared to YOY. (Fig. 11)

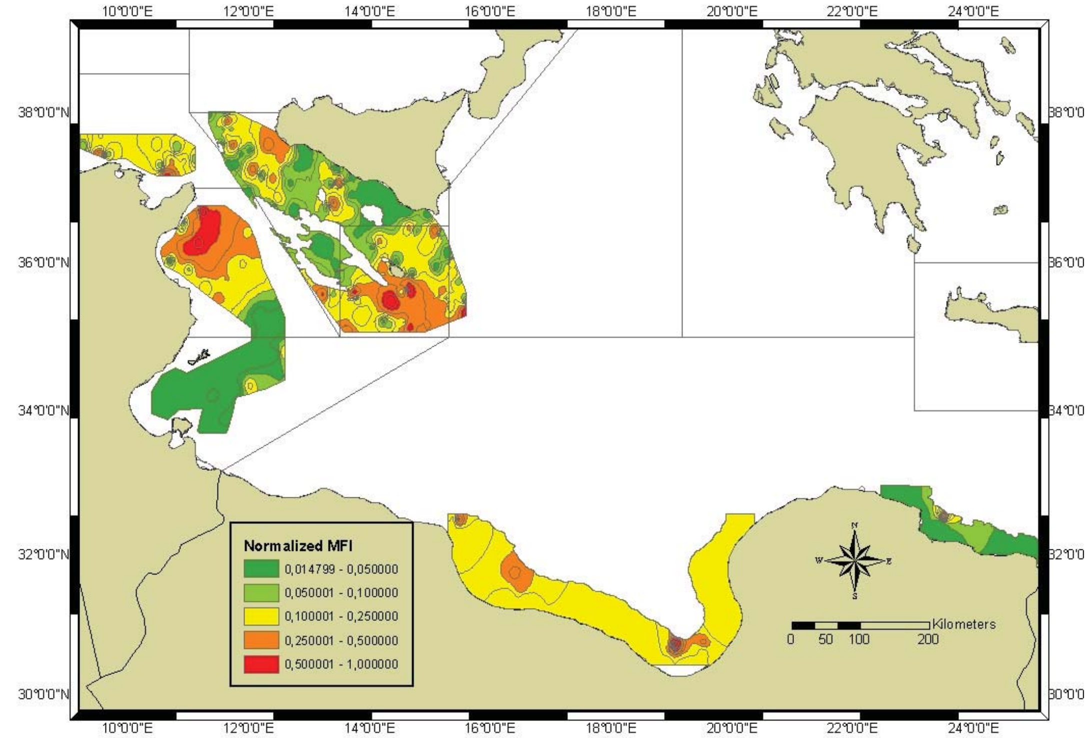


Fig. 9. Spatial distribution of normalized density index of adult females (MFI) of hake (spring–summer 2003).

