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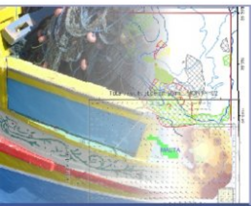
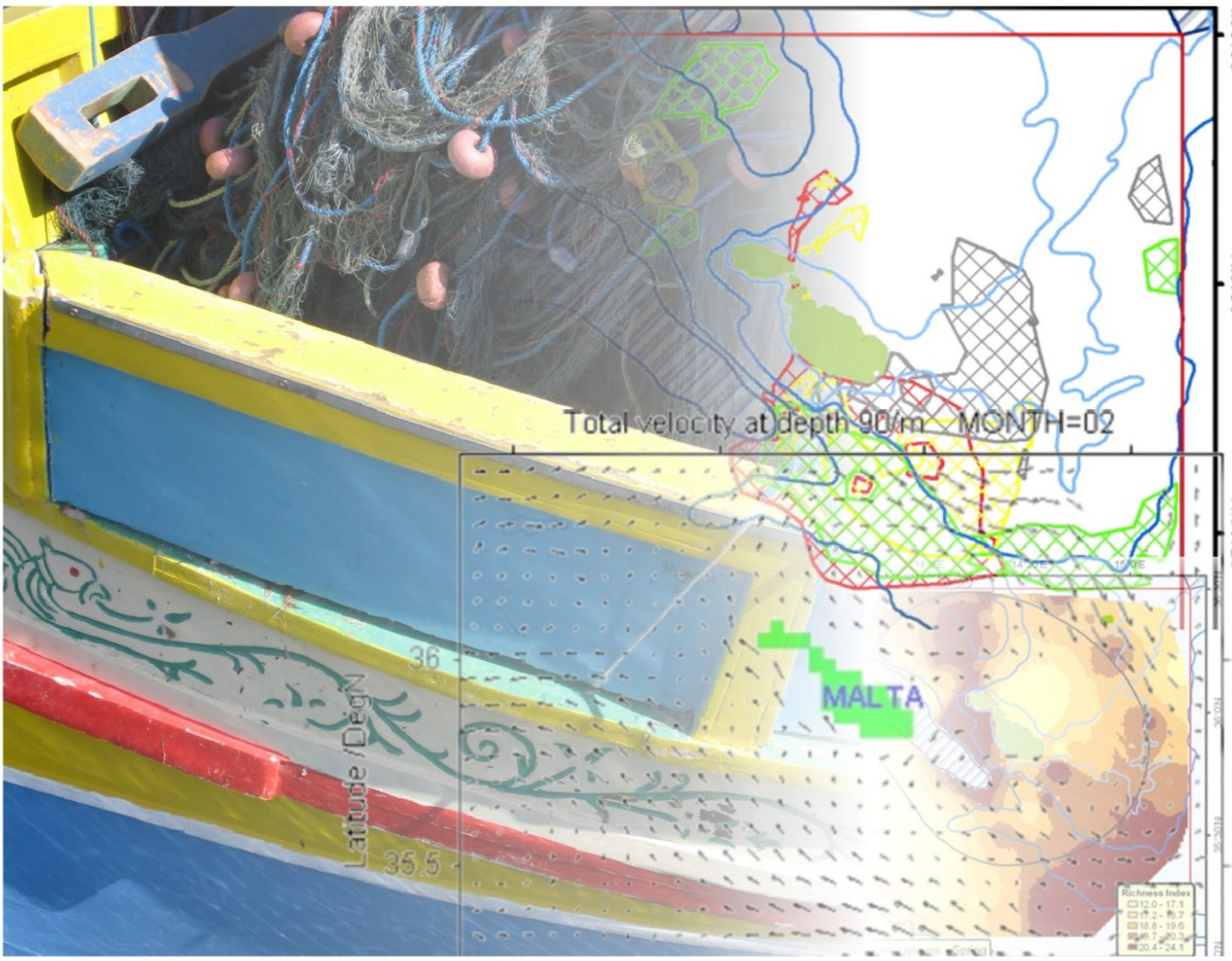


Pilot Study: spatial distribution of demersal fishery resources, environmental factors and fishing activities in GSA 15 (Malta Island)



MEDSUDMED

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GCP/RER/010/ITA

Pilot Study

Spatial distribution of demersal fishery resources, environmental factors and fishing activities in GSA 15 (Malta Island)

MedSudMed Technical Documents No.13
GCP/RER/010/ITA/MSM-TD-13

Rome (Italy), June 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 Jamairhiya, Malta and Tunisia), for the continuous and dynamic assessment and monitoring of the state of the fishery resources and the ecosystems in the Straits of Sicily.

Research and training are supported with a view to increasing and using knowledge on fishery ecology and ecosystems, and to creating a regional network of expertise. Particular attention is given to the technical coordination of the research between the countries, which should contribute to the implementation of an Ecosystem Approach to Fisheries (EAF). Consideration is also given to the development of an appropriate tool for the management and processing of data related to fisheries and their corresponding ecosystems.

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GCP/RER/010/ITA Publications

MedSudMed Project publications are issued as 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 an activity that was discussed during the Meeting on the MedSudMed Component on Spatial distribution of demersal resources in relation with environmental parameters and fishery characteristics (16–17 December 2004, Mazara del Vallo, Italy). During the meeting, it was decided to implement pilot studies that would integrate a variety of information on fish biology and ecology, physical environment, habitats, fisheries in GSAs for which information was available. The GSA 15 was then identified as an appropriate area in which to carry out such a pilot study.

Acknowledgements

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ABSTRACT

The FAO–MedSudMed Regional Project has promoted research on the improvement of knowledge on fishery ecosystems, with a view to the sustainable management of living marine resources in the central Mediterranean (Straits of Sicily). A pilot study focused on the waters around the Maltese Islands (GSA 15), with the aim of providing a comprehensive overview of the spatial distribution of the different life stages of exploitable demersal fishes in relation to the type and distribution of fishing, as well as to the oceanographic factors characteristic of the area of study.

Critical zones for their role in the ecology of the main demersal fishery target species were investigated using species abundance data disaggregated by life stage. Spatial analysis and the application of GIS techniques allowed the identification of preferred habitats (e.g. nursery, feeding and spawning areas) for *Merluccius merluccius*, *Mullus barbatus*, *Parapenaeus longirostris*, *Raja clavata* and *Raja miraletus*. The impact of fishing on these species was assessed, particularly in terms of fish assemblages. The transport paths of early life stages were also hypothesized on the basis of oceanographic factors typical of the area.

The results revealed that the spatial distribution of the main fishery resources overlaps the limits of the current GSAs. The analysis of oceanographic factors showed that some fishery resources are sustained by young individuals transported from adjacent GSAs. The results also demonstrated that the spatial distribution of the main demersal fishery resources in the Mediterranean GSA 15 straddle other GSAs, in particular as concerns nursery and spawning areas, indicating that some fishery resources are shared. This implies that harmonized fishery management should be applied over a larger area than is implied by the GSA concept. Finally, the study showed how data provided by different methods could be integrated to enhance the available scientific information in a data-limited situation.

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1. Introduction

Worldwide there is a general agreement that the fishery management paradigm needs to be significantly broadened to match the definitions and principles of sustainable development and the welfare of human society as well as of the ecosystem (Garcia *et al.*, 2000). The interactions that occur between fisheries and ecosystems, and the fact that both are subject to natural long-term variability, must be more effectively taken into consideration in fishery management. Consequently, in recent years, commitments to a wider approach to fishery management are increasingly numerous; e.g. implementation of the FAO Code of Conduct for Responsible Fisheries, CCRF, and of the Ecosystem Approach to Fisheries, EAF (FAO, 1995; FAO, 2003a; FAO 2004, 2005; Cury and Christensen, 2005; Rice and Connolly, 2007), and increasing attention has been directed to the analysis of the biological and ecological implications of the fishery management measures (Hilborn, 2007).

The broad principles of, and the approach to, effective and responsible fishery management are contained in the FAO Code of Conduct; many of them are relevant to the EAF. The key objective of the EAF is the sustainable use of the whole ecosystem and not just fishery target species (FAO, 2005). The conceptual basis of the EAF includes, *inter alia*, advances in the scientific basis for incorporating ecosystem considerations into conventional fishery management (FAO, 2003a). This approach should be applied in different situations, such as a particular fishery or management area, and under different conditions, ranging from data- and information-poor situations to cases where extensive scientific knowledge exists.

However, although the principles of the EAF have been widely described and discussed (e.g., Garcia *et al.*, 2003; AdriaMed, 2005; Garcia and Cochrane, 2005; Rice and Connolly, 2007), currently not many studies dealing with biological and environmental data try to merge them in a multi-disciplinary approach, especially in the Mediterranean region. Accordingly, integrating biological information on marine resources with the environmental features in which these resources exist is now a key challenge for fishery research in the Mediterranean (FAO, 2005; FAO/GFCM, 2006).

Examples of relevant areas of research that would lead to improved ability to implement the EAF effectively are: (i) understanding how ecosystems function, especially in terms of species interactions, and how these lead to higher ecosystemic properties; (ii) expanding knowledge on fishing (including jurisdiction, gear and vessel types) and on the impact of fishing on target stocks; (iii) assessing/defining the minimum levels of biomass compatible with the maintenance of the species' ecosystem function and the identification of spawning and nursery areas for effective management of these vulnerable stages of the life cycle; (iv) understanding the impact of fishing on non-target species and what it is doing to food web interactions, habitat and biodiversity (FAO, 2003; FAO, 2005).

Accordingly, defining a management area in terms of the spatial distribution of fish resources and species assemblages (biological features), bottom sediments, water flow, temperature and salinity (environmental characteristics), as well as in terms of spatial distribution of the fishing itself (human or socio-economic factors), is a central issue and a priority in the process of implementing EAF management.

The FAO–MedSudMed Regional Project (Assessment and Monitoring of Fishery Resources and their Ecosystems in the Straits of Sicily) (GCP/RER/010/ITA) has promoted research on the improvement of knowledge on fishery ecosystems by integrating biological and environmental features. This research was carried out to provide integrated information on fishery target species, species assemblages (including non-target species), and on the environment in which they live. The general outcome was a better understanding of the ecosystem's functioning, with a view to identifying strategic objectives for the implementation of EAF management measures in the MedSudMed Project area (central Mediterranean).

In consideration of this general framework, a pilot study was undertaken in the Straits of Sicily to investigate the spatial distribution of exploitable demersal fish stocks in terms of different life stages and factors, such as the environmental features and fishing characteristics that are supposed to affect resource distribution.

The Maltese waters were selected as a study area. They are included in the Geographical Sub-Area (GSA) 15 in the classification of the General Fisheries Commission for the Mediterranean (GFCM), which divides the Mediterranean Sea into 24 GSAs for assessment and management purposes (Figure 1). In particular, the area surrounding the Maltese Islands (the Maltese Fisheries Management Zone; Figure 2) was chosen, as several data sets from different branches of marine science are available. Furthermore, due to the highly active mesoscale variability in the Straits of Sicily and to their particular position with respect to the swift Atlantic Ionian Stream, the Maltese Islands are the optimal area for such studies.

To date, fishery management in GSA 15 was primarily based on effort control and based on a fairly good knowledge of the state of the fishery resources. However, a comprehensive overview of interactions between the fishery resources, fishing and the environment was lacking. Marine biological, ecological, oceanographic, climatological and fishery research has been carried out in Malta in recent years. The present study was an opportunity to assemble and process available data sets, in an attempt to describe different components of the ecosystems with a view to supporting ecosystem-based management.

Fishery ecosystem studies are, by definition, multi- and inter-disciplinary. They require first an appropriate identification of the key physical, biological and human components of the ecosystems and, successively, a more profound understanding of the interactions among these components and of ecosystem functioning.

Ecosystem processes, by their very nature, change across multiple spatial and temporal scales (Bakun, 1996). Therefore, examining the spatial and temporal dimensions on which abiotic, biotic and human processes occur and interact is essential to: discover patterns and factors that drive them; provide a better understanding of threats to stocks and biodiversity; supply indicators for the conservation and sustainable use of living marine resources. Clearly, although a complete understanding of ecosystems is unlikely to be achieved, efforts must be made, consistent with a precautionary approach, to move towards the application of an ecosystem approach to fishery management progressively and adaptively. Starting from limited available data and applying what is known, progress towards such a goal is likely to be made by learning through the process, developing specific topics, identifying gaps in times-series data for certain parameters, and acquiring additional data.

The pilot study carried out in the GSA 15, applying this approach, is a first attempt to conduct practical ecosystem-based research in a data-limited situation. The goal of this research is to explore the linkages between biological and physical oceanographic processes, fish population abundance distribution and dynamics, and fishing. It represents a beginning in the development of a comprehensive understanding of the way that an ecosystem is structured and functions (including the human component) and identifies some directions for continuing.

Specific aims of the study were:

- to identify the general distribution of demersal resources and the location of important habitats (e.g. feeding, spawning, nursery areas) for different life-history stages of target species (the total range of a species is the area that should be delineated to apply the ecosystem approach to the management of the a fishery on the species);
- to link the spatial distribution of fishing effort to relevant spatial structures of the resources;
- to increase knowledge on the relationships between fishery resources and the physico-chemical conditions of the marine environment.

The methods followed included an inventory of existing studies and available data concerning fishery resources, marine environment and fishing; part of the data was stored in the MedSudMed Fishery and Ecosystem Information System (FEIS). The spatio-temporal distribution of fishing, hydrographical features, seabed characteristics, demersal resources at different levels of aggregation (assemblages, taxonomic groups, life stages of target species) were explored and the spatial distribution of demersal resources relative to the environmental conditions of the water column, edaphic and biological features of the sea bottom, and fishery characteristics were interpreted.

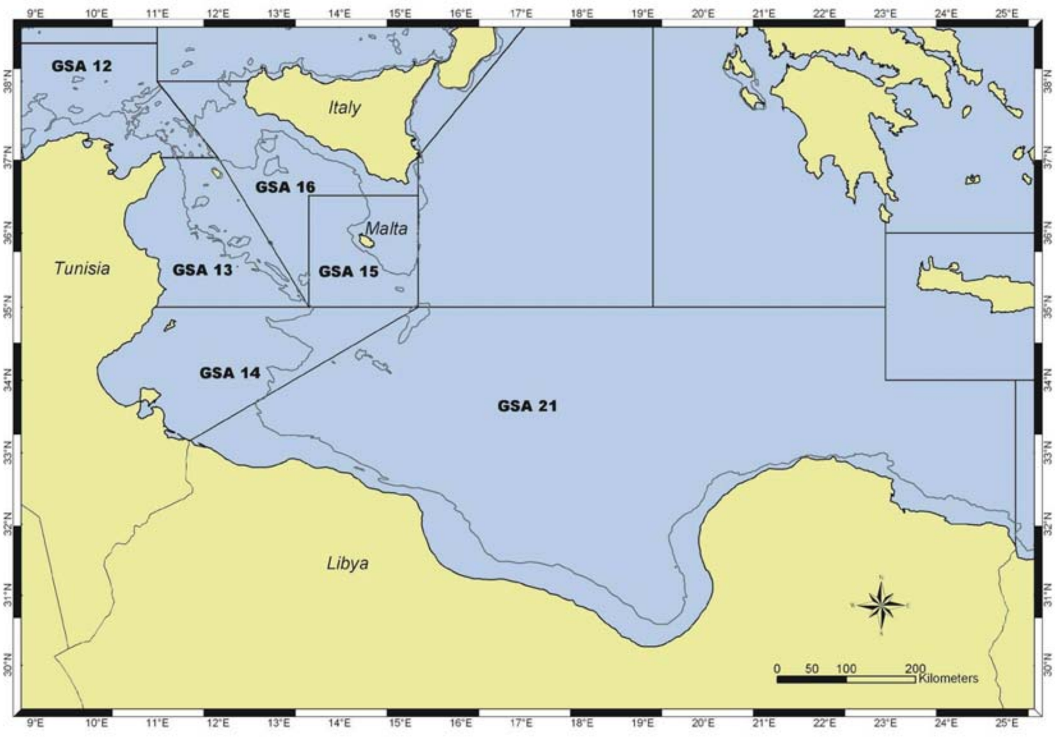

Figure 1. Geographical Sub-Area 15 and adjacent GSAs (based on the classification by the General Fisheries Commission for the Mediterranean)

2. Study area

The Maltese Islands are located in the central Mediterranean Sea, 93 km south of Sicily (Italy) and 290 km from the north coast of Africa; they are aligned in a NW–SE direction and lie on the southernmost extremity of the Sicilian continental shelf. The archipelago consists of the Islands of Malta, Gozo, Comino, and two other uninhabited islands.

Part I: Background information on the fisheries and the target species

3. The characteristics and dynamics of the Maltese fisheries

3.1 Introduction

Maltese fisheries are of a typically Mediterranean artisanal type which are not species-selective and are frequently described as multi-species and multi-gear fisheries, with fishermen switching from one gear to another several times throughout the year (Camilleri, 2003a). The social and cultural importance of the Maltese fisheries far outweighs their economic importance (about 0.1 percent of the national Gross Domestic Product). The livelihood of most of the local fishermen depends on the sale of highly prized species, which are available to the consumer as fresh fish of the highest quality, caught by traditional artisanal methods during very short fishing trips (Camilleri, 2005).

Overall, the numerical size of the full-time fleet has remained stable over the past century and has largely been dominated by traditional wooden boats which have, however, partly been gradually replaced by fibreglass replicas in recent years. The 1980s also saw the introduction of a very limited number of trawler licences, but for the last 15 years applications for further trawler licences have been refused; a trawling ban within the 3 mile zone around the Maltese Islands has at the same time been introduced. In general, licences have only been issued for small-scale fishing operations, and drift-netting and purse-seining have never been licensed; even the expansion of the blue-fin tuna fishery, which occurred in the late 1980s, took place through the exclusive use of surface longlines. Unlike the full-time fleet, however, the number of part-time and recreational fishing vessels has increased considerably in the last few decades, albeit using artisanal gears.

Malta has implemented effort-control measures routinely within its waters for several decades, in recognition of the fact that the Maltese fishing grounds have represented the only available source of fresh fish supply to Maltese consumers. The increase in the number of registered fishing vessels in recent years, to a total of 2,252 vessels, should not be taken at face value, since most of them operate on a small scale and have limited activity (Camilleri, 2003a). Camilleri (2005) reported that the number of active vessels varies according to season, with minor ports having practically no active vessels during the winter months and as little as 25 percent of the registered vessels in major ports land fish during this period. The same author added that the proportion of active vessels operating on any one day seldom exceeds 50 percent, and is normally much less, since most of them are owned by part-time fishers; and it is quite common for full-time fishers to own more than one vessel. Static gears and other passive methods are used in almost all fisheries. Considering these characteristics, Camilleri (2005) suggested that, the fishing capacity of the Maltese fleet could be more appropriately measured by such parameters as vessel size, gear size and effective fishing time, rather than the more commonly used parameters such as engine power and gross tonnage.

Malta has managed an Exclusive Fishing Zone (EFZ; Figure 2) since 1971 and as a result of the Malta–EU negotiations prior to accession in May 2004, the 25-mile Zone has been maintained as a Fisheries Management Zone (FMZ) (Camilleri, 2003b). A new Council Regulation (EC 813/2004) lays down detailed conservation measures in connection with the management regime of the Zone, which essentially limits the number, size and power of fishing vessels allowed in the zone depending on the type of fishing activities in which they are engaged (additional details provided in Annex 1).

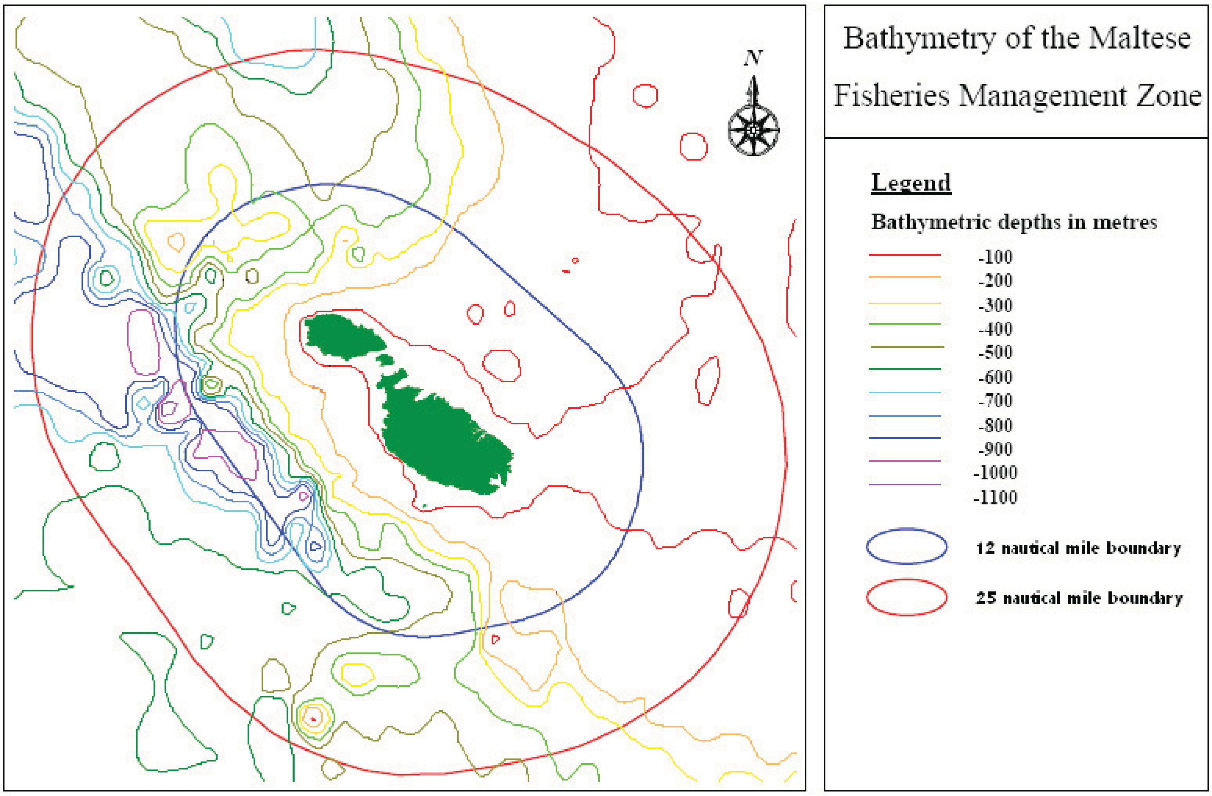

Figure 2. The boundary and bathymetry of the Maltese Fisheries Management Zone (FMZ)

3.2. Profile of the Maltese fishing fleet and its activities

3.2.1. Structural characteristics

The average size of the Maltese fishing vessels is well under 10m in length, with the exception of the trawler type, using exclusively bottom otter trawls, averaging 22.5m (Figure 3). Most of the vessels are of a traditional structure (Plate 1 and Plate 2) i.e. *luzzu* and *kajjik* with the latter being more common. The *Multi-Purpose Vessel* (MPV) type (Plate 3), a relatively recent addition to the fleet, makes up more than 35 percent of the fleet and, unlike the *luzzu*, which is the most “antique” traditional vessel constructed almost exclusively of wood, the hull material of MPVs is generally fibreglass. This material has also become the preferred choice in the construction of *kajjiks,* which until a couple of decades ago used to be made of wood. The *kajjik* differs from the *luzzu* in being generally smaller and being flat ended at the stern, whereas the *luzzu* is pointed at bow and stern.

The main engine power of the traditional vessel types and other derivatives ("other" type) is generally very low, but the MPV type has a higher average power, reflecting the larger size and different hull structure. The average main engine power of the trawler type is, as expected, very much higher than that of the other vessel types, but is relatively low for the kind of fishing operations they are often engaged in (e.g. trawling for prawns at 800m depth).

Plate 1. The *luzzu* (Camilleri, 2005)

Plate 2. The *kajjik* (Camilleri, 2005)

Plate 3. An example of a multi-purpose vessel (MPV) (Camilleri, 2005)

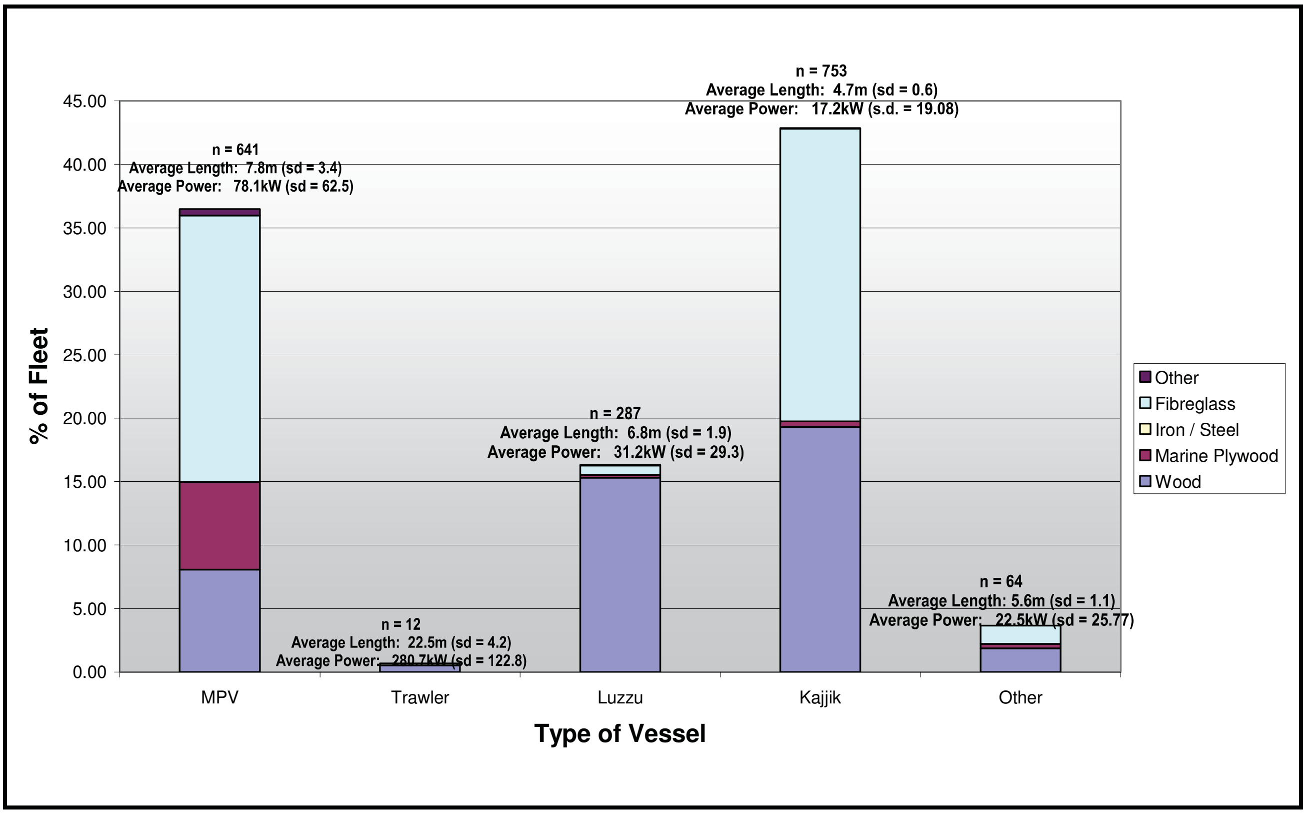

Figure 3 Structural characteristics of the Maltese fishing fleet (Camilleri, 2005)

3.2.2. Fishing gears

The main gears used by the Maltese fishing fleet are various forms of "hooks and lines" (over 60%). Different types of "gillnets and entangling nets" are also popular (20%), and traps make up over 10% of the registered main gear.

The most prevalent method of fishing is set bottom longlining which is operated during particular periods of the year by over half of the operational vessels, especially by those in the 0–5.99m and 6.00–11.99m length classes. The next most frequently used method of fishing is trammel netting, which is practised by 27% of the fishers, who also own the smaller-sized craft.

Twenty five percent of the fishers use the hand trolling line, locally known as *rixa,* which consists of a line and artificial lure, mainly made of heckle-neck feathers covering different sizes of hooks. The main species targeted by the *rixa* are dolphin fish *(Coryphaena hippurus*), frigate mackerel *(Auxis thazard)* and amberjack *(Seriola dumerili).* These fishers, the majority of whom are part-timers or recreational fishers owning vessels under 6m in length, frequently also use bogue traps. Octopus traps are used by only 4.5% of fishers who own vessels of up to 12m in length.

Drifting longlines are used by 10% of the fishers. In this case, the vessels are larger, with the length ranging between 6.00 and 23.99m. This is because the target species are bluefin tuna (*Thunnus thynnus*) and swordfish (*Xiphias gladius*) which are caught from approximately 20 miles offshore and beyond.

Apart from their registered normal fishing activity, up to 130 vessels (over 6m in length) also participate in the traditional fisheries for dolphin fish (*Coryphaena hippurus*), or *lampuki*, (August–December), for which, a fishing site, or *rimja*, is assigned to each vessel after lots have been drawn for each national district.

3.2.3. Production, seasonality and relative importance of different fisheries

Over 65 percent of the annual landings (about 1000 tonnes) originate from the tuna and dolphinfish fisheries and contribute to almost 56 percent of the total value (about $6 million) of the annual landings[1]. Trawling, bottom longlining and swordfish longlining have similar importance in terms of both weight (7–10 percent of annual landings, each) and value (11–15 percent of annual value, each). Trammel nets and other artisanal demersal gears account for about 3 percent of the annual landings, and minor pelagic gears account for over 4 percent of the annual landings.

Between the months of April and July the market is dominated by landings of bluefin tuna, with the second most available species being the swordfish. Both these species are targeted with the same method; i.e. pelagic drifting longlines.

Swordfish is the third most landed species annually in terms of weight and it is the only species with landings of more than 1 metric tonne for each month of the year. It is targeted throughout the year, albeit to varying degrees and for different reasons. During the winter months (December–April) most boats target lucrative demersal species prior to reverting to tuna longlining, which catches swordfish and albacore (*Thunnus alalunga*) as a secondary species. The peak fishing period for swordfish is between May and August.

Landings of *lampuki* occur mainly between August and December; most of the catch is made by the use of fish aggregating devices (FAD; known locally as *kannizzati*, small anchored rafts made of floating material to which a few palm fronds are attached), but if weather conditions remain favourable, the season drags on into January. Other major species associated with the dolphinfish fishery are pilot fish (*Naucrates ductor*), amberjack and small bluefin tuna, which are caught as secondary species found in considerable concentrations under FADs.

Landings of small gregarious pelagic and demersal species are generally not seasonal, except in the case of mackerel (*Scomber scombrus*); the species in these groups are landed in quantities of less than 5 metric tonnes per month. Bogue (*Boops boops*) is the most landed small pelagic species; it is caught mostly by traditional traps made out of cane strips, and is followed by mackerel. The landings of prawns originate exclusively from trawling, which takes place throughout the year, though in reduced amounts in winter months, owing to unfavourable weather. Landings of other demersal species originate from trawling, longlining and fixed netting operations (Figure 4).

[1] This sub-section is adapted from Camilleri (2005)

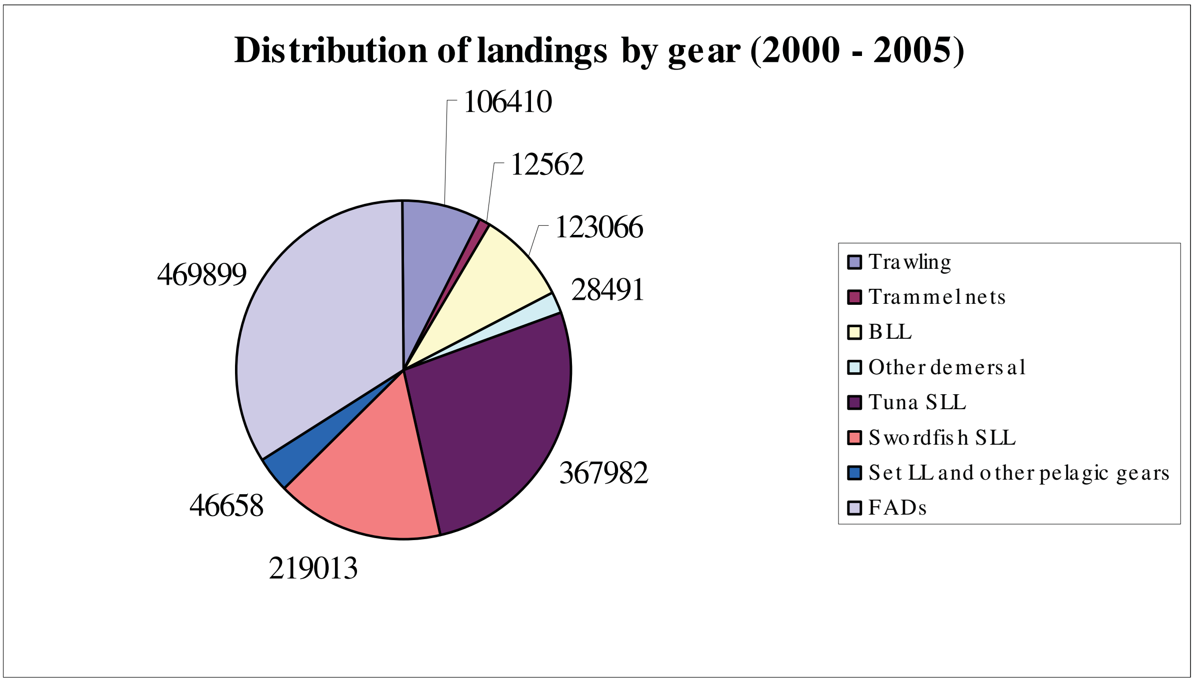

Figure 4. Distribution of landings (kg) by gear for years 2000–2005

3.3. Maltese demersal fisheries

3.3.1. Historical commercial catch rates

The only historical data available for the Maltese fisheries are those published by Giudicelli (1978), who used different gears with a high vertical opening which, while losing a certain amount of demersal fish from the lower panels, were very efficient in catching semi-pelagic species. Five fishing grounds were examined; altogether, on 2,566 effective hours of simulated commercial trawling, the commercial yield was almost 238t, resulting in an hourly catch of 93kg h^{-1}:

- Scalambri grounds (outside the Maltese FMZ), within the limits at 36°35’ on the northern side and at 36°19’ on the southern side, in the depth range 150–250m, with poor trawlability, owing to irregular bottom and the presence of debris and relics (aircraft, bombs, and so on), and poor in benthic fauna.

- Porto Palo grounds, within the limits at 36°16’ on the northern side and at 35°48’ on the southern side, in the depth range 150–350m, as a narrow belt in the N–S direction, smooth, with the exception of small rocky patches.

- NE Malta, 11 miles from Malta (i.e. inside the FMZ) within the limits 36°00–36°10’N and 14°40’–14°49’E, in the depth range 120–150m, smooth with sand, broken shells and calcareous maerl, but almost untrawlable because of the deployment of *kannizzati*.

- Marsa Scirocco, 17 miles south of Valletta within the limits 14°28’–14°57’E, in the depth range 200–400 m, belt-shaped, starting, on the eastern side just south of 35°30’N and going sinuously westward up to close to Marsa Scirocco, smooth but with relatively steep slope angles, of medium trawlability, given the large amount of debris, war relics and the *kannizzati* stones.

- Gozo grounds, a traditional area for the Maltese trawl fleet, within the limits 35°50'N and 14°12'E, in the depth range 180–230m, smooth with relatively steep slope angles, of good trawlability (with the exception of few known obstacles).

Table 1. Average hourly catches (kg h^{-1}) in the fishing grounds examined by Giudicelli (1978).

Fishig ground	Average	red mullet	horse mackerel	hake	shrimp	dogfish	skates	John Dory	rays	gurnard
Scalambri	**196**	1.4	172			2.1	1.3	4.1		
Porto Palo	**117**	0.3	72	1.2	3.7					
NE Malta	**141**	2.1		2.1						
Marsa Scirocco	**226**	7.9		7.4	1.2	7.1			23.3	11.3
Gozo	**35**	3.3		2	2.9					

3.3.2. Trend in landings and state of demersal species

The general landing trends for demersal species are fairly stable (Figure 5), with a significant raise in the last few years for trawl-caught fish, particularly shrimp, due to an increase in exploitation rate. As far as shallow shelf resources (Figure 6) such as mullets (*Mullus* spp.), gurnards (*Trigla* spp.), and common pandora (*Pagellus erythrinus*) are concerned, there was a decline in landings in the early 1990s, when several fishers geared up for the tuna fishery, followed by an increase up to 1999 and a redecline thereafter. The increase is attributable to an increase in fishing effort for these more valuable species, the fishers preferring to catch species whose sale price had risen, and the recent decline suggests that overfishing has started.

The shrimp landings (Figure 7) also show a decline and a subsequent rise, and since shrimps are only taken by trawling, one could conclude that it is the Maltese trawling effort that is mainly responsible for the increase in landings of all trawlable species.

It is therefore of great concern that Maltese trawling, even with a small fleet, is approaching the limit of production for a small trawlable shelf area. One must also consider that, while the number of boats and full-time fishers has remained stable, the number of part-time fishers, whose catches are more difficult to survey, has increased over the past few decades. This increase has also led shallow demersal fisheries to exceed the maximum sustainable yield (MSY), as indicated by the overall slight decline in catches in recent years.

The trends for deep-water resources (Figure 7) are more stable than for other resources, meaning that the longline fishery, which also exploits waters distant from Malta, outside the 25-mile Fisheries Management Zone, is not currently overexploiting the deep-water resources. This conclusion seems especially valid since the key species captured, such as groupers (*Epinephelus* spp.) and various shark species are long-lived and generally decline rapidly with even moderate levels of exploitation.

Camilleri (2001) reported that the level of abundance for 14 demersal fisheries targeted species is greater than 10kg km^{-2} on the Maltese shelf (10–200m depth). These species include, inter alia, red mullet (*Mullus barbatus*, 52.2 kg km^{-2}), striped red mullet (*Mullus surmuletus*, 26.0 kg km^{-2}), common pandora (*Pagellus erythrinus*, 65.3 kg km^{-2}), European hake (*Merluccius merluccius*, 56.8 kg km^{-2}), thornback ray (*Raja clavata*, 133.2 kg km^{-2}), John Dory (*Zeus faber*, 79.8 kg km^{-2}), picarel (*Spicara smaris*, 196.8 kg km^{-2}) and broadtail squid (*Illex coindetii* 34.7 kg km^{-2}); shrimp resources in deeper waters (500–800 m) were also found in high abundance, with giant red shrimp (*Aristaeomorpha foliacea*) and deep-water pink shrimp (*Parapenaeus longirostris*) having a biomass index of 46.5 kg km^{-2} and 20.8 kg km^{-2}, respectively (AA.VV., 2000; Camilleri, 2001).