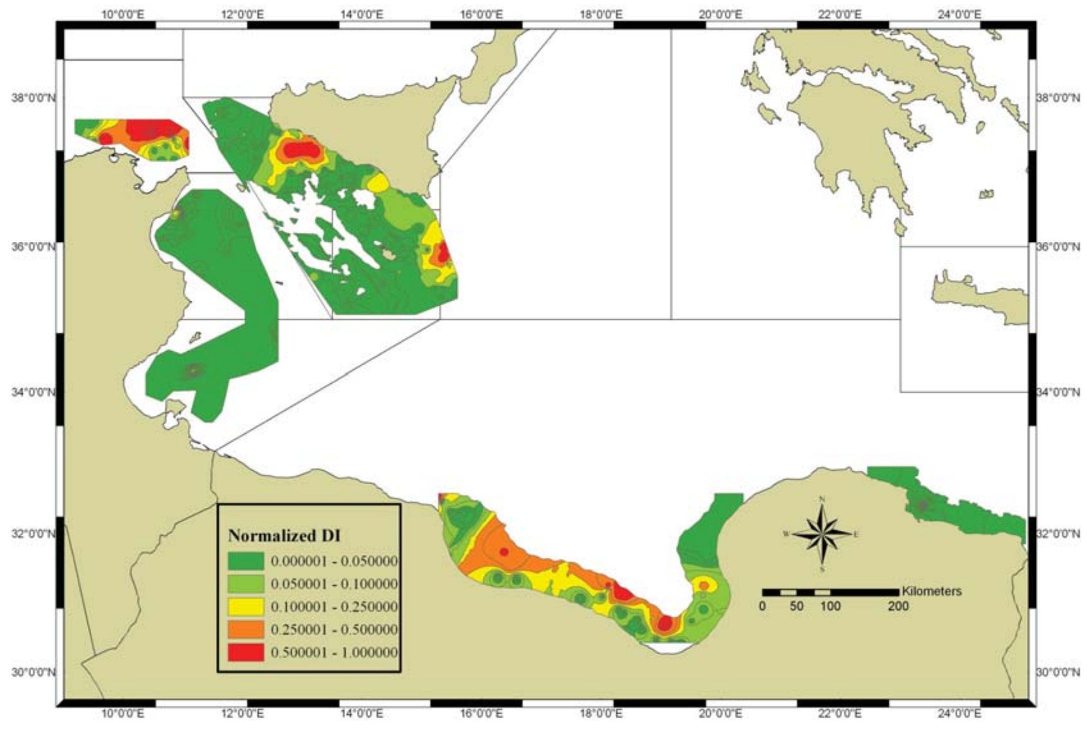
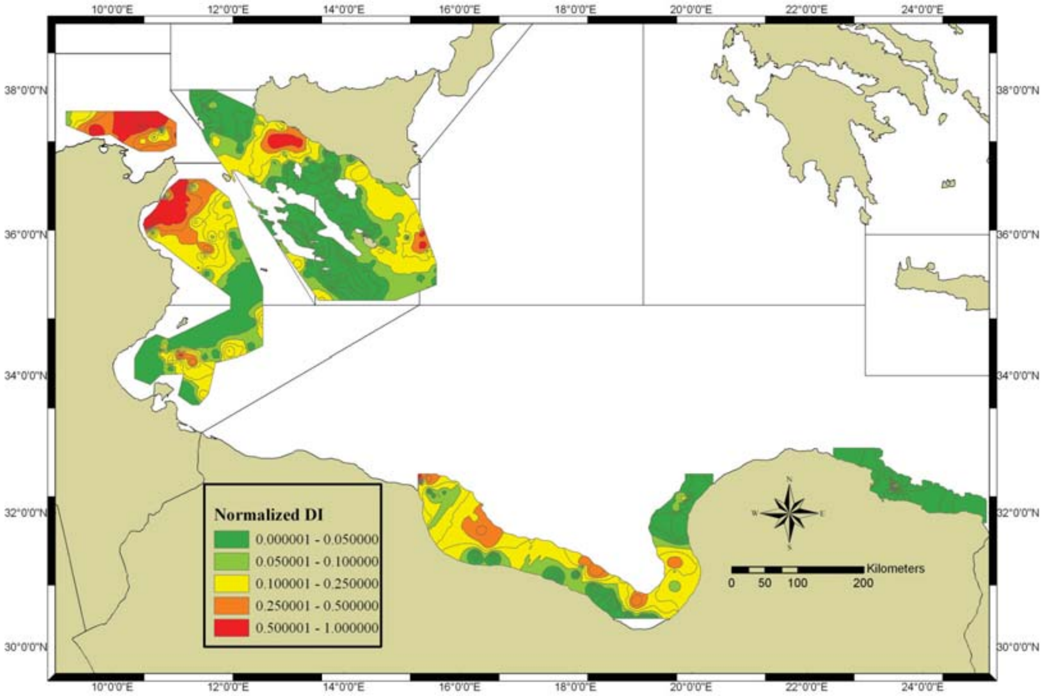


Fig. 10. Spatial distribution of normalized density index of hake young of the year (YOY) (spring–summer 2003).



Fig; 11. Spatial distribution of normalized density index of juvenile (JUV) hake (spring–summer 2003).

Figure 12 shows the spatial distribution of red mullet biomass indices. In the GSA 16, the resource preferentially occurred in the shallow waters close to the coast of Sicily (south-western corner of Sicily over the Adventure Bank and from the middle to the south-eastern coast of Sicily), whereas in GSA 15, the highest biomass values were in offshore waters east of Malta. As regards the GSAs 12, 13, 14 and 21, red mullet showed a more widespread distribution. The most important concentration areas were located in the Gulf of Hammamet (GSA 13) and in the Gulf of Sidra (Gulf of Syrta, western part of GSA 21).

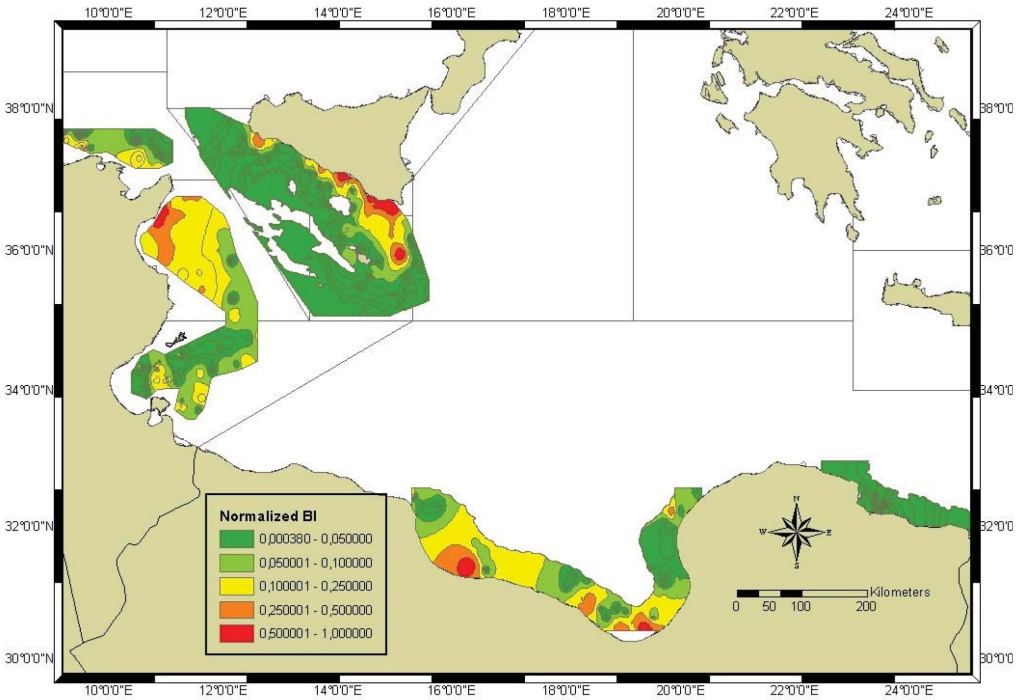


Fig. 12. Spatial distribution of normalized red mullet biomass index (BI) (spring–summer 2003).

Considering the distribution of the female adult red mullet in the Italian–Maltese sub-region (Fig. 13), three high-density patches were located close to the Sicilian coast at the westernmost and easternmost edges and at the coast in between. A minor patch was located offshore over the Adventure Bank. Another important patch was located in offshore waters east of Malta in GSA 15. Along the African coast, the main spawning areas were found in the Gulf of Tunis (GSA 12), in the coastal waters of the Gulf of Hammamet (GSA 13), and in the offshore waters of the Gulf of Gabès (GSA 14) (Fig. 13). High concentrations of adult females were identified in the western and inner sectors of the Gulf of Sidra (Gulf of Syrta, GSA 21) (Fig. 13).