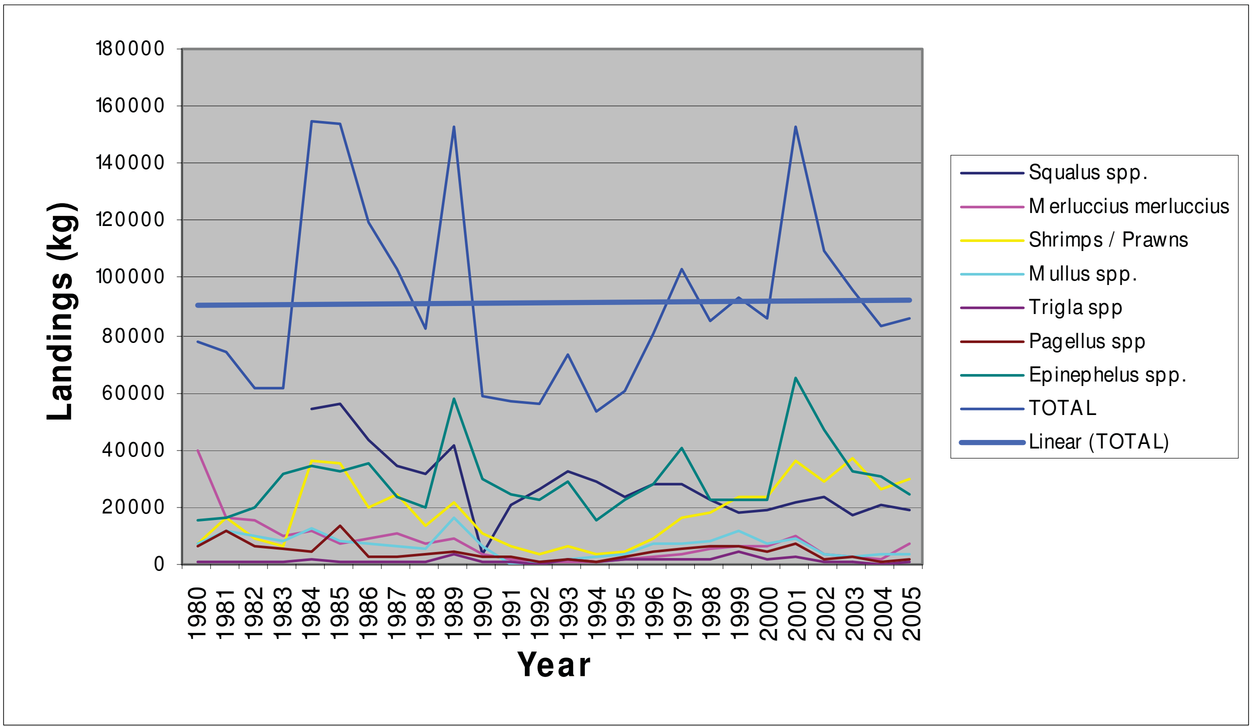

Figure 5. Landings (kg) of commercially important demersal species (1980–2005)

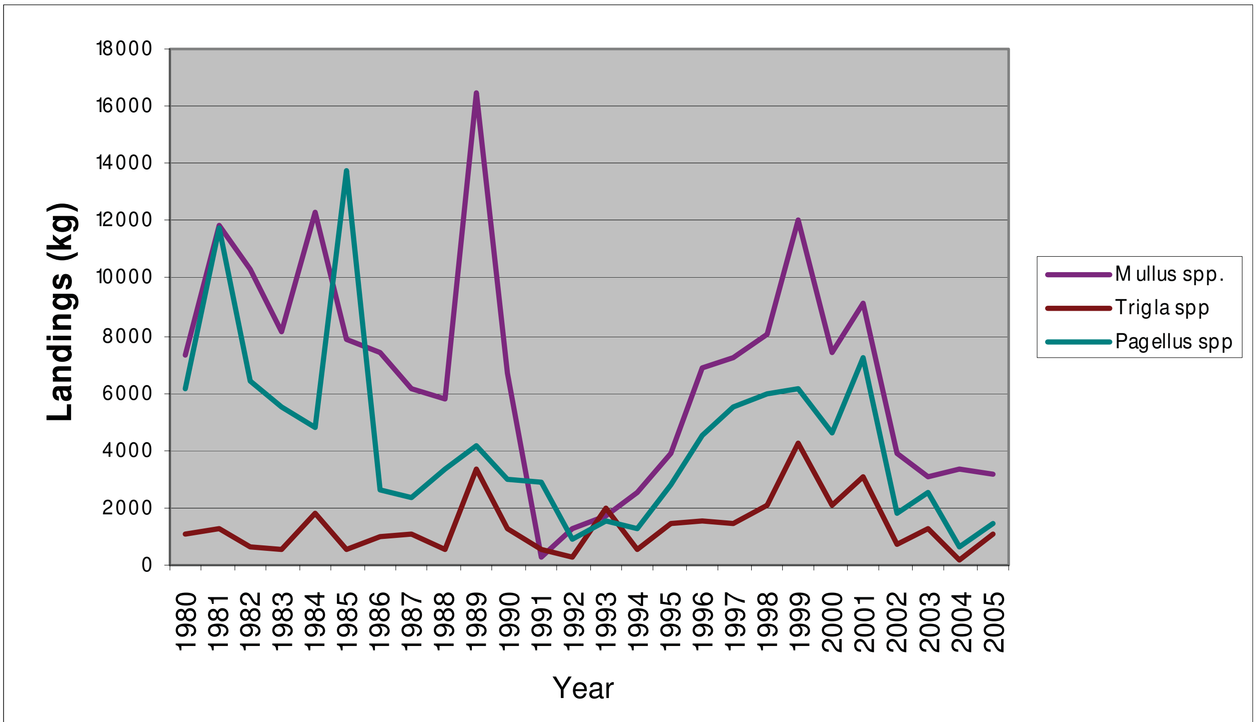

Figure 6. Landings (kg) of commercially important shallow-water demersal species (1980–2005)

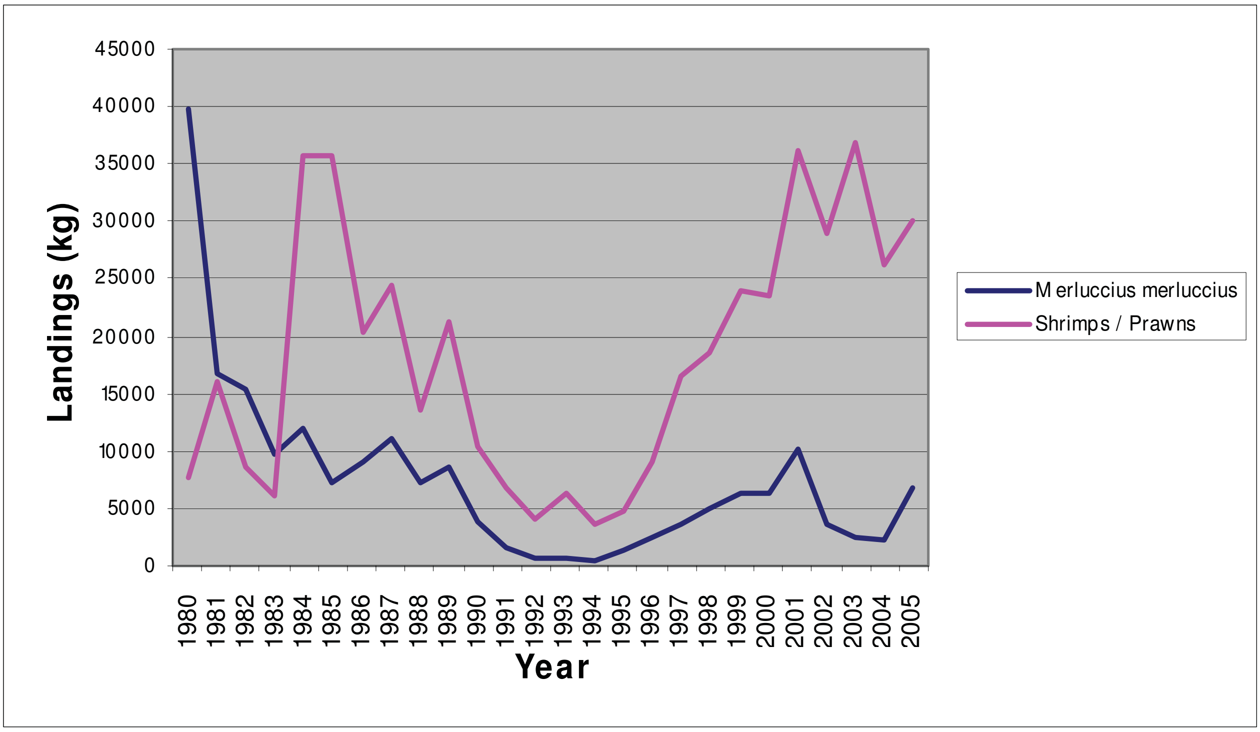

Figure 7. Landings (kg) of commercially important deep-water species (1980–2005)

Camilleri (2001) also demonstrated that, for the shelf and upper slope, the catch rates in Maltese waters are roughly double the catch rates on the Sicilian side of the the broad area between Sicily and Tunisia. These figures, higher than normal, suggest that Maltese demersal resources have been exploited at sustainable levels and that the Maltese FMZ had served as a conservation factor in this part of the Straits of Sicily, the other areas of which are greatly overexploited.

It is important to note that the trawlable fishing grounds within the Fisheries Management Zone (FMZ) represent a small proportion of the whole shelf (26% of 4,850 km^2) and slope (3% of 5,880 km^2) areas, the rest being prohibited or unsuited to trawling gear. However, it has been reported that the trawler fishing intensity on the limited slope fishing grounds is high (Anon., 2001). In fact, the overall annual swept area was reported to be about 60% and 400% for the shelf and slope fishing grounds, respectively (Camilleri, 2001).

Consequently, not considering the other bottom gears, Maltese trawl fisheries are likely to have a moderate impact on both shelf and slope bottoms and related groundfish resources, with the exception of the limited deep-water shrimp grounds which are swept roughly four times a year.

Still, the presence of species that are especially vulnerable to intensive trawling, such as sharks and rays, which have a low reproduction rate, and probably also *Zeus faber*, is an indicator that the faunal communities here have not been drastically altered by trawling. In this respect, Maltese waters may serve as a 'refugium' for these vulnerable species in the central Mediterranean (Camilleri, 2005).

4. General hydrodynamical characteristics of the central Mediterranean

4.1. General water-column characteristics

The Straits of Sicily comprise a large and dynamically active area connecting the eastern and western Mediterranean sub-basins. The flow in the sub-region is mainly thermoaline (driven by the Mediterranean thermohaline circulation), with some additional effect due to local wind. The water column has a two-layer structure, with Modified Atlantic Water (MAW), of relatively low salinity, inflowing near the surface, and a deeper, more saline Levantine Water (LW) outflowing.

The influence of the Straits' geometry on the hydrodynamics is very important. The fan-shaped configuration of the land boundaries is narrowest at the western end, where the constriction between Cape Bon (Tunisia) and Cape Lilibeo (Sicily) is only 143 km wide, and considerably wider in the eastern part. The highly irregular bottom topography, in the form of a submarine ridge, further limits the flow. This ridge is characterized by shallow banks along the Tunisian and Sicilian coasts. A central narrow passageway cuts along the NW-SE axis of the Straits of Sicly and forms an intermediate basin with an average depth of 500m. Flat-bottomed deep trenches reaching depths of 1,100–1,200m, off Pantelleria, 1,300m, off Linosa, and 1,650m, in the Malta graben (rift valley), are situated in the central part of this basin to the west of Malta.

The Straits of Sicily connect the eastern and western basins of the Mediterranean and comprises a system of sills which provide the main pathway for the exchange of Levantine Intermediate Water (LIW) between the eastern and western Mediterranean sub-basins. This area consists of a two-sill system: the first sill has a minimum depth of 365 m oriented north-northwestwards; the second sill has a minimum depth of 430 m oriented northwards (Frassetto, 1965). The main flow occurs through the narrower and deeper eastern passage close to the Sicilian shelf (Bethoux, 1980). The Straits of Sicily have not received the same attention as the Strait of Gibraltar, although it has been suggested that its role is as important. The entrance of the LIW from the east occurs mainly at the southeast of Malta through an area defined Medina sill.

To the south, the African continental shelf is very wide and covers more than a third of the broad area between Sicily and south Tunisia. In the Gulf of Gabes, the sea depth is less than 30m for large stretches away from the coast. On the southern coast of Sicily, the shelf is bounded by two wide (approx. 100km) and shallow (100m, on average) banks on the western side (Adventure Bank) and on the eastern side (Malta channel, i.e. stretch of sea between Malta and Pozzallo, South East Sicily), whereas it narrows considerably along its middle part. Along the eastern coast of Sicily and extending southwards, there is a narrow Ionian shelf break that is very steep to the east of Malta (known as the Malta Escarpment). The shelf break fans out to the south and broadens to a gentle slope to the north of Libya.

The Maltese Archipelago, consisting of a group of small islands aligned in a NW–SE direction, is located on the southernmost extremity of the Sicilian continental shelf. Figure 8 gives a three-dimensional view of the bottom relief around the Maltese Islands as seen from the west. The topography of the shelf in this area is characterized by a plateau in the middle part, with an average depth of 150m. The shelf is flanked by a submarine ridge which protrudes as a submerged extension of Cape Passero and embraces the shelf area along the eastern and southern perimeters. The Maltese Islands represent the emerged part of this ridge, while the Hurds Bank to the northeast of Malta shallows to a depth of just over 50m. To the southeast, a series of relatively shallow areas, and notably the Medina Bank, maintain an average depth of less than 300m in the sea between the Sicilian and Libyan continental shelves.

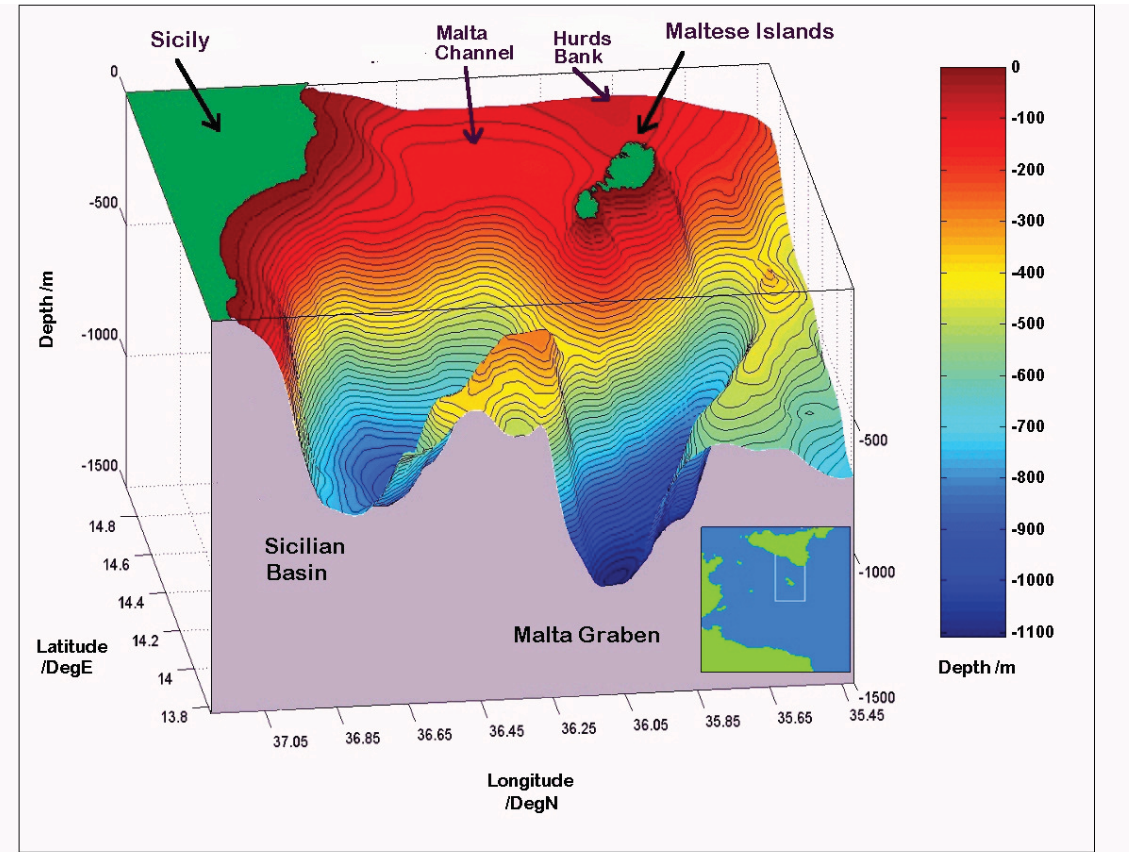

Figure 8. Three-dimensional view of the bathymetry around the Maltese Islands, based on the US Navy DBDB1 data set. (The insert shows the location of the model domain on the Malta shelf area)

4.2. General Circulation

The region is subject to a number of significant hydrodynamical processes and phenomena covering a wide range of temporal and spatial scales. The general circulation is dictated by the conservative basin-scale (vertical) thermohaline structure of the Mediterranean, and has a significant seasonal and interannual variability. In the upper layer (above the thermocline), this circulation is characterized by an energetic and meandering stream known as the Atlantic Ionian Stream (AIS; Robinson *et al.*, 1996). This underlying meandering circulation is further modified by the formation of mesoscale eddies and filaments.

Using satellite-tracked drifters, Poulain (1998) reports on Lagrangian measurements of surface currents between November 1994 and March 1997. The tortuous drifter trajectories observed are the result of both spatial and temporal variation in the circulation and reveal the complexity of the sub-tidal surface currents. The mesoscale processes responsible for this spatial and temporal variation are triggered by wind stress on the sea surface, which, with a significant sea–air (or air–sea) heat flux, constitutes the dominant factor in modifying the MAW on its way to the eastern Mediterranean.

From CTD and XCTD profiles taken during a cruise in November 1994, Robinson *et al.* (1996) identified seven water types in the north eastern area of the Strais of Sicily (i.e. the broad area between Sicily and south Tunisia) and the northwest Ionian Sea. Starting from the Levantine Intermediate Water (LIW) at the bottom, the successive overlying layers are: Transitional, Fresh, Mixed, and Modified Atlantic Water; Upper and Surface Water. The horizontal distribution of these water masses may help in identifying the processes producing these water types.

Traditionally, the three main water types or layer in the Straits of Sicily are: the upper layer Modified Atlantic Water, which enters through the region as an extension of the North African Algerian coastal current; the deeper LIW flowing westwards; and the 100-m-thick transitional/intermediate layer. The signature of the MAW is seasonal and is marked by a salinity minimum (~37.2) at about 50m depth during summer and nearer the surface during winter (Wust, 1961; Manzella et al, 1988). The core of the LIW is marked by a maximum in salinity at a depth of about 300m, with $T = 29.16^{o}C$ and $S = 38.75$. The LIW has a maximum salinity in the western and southwestern approaches to Malta. The renewal time of the total LIW in the broad area between Sicily and south Tunisia is estimated to be 9 months, long enough to maintain fairly constant salinity over the annual cycle, which suggests that the characteristics of the LIW entering the Straits from the eastern Mediterranean are also quite stable.

Moretti *et al.* (1993) report MAW transport in the Straits of less than 1Sv, and with a lower mean transport in winter than in summer. This contrasts with estimates by Manzella *et al.* (1988) that are higher in winter. Recent modelling results (Horton *et al.*, 1997) compare well with the transport estimates by Moretti *et al.* (1993). Long-term time-series of current data in the Straits of Sicily by Grancini and Michelato (1987) indicate that the Levantine Intermediate Water transport during winter is 2–3 times stronger than during summer.

Manzella *et al.* (1990) and Grancini and Michelato (1987) both report that during winter the MAW is more steeply sloped towards the African coast. This is corroborated by analysis of the climatological buoyancy fields (see Annex 2) which actually indicate an intensification of the flow on the southern side of the broad area between Sicily and Tunisia during autumn and spring, whereas the flow is concentrated against the Sicilian coast during summer. The LIW layer is thicker towards the Sicilian side, reaching salinity up to 38.77. The transition/intermediate layer is squeezed into a thickness of only a few tens of metres, sloping upward from south to north, as is typical in a system with two layers flowing in opposite directions in the northern emisphere. The transition from winter to summer stratification occurs in April–May. By July, the temperature and salinity isopleths are quite horizontal. During the summer months the transition layer is re-established to its normal uniform thickness of ~100m.

The general pattern of the circulation in the central Mediterranean is given in Figure 9 for both summer and winter. The MAW flows eastwards mainly along the AIS. This swift topographically controlled current normally starts its path as a meander to the south of

Adventure Bank. It then proceeds southeastwards and loops back northwards around Malta, forming the Maltese Channel Crest. As it reaches the sharp shelf break to the east of Malta, it abruptly gains positive vorticity and tends to deflect, with a strong northward meander, forming the characteristic Ionian Shelf Break Vortex. South of this strong current, the weaker flow of Modified Atlantic Water moves southeastwards and mostly recirculates on the Tunisian and Libyan shelf, hence contributing very little to the mean flow into the Ionian Sea. The northward flow along the Ionian shelf break is predominant during summer when the AIS is most intense and follows closely the Sicilian shelf break. The flow subsequently extends as a relatively strong velocity front (i.e. constricted flow or jet stream) into the northwestern Ionian Sea where the summer circulation is mostly anticyclonic. The contrast in temperature of the MAW exiting the broad area between Sicily and south Tunisia in the east with the warmer Ionian Sea water produces the Maltese front which constitutes a conspicuous thermal filament on AVHRR sea-surface-temperature (SST) maps.

During winter the situation is somewhat different. The AIS is less intense, and the MAW will tend to spread more along the interior of the eastern part of the Straits of Sicily. The exit of the MAW is shifted farther south where the shelf break less abrupt, and the most probable fate of the MAW is to progress along southeastward and southward branches. This situation is also favoured by an enhanced cyclonic component in the Ionian circulation, especially during winter. Poulain (1998) reports that, in winter, Langrangian drifters deployed upstream in the eastern part of the Straits of Sicioly tended to avoid the Malta channel route and proceeded south-southeastwards eventually to reach the central Ionian Sea.

The circulation in spring and autumn is more difficult to assess. On the basis of more up-to-date climatologies (Brasseur and Brankart and Brasseur, 1998 and reliable ocean-prediction systems, with assimilated detailed hydrographic data from the area (Robinson *et al.* 1999); Horton *et al.*, 1997), it appears that the summer circulation, with a northward veering of the MAW over the Malta slope is also common in both spring and autumn. This is in contradiction with earlier studies, such as those by Tziperman and Malanotte-Rizzoli (1991) and Ovchinnikov (1966), who concluded that, on exiting the Straits, the MAW will predominantly proceed northwards during summer and south and southeastwards during the remainder of the year. The model of Zavatarelli and Mellor (1995) does not attribute very pronounced seasonal variability to the flow of the MAW into the Ionian Sea. The path of the stream is more complicated in winter than in summer, but generally follows a wide anticyclonic meander extending from Sicily up to almost the entrance of the Cretan Passage. These discrepancies in results reflect the difficulty in determining the annual cycle in the Straits where various oceanographic processes interfere with the general circulation and can actually switch it between highly variable patterns of flow.

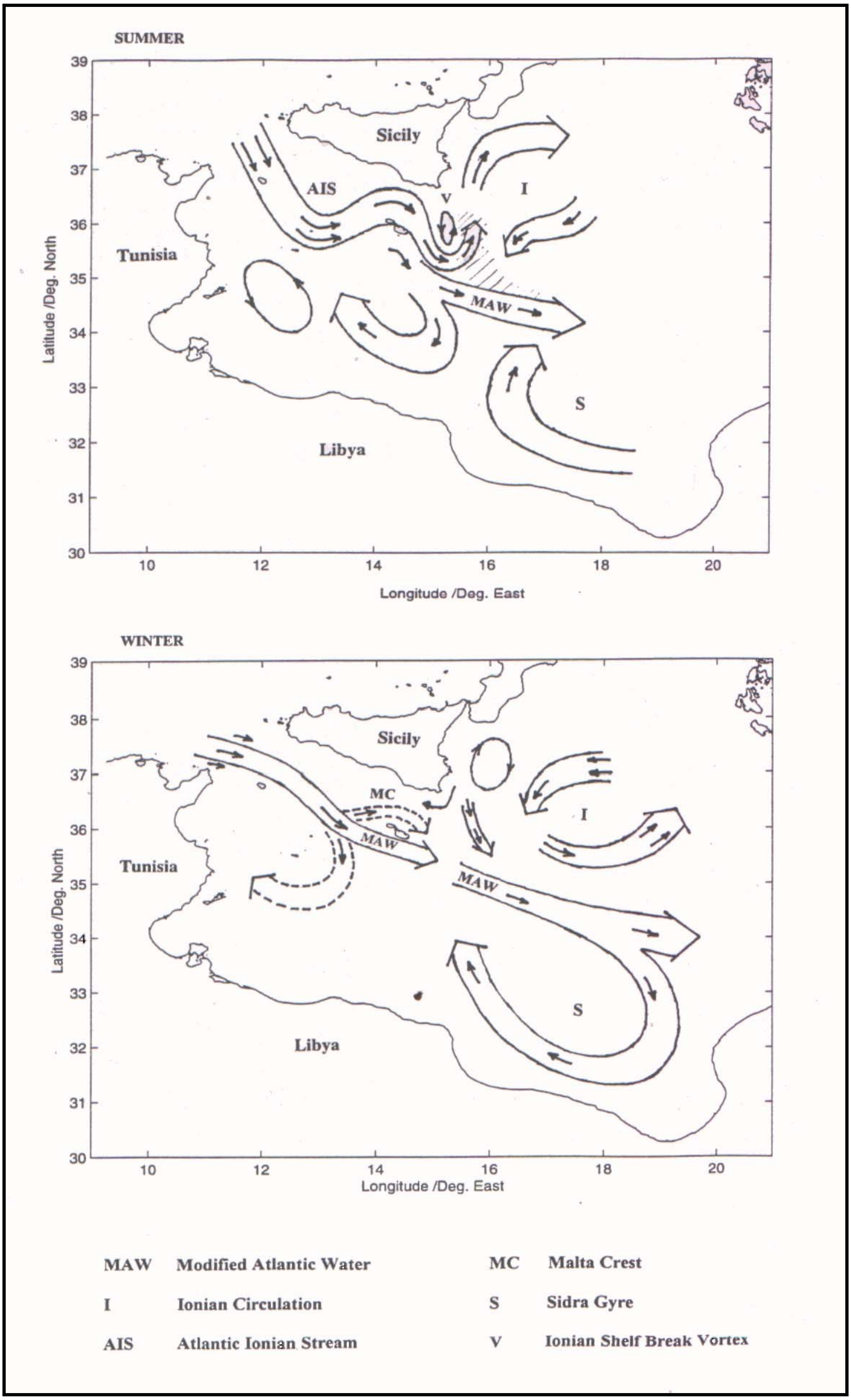

Figure 9. General circulation in the upper layer in summer and winter in the Straits of Sicily

4.3. Synoptic-scale processes

In addition to the general circulation and its mesoscale variability, the broad area between Sicily and south Tunisia and the Ionian shelf-break regions are also influenced by a number of significant synoptic-scale processes. In particular, the circulation in the Sicilo-Maltese shelf area is characterized by frequent coastal upwelling which brings to the surface cool water which is then swept along by mesoscale eddies. The upwelling zone extends over the whole southern coast of Sicily and is favoured by the northwesterly gusts that are numerous and can be particularly strong at any time of the year. In addition, the southeastward advection of these cold patches in the form of long plumes and filaments is a very characteristic feature in the thermal IR images of the region. During the colder months, surface cooling due to the influence of polar air can result in the formation of large patches of relatively cool water that accentuate the latitudinal thermal gradients in the northern parts of the Straits of Sicily, and enhance the contrast with the relatively warmer Ionian Sea water at the Maltese front. Closer to the land perimeter, the incidence of coastal currents is also very important. The Sicilian coastal current along the southern border of the island is wind-driven and associated with local and remote storms. From thermal IR images, the vein of cold water along the southern coast of Italy can often be followed down to Sicily. The penetration of cold Ionian Sea water from the eastern coast of Sicily around Cape Passero over the shelf is favoured by the northerly winds and is often associated with the meandering frontal extension northwardS of the Maltese front.

4.4. Sea-surface temperature

The satellite-derived thermal infra-red images of the Mediterranean Sea, with snapshots taken several times daily, offers the possibility of following the temporal evolution of surface flow as it is transformed by various meteorological and mixing processes. Following the first studies by Champagne-Philippe and Harang (1982) and subsequent authors, it is now known that movements and phenomena inferred from thermal IR images, and in particular thermal fronts, do indeed represent real features found at sea. Thermal-image atlases (Le Vourch *et al.*, 1992) are therefore an indispensable tool to identify oceanographic processes in a particular area.

In the eastern and wider part of the Straits of Sicily, the processes described in the previous section can practically all be related to sea-surface temperature signatures. The surface layer MAW itself, with its characteristic lower sub-surface temperature, will lead to changes in SST as it undergoes large scale movements with the associated vertical mixing. The winter cooling and summer heating of shallow areas can also be followed from time-series SST maps. Like in the rest of the Mediterranean, the surface density in the Straits of Sicily is strongly dependent on the salinity, so that even relatively weak temperature gradients can be identified against the strong seasonal signal, provided that they persist in time and space.

In the area surrounding the Maltese Islands, various processes combine to produce a very variable and complex SST field. The progression of the AIS and its eastward extension, the upwelling events south of Sicily and the warming and cooling of the shallow continental shelf waters are amongst the main driving processes. The annual cycle is indeed rather complex and significant variation can be observed from one year to another, but the general features and characteristics described below are representative of the average background synoptic situation.

Starting in December, the winter structures are characterized by a front to the south of Malta. This front is commonly broad and long, often taking the form of a "V" pointing northwestwards. It results from the contrast at the northern border of the warm Sidra gyre with the colder vein of MAW that usually flows at these lower latitudes at this time of year. This front can occasionally shift northwards up to the shelf break, very close to the Malta coast. By contrast, the sea-surface temperature over the shelf is lower and commonly very homogeneous throughout winter. The Maltese Islands are therefore very often situated within the frontal line, so that temperature differences between the northern and southern shores are appreciable. In April, the Sidra frontal zone is very much attenuated and this month is usually without significant SST features. The first summer SST features usually appear at the end of May. The reduced surface cooling and the presence of stratification mark the onset of upwelling fronts. These fronts are very common in summer and show up as extensive plumes and tentacle-like structures which are advected by their interaction with the AIS. During major mistral wind episodes, the area of upwelled water can be extensive and actually cover the whole shelf area. At the southernmost tip of Sicily and over the Malta slope, a huge filament of cooler water is usually established against the warmer Ionian Sea water to the north and the warmer Sidra gyre water to the south (Champagne-Philippe and Guevel, 1982). This Malta front can protrude southeastwards for very long distances. On other occasions it is restricted to latitudes higher than 34^{o}N under the clear influence of the northward veering of the outflowing AIS. When upwelling events are interrupted, a series of complex latitudinal fronts are established over the shelf in the Malta channel. The cooler coastal current along the southern perimeter of Sicily often appears as a thin channel of cooler water. The autumn season presents the most complicated SST structures. The variability and the number of fronts are highest in this season. The thermal gradients are usually weaker than those in summer, but a mixture of thermal structures between those occurring in summer and those occurring in winter can often be established. In October, a new frontal zone appears off the coast of Tunisia. It can be either continuous from southern Sardinia to the Straits of Sicily, or divided into two parts, one south of Sardinia, the other starting south of Cape Bon, and delineating the northern border of the warmer water of the eastern Tunisian continental shelf. In October and November, this frontal system is superimposed on the persisting summer structures off southern Sicily.

4.5. Processes of upper-layer currents

Currentmeter measurements in the Straits of Sicily are predominantly made in the area between Cape Bon and Marsala. Measurements in the eastern part of the Straits are generally lacking. The most comprehensive sea current data refer to the section between Sicily and Libya which was studied by AGIP in the framework of the Libyan Offshore to Sicily Gas Transportation System Project and conducted during July 1981–July 1982 (Grancini, 1985) by the Osservatorio Geofisico Sperimentale di Trieste. The array of moorings included four stations on the Sicilian shelf, one of which was situated to the east of Malta.

On the basis of these measurements, the current structure across the vertical section between Sicily and Libya is reported to be rather complex, due to: the presence of deep trenches and large continental shelves; the variability of atmospheric disturbances; and the vertical density structure which couples with the wind stress to produce barotropic and baroclinic responses in the current (Grancini and Michelato, 1987). On the Sicilian continental shelf, the currents are characterized by a steady southeastward flow of about 25cm s^{-1} throughout the year. Wind forcing increases the flow to 30cm s^{-1} during winter. This shows the temporal consistency of the AIS. In the vicinity of Malta, the stream funnels into a more southward direction, with a reduced average steady flow of 10cm s^{-1}. Farther south, in the mid-section corresponding to the deep trench separating the Sicilian and Libyan continental shelves, the steady flow of MAW in the upper layer is predominantly eastwards, with an intensification to values of 10cm s^{-1} during winter and spring, especially in the vicinity of Medina Bank. During autumn this steady eastward flow spreads farther to the south.

Fluctuations in the upper-layer currents are generally isotropic, except on the Sicilian shelf where the coastal currents are characterized by a noticeable longshore variability. The variability of the dynamic processes over the Sicilian shelf is evidenced by the high current variation, which is reported by Grancini and Michelato (1987) to have values in winter that are more than twice those of the surface flow in the central and southern areas of the Straits. The kinetic energy is mainly in the tidal frequency band and is found to be dominated by the semi-diurnal and diurnal signals. The semi-diurnal currents do not exhibit significant seasonal changes in magnitude. Their consistency with depth reveals a dependence on the barotropic tide. On the other hand, the diurnal currents are baroclinic in nature and represent most of the current variability. They are reported by Grancini and Michelato (1987) to be mainly confined to the Sicilian shelf and to be particularly strong in the vicinity of Malta. The diurnal currents are stronger in summer. During winter they can completely disappear in some areas. During summer, inertial currents occur throughout the section between Sicily and Libya. Inertial events, each with a duration of about 10 days, occur in succession and give rise to inertial oscillations with periods between 20h and 21h. Their amplitude can reach 25cm s^{-1} and persist for several days on the Libyan continental shelf. On the Sicilian–Maltese continental shelf, the diurnal currents and the inertial oscillations co-exist and give rise to a distinctive diurnal–inertial spectral peak in summer.

The presence of intense diurnal subsurface flows in the northwestern coastal area of Malta has recently been confirmed by measurements during a physical oceanographic survey carried out in summer 1992. These diurnal baroclinic currents are believed to be the expression of a topographically trapped wave that takes the form of an internal wave in the deep sea (a sort of Kelvin-like wave) away from the shelf break and is accompanied by wave modes propagating over the continental platform. An associated vertical oscillation of the thermocline in the form of an internal tide has been quantified to have a crest-to-trough amplitude of about 8m (Drago, 1997). The free surface displacement accompanying this internal tide is estimated to have a semi-amplitude of approximately 1.2cm. From measurements of sea level in Mellieha Bay (Malta) covering a period of 42 months (1993–1996), Drago (1999) reports that the variability of the diurnal residual shows consistent peaks during the periods from mid-October to mid-January and from mid-April to mid-July. These sea-level signatures reveal the temporal variability of the underlying dynamical processes. The semidiurnal residual does not exhibit this variability and, except for sub-seasonal variations, it remains practically constant throughout the year. In particular, the semidiurnal residual can predominate over the diurnal residual during late winter and late summer.

A strong diurnal internal tide has also been detected at a station near the shelf break on Adventure Bank from time-series of vertical temperature profiles (Artale *et al.*, 1989). These sub-inertial oscillations of the thermocline are related to baroclinic flows, with phase opposition between the upper and lower layers. They must be related to the same process of the trapping of energy at the diurnal frequency as that observed in the vicinity of Malta.

Low-frequency current components in the Straits are also remarkable. They are particularly energetic close to the Tunisian and Sicilian coasts, as well as in the deep central areas of the Straits. Their intensity is reduced over the shelves, whereas they are hardly observed over the Libyan shelf. These low-frequency currents can be very intense, especially in winter, reaching up to $30cms^{-1}$ and modulating the tidal oscillations with a mean periodicity of 10–12 days. The relationship with meteorological forcing at these time scales is rather complex. Grancini and Michelato (1987) attribute the origin of the low-frequency currents along the full extent of the Sicilian southern coast to the forcing by the local longshore wind. On the other hand, the low-frequency variability within the MAW is believed to be driven by larger-scale non-local weather patterns. Local perturbations in the low-frequency flow emanating from the area between Cape Bon and Marsala can result in the formation of mesoscale baroclinic eddies along the deeper central axis of the broad area between Sicily and south Tunisia, and thus give rise to the low-frequency clockwise-rotating currents that are observed in these areas.

5. Biology and spatial distribution of target species: interactions with environmental factors

5.1. Introduction

This section reviews and summarizes information available from the literature about the biological traits that are relevant to the exploration of relationships between the spatial distribution of the demersal resources and the causal factors. The information deals with the target species of the pilot study: European hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), deep-water pink shrimp (*Parapenaeus longirostris*), thornback ray (*Raja clavata*) and brown ray (*Raja miraletus*). Knowledge on reproduction and recruitment, in terms of period, size/age and spatial distribution by critical phases (young of the year/juveniles and adult/spawners) was selected and discussed with emphasis on the problem of identifying stock units and on the morpho-bathymetric features and hydrographical processes that can contribute to maintain population patterns in the Straits of Sicily. Most of the literature references available, concern the adjacent GSA 16 and the GSA 15, which are not included in the Maltese FMZ.

5.2. Geographical distribution and bathymetric range

Hake (***Merluccius merluccius***, L. 1758) is distributed in the eastern Atlantic Ocean and all around the Mediterranean basin, including the Italian seas and the Black Sea. This bentho-pelagic species inhabits a wide range of bottom depths, from 20m to 1000m; the smallest specimens are caught mainly on the outer shelf–upper slope (50–300m), while the largest ones are found along the slope (depth >200m) (Colloca, 1999; Orsi Relini *et al.*, 2002).

Red mullet (***Mullus barbatus***, L. 1758) is distributed all around the Mediterranean basin, including the Italian seas and the Black Sea. After recruitment, this species is strictly benthic and is frequently found on muddy grounds in a depth range of 5–250m (Voliani, 1999; Tserpes *et al.*, 2002).

Deep sea pink shrimp (***Parapenaeus longirostris***, Risso 1810) is distributed in the eastern Atlantic Ocean and all around the Mediterranean basin, including the Italian seas and the Black Sea. *P. longirostris* is an epibenthic short-lived species characterized by high rates of growth and mortality (Abellò, 2002). In the Mediterranean Sea, the species inhabits sandy-muddy bottoms and its bathymetric distribution ranges between 20m and 750m. However, its main distribution stratum is between 100m and 400m. The species shows a depth distribution related to size, the smallest specimens being caught mainly on the outer shelf (50–200m) and the largest ones, along the slope (depth >200m) (Tursi *et al.*, 1999).

Thornback ray (*Raja clavata* L., 1758) is present in the eastern Atlantic and all around the Mediterranean and Black Seas. It is a benthic species that lives over a wide depth range from shallow coastal waters down to 700m depth and inhabits different kinds of grounds, but mainly sandy-muddy bottoms. In the Mediterranean, the species is found in the range 100–200m, whereas in the Adriatic Sea this range is reduced to 100–130m. The mean individual weight tends to increase with depth, probably due to a different distribution of individuals (Serena and Abella, 1999).

Brown ray (*Raja miraletus* L., 1758) is present in the eastern Atlantic and throughout the Mediterranean Sea. It is a benthic species that is distributed over a wide depth range down to 400m, but is mainly concentrated between 50m and 150m depth. This ray can be found on very different grounds, from mud to Posidonia beds. It is also quite common on sandy and detrital grounds (Serena and Abella, 1999b).

5.3. Reproductive cycle, length/age at maturity and spawning areas

Merluccius merluccius

In the Mediterranean, hake is characterized by a long reproductive period. In the Tyrrhenian Sea, two spawning peaks were found, one in February–March and another in September (Biagi *et al.*, 1995). Off the Balearic Islands, the spawning period is from November to May (Bruno *et al.*, 1979); along the Catalonian coast and in the Gulf of Lions, the spawning season lasts all year long with a peak in autumn (Recasens *et al.*, 1998). In the eastern Mediterranean, different authors have presented a variety of results (Papaconstantinou and Stergiou, 1995): spawning periods are long, frequently lasting throughout the year, with autumn–winter and spring peaks.

Concerning the Straits of Sicily, Bouhlal (1973) observed three spawning peaks off Tunisia: in summer, winter and spring, according to the female's size. Bouaziz *et al.* (1998), studying samples from Bou-Ismail (Algeria), reported that the spawning season runs throughout the whole year, even if an evident peak in summer is observed. According to Levi (1991, mature specimens were collected in autumn and winter, similarly to what Papaconstantinou and Stergiou (1995) reported for the eastern Mediterranean (Table 2). However, in recent years, several “running” females were collected during the MEDITS surveys (spring–summer).

Hake lengths at 50% maturity, in the Straits of Sicily, are given in Table 3. According to the literature, females mostly mature at 4 years of age, whereas males do so at about 2 years. According to Fiorentino *et al.* (2003a) females’ maximum age is 15 years.

Aggregation of mature adults was reported for the outer shelf–upper slope of the Adriatic Sea (Zupanovic, 1968), and between 100m and 200m depths in the Gulf of Tunis (Boulhal, 1973). No information on localization of hake spawning areas in the Straits of Sicily is available at present.

Mullus barbatus

Red mullet spawns mainly from May to June, although an extension into late-summer/early-autumn may occur (Table 2) (Gharbi and Ktari, 1981; Levi, 1991).

Red mullet length at 50% maturity in the Straits of Sicily is reported in Table 3.

According to Garofalo *et al.* (2002), two major and clearly separate spawning areas exist at around 100m depth on the northern side of the Straits (GSA 15 and 16). They are located over the Adventure Bank, off the southwestern coast of Sicily (GSA 16) and over the Malta Bank, between Sicily and the Maltese Island (GSA 15) (Figure 10).

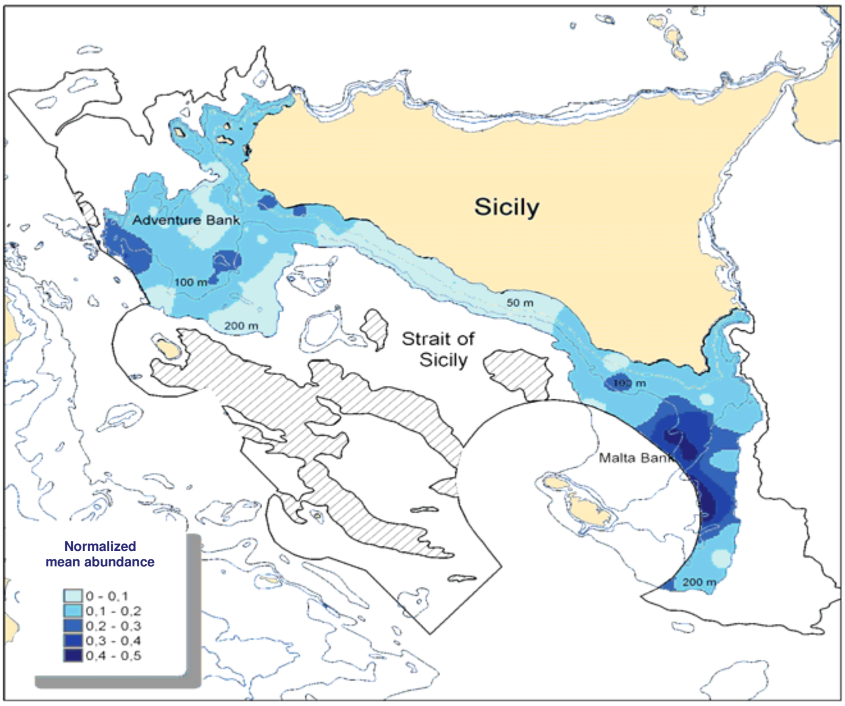

Figure 10. Map of the normalized mean abundance of *Mullus barbatus* spawners (see colour scale inset)**. The contour of the overall study area (GSAs 15 and 16, with exclusion of the Fisheries Management Zone)and the depth exceeding 800m (hatched areas) are also shown. (From Garofalo *et al.*, 2004).**

Parapenaeus longirostris

Like hake, the deep-water pink shrimp has a long reproductive period in the Mediterranean. According to De Ranieri *et al.* (1998), spawning in the northern Tyrrhenian Sea is continuous throughout the year, with a peak between June and September.

In the central and southern Tyrrhenian Sea, reproduction occurs in all seasons, although a lower number of mature females is found in winter (Ardizzone *et al.*, 1990; Spedicato *et al.*, 1996).

P. longirostris' length at 50% maturity in the Straits of Sicily is reported in Table 3. According to Bayhan *et al.* (2005), off the Turkish coasts, the highest gonadosomatic index values were obtained in December, April–May and September–October, although mature females could be found in almost every month of the year.

Although a single peak in the period November–April was reported for Tunisian waters in an old reference (Heldt, 1938), Levi *et al.*, (1995) reported the occurrence of mature females in the Straits of Sicily in all months of the year, with a wide maturity peak extending from November to February and another one in April. The lowest percentage of mature females was registered in June–July.

The life cycle of *P. longirostris* in the central Mediterranean seems to be completed in two years. Sexual maturity is probably reached at the end of the first year (Tursi *et al.*, 1999). According to Ardizzone *et al.* (1990), the life span normally lasts two years, though some larger animals may enter a third year.

Spawning areas are on muddy bottoms between 150–300m and 100–180m in the northern Tyrrhenian (De Ranieri *et al.*, 1998) and in the central Tyrrhenian (Ardizzone *et al.*, 1990), respectively.

Raja clavata

According to Serena and Abella (1999a), reproduction generally occurs during the whole year, with a peak in autumn or winter (Table 2). However, in the Straits of Sicily, the maximum percentage of mature individuals is observed in autumn and the minimum, in winter (Cannizzaro *et al.*, 1995).

The sex ratio is close to unity. Fecundity is quite moderate and directly proportional to size: one female produces from 70 to 170 eggs each year (Holden, 1975). In the Mediterranean, sexual maturity is reached at an individual length of 75cm in males and nearly 85cm in females (Serena, 2005).

In the Straits of Sicily, a length at first maturity between 57cm and 59cm for males and between 77cm and 79cm for females was observed (Table 3); and the age at first maturity was estimated at about 6 years for males and 9 years for females (Cannizzaro *et al.*, 1995).

Raja miraletus

Females reach their first sexual maturity at 24 cm of disk length (around 39 cm of T.L.), males at 22 cm (36 cm of T.L.) (Table 3; Fischer *et al.*, 1987). Fecundity increases with individual size. Egg production occurs throughout the year, with a peak in spring and a low in summer (Table 2) and the annual mean fecundity is probably 40–72 eggs (Capapé and Quignard, 1975).

Table 2. Spawning periods of the pilot study target species in the Straits of Sicily. X = spawning observed; X (bold underlined) = peak of spawning observed

Species	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**References**
M. merluccius	X	X	X	X	X	X	X	X	X	X	X	X	Bouaziz *et al.* (1998); Levi (1991)
Mullus barbatus					X	X	X	X	X				Gharbi and Ktari (1981); Levi (1991)
P. longirostris	X	X	X					X	X	X	X	X	Levi (1991); Levi (1995)
Raja clavata	X			X	X	X	X	X	X	**X**	**X**	**X**	Cannizzaro *et al.* (1995)
R. miraletus	X	X	X	X	X	**X**	**X**	**X**	X	X	X	X	Capapé and Quignard (1975)

Table 3. Length at 50% maturity ($L_{50\%}$), by sex, of the pilot study target species in the Straits of Sicily.

Species	Sex	$L_{50\%}$ (cm)	References
Merluccius merluccius	F	33.5–37.6	SAMED (2002); IRMA–CNR (2002)
	M	21.5–28	Boulhlal (1973); Bouaziz *et al.* (1998)
Mullus barbatus	F	15–16	Gharbi and Ktari (1981)
	M	14	Gharbi and Ktari (1981)
Parapenaeus longirostris	F	20.1–24	Ben Mariem *et al.* (2001); Ragonese *et al.* (2004)
	M	15.6	CNR-IAM. (2006)
Raja clavata	F	77–79	Cannizzaro *et al.* (1995)
	M	57–59	Cannizzaro *et al.* (1995); IRMA–CNR (2002)
R. miraletus	F	39	Fischer *et al.* (1987)
	M	36	

5.4. Eggs and larvae

Merluccius merluccius

Eggs, larvae and post-larvae of the European hake are pelagic. The change from the pelagic to the benthic habitat occurs when young individuals are about 3cm in total length (TL) (Colloca, 1999). Although few data are available, spawning should occur on the outer shelf–upper slope. Eggs were found between 50m and 200m depth in the Adriatic Sea (Karlovac, 1956). Similar observations were made in the Atlantic, where eggs and larvae were found at 50–150m depth (Coombs and Mitchell, 1982). Pelagic larvae in the Mediterranean were found over the outer shelf–upper slope along the Catalan coast (Sabatés, 1990). More recently, eggs and larvae of hake were found in winter and spring in the northern Tyrrhenian Sea, and during the whole year, except in winter, off the Catalan coasts. Eggs and larvae were preferentially associated with the shelf, with a peak abundance between the 100-m and 200-m isobaths (Anon., 2001).

Mullus barbatus

Red mullet eggs, larvae and post-larvae up to an individual length of 30–35mm are pelagic and live in the surface waters (Voliani, 1999). According to Sabatés and Palomera (1987), larvae are found only near the sea surface (0–1.5m depth), mainly in areas influenced by river discharges. Larvae of *Mullus barbatus* were found in the Mediterranean mainly between June and July (Lago de Lanzos, 1980; Sabatés and Palomera, 1987).

Parapenaeus longirostris

The highest densities of deep-water pink shrimp larvae are observed along the coasts of Portugal at a depth of about 100m, corresponding to the upper limit of distribution of the adults. Larvae were caught only in November and December (Dos Santos, 1998). Burukoswky (1969), studying the species in the Atlantic Ocean, reported that eggs and larvae are firstly concentrated at about 30m depth, then, as they grow, they descend to greater depth. According to Heldt (1938), larval life span is about two months.

Raja clavata and ***Raja miraletus***
These species produce benthic eggs in robust cases in which the juveniles develop without any larval phase (Serena, 2005). According to Serena (2005), in *R. clavata* and *R. miraletus* the development of the embryo lasts about five months, with the young hatching at an individual total length of 100–110mm.

5.5. Recruitment period, length/age at recruitment and nurseries

Merluccius merluccius
Settlement is a long process, which, as with reproduction, may show more than one peak (Orsi Relini *et al.*, 2002). Zupanovic (1968) showed two recruitment peaks, one in spring and another in autumn, probably linked to winter and summer spawning peaks, respectively (Table 4).

Two main peaks were observed in the Ligurian Sea, in spring and autumn (Orsi Relini *et al.*, 1986; Orsi Relini *et al.*, 1989a). Data from the Ligurian Sea suggest that, although the smallest recruits (5cm TL) settle at a depth around 100m throughout the year, in winter, when the sea water is well mixed and the inshore transport currents are stronger, settlement of very small hake occurred at around 50m depth (Orsi Relini *et al.*, 1989b). From the initial settlement zone, the young fish spread over wider areas, forming the nurseries sensu stricto. This expansion occurs into shallow and into deep water in winter, but only to the deepest level in summer–autumn (Orsi Relini *et al.*, 1989b). The depth range, including the nurseries, varies between 50m and 250m, although in certain areas and years, 0 age-class fish could be found at lower depths (eastern Ligurian Sea between 300m and 400m depths).

In the Catalan Sea and the Gulf of Lions, the existence of one fixed recruitment peak in spring was demonstrated. The peak may occasionally last until the summer and even until autumn in some years (Recasens *et al.*, 1998).

In the Gulf of Lions, the distribution and abundance of age-classes 0, I and II have been studied using catch data from the trawler fleet (Campillo *et al.*, 1991). Main concentrations of age-class 0 were found at 100–150m depth, whereas age-classes I and II appeared to be distributed along the continental shelf at 30–150m depth.

In the central Aegean Sea, the recruitment starts in March, but occurs mainly in June (Papaconstantinou and Stergiou, 1995). Regarding the distribution of young hakes (age-class 0) in the Greek seas, it was found that they appear in trawl catches in summer and until early autumn, in well defined areas, such as the Saronikos, Patraikos, Siggitikos and in certain locations in the northern and southern Aegean Sea and in the Ionian Sea (Papaconstantinou and Stergiou, 1995; Papaconstantinou, 2000). The hake recruits appear mainly at depths of 100m to 230m, (Saronikos Gulf, Patraikos Gulf, Trikeri Channel), although in some areas, recruitment takes place at depths >300m (Ionian Sea and Korinthiakos Gulf, Kassandras Gulf, Aegean Sea) (Papaconstantinou, 2000).

More recently, differences in depth affected by recruitment were confirmed by Maynou *et al.* (2003) in the Catalan Sea. Recruits were found between 60m and 160m depth in autumn and winter, whereas, in spring and summer, their depth range extended down to 300m. Investigating the seasonal variability in hake nurseries in the Catalan Sea, Maynou *et al.*, (2003) found areas where recruits were present all year round, representing the core nursery. These areas were surrounded by larger ones in which the presence of hake recruits might vary seasonally. Recruit density in the core and the surrounding areas was similar, although the contribution of the surrounding areas to the total recruitment in the Catalan Sea was more important than that of the core nursery area.

Preliminary information on the identification of nursery areas in the Straits of Sicily is provided by Ardizzone and Corsi (1997) and Ardizzone *et al.* (1999), on the basis of the Italian GRUND programmes (1985–1987) and (1995–1996) and by Lembo *et al.* (2000), based on 1995 and 1996 MEDITS data. More recently, Fiorentino *et al.* (2003b) studied the spatio-temporal distribution and abundance of hake recruits (0 age-class) in the Straits of Sicily. The estimation of the recruit abundance derived from the MEDITS programme (1994–1999) on the Italian side of the Straits of Sicily overall showed hake recruitment to be quite stable, the number of estimated recruits for an area of about 50,000 km^2 (GSA 16) ranging between 3,750,000 and 9,350,000 individuals, on the basis of spring sampling (mean = 7,400,000; sd = 1,950,000). Since more than one cohort per year may occur, these values should be considered as underestimated.

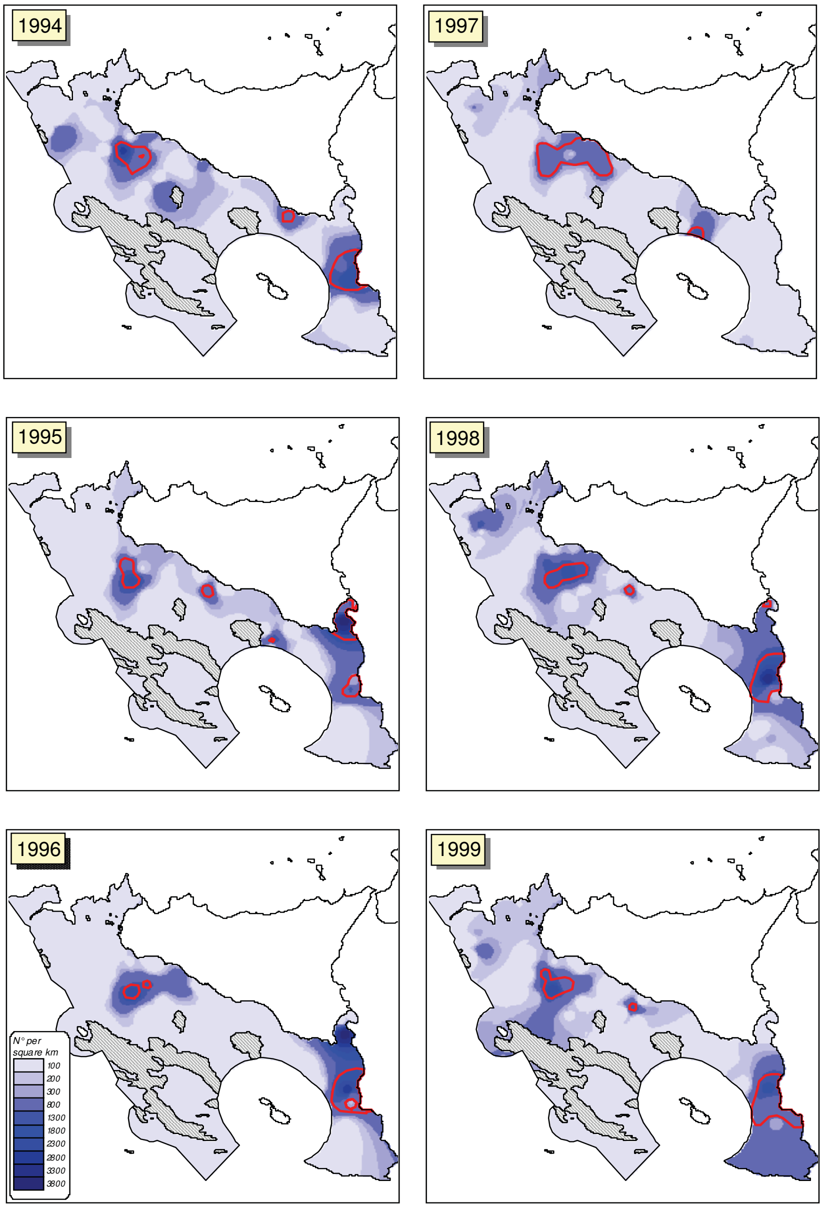

Figure 11. Distribution of recruits of *M. merluccius* for each MEDITS survey (Spring). Contoured areas are those characterized by an almost exlusive presence of high concentration of recruits (from Fiorentino *et al.*, 2003b modified).

It is noteworthy that the recruitment of hake is significantly correlated with that of the greater fork beard (*Phycis blennoides*), the strongest recruitment of both species occurring in 1998 and 1999. Although some interannual variability in the distribution of the nurseries was evident (Figure 11), two stable areas for *M. merluccius* could be identified (Figure 12), which are probably connected with the presence of meso-scale oceanographic processes (Garcia Lafuente *et al.*, 2002). These nurseries were located on the eastern side of the Adventure and Malta banks, between 100m and 200m depth.

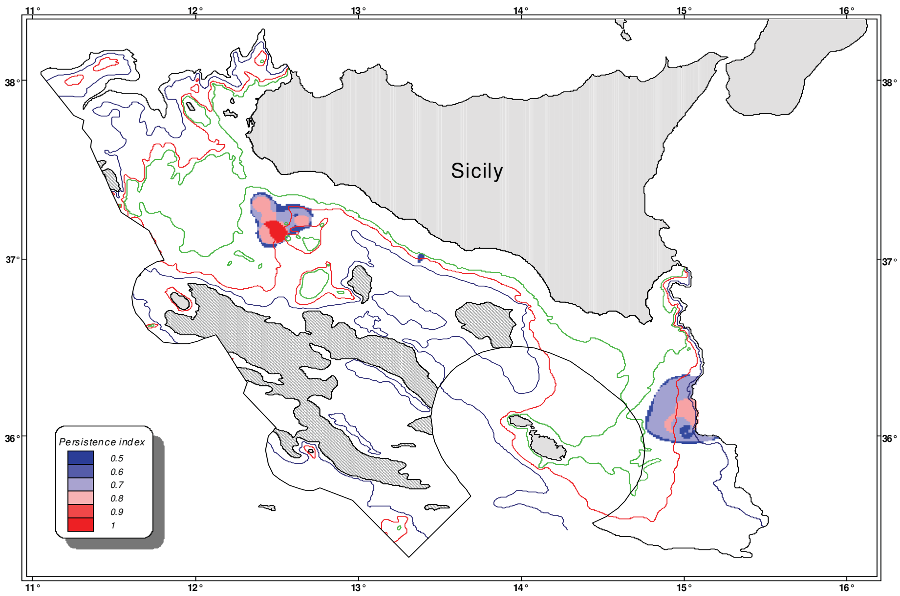

Figure 12. Areas showing the stable presence of recruits of *M. merluccius* during the MEDITS Surveys (1994–1999) (GSAs 16 and 15, excluding the Fishing Management Zone) (From Fiorentino *et al.*, 2003b modified).

Mullus barbatus

Red mullet shows a peculiar bathymetric distribution: the massive recruitment that occurs in summer (Table 4) very close to the shore is followed by a gradual dispersal to greater depths (Voliani, 1999). A first attempt at identifying the red mullet nursery in the Straits of Sicily was made by Ardizzone and Corsi (1997) and Ardizzone *et al.* (1999), on the basis of the Italian GRUND programmes (1985–1987) and (1995–1996). More recently, the spatio-temporal distribution and abundance of red mullet recruits (0 age-class) in the Straits of Sicily was studied on the basis of autumn GRUND trawl surveys (Garofalo *et al.*, 2004).

Although recruits exhibited a widespread distribution throughout the coastal waters, four main areas showing high abundance and the almost exclusive presence of recruits were found in GSA 16 (southern coast of Sicily), between 20m and 50m depth (Figure 13).

Recently, Levi *et al.* (2003) investigated the stock–recruitment relationship for red mullet in the Straits of Sicily, including environmental information in terms of the sea-surface temperature (SST) anomaly as a proxy for oceanographic processes affecting recruitment. Results showed that, for a given level of spawning stock, a higher level of recruitment corresponded to warmer-than-average SST during the early life stages (Figure 14).

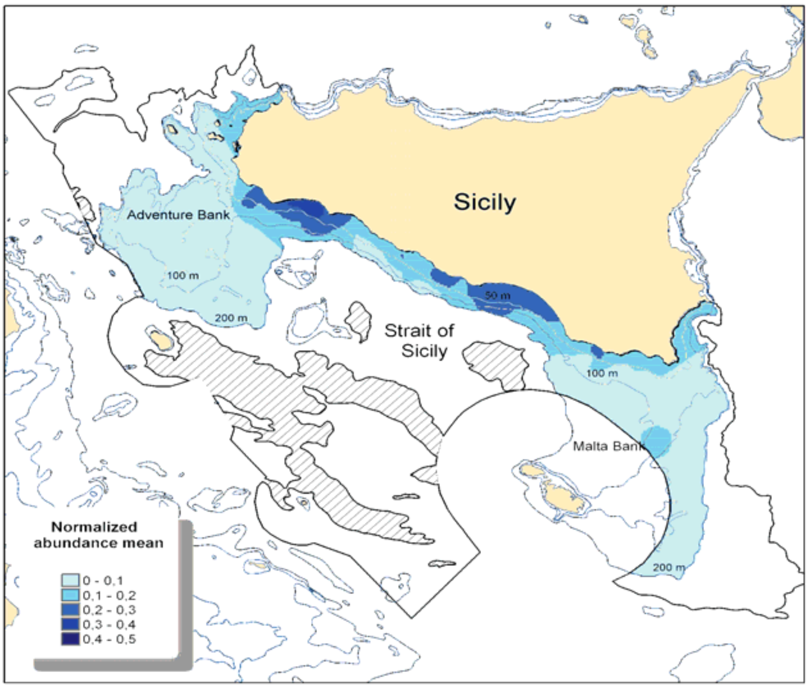

Figure 13. Map of the normalized mean abundance of *Mullus barbatus* recruits, based on data from the Italian GRUND surveys in GSAs 15 and 16. The contour of the overall area (GSAs 15 and 16) and the depth exceeding 800m (hatched areas) are also shown (from Garofalo *et al.*, 2004).

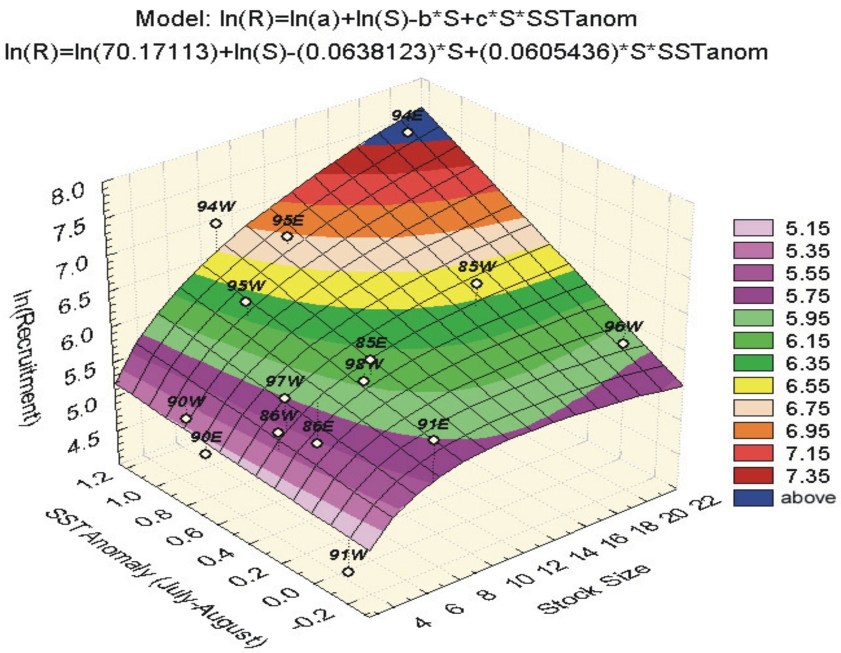

Figure 14. *Mullus barbatus* stock–recruitment relationship, including sea-surface temperature anomalies, in the Straits of Sicily (GSAs 16 and 15, excluding the Fishing Management Zone). (From Levi *et al.*, 2003).

Parapenaeus longirostris

Deep-water pink shrimp recruits are more abundant between July and October in the northern Tyrrhenian Sea (De Ranieri *et al.*, 1998), whereas recruitment in the southern Tyrrhenian Sea occurs mainly from spring to autumn (Table 4) (Spedicato *et al.*, 1996; Lembo *et al.*, 2000).

In the Straits of Sicily, the smallest individuals, between 11.5mm and 12.5mm carapace length (CL) appear all year long (Levi *et al.*, 1995).

Juveniles are mainly found between 100m and 180m depth in the central Tyrrhenian Sea (Ardizzone *et al.*, 1990), whereas a wider depth range (50–200m) is reported for the southern Tyrrhenian Sea (Lembo *et al.*, 2000).

Preliminary information on the nursery identification in the Straits of Sicily was provided by Ardizzone and Corsi (1997) and Ardizzone *et al.* (1999), on the basis of information from the Italian GRUND programmes (1985–1987) and (1995–1996). More recently, a geographical representation of nurseries on the northern side of the Straits was given by Fiorentino *et al.* (2004). The hauls characterized by the co-occurrence of high density (density index of recruits belonging to the 4th quartile) and the exclusive presence (i.e. recruits were equal to or higher than 80%.of *P. longirostris* number per square kilometre) of recruits in the GSA 16 (Sicilian side of the Straits of Sicily) are shown, by year, in Figure 15.

Over the whole period (1994–1999), the interannual variability in the sites of hauls showing the highest recruitment indices was low. One important nursery was located off Capo Rossetto, in the western-central part of the area, and another one on the eastern side of the Malta Bank, between 100m and 200m depth.

Raja clavata and *Raja miraletus*

According to Serena (2005), in both *R. clavata* and *R. miraletus*, the development of the embryo lasts about five months, with the young hatching at 100–110mm TL.

No information on areas where the juveniles are mainly concentrated is found in the literature. The recruitment period for *R. clavata* and *R. miraletus* is reported in Table 4.

Table 4. Recruitment periods of the pilot study target species in the Straits of Sicily. X **= recruitment observed; <u>X</u> (bold underlined) = peak of recruitment observed**

Species	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**References**
Merluccius.merluccius	X	X	X	X	X	X	X	X	X	X	X	X	Bouaziz *et al.* (1998); Levi (1991)
Mullus barbatus							X	X	X	X	X	X	Gharbi and Ktari (1981); Levi (1991)
Penaeus longirostris	X	X	X	X	X	X	X	X	X	X	X	X	Levi (1991)
Raja clavata	X			X	X	X	X	X	X	**<u>X</u>**	**<u>X</u>**	**<u>X</u>**	Cannizzaro *et al.* (1995)
R. miraletus	X	X	X	X	X	**<u>X</u>**	**<u>X</u>**	**<u>X</u>**	X	X	X	X	Capapé and Quignard (1975)

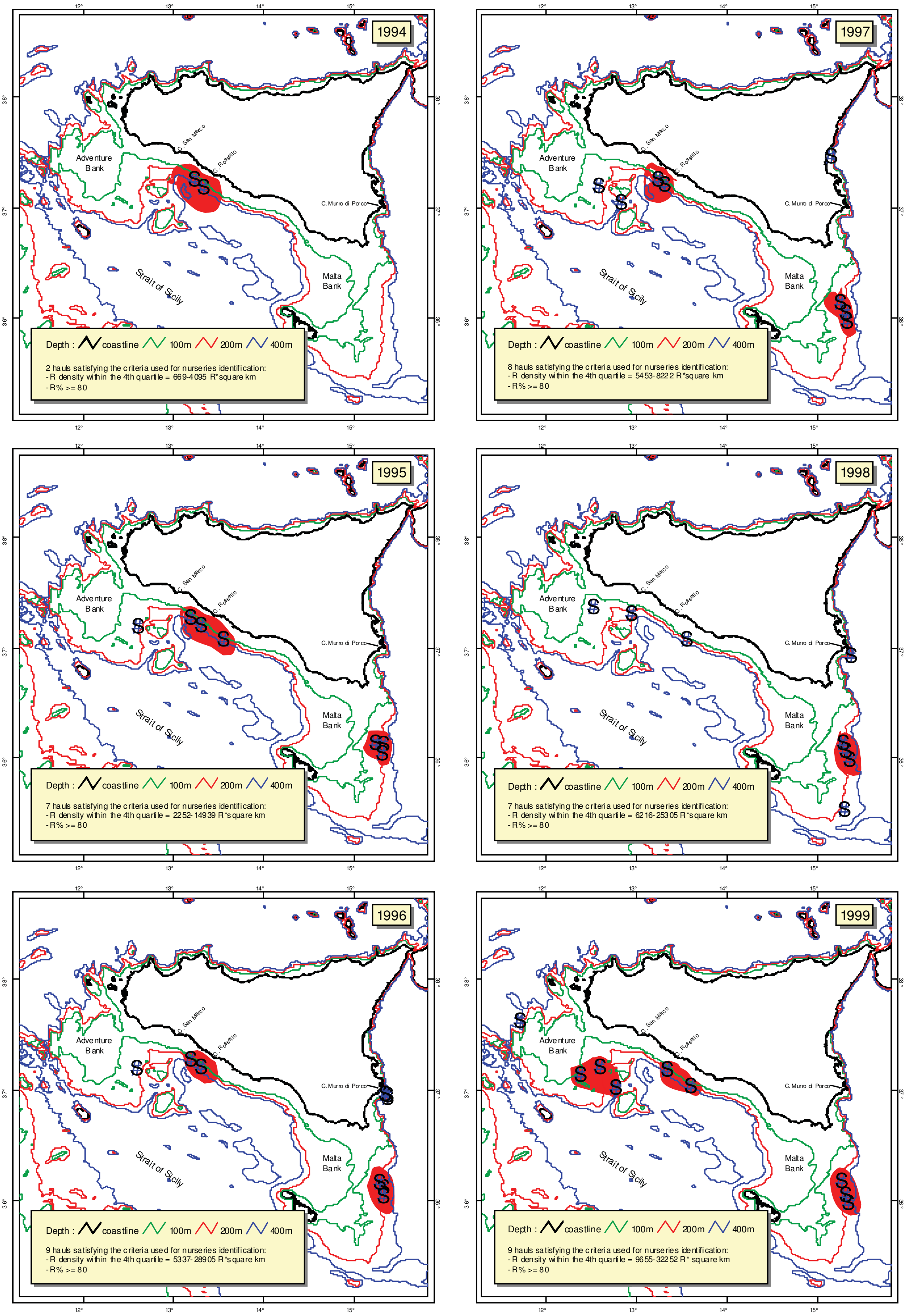

Figure 15. Areas showing presence of recruits of *P. longirostris* during MEDITS surveys (1994–1999) (contoured in red; modified from Fiorentino *et al.*, 2004).

5.6. Diet of juveniles

Merluccius merluccius
It is well known that hake recruits (4.5–12cm TL) feed mainly on small crustaceans (Euphasiacea, Misidacea and Amphipoda), caught in the water column at night (Andaloro *et al.*, 1985; Orsi Relini *et al.*, 1989b; Colloca, 1999). Some cannibalism in summer was reported for the Ligurian Sea (Orsi Relini *et al.*, 1989b).

Mullus barbatus
According to Voliani (1999) *Mullus barbatus* is a carnivorous species. Its diet is mainly composed of small invertebrates, particularly crustaceans, polychaetes and bivalve molluscs. The most frequently found crustaceans are of the Orders Ampipoda, Mysidacea and Isopoda. Echinoderms and cephalopods can be considered occasional preys.

Parapenaeus longirostris
Burukovsky (1969) found that samples from the Gulf of Cadiz and off the northwest African coast indicate different diets, according to age. The diet of younger individuals consisted mainly of Foraminifera and planktonic crustaceans.

In the Ionian Sea, the most common prey items of small male individuals (CL <15mm) were polychaetes, crustaceans—mainly ostracods—and plant debris (72% of the total diet). In the case of females of the same age-class, cephalopods, nematodes, crustacea (mainly Euphausiacea) and plant debris (almost 50% of their total diet) prevailed. (Kapiris, 2004).

Raja clavata
In Tunisian waters, it was observed that the diet changes with age, probably in relation to the increased predatory ability of older individuals. The diet is mainly malacophagic in younger individuals and always more ichthiophagic in older individuals (Capapé, 1977).

Raja miraletus
Younger individuals feed almost exclusively on crustaceans, whereas the diet of older individuals also includes fish and molluscs (Serena and Abella, 1999b).

5.7. Interactions with environmental factors

Wild populations maintain their distribution by active displacements (migrations of adult from feeding to spawning areas and of juveniles from nurseries to feeding areas, for example) and passive transports (egg and larval dispersal). Several authors (Harden-Jones, 1968; Cushing, 1975; Pawson and Jennings 1996; Jennings *et al.*, 2001) have pointed out the fact that identifying spawning, nursery and feeding areas, as well as understanding migratory and dispersal patterns, is a prerequisite for effective stock assessment. It is clear that the observed spatial distribution of an exploited population is the result of complex adaptation of the biological cycles to the ecological factors (sedimentological, hydrographical and biocenotic) and to the effect of exploitation, which affect the stock dynamics.

The role of hydrographical factors in controlling spawning, egg and larval dispersal and recruitment has been discussed by many authors (Beamish and McFarlane, 1989; Chambers and Trippel, 1997).
Much of the literature on the Straits of Sicily highlights a clear role of the relevant hydrographical features of the area in determining the structure, composition and abundance of the biological resources (Jereb *et al.* 2001; García Lafuente *et al.* 2002; Fiorentino *et al.*, 2003b; Levi *et al.* 2003; Patti *et al.*, 2004). On the other hand, although an increasing number of studies indicate that the abiotic and the biotic components of the sea bed are of great importance in determining the distribution of the main critical phases (spawning, nursery and feeding areas) of biological resources (Stoner and Abookire 2002), little information is available on the Straits of Sicily (Garofalo *et al.*, 2004) (Figure 16).

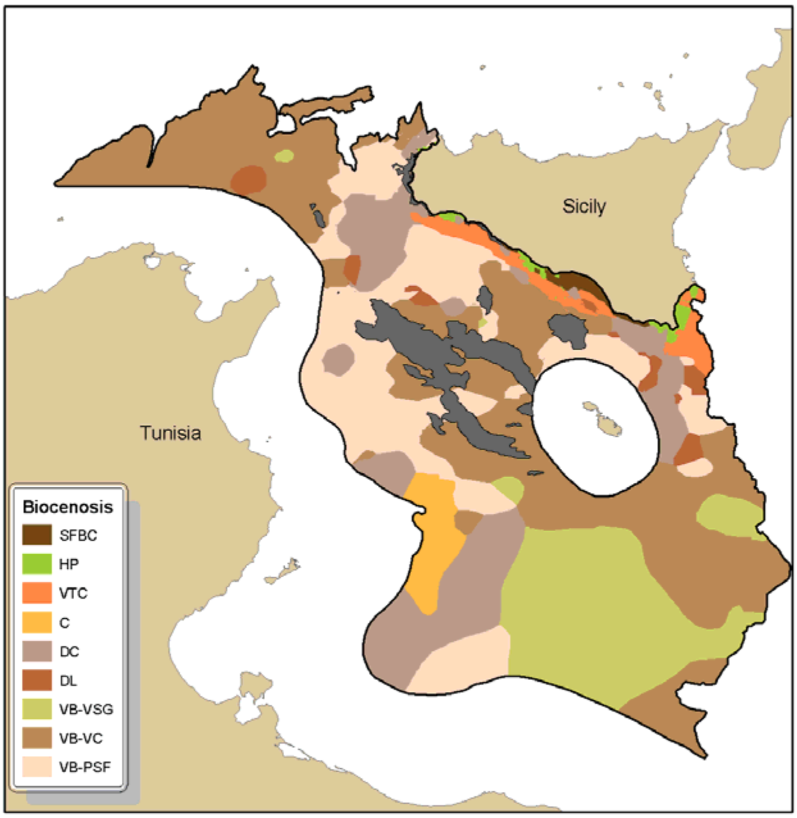

Figure 16. Map of the benthic biocenoses in the Straits of Sicily. SFBC = Well graded fine sands; HP=Posidonia oceanica meadows; VTC= Coastal terrigenous muds; C= Coralligenous; DC= Coastal detrital bottoms; DL= Open Sea detrital bottoms; VB-VSG= Bathyal sandy muds with gravels; VB-VC= Bathyal compacted muds; VB-PSF= Bathyal soft muds with fluid surface films. (From Garofalo *et al.*, 2004).