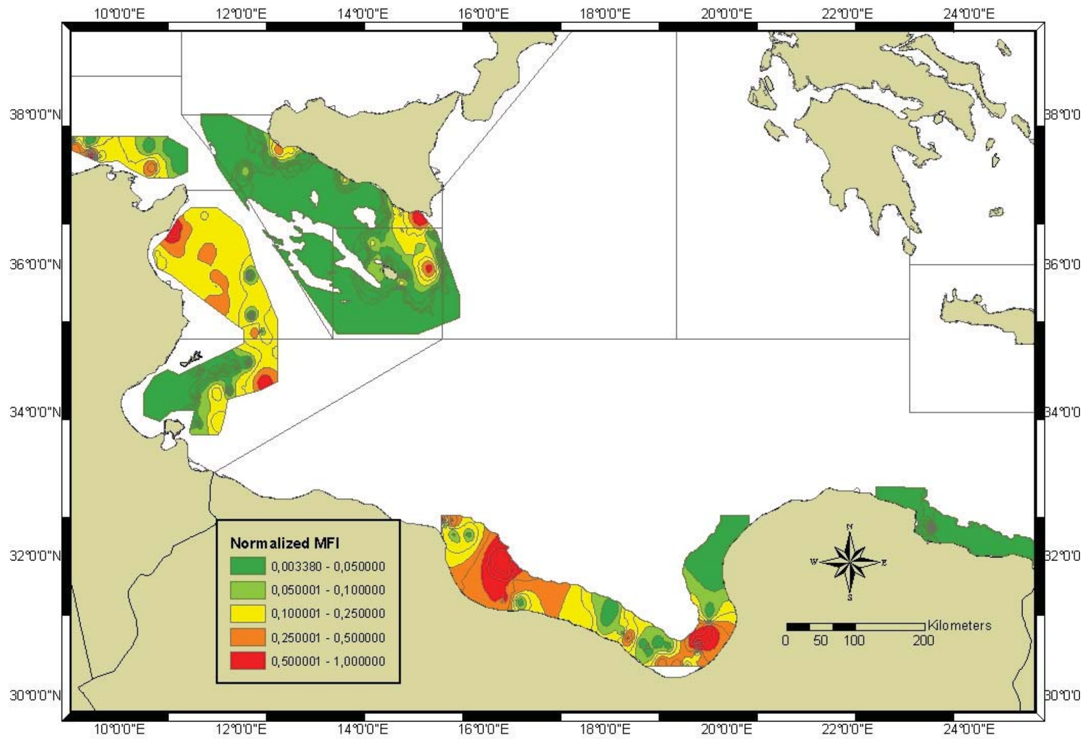


Fig. 13. Spatial distribution of normalized density index of female adult red mullet (spring–summer 2003).

Red mullet recruits occurred in shallow coastal waters and were recorded along the mid-southeast coast of Sicily (GSA 16), in the inner sector of the Gulf of Sidra (Gulf of Syrta, GSA 21 west) and in the central part of the Cyrenaica coast (GSA 21 east) (Fig.14). Red mullet recruits were not recorded in the Tunisian waters.