The available synoptic map of bottom types for most of the area inside the FMZ originates from the Admiralty charts and shows a rough picture of the bathymetry and 10 seabed types (e.g. sand, mud, sand and mud, coral) (Figure 17). At the south of the Island, there is a transition zone between sand and mud, which encompasses five different categories of sediment. In the northern part, only one type of bottom can be found.

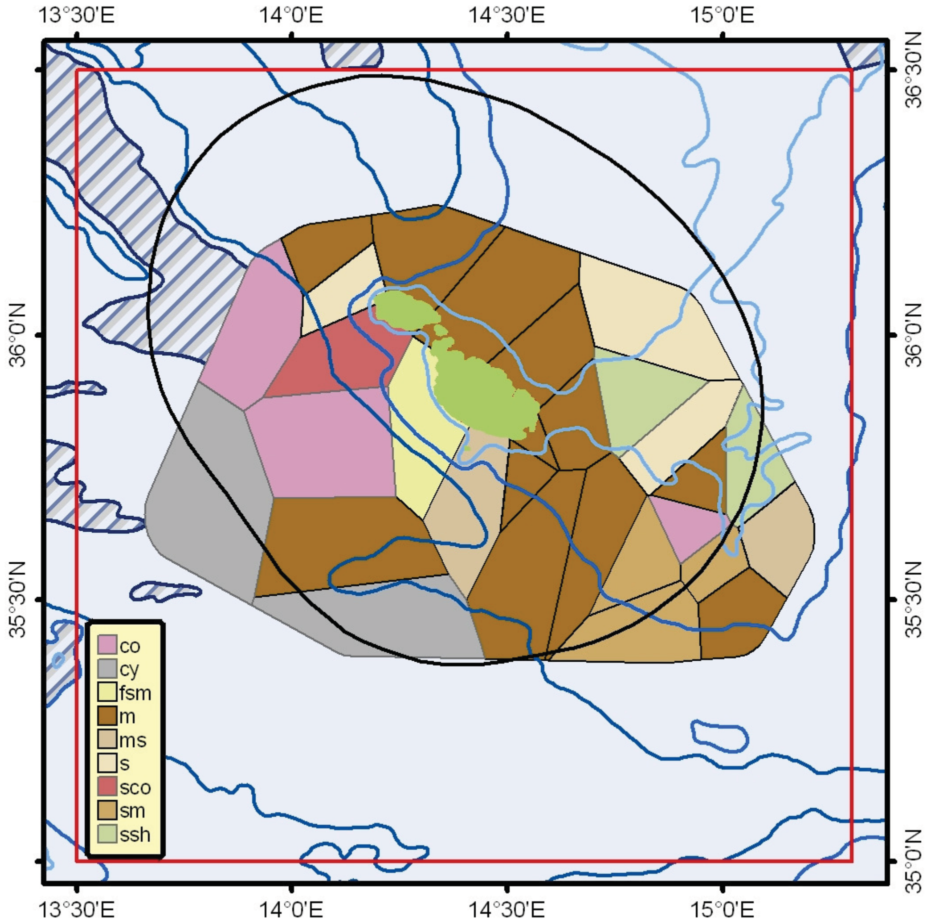

Figure 17. Synoptic map of the bottom types inside the FMZ. co = coral; cy = clay; fsm = fine sand and mud; m = mud; ms = mud and sand; s = sand; sco = sand and coral; sm= sand and mud; ssh = sand and shale.

In the case of hake of the Straits of Sicily, the distribution of recruits observed suggests that oceanographic features play a major role, with the eddies and the frontal system, produced by the AIS, influencing and maintaining the spatial structure throughout the period of hake nurseries (Fiorentino *et al.*, 2003b) (Figure 12). Hydrographical features also affect spatial distribution of juveniles, with the transport from the spawning areas to the nurseries. According to Orsi Relini *et al.* (1989b), the distance between the hake spawning areas and nurseries in the Mediterranean, covered through the larval dispersion by the current, may be important. Similar patterns were well known for other species of the genus *Merluccius*, such as *M. productus* (Bailey, 1981; Babcock Hollowed and Bailey, 1989).

García Lafuente *et al.* (2002) pointed out the importance of frontal systems and eddies in influencing the spawning, larval drift and recruitment of anchovy in the Straits of Sicily. Sanchez and Gil (2000), studying the relation of hake recruitment with hydrographical features in the Bay of Biscay, reported that the size and location of nurseries over the continental shelf are influenced by mesoscale hydrographical anomalies (eddies). These eddies appear to retain larvae and juveniles, and sustain the feeding behaviour of the recruits. Thus, these aggregations are located in areas of the continental shelf where the anomalies are repeated to a greater or lesser extent every year.

In the case of *Parapenaeus longirostris*, the migration of juveniles from the continental shelf to the slope (e.g. Held, 1938) is common in many species of the family Penaeidae and has been observed also in the central–southern Tyrrhenian Sea (Ardizzone *et al.*, 1990; Spedicato *et al.*, 1996). In this basin, the adult fraction of the population lives mainly between 150m and 350m depth, whereas juveniles are mostly observed between 100m and 180m (Ardizzone *et al.*, 1990). Furthermore, Spedicato *et al.* (1996), analysing data from different seasons and years, reported an average carapace length increasing significantly with depth. Comparable results are also mentioned by D'Onghia *et al.* (1998) for the Ionian Sea.

After the dispersion phase in shallow water, the shrimp move to deeper water. Young and old generations, moving from the shelf to the continental slope, mix and, consequently, it is often difficult to follow a selected brood (Tursi *et al.*, 1999).

Levi *et al.* (1995) suggested a working hypothesis for deep-water pink shrimp, based on migration, as a continuous flow from east to west, supported by the flow of Levantine Intermediate Water from the eastern to the western Mediterranean.

In the case of red mullet, a scenario with spawning at 80–120m depth offshore and a movement of eggs and larvae inshore by surface current was suggested by Saccini (1947). As noted earlier, Levi *et al.* (2003) investigated the stock–recruitment relationship for red mullet in the Straits of Sicily, including environmental information in terms of sea-surface temperature (SST) anomaly as a proxy for oceanographic processes affecting recruitment. Results showed that, for a given level of spawning stock, higher levels of recruitment corresponded to warmer SST than average during the early life stages. These authors related this feature to the occurrence of weak coastal upwelling and consequent offshore transport.

Considering what is known on other demersal species, Jereb *et al.* (2001) show the existence of an important area of recruitment for the squid *Illex coindetii* off Gela (Figure 18) and attribute the difference in the juvenile abundance observed between the two years to features of the surface waters in the area. According to the authors, the existence of a frontal zone right in the middle of the area may offer an ideal situation for small predatory organisms, such as squid paralarvae, due to the richness of food particles concentrating at the convergence front.

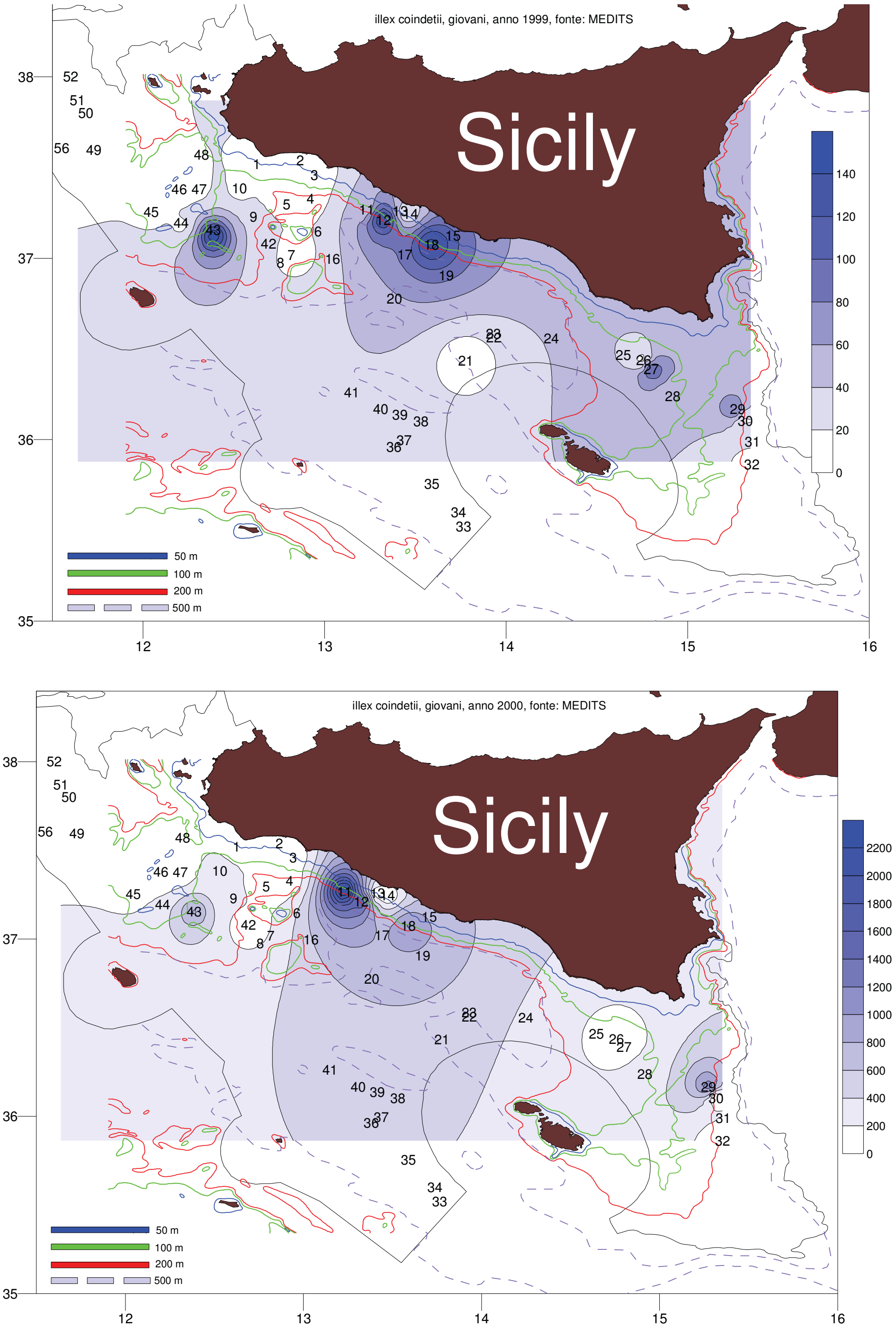

Figure 18. Areas showing presence of recruits of *I. coindetii* in 1999 (*top panel*) and 2000 (*bottom panel*) in spring – MEDITS surveys. (From Jereb *et al.*, 2001)

If this frontal zone becomes continuous with a pycnocline area below, the ideal condition for egg-mass development (and subsequent survival of squid paralarvae) as proposed by Bakun and Csirke (1998), would be guaranteed.

The difference in juvenile abundance observed between the two years may be related to the different distribution of sea-surface temperatures, which clearly indicate an eastward shift of the frontal zone in the year 2000 (Figure 19). Similar hydrographical phenomena were recently found to be associated with high recruitment pulses of *I. illecebrosus* in the North Atlantic (Dawe *et al.*, 2000).

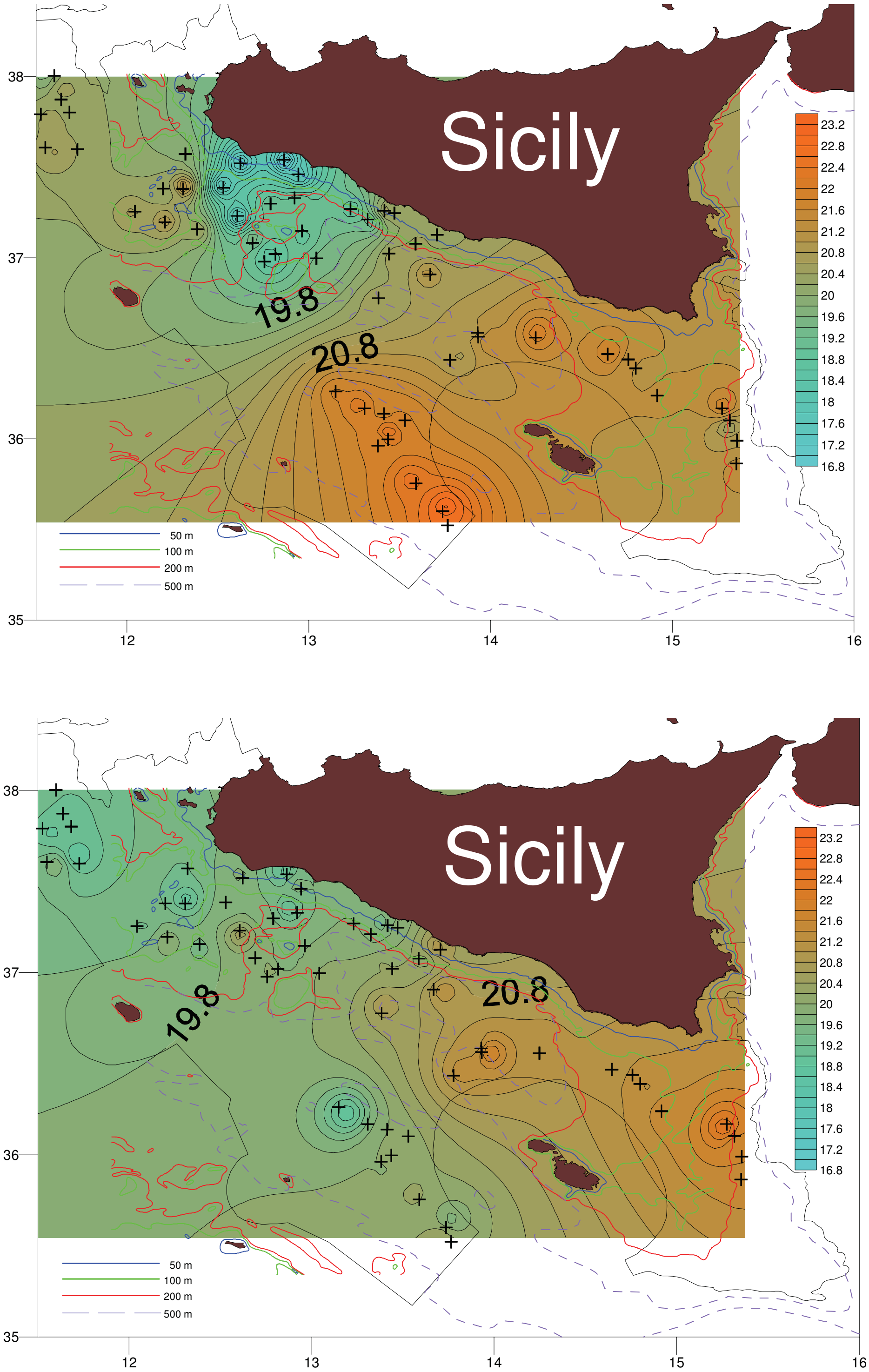

Figure 19. Sea-surface temperature in the Straits of Sicily in the spring of 1999 (*top panel*) and of 2000 (*bottom panel*) – MEDITS surveys. (From Jereb *et al.*, 2001).

As for the previous species, the yearly maps of recruit density for *Phycis blennoides* also showed a definite distribution, with two extended areas of recruit concentration located on the western and the eastern side of the Adventure Bank (Figure 20). Only in the final two years (1998 and 1999) were relevant nurseries found along the eastern border of the Malta Bank.

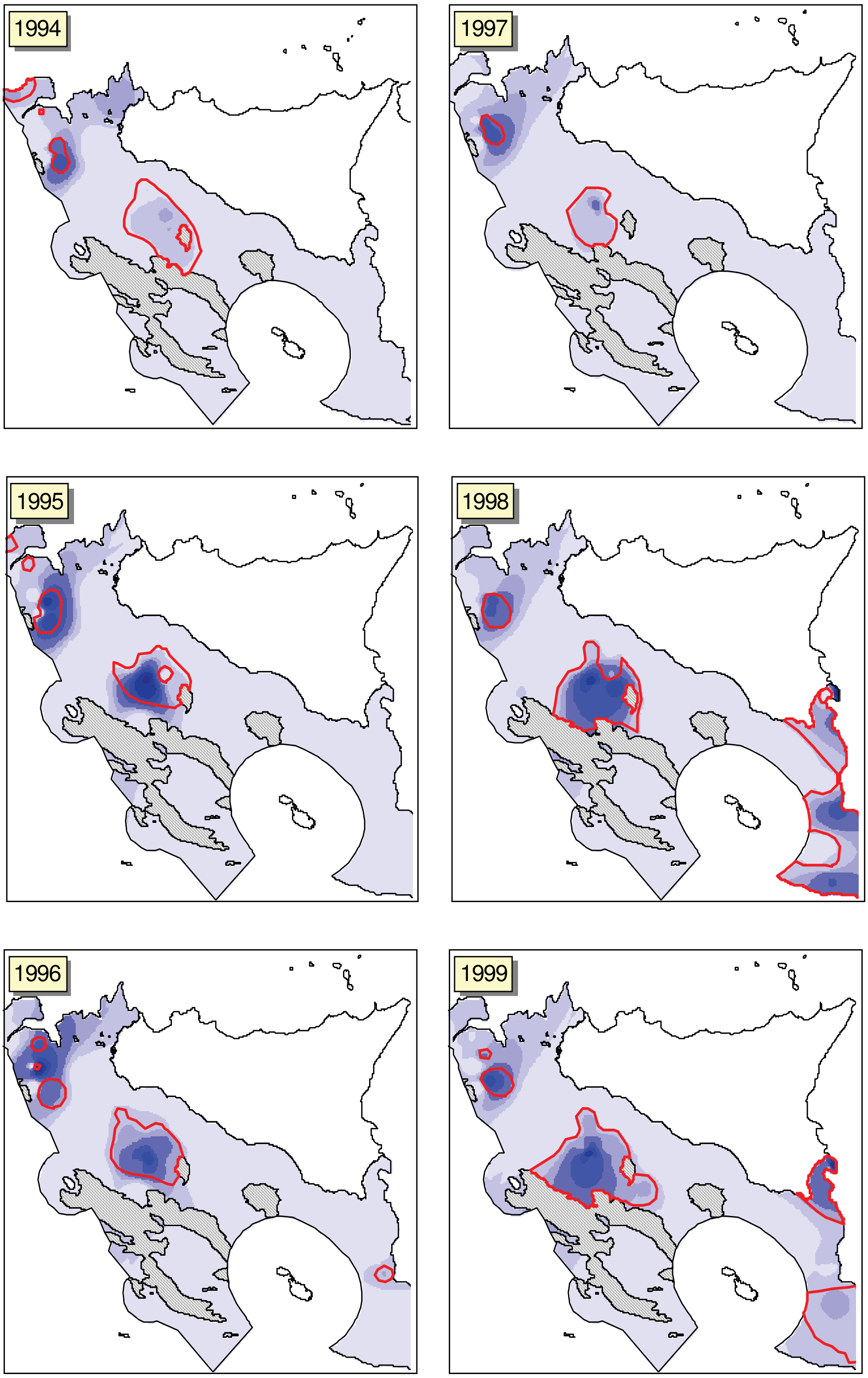

Figure 20. Distribution of recruits of *Phycis blennoides* for MEDITS survey (spring). Contoured areas are those characterised by an almost excusive presence of high concentration of recruits. (From Fiorentino *et al.*, 2003b, modified).

Only two stable nurseries can be identified, between 200m and 400m on the western and eastern sides of the Adventure Bank (Figure 21).

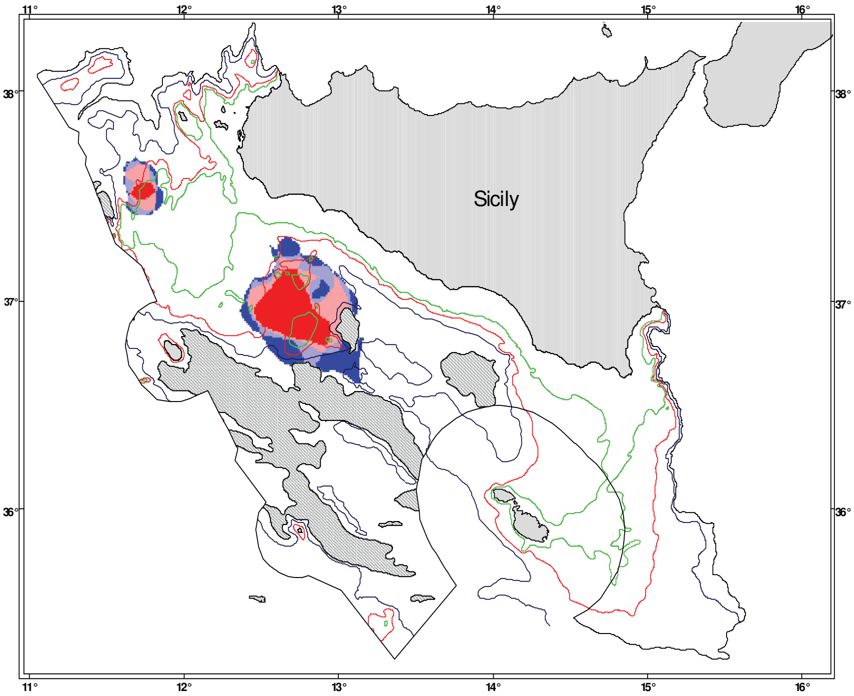

Figure 21. Areas showing stable presence of recruits of *Phycis blennoides* during MEDITS surveys (1994–1999). (From Fiorentino *et al.*, 2003b).

According to Fiorentino *et al.* (2003b), the importance of environmental factors in determining the recruitment dynamics in the Straits of Sicily could also be envisaged from the high correlation between recruit abundance in hake and greater forkbeard, with 1997 being the poorest year-class and 1998 the best for both species. The recruitment strength of the two species was significantly correlated ($r = 0.844$; $p<0.01$), suggesting that species fluctuation might be synchronized.

In conclusion, the similarity in the spatial distribution and the high stability of nursery locations of many investigated species suggests that the hydrographical features could be the main factor influencing nursery distribution and persistence. In particular, the eastern edge of the Adventure Bank and of the Malta Bank seems to be very important grounds for recruitment of many commercial species.

It is interesting to highlight another element of symmetry of the two banks. A recent study evaluating the performance of an indirect index of trawling disturbance, the Bottom-dwelling Index (BOI) (Gristina *et al.*, 2004), showed that the Malta Bank, in the wider context of the Straits of Sicily is the area where the BOI is highest (similarly to Adventure Bank) (Figure 22); i.e. an area where the sea bottom is less stressed by trawling activities. In particular, the areas characterized by the higher values of BOI are inside the FMZ and on the eastern side of the Adventure Bank.

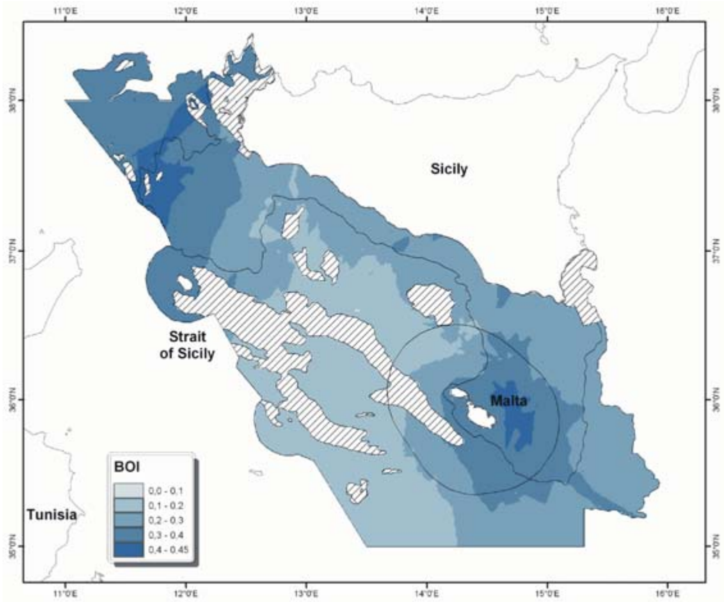

Figure 22. Map of Bottom-dwelling Index (BOI), an indirect measure of trawling disturbance. Highest BOI values mean lowest disturbance. (MEDITS, 2003 (from Gristina *et al.*, 2004)

Part II: Integration of multidisciplinary data, preliminary analyses and understanding of the fishery ecosystem structure and functioning

An analytical framework based on a simple geographic information (GIS) system was developed in this study to explore, identify, investigate and explain the spatial distribution of demersal resources and their relationships to hydrographical features and and the distribution of fishing.

GIS are particularly well suited to address the heterogeneity and spatio-temporal nature of the datasets involved. Indeed, GIS, by their very nature, provide a powerful environment for integrating and analysing a large amount of diverse data, effectively incorporating the complexities of the spatial dimension in such analyses. As a matter of fact, the benefits of using GIS technology in fisheries have been widely reported (FAO, 1996, 2003; De Graaf *et al.*, 2000; Nishida *et al.*, 2004). These systems allow the incorporation of a spatial perspective into research which has the potential to integrate data and information from different disciplines.

From a methodological point of view, the approach adopted relies on the delineation of areas where resources (taxonomic groups, single species or species' critical life-stages) consistently aggregate. The assumption is that sites where high abundances of resources are consistently found are of particular concern and potentially "essential" to the ecosystem functioning and, hence, deserve further investigation to highlight their biotic and abiotic characteristics. Based on available information, hypotheses on the role of oceanographic factors in determining observed distributions and in influencing species dynamics were discussed.

The ArcGIS 8 (ESRI, 2001) package was used to manage, analyse and display all spatially referenced information (point samples as well as interpolated continuous surface distributions). The digital bathymetry and coastline of the first edition of the International Bathymetric Chart of the Mediterranean (IBCM) was chosen for the basic cartography. It is at the scale of 1:1,000,000 and is incorporated into the IOC–IHO General Bathymetric Chart of the Ocean Digital Atlas. In the area of interest, the dataset includes the contour lines at 0m, 50m, 100m, 200m, and at increments of 200m thereafter. The reference system is the Geographic Coordinate System using the WGS84 datum. Projected representations of the data are obtained using the Mercator projection (at 38°N), as the original nautical charts.

6. Availability of data and methods applied

6.1. Fishing effort

Information on the spatial distribution of fishing effort (annual) for trammel netting and bottom longlining was recorded during a census using a grid at three different levels of resolution (Figure 23): cell sizes of 5', 20' and 1° (Camilleri, 2005). Nominal effort was estimated by the product of the number of gear units (number of hooks or number of nets) and number of fishing trips. The nominal effort results were standardized to obtain fishing-intensity estimates by dividing the values by an area coefficient depending on the size of the cell to which the fishing-effort values were attributed. Thus, the values of fishing intensity for each cell within the grid were calculated as follows:

Cell size 05':	Nominal effort / 1
Cell size 20':	Nominal effort / 16
Cell size 1°:	Nominal effort / 144

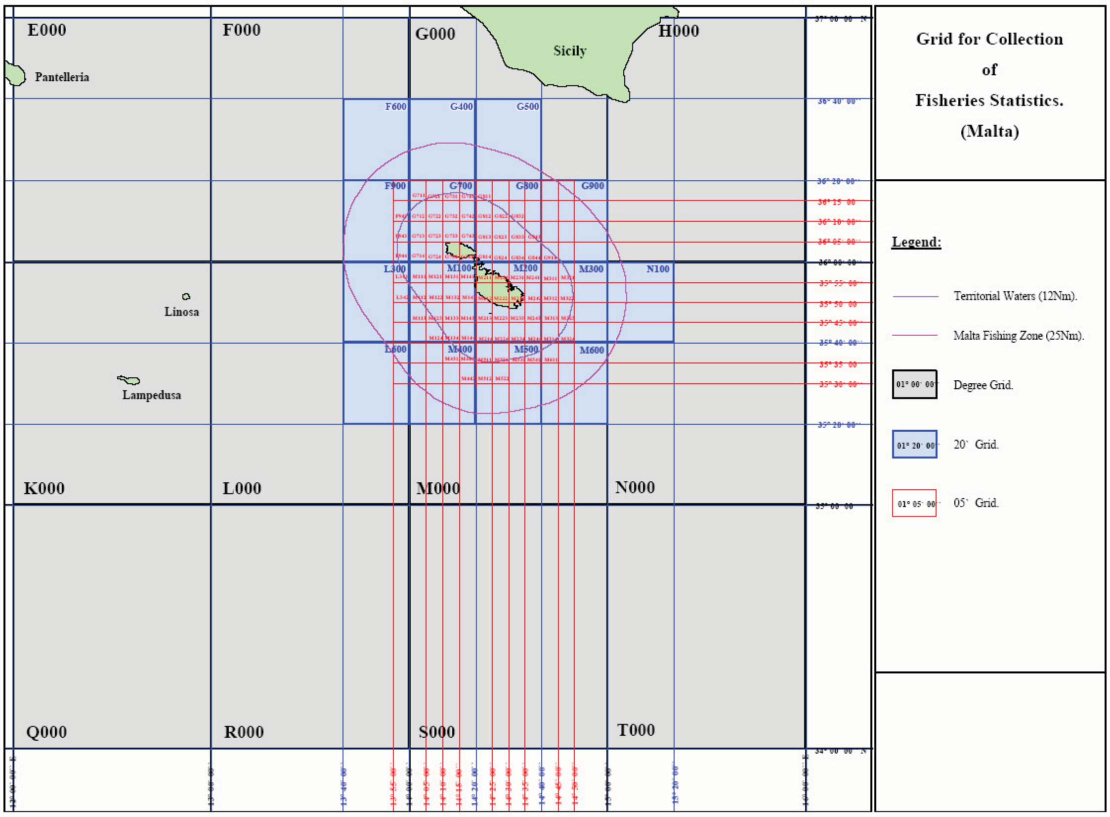

Figure 23. Definition of grid used for collecting fishery statistics (Camilleri, 2005).

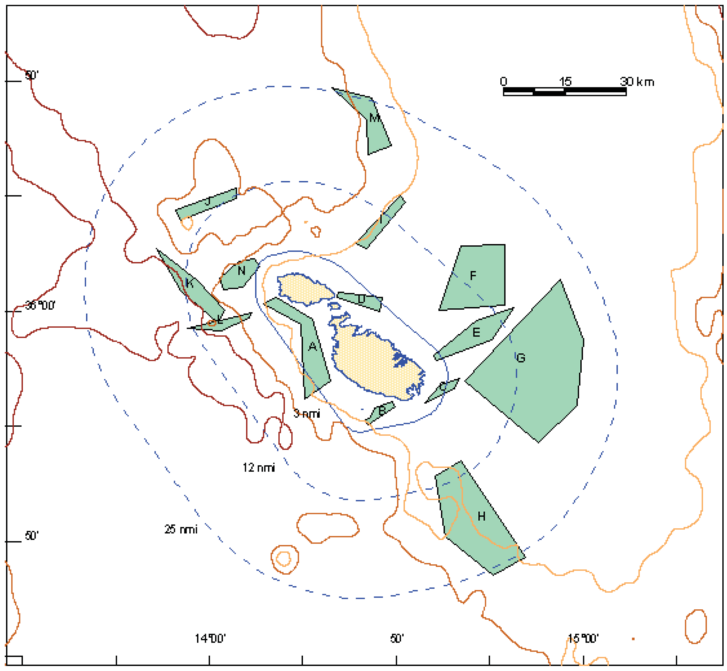

Figure 24. Trawlable areas around the Maltese Islands (A, B, C, D – protected; E, F, G, H, I – shelf/shallow; J, K, L, M, N – slope/deep). Adapted from Giudicelli (1978) as cited in Camilleri (2005).

Fishing-intensity estimates for trawling are not available in grid format; however, the fishing areas are determined by bathymetric characteristics and bottom types (see Figure 24), and are nevertheless defined by legislation (EC813/2004).

6.2. Oceanographic data

The fields of the basic abiotic parameters (temperature, salinity, current direction and speed) for the area of investigation are calculated on the basis of a numerical model that runs in hindcast mode (see Annex 2); values of several parameters at basin scale are taken into consideration. The model takes into account a variety of fluxes and was run for five years (2000–2004) for GSA 15, to produce the monthly averages of the different parameters. Instead of calculating them as depth-averaged values over the five depth strata used in trawl surveys, 23 discrete depth levels were chosen (Table 5). The reason for this is that depth-averaging smooths the seasonal signature and important information necessary for the correlation with biological processes may be lost.

Table 5. Depth levels for which oceanographic fields were calculated

Level	Depth (m)	Level	Depth (m)
1	1	13	320
2	5	14	360
3	15	15	400
4	30	16	440
5	50	17	480
6	70	18	520
7	90	19	580
8	120	20	660
9	160	21	775
10	200	22	925
11	240	23	1,150
12	280		

The model provided raw data in text format that can be used in the MedSudMed Fishery and Ecosystem Information System (FEIS), as well as for GIS software and for multivariate analysis.

Maps were plotted by means of an application (developed under MatLab) which allows plotting either one field at a time or several fields/months/depths in a single picture of four maps. It is also possible to plot vertical casts for all months at a time, by choosing any point on the horizontal map. For this study, maps corresponding to February, May, August and November, as typical representative months of the four seasons, were plotted.

6.3. Sediment data

To provide data on the physical and chemical characteristics of the sedimentary habitat in the Maltese trawling grounds, sediment samples, analysed for sediment grain size and organic carbon content, were collected as part of the MEDITS trawl survey programme using a box corer (Khalsico) of effective sampling area $0.0625m^2$ from 23 of the 45 MEDITS stations

(Table 6). Box-core samples were obtained from the stations marked in red on Figure 25. Sampling was actually attempted in most of the 45 MEDITS stations, but owing to bad weather conditions, if no core was retrieved after three to five trials, then sampling at that station was abandoned. Where sampling was successful, three replicate box-core samples were collected at the station.

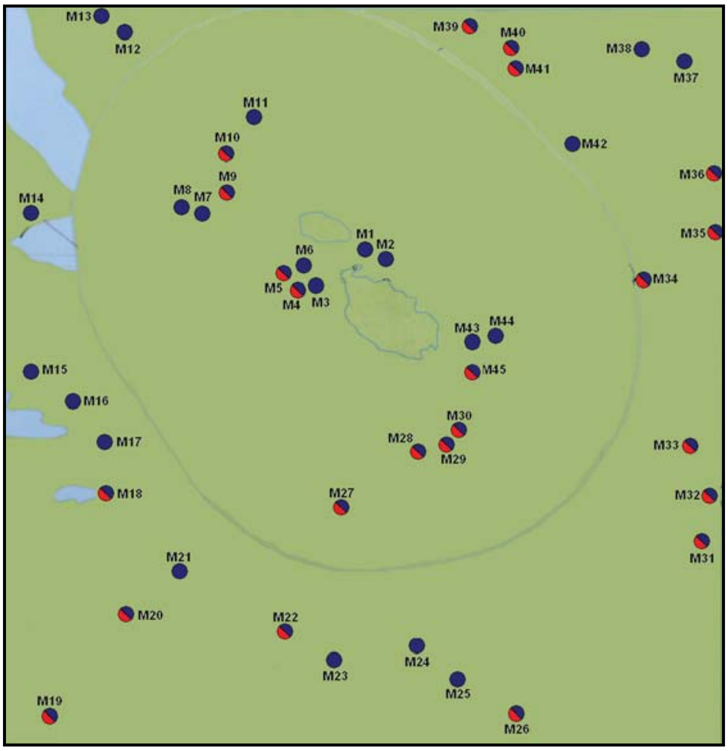

Figure 25. Map of GSA 15 and the Malta FMZ (oval round the Maltese Islands), showing the position of the trawl sampling stations. Box cores were taken at the stations marked in red.

From each intact box core, two subsamples were collected using a hand-held corer with an internal diameter of 5cm; one subsample was used for granulometric analysis and one for determination of the percentage of organic carbon. These subsamples were frozen at –20^{o}C on board the vessel and then transported to the laboratory and stored at –20^{o}C for later analysis. The remaining sediment in the box core was then sieved through a 0.5-mm mesh on board the vessel and fixed in 5% formaldehyde in sea water.

In the laboratory, the sub-sample for the determination of granulometry was thawed at room temperature, thoroughly mixed, and washed in distilled water in a 2-litre beaker to remove salt. Most of the water was removed by air-drying in a greenhouse at about 45^{o}C. A 20-g subsample was taken from the dried sample and mixed for 15 minutes with a solution of sodium hexametaphosphate $(NaPO_3)_6$. The sediment sample was initially split into sand and silt–clay fractions by wet-sieving through a 63-µm Endecott test sieve, according to the procedures described by Buchanan (1984).

The sand fraction retained on the 63-µm sieve was dried in an oven at 70^{o}C for 24h. After drying, granulometry of the sand fraction was determined according to the procedure described by Buchanan (1984), which consists of sieving the sand fraction through a series of nested Endecott test sieves of mesh sizes 4mm, 2mm, 1mm, 0.5mm, 0.25mm, 0.125mm and

0.063mm. The sieves were placed on a mechanical sieve-shaker and agitated for 15 minutes at moderate amplitude.

The silt–clay fraction which passed through the 63-μm sieve during wet sieving was analysed using the sedimentation analysis procedure described by Buchanan (1984). Sedimentation analysis was carried out in a water bath at a temperature of 25°C.

Each fraction from the sieve-shaker and from the sedimentation analysis was weighed and the percentage weight of each particle size-class was calculated. Statistical descriptors were calculated using the software GRADISTAT Version 4 (Blott and Pye 2001) according to Folk (1974). Calculations and graphical representations were made using Microsoft Excel 2003.

The frozen sediment subsample for the determination of organic carbon was thawed at room temperature and about 8g were weighed out and analysed according to the Walkley and Black method, as given in Buchanan (1984).

Sediment characteristics were analysed using hierarchical agglomerative clustering based on the normalized Euclidean distance similarity coefficient (Clarke and Warwick, 1994) using the PRIMER 6 statistical package.

Table 6. Coordinates and depth of the box-corer sampling stations.

Station	Depth (m)	Position	
		Latitude	Longitude
M04	199	35°57.94	14°13.81
M05	183	35°.57.22	14°16.49
M09	555	36°08.18	14°04.25
M10	267	36°12.99	14°04.02
M18	537	35°25.40	13°32.18
M19	431	35°02.70	13°38.01
M20	558	35°15.99	13°50.16
M22	597	35°13.25	14°13.55
M26	554	35°04.39	14°44.18
M27	570	35°29.01	14°23.39
M28	420	35°36.04	14°31.49
M29	216	35°40.04	14°35.29
M30	172	35°38.06	14°39.06
M31	280	35°25.82	15°11.47
M32	260	35°31.65	15°16.83
M33	149	35°37.43	15°13.06
M34	101	35°58.37	15°05.63
M35	182	36°03.48	15°17.63
M36	149	36°10.38	15°17.15
M39	134	36°28.13	14°42.13
M40	131	36°23.91	14°46.80
M41	130	36°23.28	14°49.25
M45	139	35°45.30	14°37.75

6.4. Demersal resources

Biological information on groundfish in GSA 15 was obtained within the framework of two main programmes on evalutation of demersal resources (Figure 26): the international programme MEDITS, supported by the European Union (Bertand *et al.*, 2002), and the GRUND programme, funded by the Italian government (Relini, 2000). The surveys were carried out in the spring and autumn of 2003 and 2004, respectively, using the professional stern trawler *S. Anna* and two standardized gears having a fine mesh in the cod-end (20–30mm mesh opening; Levi *et al.*, 1998). But, whereas the MEDITS survey used a GOC73, high-vertical-opening trawl net (2.4–2.9m), the GRUND survey used an Italian *tartana*, low-vertical-opening trawl net (0.6–1.3m). Both surveys were carried out according to a random stratified design, with a number of samples proportional to the extent of each depth stratum: five depth strata were defined, ranging from 10m to 800m (10–50m; 51–100m; 101–200m; 201–500m and 501–800m).

Catch rates by haul were elaborated using the SEATRIM software (De Santi *et al.*, 2004) in order to obtain abundance indices per species in terms of number (DI) and biomass (BI) per km^2 by the swept-area method (Sparre and Venema, 1998).

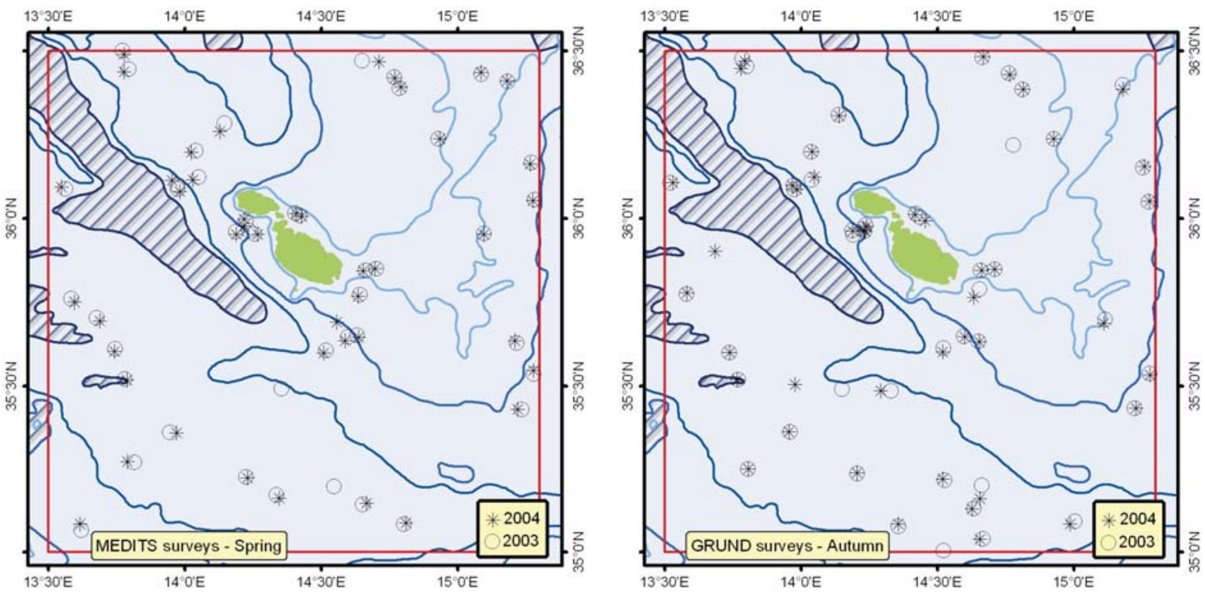

Figure 26. Sampling stations of the MEDITS and GRUND surveys in the years 2003 and 2004.

6.4.1. Fish assemblages

Using the PRIMER analytical package (Clarke, 1993), ordination and clustering techniques were applied to show the degree of similarity in the species composition at each sampling station. All the caught taxa were considered in the analysis, but taxa appearing fewer than five times in the surveys and strictly pelagic were omitted from the analysis.

Cluster analysis was used to describe the relationship within areas taking into account individual species weight, using the Bray–Curtis index of similarity and the group-average method of linkage on fourth-root-transformed data, in order to reduce the influence of abundant species. The relationship was further investigated using multi-dimensional scaling

(MDS) to produce a two-dimensional plot, where the distances among areas represent their relative similarity (Clarke and Warwick, 1998).

Similarity of percentages analysis (SIMPER) was used to identify the species that typified the catches within the areas and those species that discriminate between them.

An analysis of similarity test (ANOSIM) was performed to detect spatial and seasonal differences within each of the identified assemblages.

The spatial structure of the identified assemblages was investigated using geostatistics with indicator kriging of each cluster. The clusters were assigned to their corresponding station locations and were treated as continuous variables. Spatial interpolation was then used to produce a map of conditional probability of occurrence for each cluster. Predictions for unsampled locations were obtained by overlaying different maps and selecting the category with the largest conditional probability. The classification procedure resulted in a univariate distribution map of the assemblages.

6.4.2. Taxonomic groups and target species

The overall catch by haul was considered as a whole and separated into the main taxonomic groups: bony fish, elasmobranchs, crustaceans and cephalopods. For the target species, *Mullus barbatus, Merluccius merluccius, Parapenaeus longirostris, Raya clavata* and *Raja miraletus*, abundance indices were calculated both for total population and main life-history stages, particularly juveniles and adult females. In the cases of *Mullus barbatus*, *Merluccius merluccius* and *Parapenaeus longirostris*, juveniles were identified as young of the year (YOY) (0 age-class) from the analysis of length–frequency distributions (LFD) according to the methodology in Levi *et al.* (2003) and Fiorentino *et al.* (2003b). Since splitting of ray species was difficult, juveniles of *Raya clavata* and *Raja miraletus* were identified as the immature fraction of catch.

Adult females were identified on the basis of the gonad maturity stage (stage 3 – maturing; stage 4 – mature; and stage 5 – spent/recovering).

On the whole, the set of parameters listed in Figure 27 were entered into the GIS for the spatial analysis. The main objectives of the spatial analysis were: to predict the continuous spatial distribution of resource abundance; and to identify “stability areas”, where abundance is consistently high. Distribution maps of each parameter were produced applying the deterministic inverse-distance weighted interpolation (IDW) with 2 as the exponential power of distances.

"Hot-spots" of biomass (for taxonomic groups and target species) or density (for YOY and adult females) were determined by delineating areas over which the estimated values exceeded a specified level. This threshold was decided so as to correspond to the upper limit of the 3rd quartile of the respective distribution. Hence, the “stability areas” were identified as areas that held consistently, over the four surveys, the highest biomass (resource concentration areas) or density values (preferential habitats of specific life stages).

All taxonomic groups →	Biomass index, Richness
Bony fish Selachians Cephalopods Crustaceans →	Biomass index
Target species Merluccius merluccius Mullus barbatus Parapenaeus longirostris →	Biomass index Density index of YOY Density index of adult females
Raja clavata Raja miraletus →	Biomass index Density index of YOY

Figure 27. Indexes calculated and mapped for each taxonomic group and target species.

7. Spatial distribution of resources, environmental features and fishing effort

7.1. Spatial distribution of fishing

In general, Maltese fishermen operate rather close to their homeport and perform one-day trips; the results of catch and effort surveys show that most of them fish at less than 200m depth and not beyond, because of the great distance that they would have to cover.

7.1.1. Trawling

The trawlable[2] areas within the 25-mile Fisheries Management Zone (Figure 24) cover an area of about 1,600 km^2 of which about 10 percent lies within 3 nautical miles of the Islands' baselines and has been protected from trawling for more than 15 years (Camilleri, 2005). Only about 240 km^2 of trawlable area is found in waters deeper than 200m; i.e. slope and deep water.

The effort surveys show that the trawlers fish within the 25-nautical mile MFZ, mostly north-west of Malta in deep water, targeting red shrimp. Very few trawlers operate in the shallow water to catch demersal species other than shrimp. Camilleri (2001) reported that the overall annual swept area was about 60% and 400% for the shelf and slope fishing grounds, respectively.

[2] The term "trawlable" means that the bottom type allows the commonly used Mediterranean otter trawl (Mazara type) to operate effectively. It is designed to operate on sandy and muddy bottoms with no beams, chains or rock hoppers attached to the ground rope to operate on hard substrates.

7.1.2. Trammel netting

Analysis of the spatial distribution of fishing effort shows that trammel nets operate almost exclusively within 12 nautical miles of the coast (Figure 28). Most of the effort of trammel netting is concentrated within a short radius around the major fishing ports, particularly those located in the south-east of Malta, with large areas being only lightly exploited.

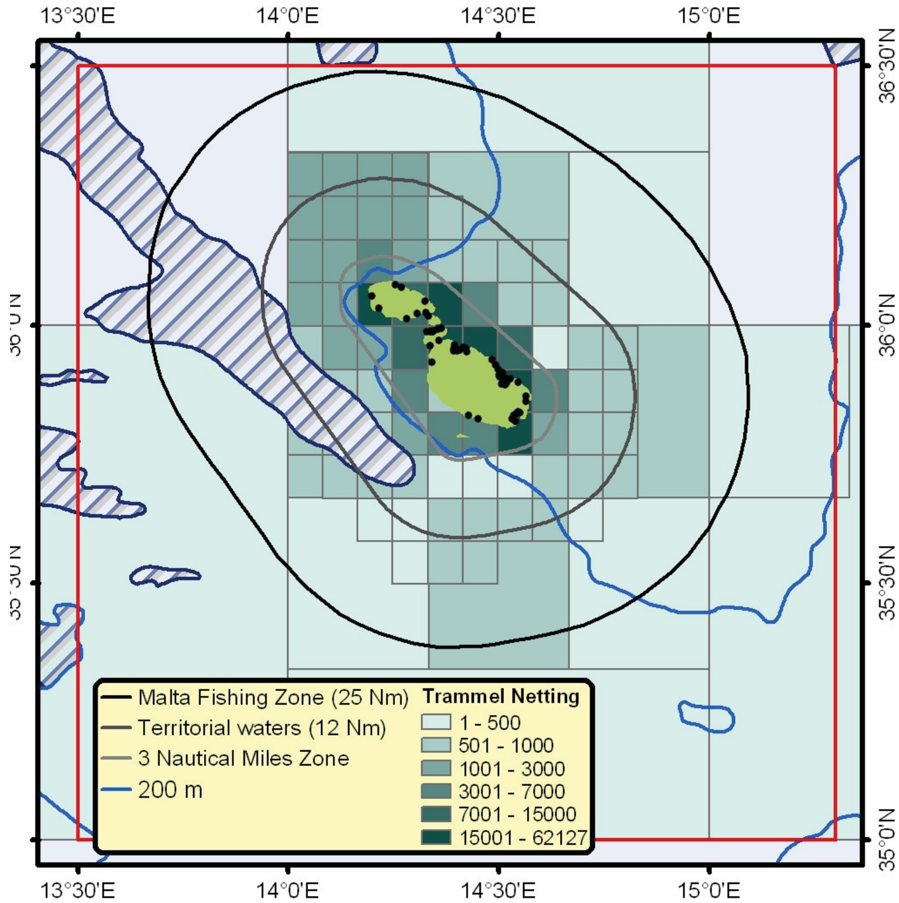

Figure 28. Spatial distribution of fishing intensity for trammel netting (annual snapshot). Data source: MaltaStat fleet register. Units: (number of nets*number of fishing trips)/area coefficient).

7.1.3. Bottom longlining

Bottom longlining takes place over vast areas which extend beyond the 25-mile Fisheries Management Zone and all over the broad area between Sicily and south Tunisia (Figure 29); however, the small-scale fleet operates only in areas concentrated close to their base port, as reported by Camilleri (2003).

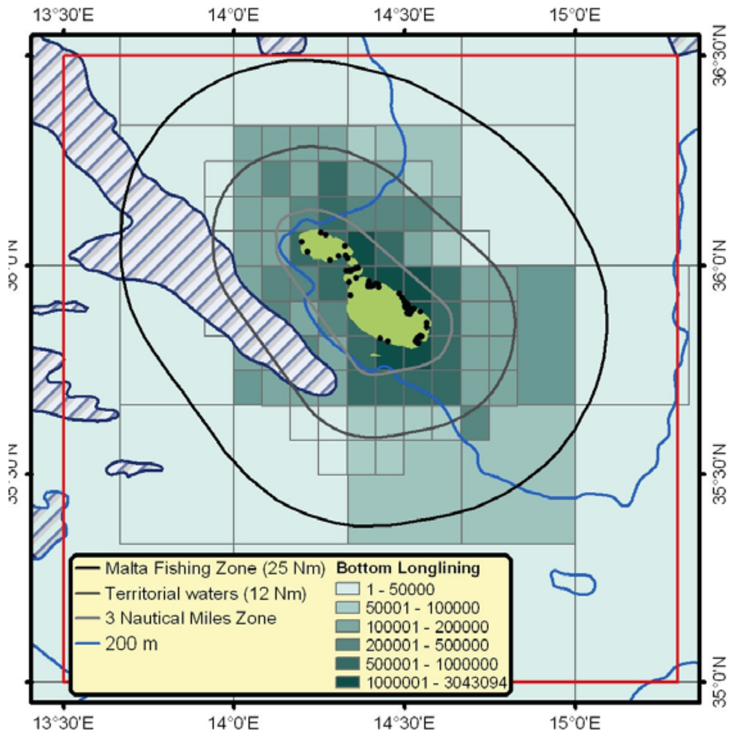

Figure 29. Spatial distribution of fishing intensity for bottom longlining (annual snapshot). Data source: MaltaStat fleet register. Units: (number of hooks*number of fishing trips)/area coefficient.

7.2. Main hydrographical features

This section presents a selection of the 2-D maps of hydrographical features produced by the model which are considered more relevant to the formulation of a hypothesis on oceanographic processes that may explain observed spatial distribution of resources in GSA 15.

The model reproduces many of the oceanographic features that are known to exist in the area (described in section 0); in particular, the presence of a front characterized by northern areas much cooler than southern areas (Figure 30 – Figure 31). The Atlantic Ionian Stream (AIS) is stronger in summer and includes all the Maltese area, whereas in winter, it is more constrained and flows farther north from Malta (Figure 32). The consequence is that warmer and saltier water flowing down from the coast of Sicily is found in the north-eastern corner of the GSA 15 during summer and autumn (Figure 30 - Figure 34). There is always higher salinity in the north-eastern part of the GSA (Figure 35). Surface (Figure 32) and subsurface (Figure 36) currents may be responsible for the transportation, from north of the Maltese Islands, of eggs and larvae of species whose dispersal phases are strictly linked to the surface layers. Between 200m and 280m depth, there is a quite stable distribution of the Levantine Intermediate Water which circulates from south-east to north-west (Figure 37 – Figure 38). This westward current at the edge of the shelf may shift vertically upward along the outer shelf and enhance the biological productivity south of the Maltese Islands. It is known that favourable surface conditions further produce some consistent upwelling south of Gozo, especially in summer.

It is important to note that the maps produced are based on averages of daily model outputs and that there is a short-term variability that may be worth analysing in terms of mesoscale processes, as parameter distributions may be very variable (such variability can be seen from forecasts published on the web site at www.capemalta.net\MFSTEP\results.html).

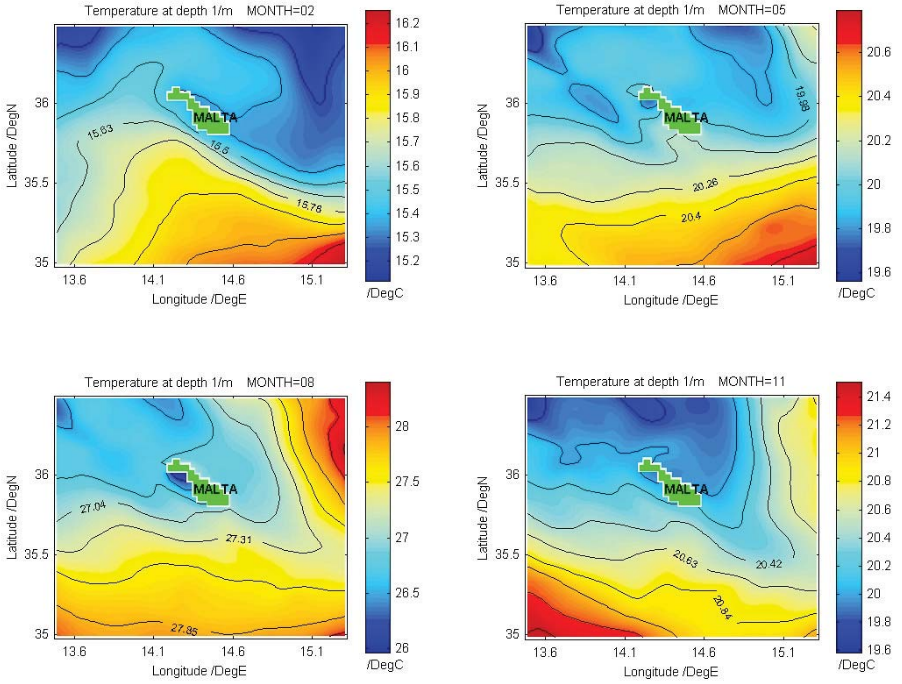

Figure 30. Isotherms at 1m depth. Note that the northern area is much cooler than the southern area.

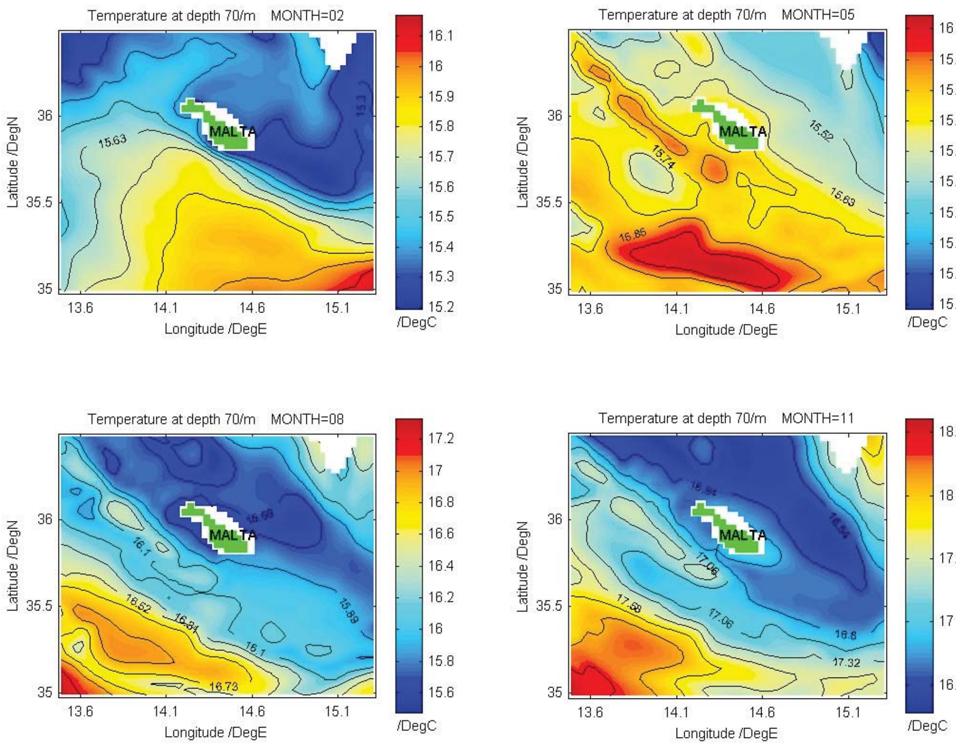

Figure 31. Isotherms at 70m depth. A frontal system south of the Maltese Islands is evident, particularly in winter. The front weakens and shifts south in summer and spring.

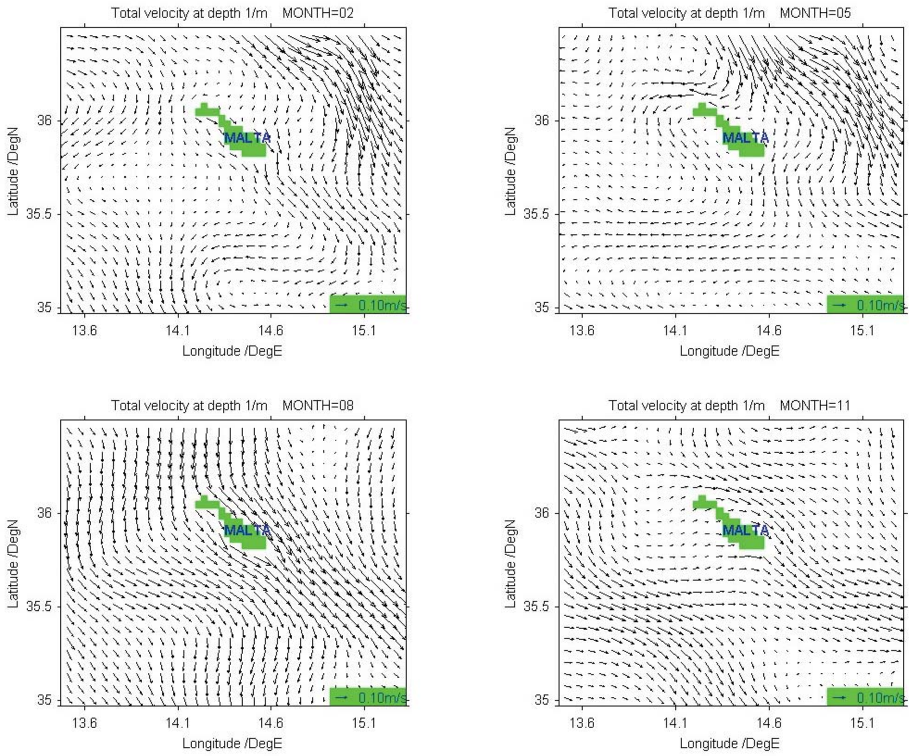

Figure 32. Field of velocity at 1m depth. The current distribution suggests the possibility of the transportation of eggs and larvae from north of the Maltese Islands of species, such as *Mullus* spp., whose dispersal phases are strictly linked to the surface layer.

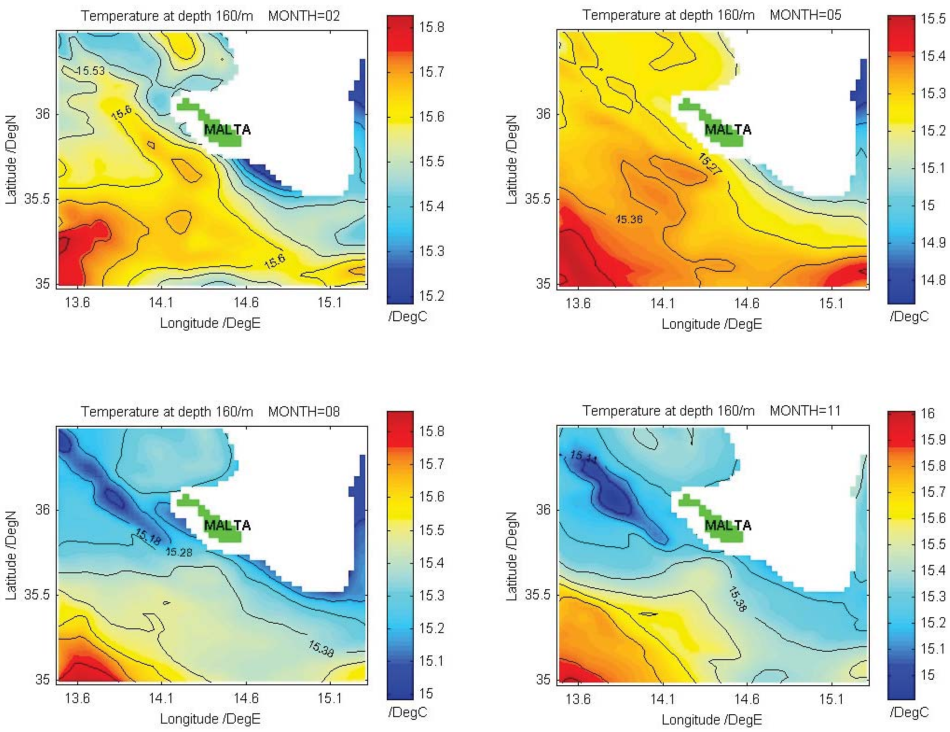

Figure 33. Isotherms at 160m depth. A frontal system over the shelf break south of the Maltese Islands is evident, particularly in winter and spring.

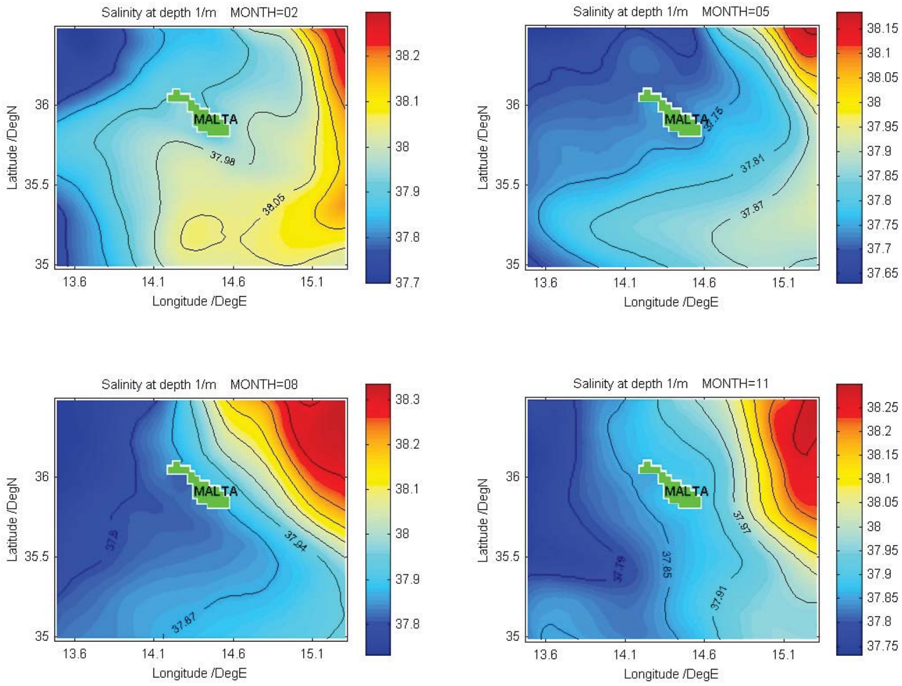

Figure 34. Isohalines at 1m depth. The flow of warm and salty water from the coast of Sicily determines the occurrence of an area of high salinity in the north-eastern corner of the GSA 15 during summer and autumn.

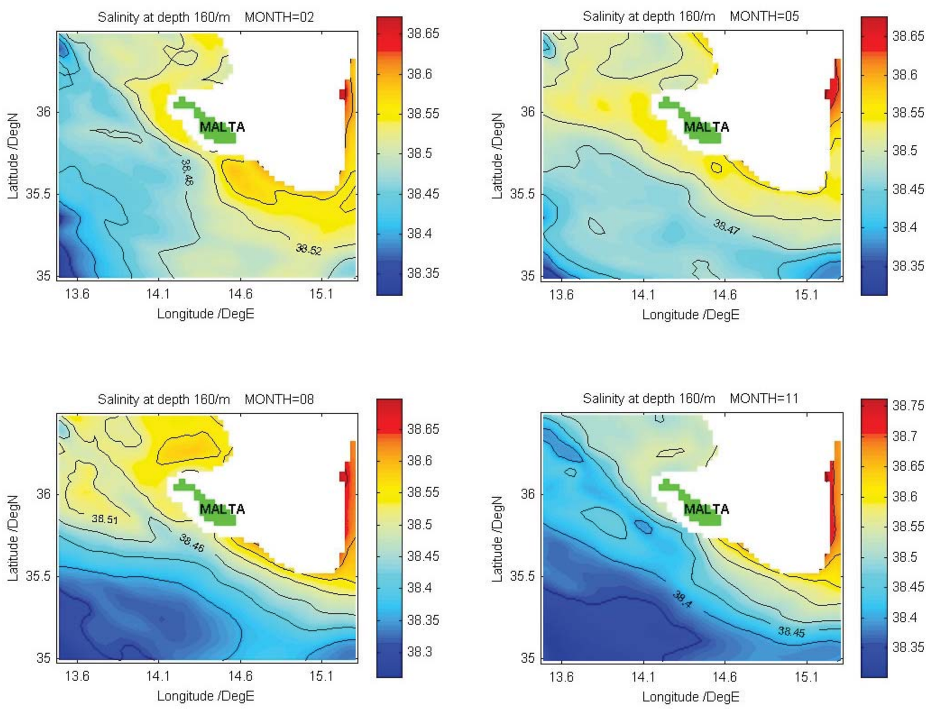

Figure 35. Isohalines at 160m depth. A frontal system on the shelf break south of the Maltese Islands is evident, particularly in summer and autumn.

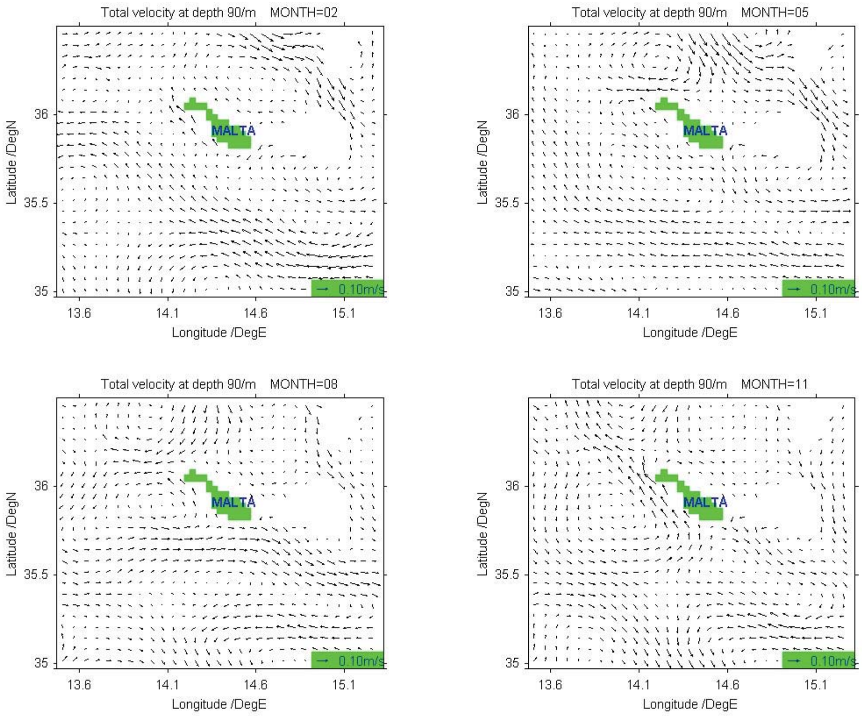

Figure 36. Field of velocity at 90m depth. The current distribution suggests the possibility of the transportation of eggs and larvae from north of the Maltese Islands in winter, spring and summer, and a northwestward transportation from the southern coast of the Maltese Islands in autumn.

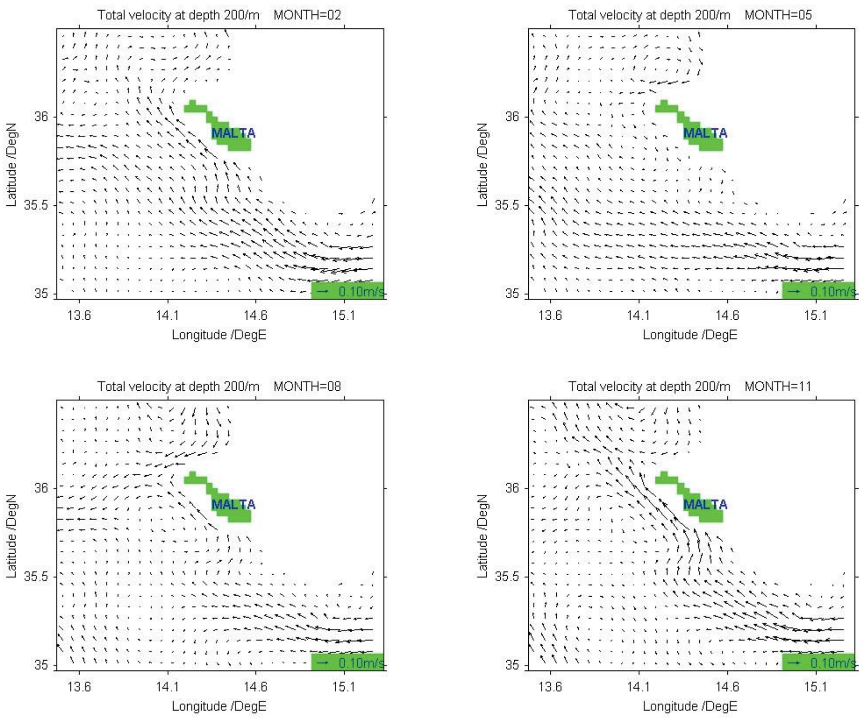

Figure 37. Field of velocity at 200m depth. The stable currents at the edge of the shelf support the hypothesis of a vertical movement of LIW over the outer shelf, which could enhance the biological productivity south of the Maltese Islands. These currents could also contribute to the dispersal of hake and deep water pink shrimp eggs and larvae produced by spawners over the outer shelf–upper slope, west of the Maltese Islands.

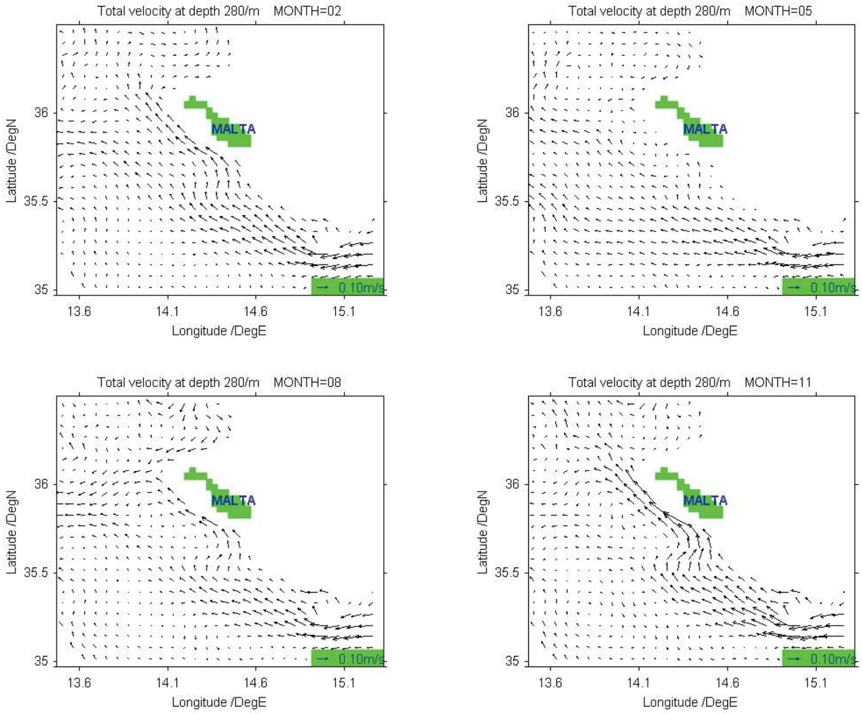

Figure 38. Field of velocity at 280m depth. The stable currents at the edge of the shelf support the hypothesis of vertical movement of LIW over the outer shelf, which could enhance the biological productivity south of the Maltese Islands. These currents could also contribute to the dispersal of hake and deep-water pink shrimp eggs and larvae produced by spawners over the outer shelf–upper slope, west of the Maltese Islands.

7.3. Sediment analysis

Table 7 shows the depth, bottom temperature, percent of organic carbon in the sediment and the relative abundances of the various grain-size fractions making up the sediment at each of the stations sampled. All the stations had sediment that was mainly composed of mud (silt and clay). In fact, the silt and clay fraction ranged from 75% to 98% and the sediment from all the stations was classified as silt (Figure 39). The percentage organic carbon was very low at all the stations and ranged from 0.069% to 0.178%, by weight.

Table 8 shows the standard granulometric statistical parameters calculated and their descriptive classification. Most of the stations had sediment that was poorly sorted, except for stations M34 and M35 where the sediment was moderately sorted. The sediment grain-size distribution at all the stations was "coarse skewed" to "very coarse skewed" and ranged from "platykurtic" to "very platykurtic", except for stations M33 and M35 where the sediment was "very leptokurtic". The sediments analysed all had a bimodal or a trimodal distribution.

Agglomerative hierarchical cluster analysis of the normalized data, using the normalized Euclidean distance similarity measure, gave two main clusters at a normalized Euclidean distance of 6.7 (Figure 40). There was no relationship whatsoever between these clusters at the depth of the component stations.

Table 7. Results of sediment analyses for particle-size distribution and organic carbon content. Nomenclature and general classification of the sediment is according to Folk (1974).