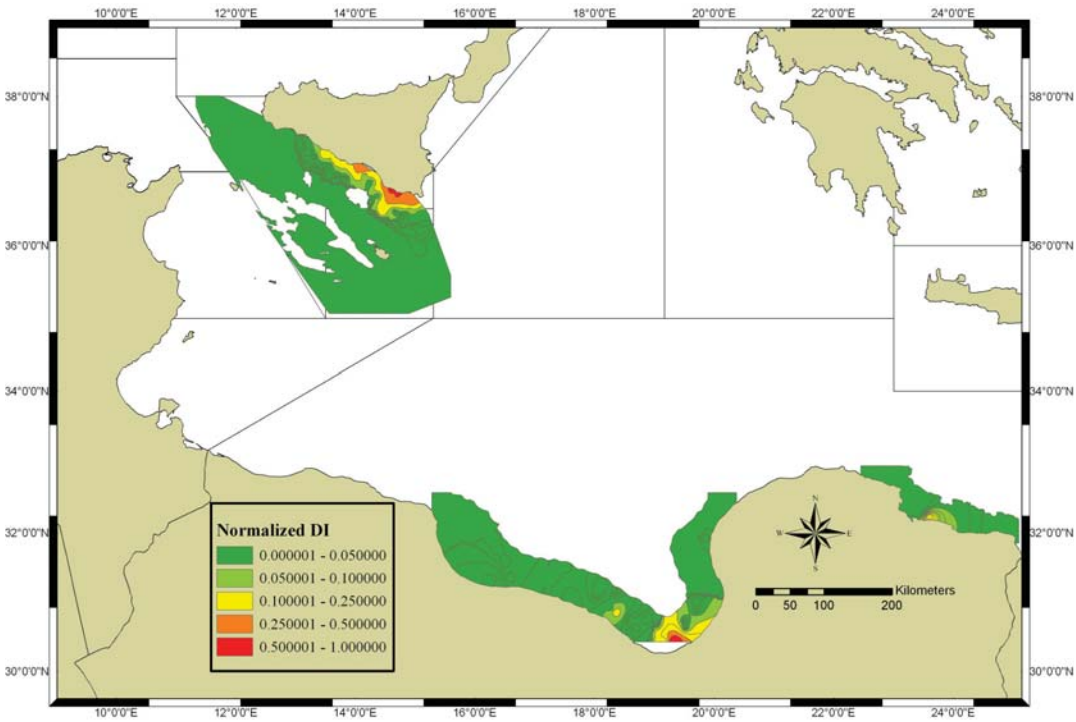


Fig. 14. Spatial distribution of normalized density index of red mullet "young of the year" (YOY) (spring–summer 2003).

6. Discussions

Qualitative comparison of hake and red mullet stocks among the Italian–Maltese, the Tunisian and the Libyan sub-regions, revealed large differences in biomass and density indices and stock age-structure. It is noteworthy, however, that the two species exhibit the same pattern of variation across areas. Catches in the Italian–Maltese sub-region are constituted by high numbers of small-sized specimens, with large size-classes being under-represented. In the Tunisian area, catches consist mainly of large-size fish. Both small-size and large-size fractions of the stocks are well represented in Libyan catches. Several factors may contribute to explain these differences.

The scanty abundance of small specimens in the GSAs off the Tunisian coasts is probably due both to seasonal factors (recruitment occurs in summer, whereas surveys were conducted in spring) and the differential selectivity of sampling gear (mesh opening size in the cod-end is 20 mm in the Italian–Maltese and the Libyan gear, versus 40 mm in the Tunisian gear). Most likely, the low occurrence of large-size specimens in the Italian–Maltese catches is due to a lower abundance of these specimens in GSAs 15 and 16 than on the sea bottom off the Tunisian and Libyan coasts. Moreover, the presence of very large size-classes in Tunisian samples is presumably due to a greater capacity of the Tunisian gear, a high-vertical-opening net, to catch large specimens.

Analysis of species distribution maps by life stages has shown that using densities of juvenile stages (JUV) (TL $<L_{50}$) and adult females (TL $\geq L_{50}$) as proxies of recruits and spawners, respectively, does not ensure an accurate localization of nursery and spawning areas. The YOY index delineates more clearly areas of concentration of recruits, whereas the distribution of the JUV index is more spread and indicates a migration of juveniles from the

nursery areas, sensu stricto, to the grounds occupied by adults. As regards spawners, estimates should be based on observed maturity stages.

It should be noted that nursery and spawning grounds in the Italian–Maltese sub-region and in the Tunisian sub-region extend beyond the limits of the national maritime jurisdictions concerned. Regarding the hake population in the Italian–Maltese sub-region, spawning and recruitment are preferentially located on the Adventure Bank (GSA 16) and the Malta Bank (GSA 15) and in areas adjacent to these Banks. Hake abundance is very scanty on the narrow shelf between these two Banks. The observed spatial distribution is consistent with findings from previous studies (Lembo et al., 2000; Fiorentino et al., 2003; Fiorentino et al., 2006). Fiorentino et al. (2003) identified two stable nursery areas located on the eastern sides of the Adventure Bank and the Malta Bank, mainly between 100 and 200m depth. A further study reported by Fiorentino et al. (2006), investigating preferential habitats of young of the year, juveniles (immature hake older than 1 year) and spawning females, found that two spatially discrete stock sub-units of hake exist in the northern part of the Strait of Sicily, localized, respectively, over the Adventure Bank and the Malta Bank and along their eastern edges. On both Banks, key life stages occur in a persistent patchy distribution with a clear separation between nurseries and other grounds. The role of the mesoscale oceanographic features in the area (upwelling, eddies, filaments and frontal systems) should be investigated further so as to understand how they influence and maintain the observed spatial structure.