Station	Seabed depth (m)	Bottom Temp. (^oC)	Organic carbon (%)	Pebble (%)	Granule (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)	Very coarse silt (%)	Coarse silt (%)	Medium slit (%)	Fine silt (%)	Clay (%)
M04	189	14.50	0.069	0.00	0.00	0.03	0.16	1.96	6.19	11.99	7.58	15.92	18.63	24.26	13.27
M05	208	14.35	0.128	0.00	0.00	0.02	0.08	0.43	2.13	10.62	13.66	18.69	18.71	33.26	2.40
M09	191	14.50	0.126	0.00	0.28	0.20	0.10	0.27	1.45	9.99	13.24	21.08	12.94	33.09	7.37
M10	197	14.20	0.082	0.00	0.00	0.02	0.06	0.22	3.22	8.96	6.51	19.62	17.48	35.87	8.03
M18	505	13.90	0.099	0.00	0.00	0.09	0.28	0.95	2.24	6.87	1.99	20.92	12.85	42.29	11.53
M19	466	13.90	0.065	0.00	0.07	0.05	0.29	1.68	5.57	0.53	14.03	18.62	22.37	24.05	12.72
M20	701	13.90	0.102	0.00	0.00	0.02	0.28	4.49	6.22	13.01	2.67	12.64	10.67	35.85	14.15
M22	561	13.90	0.076	0.00	0.00	0.22	0.62	2.06	4.17	11.46	3.21	13.73	21.71	32.21	10.62
M26	644	13.75	0.114	0.00	0.00	0.29	1.14	1.10	3.11	5.48	5.36	12.91	15.67	42.64	12.31
M27	603	13.90	0.121	0.00	0.00	0.60	0.64	0.28	1.34	5.78	4.96	11.72	8.93	55.37	10.38
M28	543	13.75	0.113	0.00	0.00	0.27	0.38	1.48	2.09	7.31	1.95	10.32	34.29	19.79	22.12
M29	576	13.75	0.094	0.00	0.00	0.35	1.91	3.63	5.59	8.37	5.65	11.29	12.91	38.56	11.75
M30	420	13.75	0.123	0.00	0.00	0.29	0.33	0.70	1.78	5.49	2.51	13.45	6.57	42.05	26.82
M31	226	14.05	0.116	0.00	0.13	0.09	0.19	1.05	5.51	18.04	8.19	13.84	14.39	26.15	12.42
M32	179	14.65	0.143	0.00	0.00	0.11	0.08	0.61	3.63	12.92	8.56	14.58	13.38	37.02	9.12
M33	331	13.75	0.152	0.00	0.05	0.49	1.81	1.79	1.03	1.15	1.89	5.30	13.62	65.72	7.14
M34	253	13.90	0.117	0.00	0.00	0.09	0.36	1.09	1.72	1.57	1.82	7.41	12.44	53.07	20.44
M35	163	14.05	0.178	0.00	0.00	0.10	0.57	2.23	2.31	2.58	0.90	8.04	72.19	1.62	9.46
M36	142	14.20	0.113	0.00	0.03	0.05	0.06	0.07	0.25	1.33	17.53	9.31	8.61	56.35	6.41
M39	137	14.65	0.089	0.00	0.03	0.09	0.26	0.45	0.89	4.14	5.48	10.36	14.65	46.07	17.60
M40	133	14.65	0.081	0.16	0.04	0.16	0.12	2.55	2.44	13.96	7.10	10.81	17.45	34.21	11.01
M41	132	14.65	0.090	0.00	0.00	0.28	0.36	0.71	3.41	12.28	5.92	9.01	30.20	30.65	7.18
M45	124	14.65	0.155	0.00	0.00	0.06	1.24	1.46	2.29	7.55	15.73	17.89	10.69	32.84	10.27

Table 8. Standard granulometric statistical parameters of sediment analyses for particle-size distribution and organic carbon content. Nomenclature and general classification of the sediment is according to Folk (1974), continued.

	Standard statistical parameters				Descriptive classsification of the standard statistical parameters					
Station	Mean (μm)	Sorting	Skewness	Kurtosis	Mean	Sorting	Skewness	Kurtosis	Textural group	Sediment name
M04	8.20	3.48	0.41	0.70	Medium Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M05	7.89	2.92	0.23	0.78	Medium Silt	Poorly Sorted	Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M09	7.44	2.87	0.24	0.72	Fine Silt	Poorly Sorted	Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M10	6.36	2.79	0.43	0.82	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M18	4.86	2.50	0.62	0.83	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M19	6.58	2.95	0.35	0.85	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M20	7.36	3.83	0.72	0.66	Fine Silt	Poorly Sorted	Very Coarse Skewed	V. Platykurtic	Sandy Mud	V. Fine Sandy V. Fine Silt
M22	7.42	3.37	0.55	0.88	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M26	5.10	2.73	0.67	0.92	Fine Silt	Poorly Sorted	Very Coarse Skewed	Mesokurtic	Mud	Very Fine Silt
M27	4.61	2.45	0.72	0.95	Fine Silt	Poorly Sorted	Very Coarse Skewed	Mesokurtic	Mud	Very Fine Silt
M28	5.35	2.37	0.49	0.93	Fine Silt	Poorly Sorted	Very Coarse Skewed	Mesokurtic	Mud	Fine Silt
M29	7.17	3.83	0.72	0.85	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Sandy Mud	V. Fine Sandy V. Fine Silt
M30	4.57	2.21	0.99	0.84	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M31	8.77	3.49	0.36	0.56	Medium Silt	Poorly Sorted	Very Coarse Skewed	V. Platykurtic	Mud	Very Fine Silt
M32	7.18	3.14	0.53	0.69	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M33	3.65	2.23	0.62	2.25	Very Fine Silt	Poorly Sorted	Very Coarse Skewed	V. Leptokurtic	Mud	Very Fine Silt
M34	3.66	1.85	0.84	1.24	Very Fine Silt	Moderately Sorted	Very Coarse Skewed	Leptokurtic	Mud	Very Fine Silt
M35	5.92	1.94	0.30	2.73	Fine Silt	Moderately Sorted	Very Coarse Skewed	V. Leptokurtic	Mud	Fine Silt
M36	5.19	2.45	0.64	0.71	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M39	4.33	2.21	0.75	0.88	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Very Fine Silt
M40	7.34	3.29	0.56	0.68	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Slightly Gravelly Mud	Slightly V. Fine Gravelly V. Fine Silt
M41	7.52	3.13	0.47	0.87	Fine Silt	Poorly Sorted	Very Coarse Skewed	Platykurtic	Mud	Fine Silt
M45	7.24	2.98	0.33	0.67	Fine Silt	Poorly Sorted	Very Coarse Skewed	V. Platykurtic	Mud	Very Fine Silt

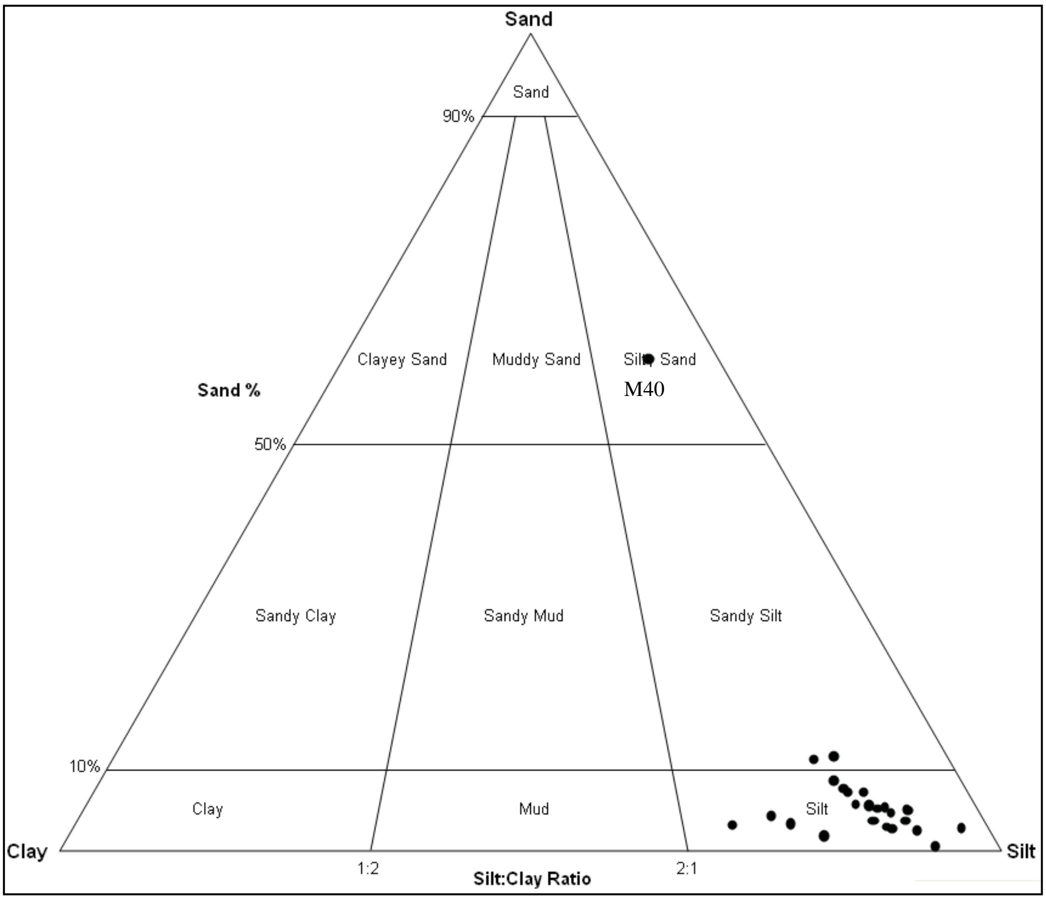

Figure 39. Ternary diagram showing the classification of each station according to its percent sand, silt and clay composition.

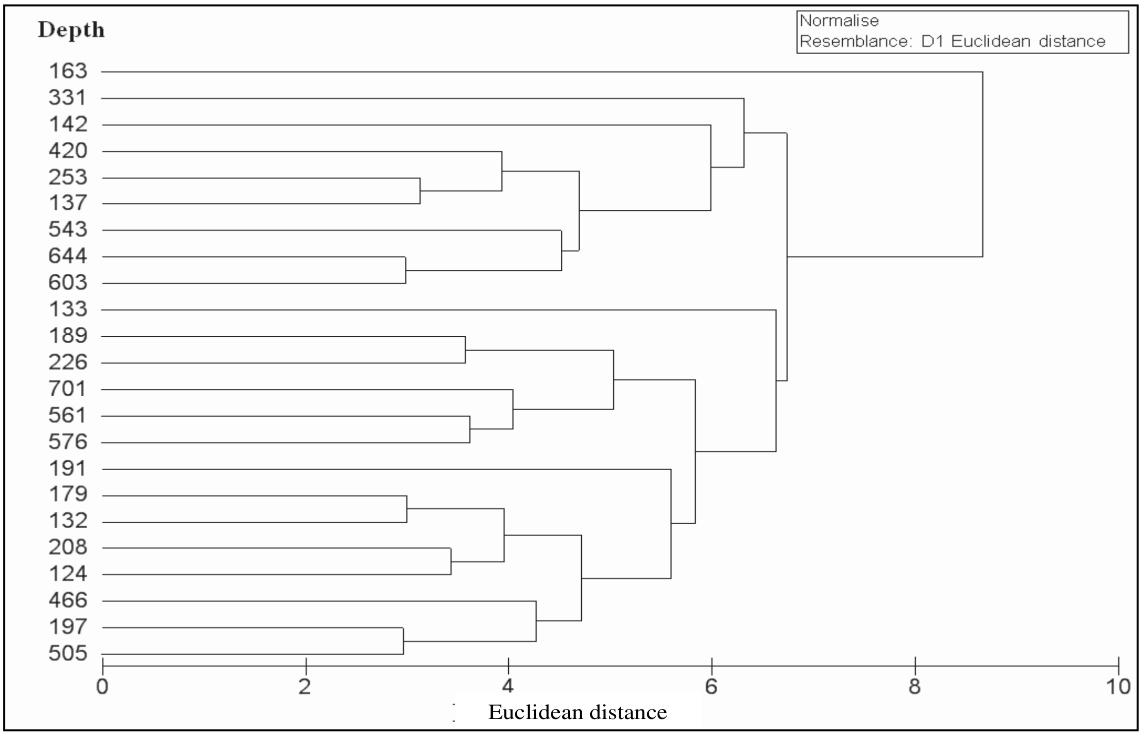

Figure 40. Dendrogram resulting from agglomerative-group average-linkage hierarchical cluster analysis of the normalized sediment granulometric data for the 23 stations sampled, based on the Euclidean similarity measure.

7.4. Demersal resources

7.4.1. Fish assemblages

7.4.1.1. Structural characteristics of the assemblages

A total of 7,559,405 specimens (weighing 131,563.35kg) belonging to 264 demersal taxa (162 bony fishes, 32 selachians, 38 crustaceans, 32 cephalopods) were captured in the four surveys considered. Cluster analysis shows the existence of five main groups of samples (Figure 41).

The Inner-Shelf group separated from the other assemblages at about 15% similarity, whereas the main blocks of Continental-Shelf and Upper-Slope groups separated at about 30% similarity. A third level of dichotomy separates the Outer-Shelf group from the Shelf-Break group (on the continental shelf) and the Slope-Shallow group from the Slope-Medium/Deep group (on the Upper Slope) at about 60% similarity.

The structural characteristic and the bathymetric range for each group are given in Table 9. Very thin bathymetric overlaps were observed between the five groups identified (Figure 42 and Table 9). Their spatial distribution is shown in Figure 43. It appears that, in similar bathymetric zones, assemblages are homogeneous and that assemblages are more influenced by depth than by bottom type, as the same assemblages can be found in the north and in the south, but on different types of bottom.

The similarity within each group ranges from 52.1% in the Inner-Shelf group to 65.6% in the Shelf-Break group. The average dissimilarity (Table 10) between the five assemblages described by the cluster analysis ranges from 47.5% (between Outer Shelf and Shelf Break) to 96.7% (between Inner Shelf and Slope Medium/Deep).

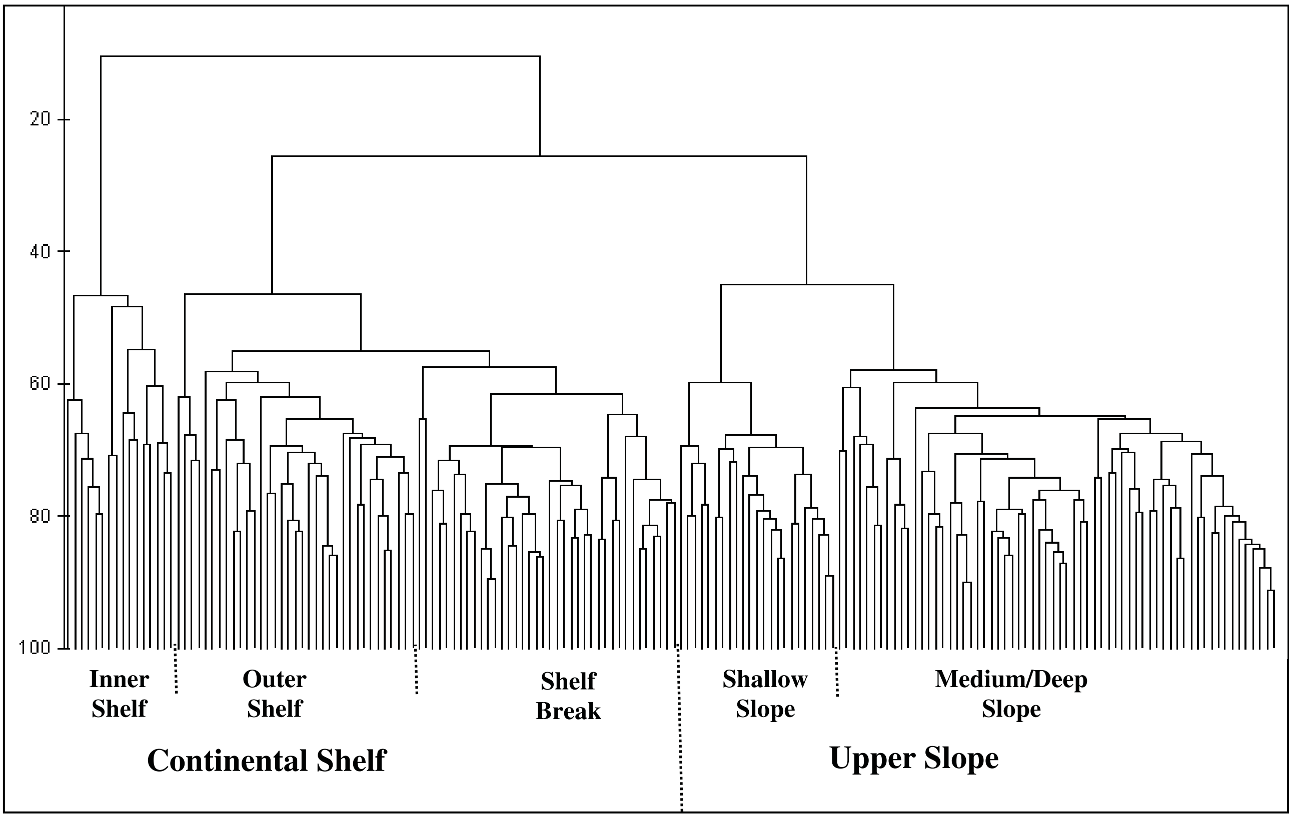

Figure 41. Dendrogram of samples collected during the GRUND 2003–2004 and the MEDITS 2003–2004 Surveys.

Table 9. Biological characteristics of each assemblage classified by multivariate analysis of the demersal community. Mean values (± standard error) of species richness and abundance for each group identified in the cluster analysis. Mean depth, depth range and number of samples for each group are also shown.

Index	INSH	OUSH	SHBR	SLSH	SLMI-DE
Mean species richness	28.8 (±3.6)	27.45 (±5.1)	30.6 (±6.2)	27.8 (±6.2)	33.3 (±7.1)
Mean abundance	526.9 (±306)	731.2 (±569)	1027.8 (±646)	613.9 (±601)	675.2 (±501)
Mean Shannon diversity	2.4 (±0.3)	2.4 (±0.2)	2.3 (±0.3)	2.3 (±0.2)	2.3 (±0.3)
Mean depth (m)	65 (±15)	123 (±21)	213 (±41)	400 (±72)	600 (±43)
Depth range (m)	46–83	84–163	140–331	259–520	526–701
Number of samples	16	35	35	31	64

Table 10. Simper analysis; in the first column, the similarity within each group is indicated, and in the matrix, the average dissimilarity between the five groups of samples identified by the cluster analysis is shown.

Similarity within each group		INSH	OUSH	SHBR	SLSH	SLMI-DE
52.1	**INSH**					
61.1	**OUSH**	78.7				
65.6	**SHBR**	84.7	47.5			
63.2	**SLSH**	93.4	66.5	51.9		
62.7	**SLMI-DE**	96.7	84.1	77.5	58.4	

The differences between the five groups of samples classified by the multivariate analysis were due to the different contributions of the species in each group (Table 11). The species that mainly typify each group are as follows:

Group name	**Typical species**
Inner Shelf	*Serranus cabrilla, Octopus vulgaris, Mullus surmuletus* and *Pagellus erythrinus*
Outer Shelf	*Parapenaeus longirostris, Merluccius merluccius, Illex coindetii* and *Argentina sphyraena*
Shelf Break	*Argentina sphyraena, Scyliorhinus canicula, Capros aper* and *Merluccius merluccius*
Slope Shallow	*Chlorophthalmus agassizi, Merluccius merluccius, Scyliorhinus canicula* and *Parapenaeus longirostris*
Slope Medium-Deep	*Galeus melastomus, Phycis blennoides, Aristaeomorpha foliacea* and *Etmopterus spinax*

The mean values of the biological parameters of each of the five groups are shown in Table 9. The highest richness was observed in the Slope-Medium/Deep group (33.3), and the lowest was recorded in the Outer-Shelf group (27.4). The highest value of abundance was observed in the Shelf-Break group, and the lowest value was observed in the Inner-Shelf group.

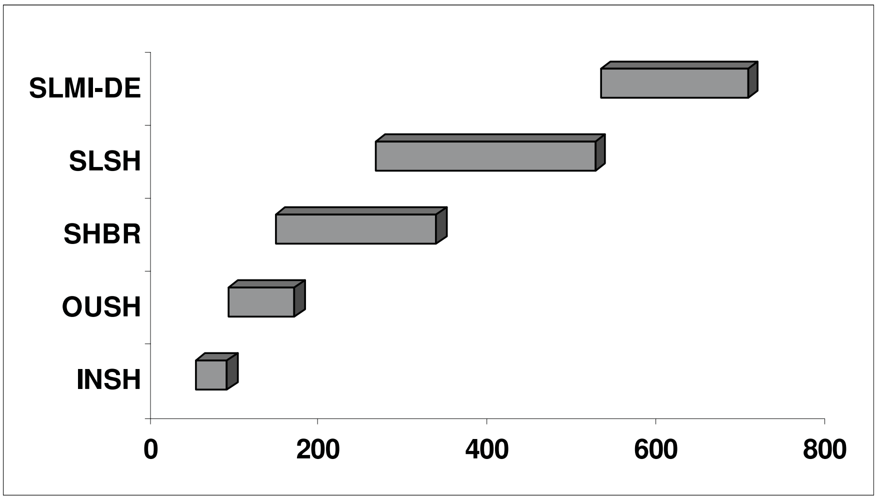

Figure 42. Depth range of clusters of stations that define the five demersal assemblages around the Maltese Islands.

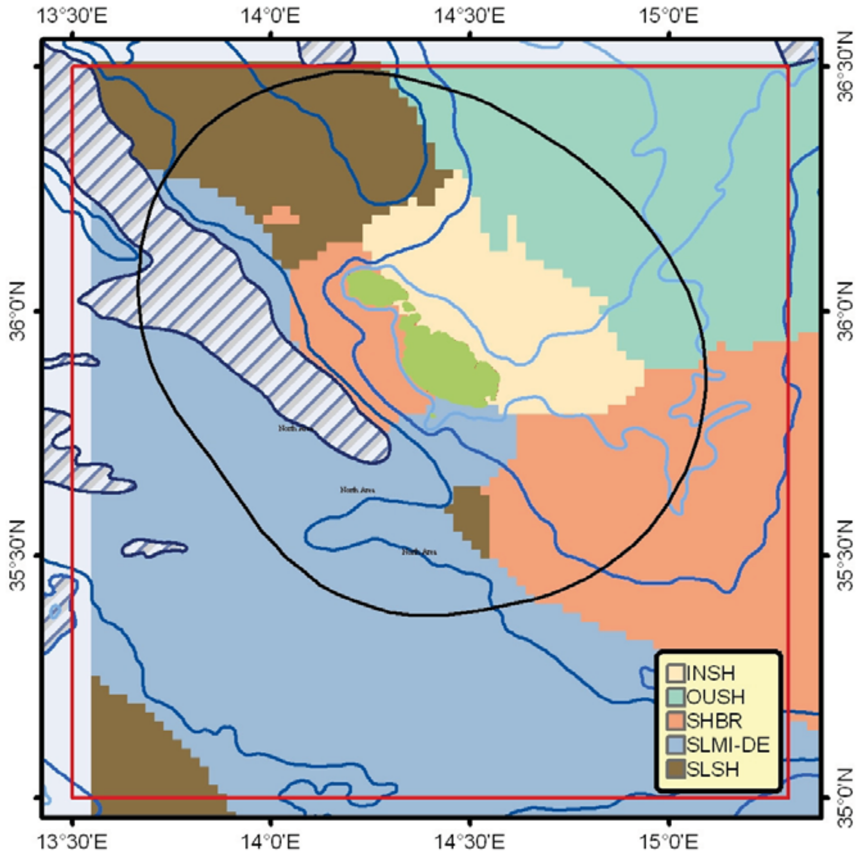

Figure 43. Spatial distribution of the five demersal assemblages around the Maltese Islands.

Table 11. Simper analysis; average abundance (Av. Ab.) and percentage contribution (%) to the similarity of each group of species that contributed at least 90%

CONTINENTAL SHELF

INNER SHELF

	Av. Ab.	%
Serranus cabrilla	136.28	18.61
Octopus vulgaris	46.56	12.11
Mullus surmuletus	78.62	11.98
Pagellus erythrinus	34.52	8.34
Spicara smaris	40.38	7.88
Zeus faber	11.10	5.80
Pagrus pagrus	39.40	5.42
Myliobatis aquila	65.63	5.03
Raja radula	27.52	4.94
Dasyatis pastinaca	60.55	4.05
Spicara flexuosa	18.89	3.79
Raja miraletus	7.85	2.34

OUTER SHELF

	Av. Ab.	%
Parapenaeus longirostris	58.67	11.14
Merluccius merluccius	53.74	11.06
Illex coindetii	37.19	9.51
Argentina sphyraena	29.30	8.78
Trachurus trachurus	141.13	8.68
Trisopterus minutus	14.69	7.06
Mullus barbatus	17.27	6.22
Zeus faber	11.83	5.22
Macrorhamphosus scolopax	14.69	4.53
Spicara flexuosa	21.40	4.31
Lepidotrigla cavillone	20.15	4.21
Scyliorhinus canicula	15.09	2.65
Capros aper	2.40	2.62
Lophius budegassa	6.44	2.31
Lepidotrigla dieuzeidei	12.46	2.10

SHELF BREAK

	Av. Ab.	%
Argentina sphyraena	131.25	8.91
Scyliorhinus canicula	86.17	8.78
Capros aper	196.92	8.17
Merluccius merluccius	56.85	7.51
Parapenaeus longirostris	44.63	7.43
Illex coindetii	41.18	6.41
Raja clavata	51.24	6.07
Macrorhamphosus scolopax	45.43	5.25
Peristedion cataphractum	27.46	4.66
Todaropsis eblanae	20.80	4.33
Helicolenus dactylopterus	9.47	4.20
Lophius budegassa	11.85	3.51
Zeus faber	17.65	3.34
Trachurus trachurus	14.78	2.82
Mullus barbatus	12.60	2.57
Lepidotrigla dieuzeidei	39.55	2.43
Mullus surmuletus	7.80	2.07
Raja oxyrinchus	35.80	2.05

UPPER SLOPE

SLOPE SHALLOW

	Av. Ab.	%
Chlorophthalmus agassizi	289.91	10.85
Merluccius merluccius	52.21	9.14
Scyliorhinus canicula	42.36	7.64
Parapenaeus longirostris	27.72	7.44
Caelorhynchus caelorhynchus	67.90	7.21
Phycis blennoides	20.86	6.74
Todaropsis eblanae	20.31	6.57
Helicolenus dactylopterus	20.73	5.96
Raja clavata	64.25	5.39
Gadiculus argenteus	40.26	4.95
Raja oxyrinchus	32.51	4.40
Argentina sphyraena	26.63	3.70
Lophius budegassa	7.18	3.37
Peristedion cataphractum	13.98	3.35
Galeus melastomus	4.27	2.56
Squalus blainvillei	31.33	2.24

SLOPE MEDIUM - DEEP

	Av. Ab.	%
Galeus melastomus	58.31	12.23
Phycis blennoides	22.27	10.04
Aristaeomorpha foliacea	21.62	9.89
Etmopterus spinax	14.99	7.87
Plesionika martia	8.64	7.55
Helicolenus dactylopterus	34.98	7.48
Hoplostethus mediterraneus	17.61	7.27
Nezumia sclerorhynchus	9.92	6.83
Merluccius merluccius	32.03	6.64
Caelorhynchus caelorhynchus	13.34	6.14
Parapenaeus longirostris	2.84	3.33
Chimaera monstrosa	12.12	2.89
Chlorophthalmus agazzisi	30.73	2.85

7.4.1.2. The fishing impact

To avoid the influence of the bathymetric gradient, which strongly affects the distribution of the species and the structure of the assemblages (Gaertner *et al.*, 1999, 2002), the impact of trammel-net fishing on the demersal communities was investigated separately for each group of hauls previously discriminated by the cluster analysis. Owing to the lack of information on the fishing effort in the deepest strata (Shallow Slope; Medium/Deep Slope), this analysis was performed only on the shelf assemblages (Inner Shelf, Outer Shelf, Shelf Break).

Owing to the low number of hauls for the spring and autumn fishing seasons, and after verifying the lack of seasonal significant differences (ANOSIM – Inner Shelf: R = 0.12, p >0.5; Outer Shelf: R = 0.11, p >0.5; Shelf Break: R = 0.12, p >0.5), we analysed the groups of hauls determined by the cluster analysis, pooling together the hauls of the four surveys examined.

The ANOSIM test performed a posteriori on the two sets of hauls on the Inner-Shelf assemblage, discriminated by the nMDS, showed significant differences (R = 0.6, p <0.005) (Figure 44).

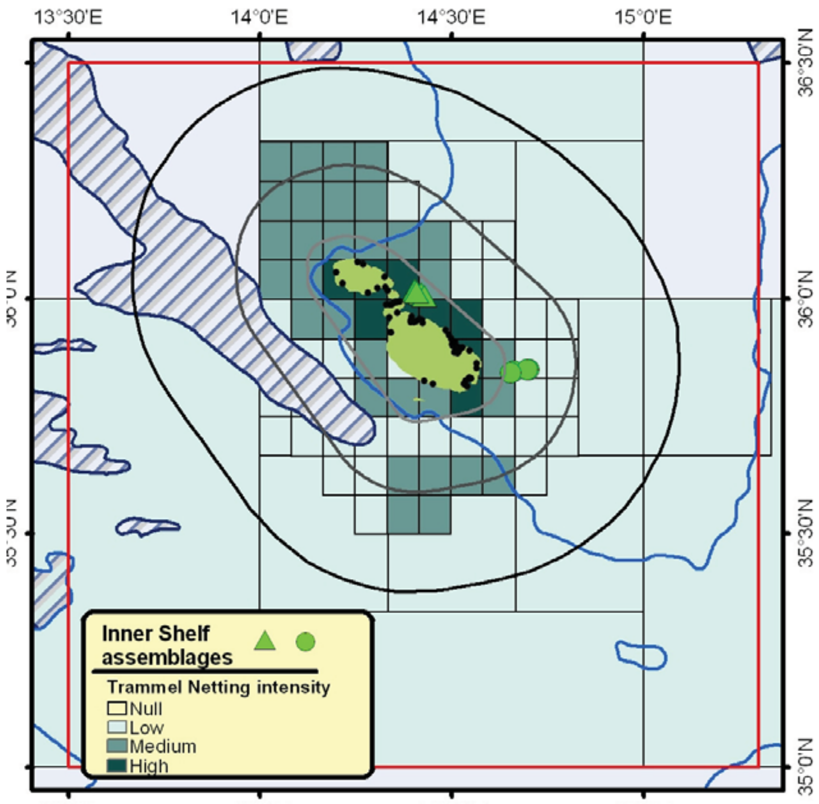

Figure 44. Inner-Shelf assemblages discriminated by different levels of fishing intensity (*triangle* ↔ high; *circle* ↔ low). The degree of fishing intensity described in legend correspond to: Null = 0; Low, from 1 to 2; Medium, from 2 to 4; High > 5 for commercial fishing operations per gear per year.

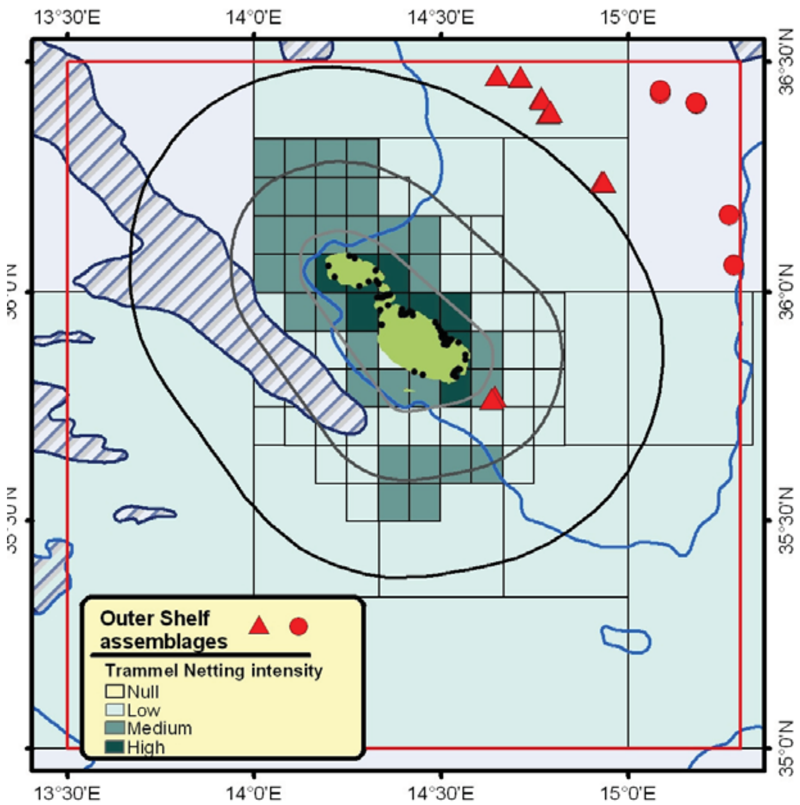

Figure 45. Outer-Shelf assemblages discriminated by different levels of fishing intensity (*triangle* ↔ medium; *circle* ↔ null).

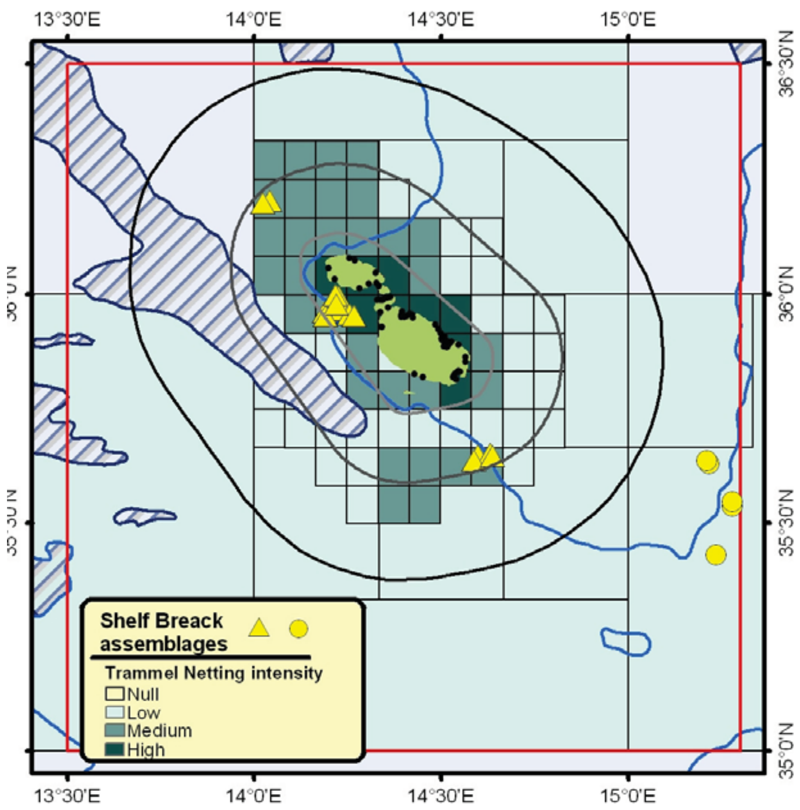

Figure 46. Shelf-Break assemblages discriminated by different level of fishing intensity (*triangle* ↔ medium; *circle* ↔ low). The degree of fishing intensity described in legend correspond to: Null = 0; Low, from 1 to 2; Medium, from 2 to 4; High > 5 for commercial fishing operations per gear per year.

The same distribution was observed for the Outer-Shelf group (ANOSIM – R = 0.45, p <0.005) (Figure 45) and the Shelf-Break group (ANOSIM – R = 0.68, p <0.001) (Figure 46), suggesting that the trammel net fishing effort may be the factor responsible for producing significant changes in the demersal assemblages

7.4.2. Taxonomic groups

All distribution maps presented below use a coloured scale based on quintiles of the distributions, with yellow corresponding to the lowest quintile and brown corresponding to the highest quintile. This allows a comparison of resource distributions from the two data sets (MEDITS and GRUND), also highlighting likely seasonal differences. It will be observed that, generally, MEDITS surveys produce higher estimates of biomass index than do the GRUND surveys.

Figure 47 shows the geographical distribution of the biomass index of the overall catch. In both seasons, the highest values are concentrated inside the FMZ, along the edge of the continental shelf north-west and south of Malta, and within the range of a major depth gradient, varying from about 100m to 500m. The area seems to coincide mainly with the distribution of mud and of mud and sand, unless this is a result of a sampling effect. In contrast, the large area including the south-western bathyal bottoms of the GSA 15 shows the lowest biomass values.

The clear orientation of the mean total biomass distribution along a NW–SE direction is common to some other distribution maps of the area of investigation. It is most probably a result of several factors, such as morphological constraints (a steep depth gradient exists perpendicularly to this axis) and oceanographic features (a permanent front occurs along this axis around 160m; Figure 33–-Figure 35), but may also be an effect of interpolation due to the unevenness of the sampling.

Results suggest the necessity of intensifying the sampling in the zone between 12 and 25 nautical miles from the Maltese Islands.

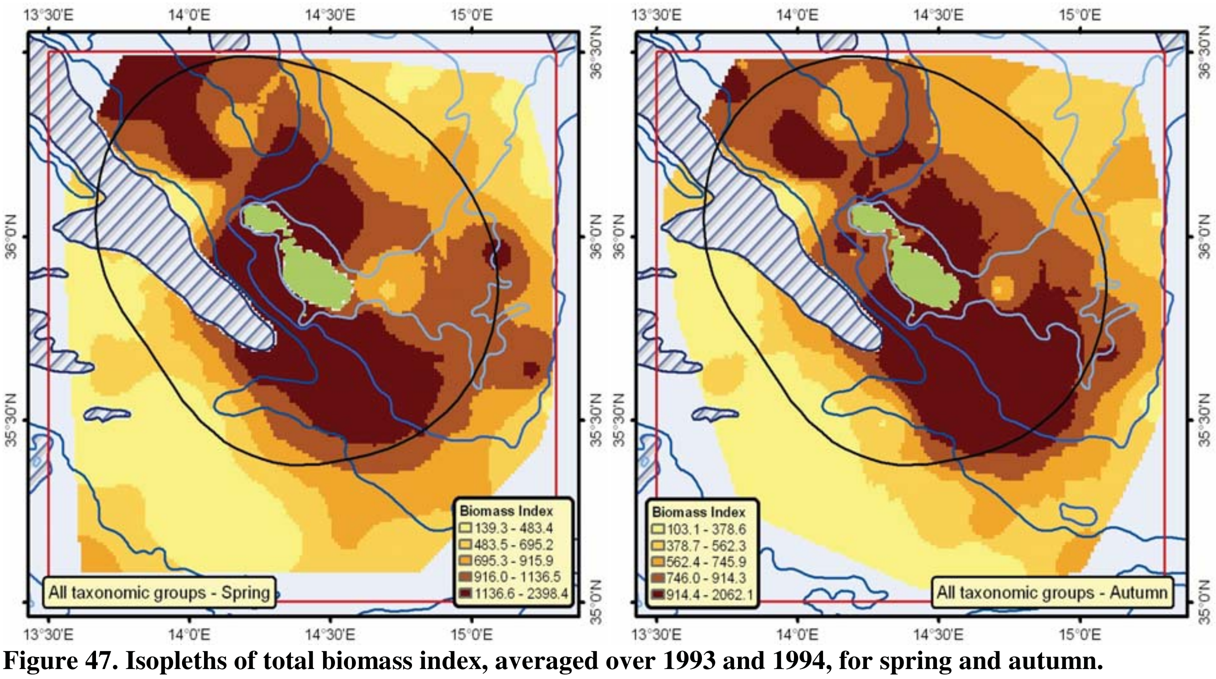

Figure 47. Isopleths of total biomass index, averaged over 1993 and 1994, for spring and autumn.

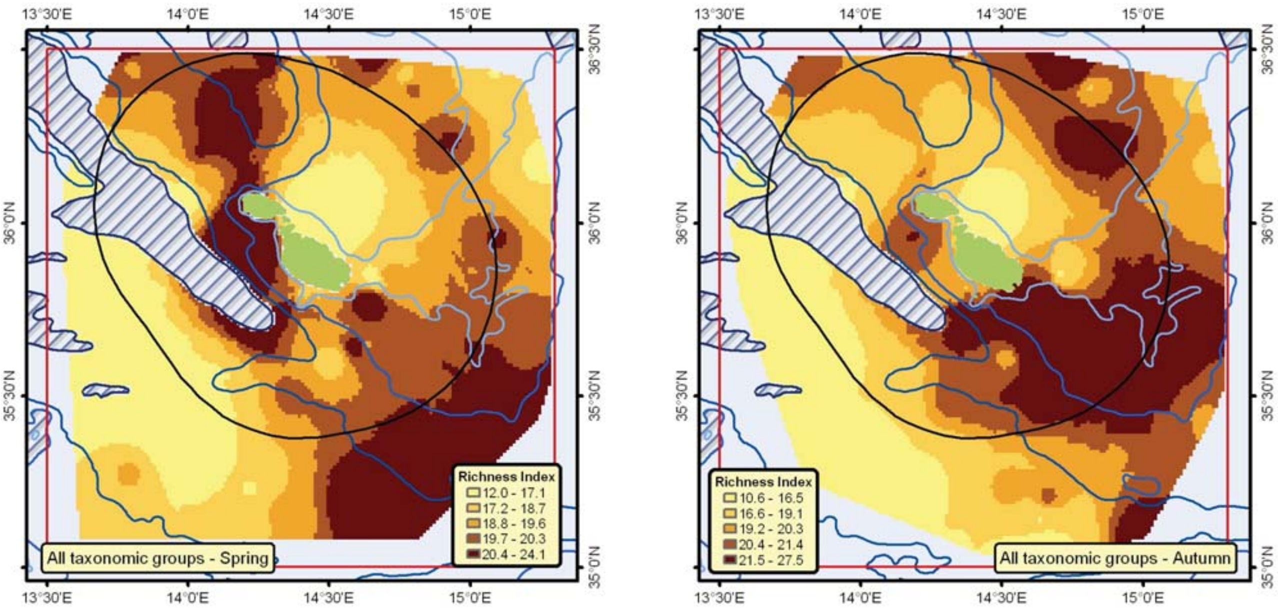

Figure 48. Isopleths of richness index, averaged over 1993 and 1994, for spring and autumn.

Regarding the index of species richness (Figure 48), values and overall spatial distribution are comparable between the spring and autumn seasons, with some difference lying in the relative distribution of the highest values of the index (4th and 5th quintiles). A significant observation is the very low richness index (but high biomass) in the area extending from the north coast of Malta to the western edge of the shelf, as well as on the Hurd Bank east of Malta.

Bony fishes

Distribution maps of bony fishes (Figure 49) are comparable to the maps of total biomass, highlighting the predominant role of this taxonomic group. Bony fishes are observed at much higher rates within the 25-nautical-mile zone at depths between 100m and 500m, whereas very low abundances are found deeper than 500m. The pattern observed is consistent with results reported by Giudicelli (1978), who obtained the highest catch rates for demersal species, particularly red mullet, hake and gurnard, over the Marsa Scirocco grounds 17 miles south of Malta in the depth range 200–400m (see section 0).

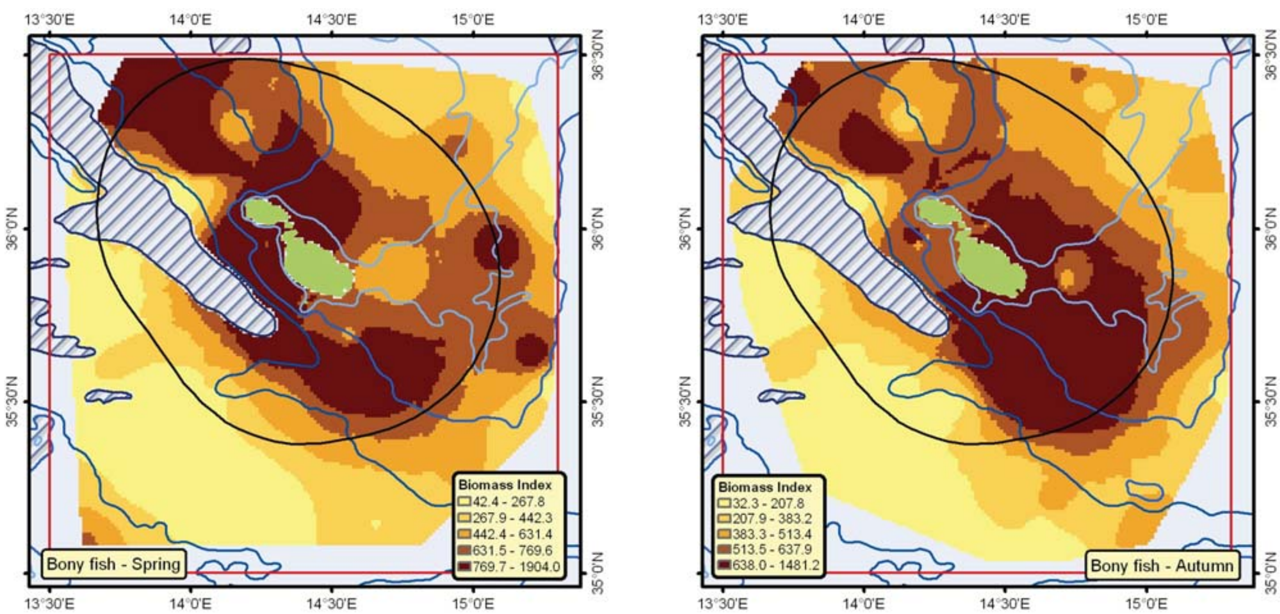

Figure 49. Isopleths of bony-fish biomass index, averaged over 1993 and 1994, for spring and autumn.

Selachians

Distribution maps for selachians show an area of very low biomass over the shelf in the north-eastern corner of the GSA 15 (Figure 50). Hydrographical features of these bottoms are high salinity (Figure 35) and low temperature (Figure 33). Low abundances are also observed over the Hurd Bank, east of Malta, whereas most of the biomass is concentrated south of the Maltese Islands; here (the Marsa Scirocco grounds), Giudicelli (1978) already reported very high catch rates of rays and dogfish (see paragraph 0).

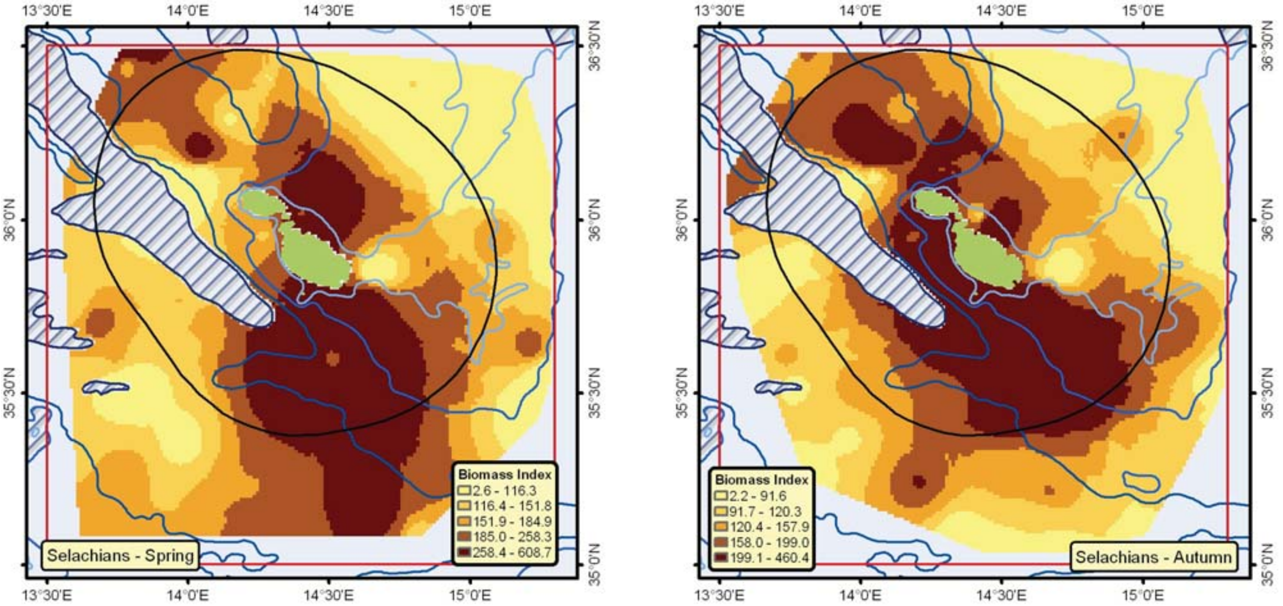

Figure 50. Isopleths of selachian biomass index, averaged over 1993 and 1994, for spring and autumn.

Cephalopods

Cephalopods show a very distinctive distribution with most of the biomass over the shallow Malta Bank (Figure 51). One exception is a small area between 300m and 400m depth north-west of Gozo. This group of opportunistic species would normally take advantage of the fishing pressure on bony and cartilaginous fishes, whereas, whenever the fish communities are stable, cephalopods would not normally have the opportunity to proliferate.

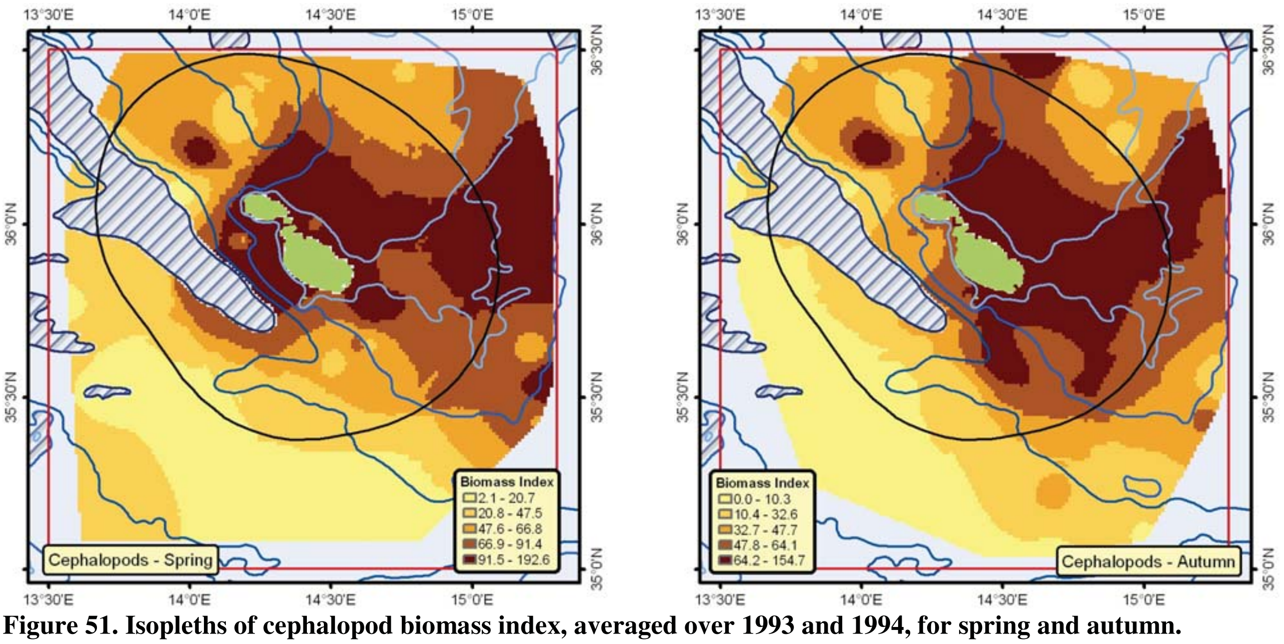

Figure 51. Isopleths of cephalopod biomass index, averaged over 1993 and 1994, for spring and autumn.

Crustaceans

Crustacean biomass distribution appears almost the reverse of that for cephalopds (Figure 52), consistent with the bathymetric preferences of this taxonomic group. Actually, crustacean abundance is uniformly low in most of the wide shelf north of Malta, where cephalopod biomass is consistently high.

Values of the crustacean biomass index are highest along the eastern and southern edge of the shelf at depths between 100m and 500m, as well as north-west of Gozo at depths greater than 200m, where there is a deep-water shrimp fishing ground. Regarding biomass values, there is little difference between the MEDITS and GRUND estimates.

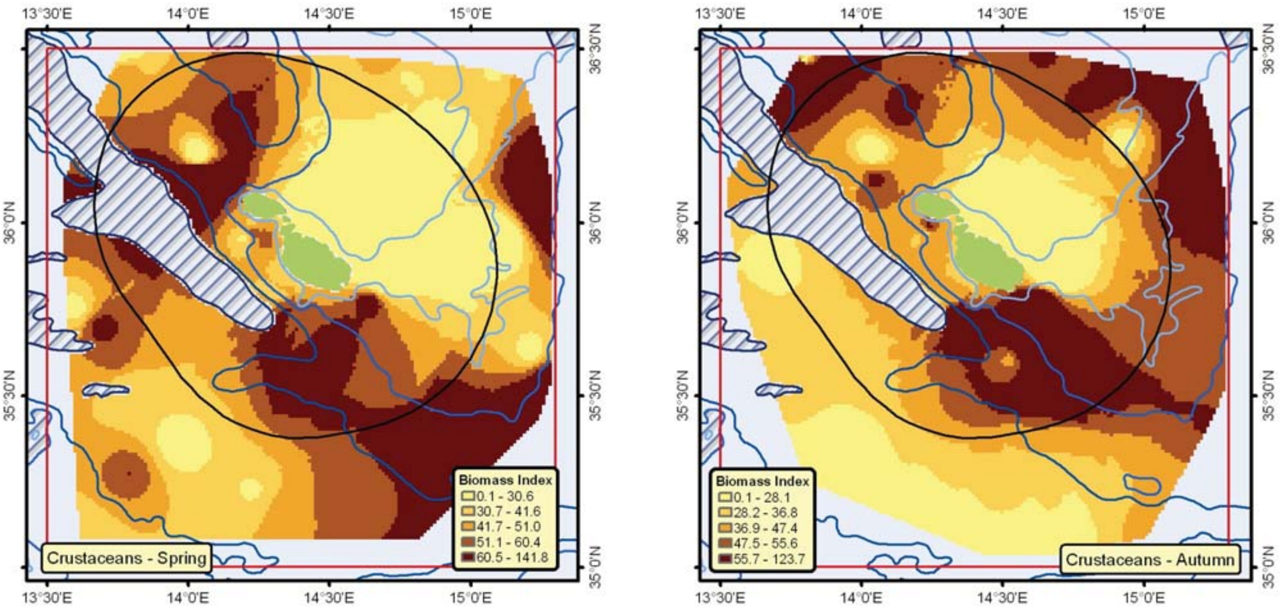

Figure 52. Isopleths of crustacean biomass index, averaged over 1993 and 1994, for spring and autumn.

All taxonomic groups

Stability areas for each taxonomic group were identified on the basis of the 5th quintile; all areas of stability (Figure 53) are concentrated south and south-east of the Maltese Islands, inside the 25-nautical-mile zone and correspond to the artisanal fishing zones. Signs of stability can also be detected in the trawling zones NW of Gozo (with the exception of selachians). Bony fishes, crustaceans and selachians greatly overlap south of Malta in a bathymetric range between 100m and 500m, whereas the stability area for crustaceans is mainly located east of Malta at a depth of less than 100m.

This result shows that the shelf-break south and south-west of Malta is a critical area, with high production and species richness. The nature of the seabed is very heterogeneous (Figure 39), as are the fish assemblages (Figure 43). The distribution observed is probably influenced by the bathymetric and hydrographical features of the area. It is therefore important to analyse the oceanographic parameters in this area. Indeed, it is well known that movements of fish are strongly related to the physical characteristics and dynamics of the water body in which they live, and are strongly correlated with temperature fronts, borders of flow and zones of divergence and convergence. In this case, we suspect that the elevated values of biomass reflect high rates of primary production due to upwelling events, linked to the westward flow of the LIW, bringing deep water onto the shelf.

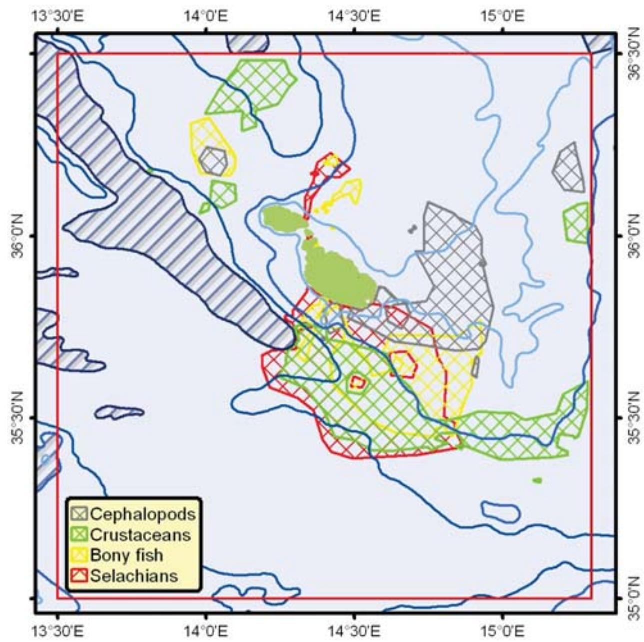

Figure 53. Stability areas for the principal taxonomic groups for spring and autumn 1993 and 1994.

7.4.3. Target species

Mullus barbatus

The spatial distribution of biomass of *Mullus barbatus* is similar in the two seasons considered (Figure 54). The species is concentrated in the eastern side of the Malta Bank mainly shoreward of the 100-m isobath.

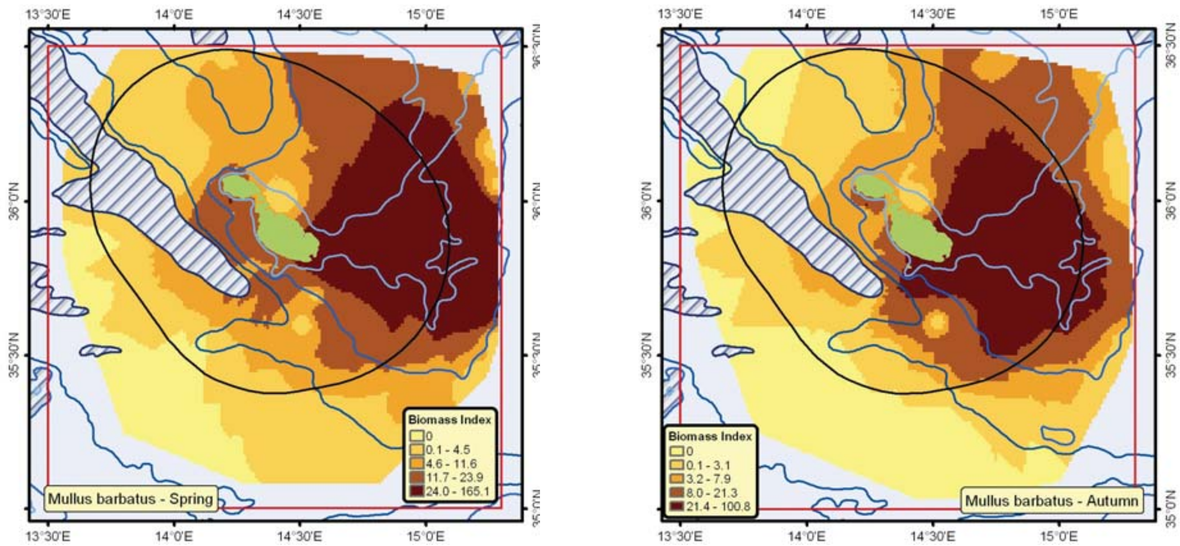

Figure 54. Isopleths of *Mullus barbatus* biomass index, averaged over 1993 and 1994, for spring and autumn.

During MEDITS 2003, no sign of recruitment was detected (no recruits caught; see Annex 3), whereas during GRUND 2004, recruits were found only in one haul, characterized by clay-silt sediment. There seems to be a marked coastal recruitment during GRUND, whereas the recruitment zone is found farther NE during MEDITS. Young of the Year (YOY) concentrations are known along the Sicilian coasts, both from the MEDITS and the GRUND data.

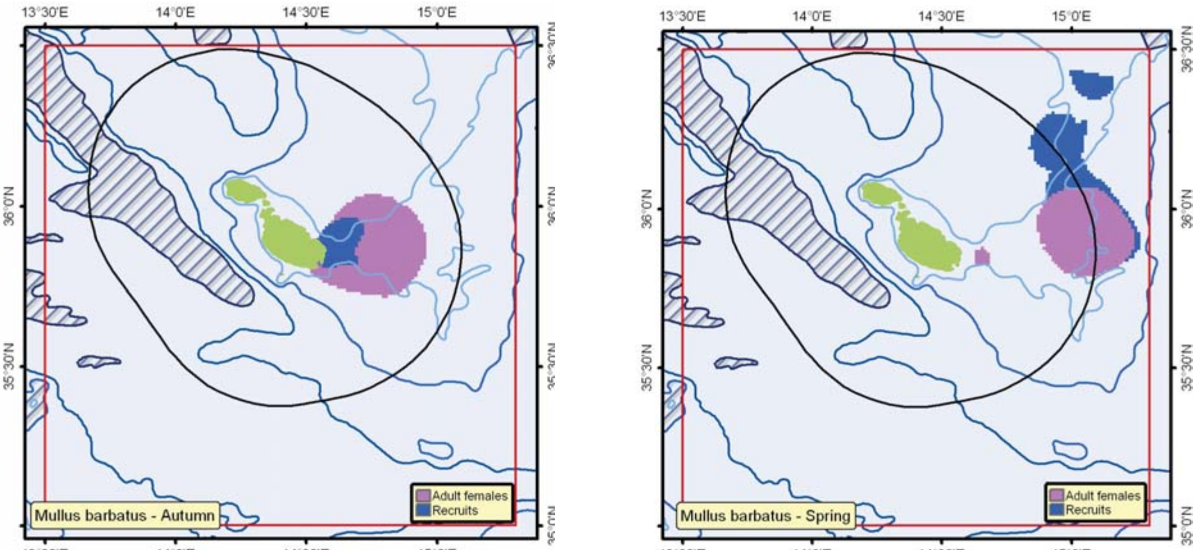

Figure 55. Stability areas of the density index of recruits and adult females of *Mullus barbatus* for spring and autumn.

Adult abundance is higher in 2004 than in 2003 for both the MEDITS and the GRUND data. The occurrence of a high aggregation of spawners in the north-eastern corner of GSA 15 during spring and a high abundance of post-spawning adults near Malta in autumn suggests that the adults move into colder water during the spawning period (Figure 55).

Merluccius merluccius

Spring abundances showed the highest values south of Malta (Figure 56). A similar distribution was found using the GRUND data, with a wider distribution towards the southeastern corner of the GSA.

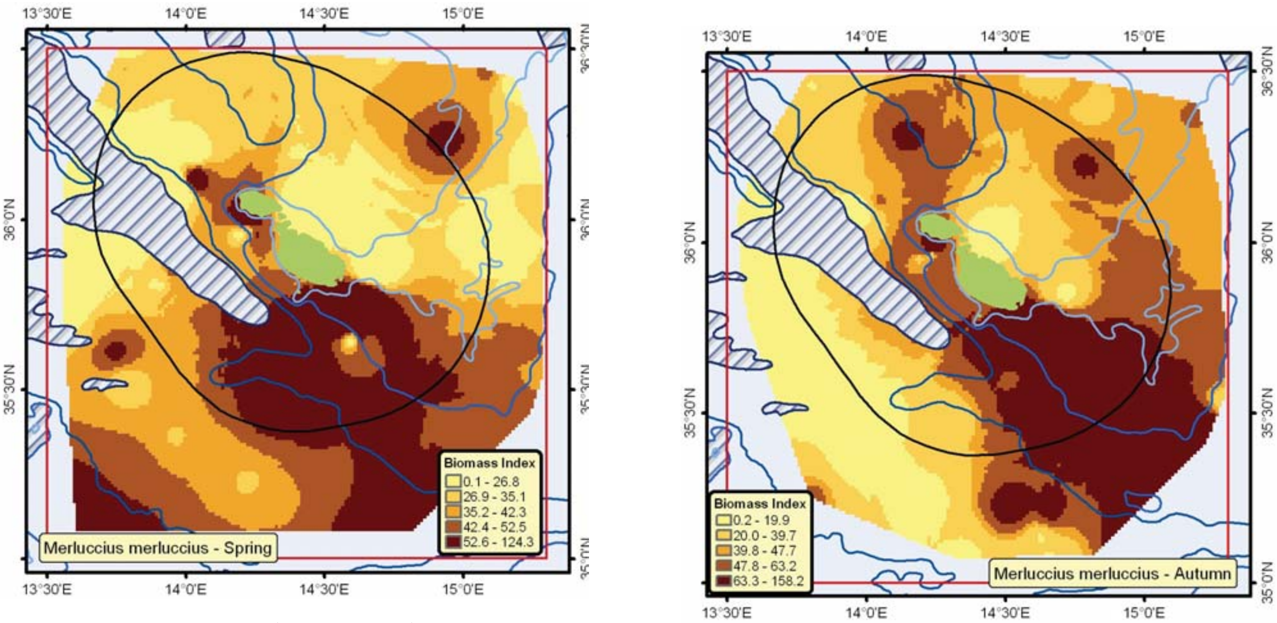

Figure 56. Isopleths of *Merluccius merluccius* biomass index, averaged over 1993 and 1994, for spring and autumn.

The Maltese Islands seem to be an aggregation area for spawners (Figure 57). They form spawning aggregations of about 100 individuals at consistent sites from July to September.

The distribution of mature females follows the same pattern as the biomass in each survey, with concentrations south of Malta. These spawning areas could be those that supply the Sicilian recruitment areas over Adventure Bank.

MEDITS data show that YOY in Malta were found outside the 25-nautical-mile zone, with one concentration zone in the extreme southwest and another one in the eastern part of the GSA over the shelf. GRUND data show concentrations that reflect the spawning distribution in the southeastern part, as well as concentrations in the eastern part. The YOY observed here may come from the spawning areas of the Ionian Sea, farther north from Malta.

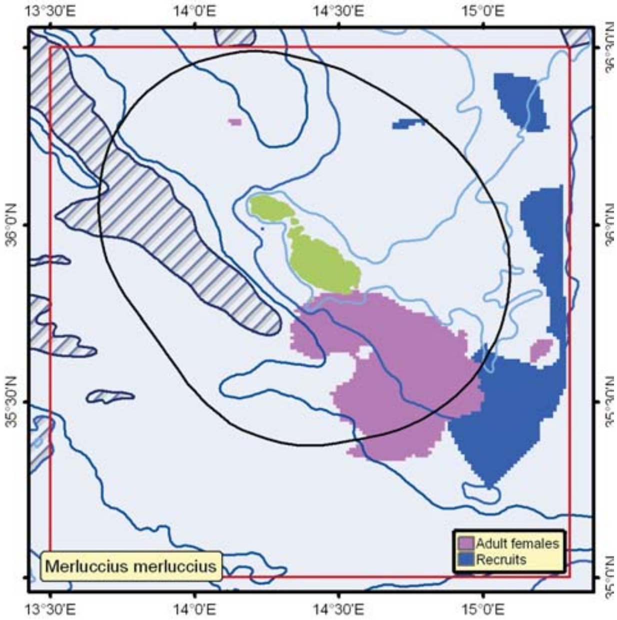

Figure 57. Stability areas of the density index of recruits and adult females of *Merluccius merluccius*.

Parapenaeus longirostris

This species is mainly concentrated to the southeast of Malta and coincides with the area of concentration of fishing effort for this species (Figure 58). An area of high biomasses was also detected south of Gozo, but only for three of the GRUND surveys out of four (i.e. except for GRUND 2004). In the same way, high values were observed on the outer shelf to the northeast of Malta. This species seems to react to a seasonal factor. In fact, it showed biomass values in 2004 higher than those in 2003, and, in 2003, higher values were recorded during the MEDITS than during the GRUND survey, in contrast to 2004, for which the opposite was true (higher values for the GRUND than for the MEDITS survey).

Considering the strong interannual variability, the stability areas should be identified on the basis of the two highest quintiles.

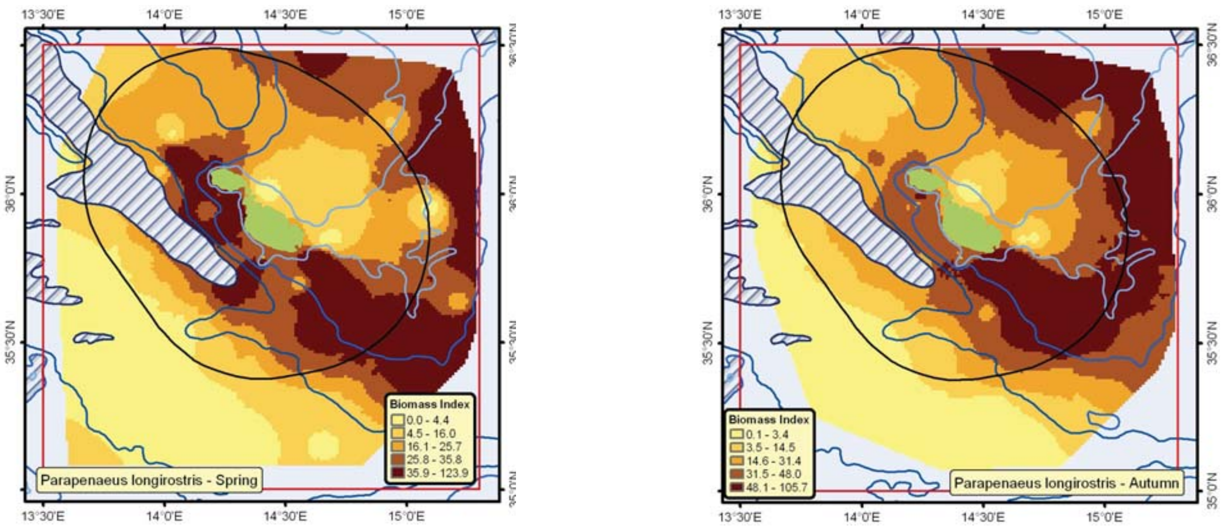

Figure 58. Isopleths of *Parapenaeus longirostris* biomass index, averaged over 1993 and 1994, for spring and autumn.

Stability analysis shows that mature females are concentrated to the southeast of Malta and on the shelf between 100m and 200m depth (Figure 59).

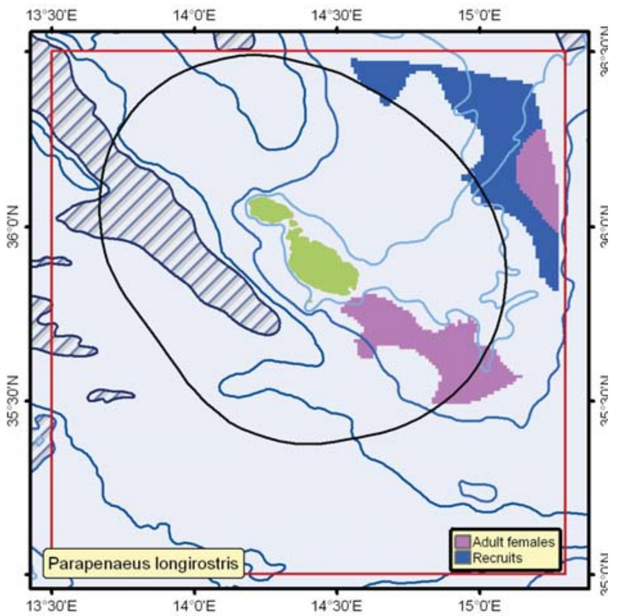

Figure 59. Stability areas of the density index of recruits and adult females of *Parapenaeus longirostris*.

YOY are concentrated on the shelf (NE of GSA 15), between 100m and 200m depth, with comparable abundances between seasons and years. YOY can also be found to the southeast of Malta.

Raja clavata

This species is distributed along a NW/SE axis (Figure 60). Abundances recorded during the MEDITS surveys are two-times higher than those of the GRUND surveys. The highest biomasses recorded during MEDITS are concentrated in two places to the southeast and to the northwest of Malta, both characterized by muddy bottoms. GRUND biomasses show a similar pattern. Conversely, it is surprising to see that there are no concentrations on the similar bottoms to the northeast.

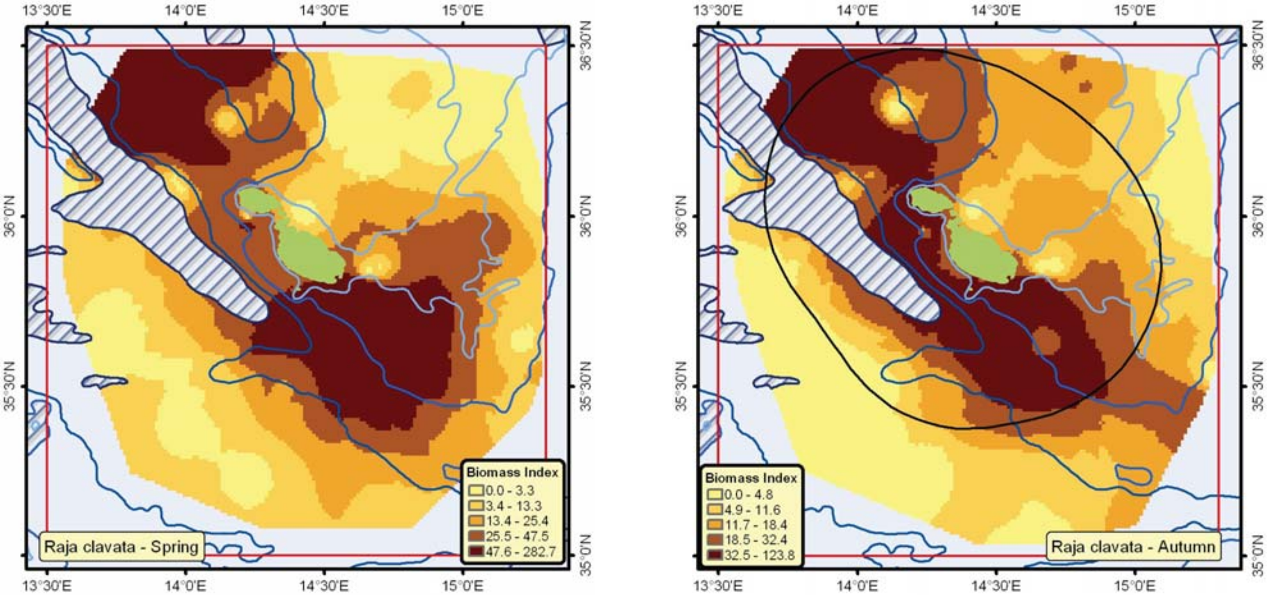

Figure 60. Isopleths of *Raja clavata* biomass index, averaged over 1993 and 1994, for spring and autumn.

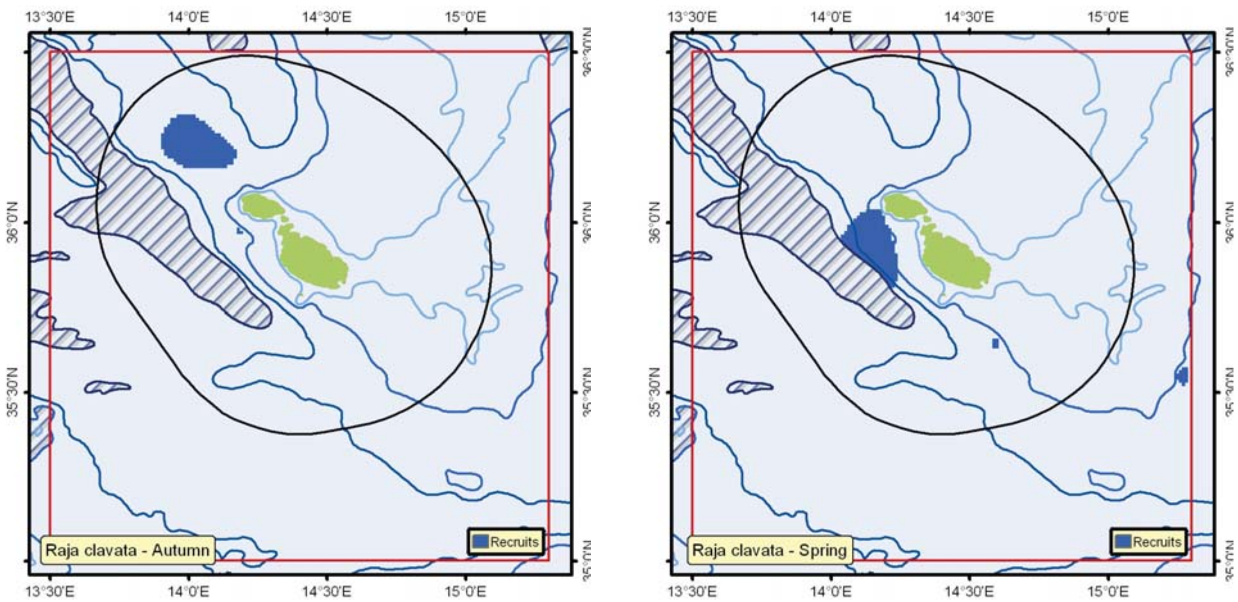

Figure 61. Stability areas of the density index of recruits of *Raja clavata* for spring and autumn.

YOY are concentrated south of Gozo according to the MEDITS surveys, whereas they are northwest of Gozo according to the GRUND surveys (Figure 61). The recruitment of this species seems limited to the edge of the continental shelf, whereas the adults have a wider distribution on both shelf and slope muddy bottoms.

Maturity stage data are not available for skate species; therefore it was not possible to map the spawning areas. However, maps could be produced by splitting the length–frequency distribution by applying length-at-sexual-maturity functions.