The distribution of hake is more even along the North African coast. Spawning areas were observed in the Gulf of Hammamet and the Gulf of Tunis. Aggregation of mature adults between 100 and 200 m depth in the Gulf of Tunis was already reported by Bouhlel (1973). Unfortunately the lack of information about nurseries in Tunisian waters, which might be connected to the observed spawning areas, does not allow delineation of the spatial structure of putative local stocks.

Off the Libyan coast, adult females seem to be uniformly distributed in the Gulf of Sidra (Gulf of Syrta, GSA 21 west), with three major patches of high density close to the 200 m isobath, whereas recruits show an almost continuous distribution along the shelf edge. Unlike what is observed in the GSAs 15 and 16, there is overlap in the concentration areas of key life stages.

Considering the information available on the oceanographic characteristics of the study area and the biological features of the species, the location of spawning and nursery grounds is consistent with the transport of larval stages via the west-to-east currents along the African (ATC) and Sicilian (AIS) shelf-edge. Eggs, larvae and post-larvae of *M. merluccius* are pelagic (Lloris et al., 2003) and are generally found between 50 and 200 m depth (Fiorentino, 2007a). According to Orsi Relini et al. (1989), the distance between spawning areas and nurseries covered through larval dispersion due to currents may be substantial.

In the northern region of the Strait of Sicily, two major mesoscale features, the cyclonic Adventure vortex east of the Adventure Bank and the thermal filament east of the Malta Bank, are thought to play an important role in retaining and concentrating hake recruits in the identified nursery areas (Fiorentino et al. 2003; Fiorentino et al. 2006; Abella et al., 2008). However, it cannot be excluded that a fraction of eggs and larvae may be lost offshore through divergence of the main stream and may drift from the Adventure Bank towards the Tunisian platform and from the Malta Bank towards the Libyan platform. Similarly, it is not possible to exclude some transport of eggs spawned on the slope offshore from the Malta Bank towards the nurseries on the Adventure Bank via the current (LIW) flowing east to west.

A major question is whether these hypothetical larval exchanges between local stocks are enough to maintain a certain degree of genetic homogeneity in the region. As regards the southern region of the Strait of Sicily, the stable stream flowing along the African edge (ATC) allows a hypothesis of dispersal of hake larval stages in an east–west direction along the entire shelf edge from Libya to Tunisia. This could explain the almost uniform spatial distribution of recruitment off the Libyan coast and suggests a high degree of connectivity among stock sub-unit(s) along the African coast.

The few studies that have investigated population parameter variation (Levi et al., 1994) or genetic differentiation (Lo Brutto et al., 1998) between populations from the northern (GSAs 15 and 16) and the southern side (GSAs 13 and 14) of the Strait of Sicily have found no significant differences. More recently, Levi et al. (2004) have observed some significant phenotypical difference between stocks from the North African continental shelf off the Tunisian coast and the shelf off the southern Sicilian coast.

Red mullet appears patchily distributed in the Italian–Maltese sub-region, whereas it is rather spread over the wide and shallow North African continental shelf. The spatial distributions of spawners and of recruits reveal the changes in the species' habitat preferences during its life-cycle, with recruits concentrated along coasts and adults moving offshore. According to Voliani (1999), this movement may represent a seasonal (autumn) migration of red mullet from shallow to deeper grounds.

The distribution of red mullet adult females is similar on the two banks of the GSAs 15 and 16, with high-density patches located close to the coast and in offshore waters. The entire south-eastern Sicilian coast appears to be an important nursery area for red mullet. It is worth noting that no recruitment area was observed along the Maltese coast in this study. Results are in line with findings from a previous study by Garofalo et al. (2004) analysing a time-series of spawner and recruit density indices in the Italian–Maltese sub-region. According to the authors, two major and clearly separate spawning areas exist in the GSAs 15 and 16, located over the Adventure Bank and the Malta Bank at approximately 100 m depth, whereas recruits exhibit a widespread distribution throughout the Sicilian coastal waters, between 20 and 50 m depth.

Several important high-density patches of red mullet adult females were found along the continental platform off both the Tunisian and the Libyan coasts. Some spawning areas are far from the coast, similarly to what was observed in the Italian–Maltese area. On the Libyan shelf, only one coastal nursery (inner part of the Gulf of Sidra) is associated with the several spawning components observed in the area.

Since red mullet larval stages live only in surface waters (Fiorentino, 2007b), the transport from spawning areas to nursery areas is probably due to wind-driven surface currents. Fiorentino (2007b) states that, considering the biological features of *Mullus barbatus*, a coastal resource, and given the particular morphology of the Strait of Sicily, characterized by wide deep bottoms separating the northern and southern platforms, the existence of different red mullet stocks in the region is highly probable. Some previous studies support this hypothesis: Levi et al. (1992) found significant differences among growth parameters of red mullet from the Sicilian side of the Strait of Sicily (GSA 15 and 16) and the Gulf of Gabès (GSA 14); a large infestation by a trematode of the genus *Stephanostomum* seriously affecting the red mullet fishery in the Tunisian waters for several months in 1990, was not observed in the fish landed at the Sicilian base-ports of the Strait of Sicily (Levi et al., 1993); the independence of water masses and the circulation system along the Sicilian and North African borders of the Strait of Sicily support the hypothesis of distinct local stocks (Levi et al. 1995b). A recent study conducted on red mullet stock in the Adriatic Sea (north-central Mediterranean) (Garoia et al., 2004) indicated that the species may be grouped in local, genetically isolated populations at a spatial scale of 100–200 km.

7. Conclusions

Despite the limitations of the available data, the results of this study appear useful in the formulation of some preliminary hypotheses about the spatial distribution of stocks of hake (*Merluccius merluccius*) and red mullet (*Mullus barbatus*) in the south-central Mediterranean. Two geographically distinct nursery and spawning grounds of *Merluccius merluccius* on the northern side of the Strait of Sicily suggest the existence of two main stocks sub-units, one over the Adventure Bank (GSA 16) and the other over the Malta Bank (GSA 15). In contrast, there is no clear picture of stocks diversification along the southern side of the Strait of Sicily (GSAs 12, 13, 14 and 21), where several different spawning and nursery grounds have been identified, partially overlap each other and are probably interconnected. Given the pattern of main currents in the Strait of Sicily, passive dispersion of larvae may be responsible for a certain degree of stocks mixing, not only along the Italian–Maltese and the North African coasts, but also between the two sides of the Strait of Sicily.

The entire life-cycle of the hake populations generally occurs over large areas extending across the boundaries of national maritime jurisdiction and the adjacent high seas.

The present study suggests that there are two separate stocks of *Mullus barbatus,* one on the northern and one on the southern side of the Strait of Sicily. The results do not justify the identification of other local stocks at a smaller space-scale along the two coasts, but their occurrence can not be excluded. Despite the fact that red mullet nurseries are in shallow coastal waters, the species' offshore migration results in a distribution of the species beyond the limits of the national maritime jurisdictions of the countries concerned and, in the case of the Italian–Maltese sub-region, across the boundary between GSA 16 and GSA 15.

The next major challenges or recommendations for action are:

- More effort is needed to establish and develop a standardized framework of data collection and analysis among the countries bordering the area covered by the MedSudMed Project.
- Analysis should be extended to other year(s) of data/surveys in order to investigate the temporal stability of the distributions described in this study.
- Further research is needed to ascertain the environmental factors (bottom sediments, oceanographic processes) explaining the observed spatial distribution of the stock(s).
- Analysis should be extended to other species, giving priority to those fishery resources that are likely to be shared by two or more countries.
- Genetic studies should be carried out, or other innovative methods applied, to investigate larval dispersal and interactions (including exchanges) between stocks of target species among sub-regions.

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Notes

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