Raja miraletus

Distribution areas of *Raja miraletus* are similar for the two surveys (Figure 62). During MEDITS, the highest values were found over the shelf edge, between 100m and 200m depth, but closer to the 100m depth south of Gozo. In the autumn, a similar distribution can be found, with an additional coastal concentration to the southeast of Malta.

For both skate species, higher biomass values have been recorded during MEDITS, probably because the MEDITS gear has a better capacity to catch the bigger individuals.

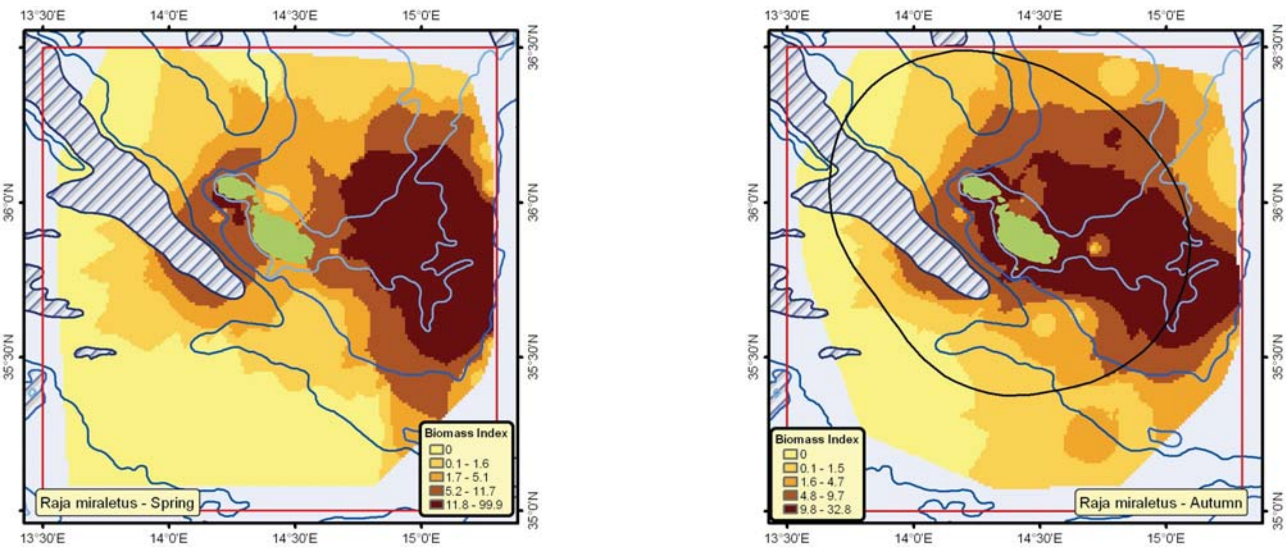

Figure 62. Isopleths of *Raja miraletus* biomass index, averaged over 1993 and 1994, for spring and autumn.

The YOY pattern reflects the abundance distribution for both surveys (Figure 63), suggesting the coincidence of the spatial distribution of adults and juveniles. During MEDITS and GRUND, the concentration was highest to the east of Malta, on detrital bottoms, around the 100-m isobath.

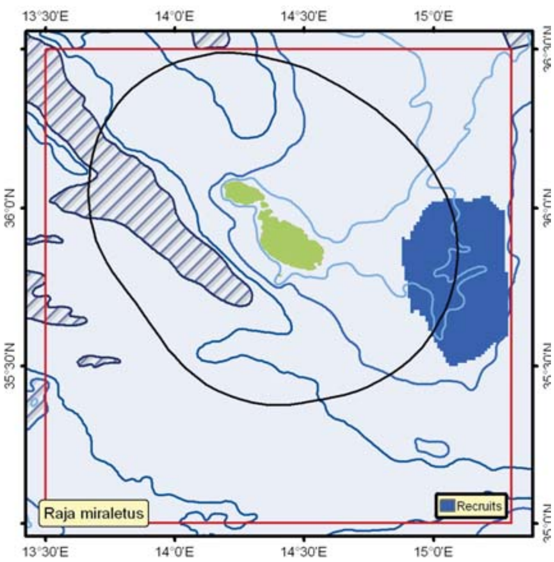

Figure 63. Stability areas of the density index of recruits of *Raja miraletus*.

The Maltese stock of *Raja miraletus* seems isolated, as this species generally lives on the shelf in relatively shallow waters (< 150m) and does not undertake significant migrations. Preliminary information provided by SeaTrim shows the presence of *R. miraletus* on Adventure Bank only and not elsewhere farther south in the GSA 16. These findings support the hypothesis of the presence of two isolated stocks inhabiting the detrital bottoms of the northern sector of the Straits of Sicily: the first on the western side of Adventure Bank, the second on the eastern side of the Malta Bank.

8. Discussion

8.1. Integrated environmental and resource analysis

The Straits of Sicily is one of the most productive areas of the Mediterranean for demersal fisheries. Considering the northern sector (GSA 15 and 16), the high productivity is due to enrichment of the surface water through the coastal upwelling, with two long filaments of upwelled water persisting over Adventure Bank and the Maltese shelf (Piccioni *et al.*, 1988; Nardelli *et al.*1999), and the cyclonic vortices along the AIS current (Robinson et al 1999) (Figure 64). In the case of the GSA 15, the enrichment factors are coupled with an important retention and concentration structure determined by the intermittent anti-cyclonic vortex in the Malta channel (Beranger *et al.*, 2004) and the permanent front on the eastern edge of the Malta Bank (Figure 65).

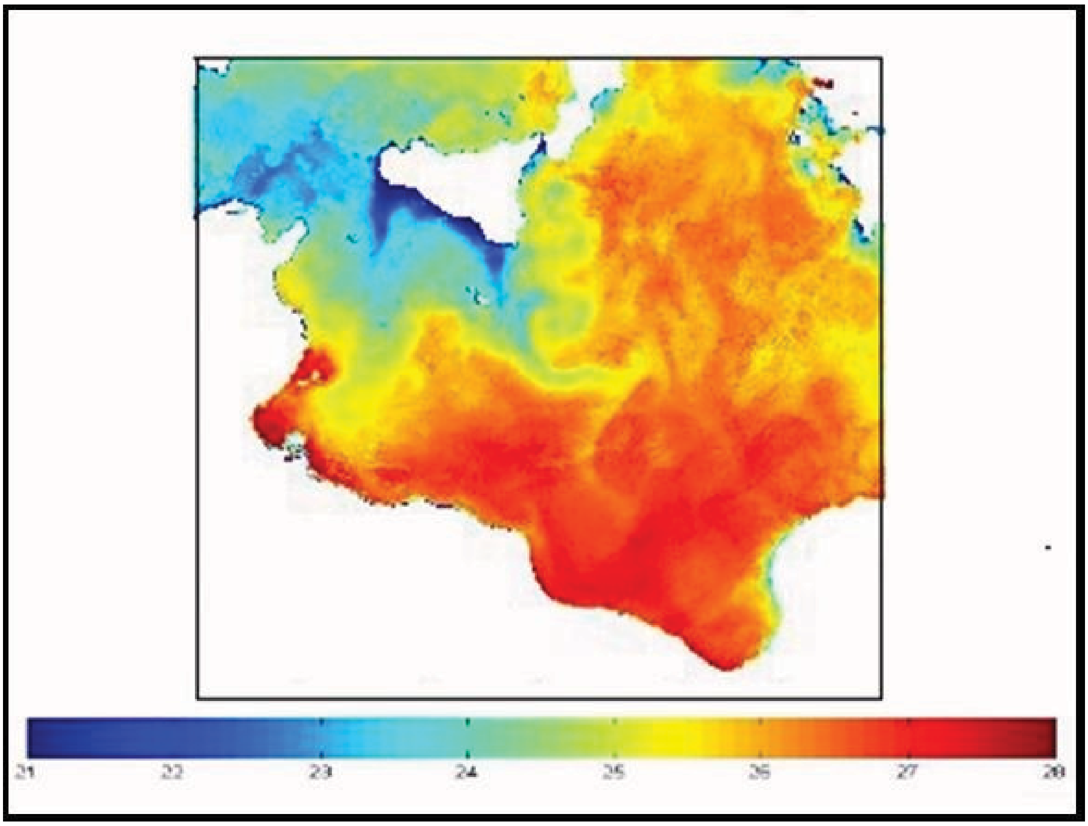

Figure 64. Typical sea-surface temperature distribution in summer in the Straits of Sicily, from satellite data; upwelling, eddies, filaments and fronts are evident.

As earlier noted, the role of quite stationary mesoscale hydrographical features of the area in determining the structure, composition and abundance of the biological resources was reported for many demersal species (*Illex coindetii*, by Jereb *et al.* 2001; *Engraulis encrasicolus* by García Lafuente *et al.* 2002; *Merluccius merluccius* and *Phycis blennoides* by Fiorentino *et al.*, 2003b; *Mullus barbatus* by Levi *et al.* 2003; Garofalo *et al.*, 2004; *Engraulis encrasicolus* and *Sardina pilchardus* by Patti *et al.*, 2004). The hydrographical features are themselves strongly influenced by the bottom topography of the area – the existence of two large banks separated by a narrow shelf area – which leads to evident symmetry in the distribution of the demersal resources, both at single species (see e.g. Fiorentino *et al.*, 2003b; Fiorentino *et al.*, 2006) and at community level (see e.g. Garofalo *et al.*, 2007; Gristina *et al.*, 2004).

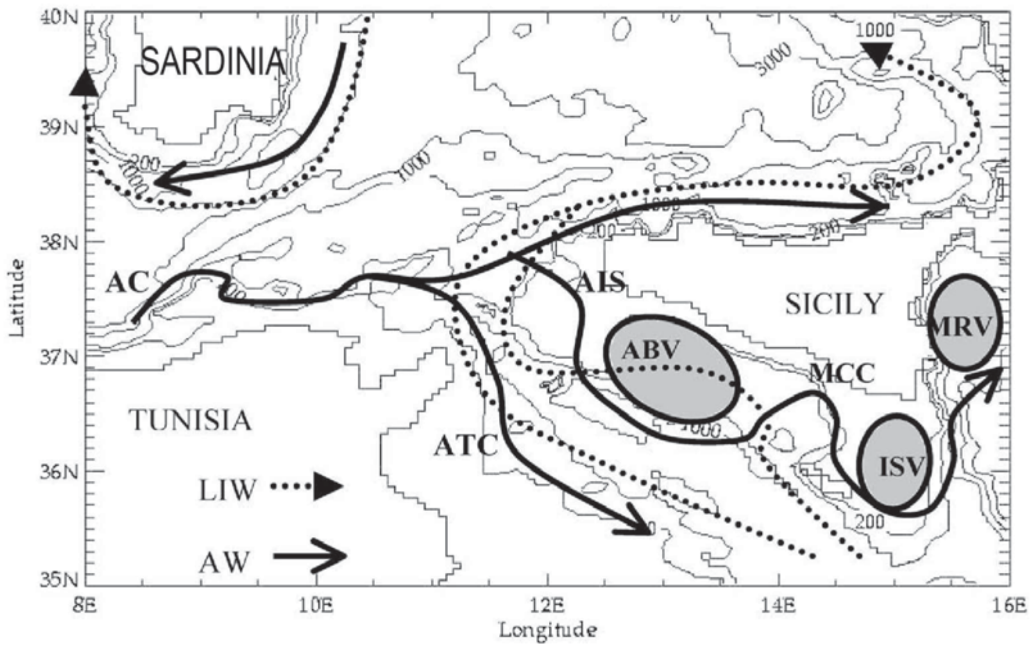

Figure 65. Diagram showing the currents (AC; Atlantic current) derived from the Atlantic Water (AW; surface) and Levantine Intermediate Water (LIW; at depth) in the Straits of Sicily. The mean path the Atlantic Tunisian current (ATC) and of the Atlantic Ionian Stream (AIS), with the main anti-cyclonic vortexes (*ABV*: Adventure Bank Vortex; *ISV*: Ionian Shelf-Break Vortex; MRV: Messina Rise Vortex) and the Maltese Channel Crest (MCC) are shown. (Modified from Bèranger *et al.*, 2004).

Based on the comparison of maps produced for this study on the spatial distribution of target species in terms of nursery and spawning areas, and on the available oceanographic and bottom-topographical information (Bakun, 1996; Bailey, 1997; Pawson and Jennings 1996), various scenarios could be hypothesized about the existence of sub-populations of target species in the northern sector of the Straits of Sicily (GSA 15 and 16) and the possible relationship between them (Figures 66, 67 and 68).

In the case of red mullet, whose recruitment occurs strictly on coastal bottoms, the nursery area observed in the GSA 15 during early spring may be interpreted as an extension of the nursery areas of the Sicilian coast, given the occurrence of the shallow bottoms between Malta and Sicily. Another hypothesis is that eggs/larvae are transported by wind-driven currents (in particular southern winds during the summer – the *scirocco* – which may contribute to the transport of the larvae northwards). With regard to the nursery area observed in autumn, the water current maps at 70m depth between June and September suggest that there is a circulation that favours the retention of the juveniles in the northeastern part of the GSA. Then, starting from October, the current flows southeastwards.

Red mullet spawners are mainly concentrated on the eastern border of the shelf in spring, whereas post-spawners are closer to Malta in autumn. On examining the temperature and currents at 80m depth in spring, the area of spawning is characterized by bottom sea water at about 15°C and currents flowing southeastwards. In autumn, the decreasing temperature gradient from east to west (17°E to 16°E) may explain the movement of the adults from the border of the GSA 15 to bottoms close to Malta.

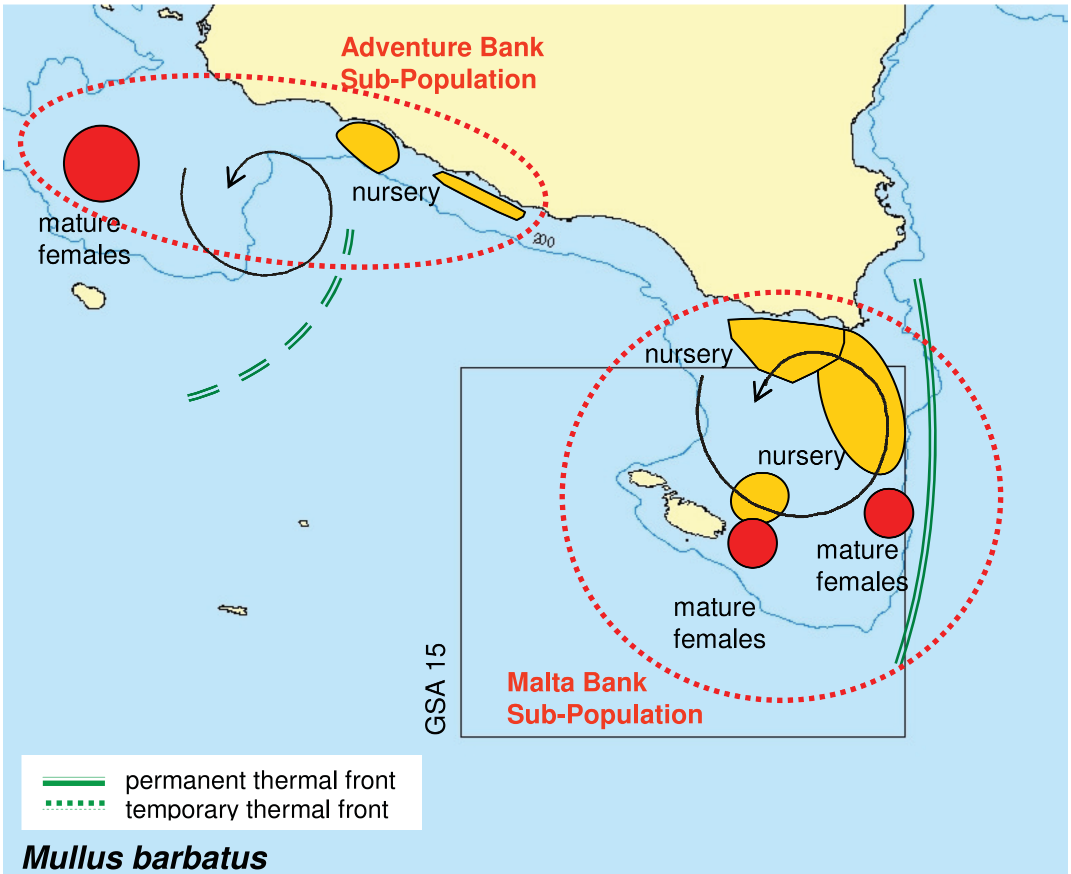

Figure 66. Hypothesized scenario depicting sub-populations of *Mullus barbatus*

Available information on both nursery and spawning areas and hydrographical patterns in the area suggests the existence at least of two quite separate sub-populations of red mullet associated to the two Banks (Figure 66). Although this hypothesis needs to be further verified, the existence of local, genetically isolated, populations in red mullet at small spatial scale was recently reported by Garoia *et al.*, (2004) in the Adriatic Sea.

The spatial distribution of the other target species with recruitment at the edge of the shelf, show a more evident symmetry of distribution, by life phase, around the banks than for red mullet.

In the case of *Merluccius merluccius*, the distribution observed can be described by a scenario with distinct stable areas on both banks, where spawners and recruits concentrate (Figure 67). This distribution is consistent with the role of AIS in the transport from spawning to nursery areas. In the case of GSA 15, the presence of the permanent front on the eastern side of the Malta Bank is thought to be the main factor in concentrating recruits in the nurseries.

On the basis of the AIS flow, it is possible that most of these recruits come from the spawning areas on the southern edge of the Malta Bank shelf. However, in view of the available information, it is not possible to exclude the possibility that some transport of spawning hake occurs on the slope off Malta Bank, and that they lay their eggs in the current flowing south of Malta and towards Adventure Bank. This current, at a depth of 160m, where the hake eggs can float, appears to be strong, especially in autumn and winter; considering the intensity and direction of this current, it appears plausible that some fraction of eggs/larvae produced by the Maltese spawners are transported from the eastern spawning areas to the western nurseries on Adventure Bank.

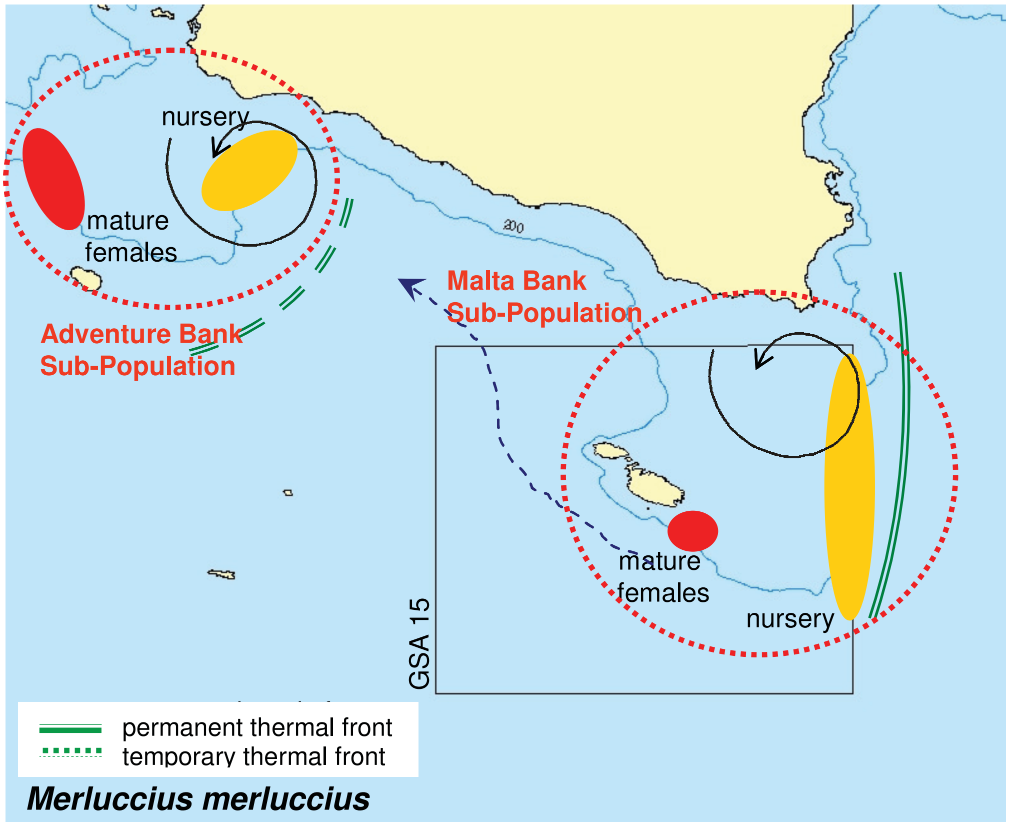

Figure 67. Hypothesized scenario depicting sub-populations of *Merluccius merluccius*.

Considering *Parapenaeus longirostris*, different spawning areas were identified and the spawners are mainly concentrated on the eastern sides of the Adventure and Malta banks along the 100-m isobath. Recruits are more abundant at the same depth, but to the northwest of the spawning areas.

Similar consideration to that of hake can be given to deep-water pink shrimp, although this species seems more closely linked to the frontal system than is the hake.

Information on the spatial distribution by life phases in the northern sector synthesized in the above-mentioned scenarios showed that the entire life cycle (recruits and spawners) of the target demersal species having dispersal phases is not confined to the current borders of the GSA 15. In particular, the occurrence of stable nurseries of hake and deep-water pink shrimp on the outer shelf outside the eastern border (GSA 19) and red mullet nurseries on the coastal bottoms off Sicily (GSA 16) show that some redefinition of the geographical limits of GSA 15 are needed to capture the entire life cycle of these species.

Comparing the distribution of two species of rays (fish without dispersal phases), some differences were clear. Spatial distribution of *Raja clavata* in the GSA 15 suggests movement of adults during the year. The analysis of the distribution over a wider area (GSA 15 and 16) does not show a segregation of sub-units in the northern sector of the Straits of Sicily (Garofalo *et al.*, 2003). Conversely, *R. miraletus* was found to be absent in the narrow shelf connecting the Adventure and the Malta banks (Garofalo *et al.*, 2003), suggesting the existence of two distinct populations on these two banks. Furthermore, the comparison of occurrence in the GSA15 with the information on the sea-bottom type indicates that this species is associated with detrital bottoms east of the Maltese Islands.

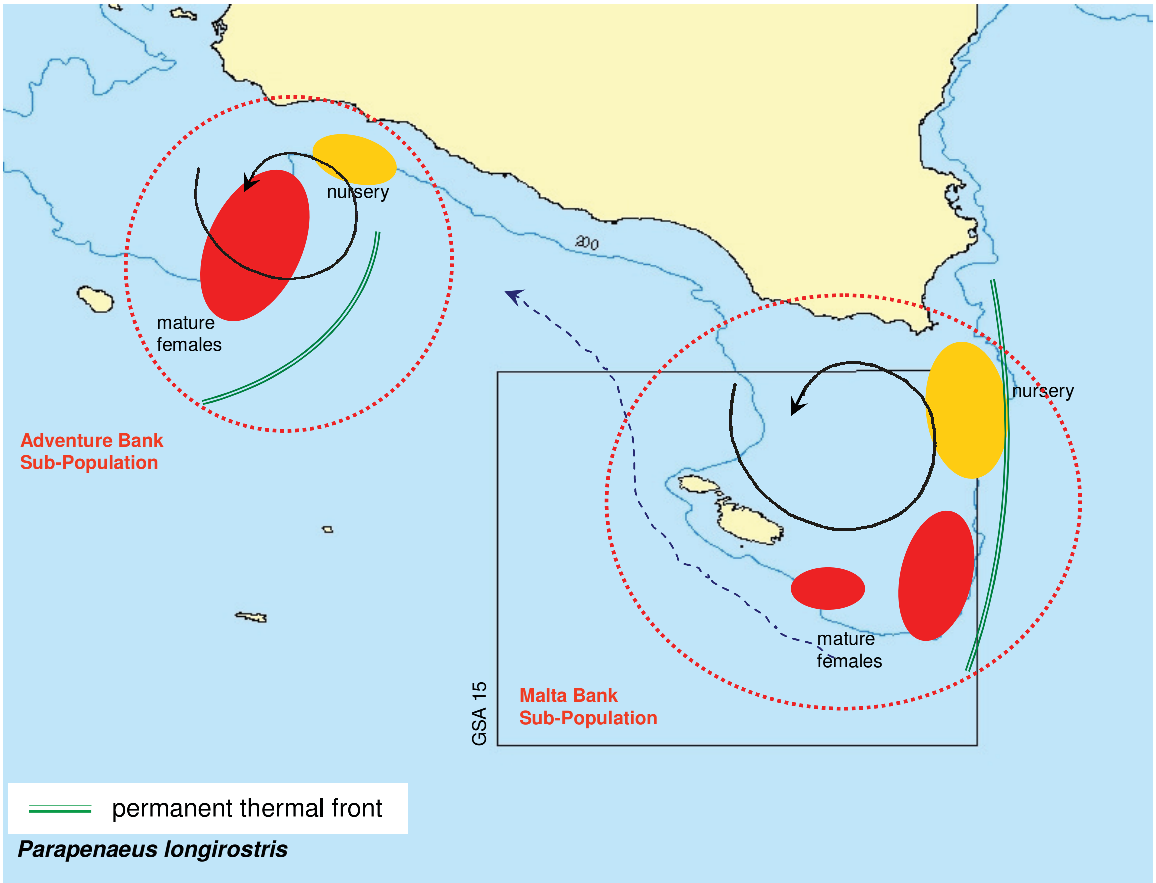

Figure 68. Hypothesized scenario depicting sub-populations of *Parapenaeus longirostris*.

When evaluating the distribution of the total biomass and taxonomic aggregates, with the exception of cephalopods, the abundance was higher along the axis oriented from northwest to southeast along the shelf break front, suggesting an active role of this hydrographical feature in maintaining high standing stock in the area.

The stable, strong currents at the lower shelf support the occurrence of the upwelling of LIW on the outer shelf, which could enhance the biological productivity south of the Maltese Islands. As previously observed, these currents could also contribute to the dispersal of a fraction of hake and deep-water pink shrimp eggs and larvae originated by spawners on the outer-shelf upper slope westward of the Maltese Islands, contributing to maintaining genetic mixing between the sub-populations of GSA 15 and 16.

Most of the fishing effort in the GSA 15 is carried out along the axis from northwest to southeast, close to the Maltese Islands, which correspond to areas characterized by highest abundance of biomass. It is worth noting that the highest abundance of crustaceans was recorded in areas northwest of Gozo Island where the highest values of trawling effort are also recorded, whereas areas with the highest level of effort of the artisanal fleet correspond to the highest values of abundance of fish. In the northwest sector, where trawling effort is highest, elevated abundance of crustaceans corresponds to low values for elasmobranchs, suggesting the possibility that trawling plays a role in modifying the demersal community structure.

The fishing impact of artisanal fisheries seems to be more moderate, allowing the co-occurrence of highest biomass value where the fishing effort is greatest. A prolonged monitoring of spatial distribution of demersal resources and fishing effort would allow for improved evaluation of the sustainability of the current distribution of fisheries in GSA 15.

The analysis of the assemblages suggests that fisheries affect community characteristics, although information on the sediments and the macrobenthos is too fragmentary to disentangle the respective effects of fisheries and environment. Indeed the stability areas for total biomass seem to coincide mainly with the distribution of mud and sand, unless this results from a sampling effect. The necessity to collect new information on the seabed type should be underlined.

It is well known that natural environmental variables act jointly with human factors and that it is difficult to distinguish the different sources of stress. Further investigations are needed to discriminate the different effects. However, the general pattern drawn in this study could allow us to identify a more specific sampling design, with the final aim of understanding which factors determine the spatial distribution of the demersal resources.

For this study, the data used were obtained from trawl surveys aimed at assessing the demersal resources according to traditional single-species approaches. For this reason, in the event of further studies, fine-tuning of the sampling scheme (or possibly an *ad hoc* sampling scheme) should be taken into consideration.

8.2. Some considerations on the approach applied

In recent years, fishery research and management have been rapidly evolving from single-species towards multi-species strategies. The latter approach was further broadened by introducing ecosystem-based principles into the management: the ecosystem approach to fisheries. The EAF reflects the merging of two different but related and converging paradigms: the ecosystem management**,** which aims to meet its goal of conserving the structure, diversity and functioning of the ecosystem through actions that focus on the biophysical components of the ecosystems (e.g. introduction of protected areas); and fishery management, which aims to satisfy societal and human needs for food and economic benefits through management actions that focus on the fishing activitiy and the target resources (Garcia, 2000; Garcia *et al.*, 2000; FAO, 2003a). Integrated studies gain a primary importance in management by providing the information necessary to identify possible factors of both weakness and strength in a system (either a fishery or a geographical area), and to define broad objectives relevant to that system. In this respect, three lines of study can be considered: (i) resource-oriented studies, finalized to understand, for example, the main aspects of the species' population dynamics, spatial distribution and ontogenetic migrations; (ii) environmental studies that aim to know the physico-chemical characteristics of the water column and the sea bed where the species live; and (iii) human-oriented studies that aim to define, for example. the fishing gears, the number of vessels, and the distribution of the fisheries, and all the socio-economic aspects linked to the fisheries. A further and somehow higher level of investigation includes the critical analysis of the outcome of these three main lines with the final goals of achieving a broad understanding of the whole ecosystem, identifying the strategic objectives to be considered in the formulation of a management plan, and breaking these objectives into smaller priority issues to be addressed by management measures.

For these reasons, the fishery scientists are focusing on defining the spatial distribution of the vulnerable life stages of target species as a function of environmental factors (Harden-Jones, 1968; Cushing, 1975; Pawson and Jennings 1996; Jennings *et al.*, 2001; Caddy, 1999) and on the identification and monitoring of fishery assemblages (e.g. Bianchi 1991; Gaertner *et al.* 1999; Ungaro *et al.* 1999; Biagi *et al.* 2002; Colloca *et al.*, 2003; Massutti *et al.* 2005; Šifner *et al.*, 2005; Gristina *et al.*, 2006; Dimech *et al.* 2008). As a follow up, and with the aim of implementing an

EAF, the overall information deriving from these studies should be integrated into the management framework as the background necessary to develop precautionary plans aimed to protect, inter alia, the critical habitat at each life history stage.

However, to date, this process is at a preliminary stage (e.g. FAO, 2005) and several constraints, such as the lack of integrated multi-disciplinary information, still limit its implementation.

In this context, this pilot study promoted by the MedSudMed Project represents an advance in the scientific research carried out with the objective of providing integrated information on both the biological and environmental characteristics of a specific geographical area (GSA 15) and of its fisheries. The results of the study can be considered part of the information needed to draw a general picture of the spatial distribution of the demersal resources and of the interactions between them, the physical environment and the fishing, representing the starting point for the development of an EAF-based management plan.

The interdisciplinary approach followed during this study is an example of how an integrated biological and environmental (physico-chemical) study can lead to the identification of areas and habitat (bottom type, depth, temperature, water flow) of basic importance for the well-being of the target and non-target fishery species, as well as for the functioning of the ecosystem as a whole. Such habitats, which are essential for the survival and health of the fish stocks and of the fisheries that exploit them, comprise spawning grounds, nursery areas, areas of seabed that form part of a migration route (Hintz *et al.*, 2003) and have been defined “Essential Fish Habitat” (Magnuson–Stevens Management Act, of 1996, see Federal Register, 2002).

Accordingly, the essential areas identified in the study, as well as the possible areas of stability for fisheries (e.g. Garofalo *et al.*, 2007) that have been highlighted should be taken into consideration as target areas in defining strategic objectives and precautionary management measures in the context of an EAF.

This multidisciplinary study and its conceptual framework need to be expanded. A wider approach, which also encompasses more detailed fishery-related socio-economic aspects (e.g. persons employed, revenue per crew, crew/GRT, landings per vessel, landings per day, net profit per vessel, see Ungaro *et al.*, 2006; Ceriola *et al.*, 2008), is necessary to support the full implementation of an EAF. Nonetheless, this preliminary comprehensive study shows how powerful and effective the joint investigation of biological and environmental factors can be in identifying key features of fishery resources. Accordingly, the application of this approach to other regional fisheries or geographical sub-areas should be pursued in order to support the identification of key aspects that should be taken into consideration in the definition of ecosystem-based management measures.

9. Final conclusions and suggestions for further research

The outcomes of this Pilot Study on the spatial distribution of demersal fishery resources, environmental factors and fisheries in the GSA 15, allow some general considerations on both the fishery resources in Maltese waters and on the approach applied.

The analysis provided the opportunity to identify key areas in the GSA 15, including areas of stability for fisheries and essential areas for fishery target species (e.g. nursery or spawning areas). The integration of this information with oceanographic data, such as those on currents, salinity and temperature, allowed the formulation of some hypotheses on the distribution and on the phase of passive movement of juveniles of the investigated species. Finally, the description of distribution of some fishery target species, enabled to formulate some hypotheses in stock's structure and relationships among different GSAs in terms of essential areas for demersal fishery resources. In particular it was evident that the spawning and recruitment of the selected species in GSAs bordering GSA 15 may be interdependent or may affect each other (e.g. reproduction in one GSA and recruitment in an adjacent one), introducing the need to consider a wider area, possibly the whole region, in stock assessment and management.

From a methodological point of view, the Pilot Study was a good opportunity to test a procedure to be used to understand the factors affecting the demersal resources distribution, and how fish stocks react to environmental variations and fishing impacts. The followed approach was based on the comparison of distribution in variables thought relevant in stocks dynamics (Bakun, 1996). The effectiveness of the results highlights how powerful the chosen approach can be, including the use of GIS to integrate different types of data (e.g. resource-abundance data, fish assemblages, biocoenoses, substratum type, hydrographical features), in order to explain the spatial distribution of demersal resources and their interactions with "abiotic" (environmental and human) factors.

The long-term purpose of such study was to translate the resulting information into part of the background necessary for the implementation of an EAF-based management. However, to this extent, further information will be required, especially on the socio-economic aspects of the fisheries.

Based on these considerations, advances in the research in the GSA 15, in order to integrate the available knowledge with socio-economic data, should be planned and implemented. This would provide sound information on the whole fishery system useful for the identification of relevant issues and would allow setting strategic objectives, to be translated into operational measures, in the framework of an EAF-based management.

Furthermore, in view of better understanding the dynamics of fish stocks (fishery target and non-target species) and fish assemblages, and to identify the real distribution of demersal resources in the Mediterranean basin, the replication of this type of studies should be considered in other GSAs.

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Annex 1. Background information on the Malta Fishery Management Zones

"In 1971, Malta declared an Exclusive Fishing Zone (EFZ) that extended to 25 nautical miles (Figure 2) *from the baselines of the Maltese Islands (Act XXXII of 1971), in accordance with the United Nations Convention of the Law of the Sea. With the entry of Malta into the European Union in 2004, this zone was maintained as a Fisheries Management Zone (FMZ) around the Maltese Islands by EU Council Regulation (Council Regulation (EC) No 813/2004 of 26.04.2004). The Malta EFZ, the first of its kind in the Mediterranean, has an overall area of 6735 km^2.*

The key aim of the Malta FMZ is to protect the fisheries resources of Malta's sea area and the ecosystems on which they depend. During the accession negotiations with the EU, Malta presented to the EU a number of studies which showed the negative effects that purse-seining and industrial long-lining (two very intensive fishing methods), as practised by EU fishers, would have in the Maltese EFZ area if this was opened up to these fishery types. The EU recognized the conflict that exists between these intensive fishing methods and the less intensive passive fishing operations practised to date by the Maltese fishing fleet. For this reason, the EU agreed that when Malta becomes a member state, sustainable fishing in the previous EFZ would be safeguarded through the setting up of a Fisheries Management Zone and the implementation of a variety of management actions. Thus, the Malta FMZ in effect functions as a 'marine protected area' albeit being a new type for the Mediterranean.

The measures adopted for the management of resources within the FMZ are designed to limit fishing effort and capacity by restricting size and engine power of fishing vessels. In particular, only vessels smaller than 12 m are allowed to fish within the Zone since these are considered as boats which practise small scale coastal fishing and which are therefore least harmful to the ecological regime within the zone".

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Annex 2. Derivation of climatological fields

The climatological fields are calculated in the form of monthly averages from the output of a numerical model run over the period of five years (4 January 2000–27 December 2004). The numerical code used is that based on an application of the Princeton Ocean Model, POM (Blumberg and Mellor, 1987). The model runs with full atmospheric forcing and includes full thermohaline dynamics. POM is a primitive equation, stratified and non-linear numerical ocean model that utilises the Boussinesq approximation and hydrostatic equilibrium. It uses the free surface, potential temperature and salinity, the three orthogonal components of velocity, the turbulence kinetic energy and the macro-scale turbulence as the prognostic variables. The model features a split-mode time step and a sigma-coordinate transformation for the vertical grid. The bottom-following sigma layers allow the model to represent accurately regions of high topographic variability. The horizontal grid uses orthogonal coordinates and an ‘Arakawa C’ differencing scheme. The Mellor and Yamada (1982) turbulence closure scheme is used to calculate the coefficients of vertical mixing of momentum, the vertical eddy viscosity and the eddy diffusivity of heat and salt. Density is calculated by an adaptation of the UNESCO equation of state (UNESCO, 1981), revised by Mellor (1991).

The model is run over a wider domain than the GSA 15 area of study. The U.S. Navy Digital Bathymetric Database (DBDB1) with a $1/60^{o} \times 1/60^{o}$ resolution is used directly for the computation of depth at each grid cell using a bilinear interpolation method.

The model depends on a hierarchy of embedded models. It runs in one-way offline nested mode to the basin scale Mediterranean Ocean General Circulation Model from which analysis fields are used. The nesting techniques have been amply tested for robustness (Drago et. al, 2003; Sorgente et. al, 2003).

The model makes use of an asynchronous air–sea coupling scheme consisting in the use of a well-tuned set of bulk formulae for the computation of momentum, heat and freshwater fluxes at the air–sea interface where the heat flux components depend directly upon the state of the ocean. The atmospheric parameters used come from the ECMWF operational analyses, covering years 2000 to 2004, with a longitude and latitude resolution of 0.5 degrees. The temporal resolution is of 6 hours (0:00, 06:00, 12:00, 18:00 UTC).

The momentum flux used is given by:

$$\rho_0 K_M \frac{\partial \vec{u}}{\partial z}\bigg|_{z=\eta} = \vec{\tau} \tag{3.2}$$

where ρ_0 is the density and τ is the wind stress calculated from the surface winds with the Hellerman and Rosenstein (1983) formula. The surface boundary condition for heat is interactive and is given by:

$$K_h \frac{\partial T}{\partial z}\bigg|_{z=\eta} = \frac{Q_t}{\rho_o C_p} + \frac{C_1}{\rho_o C_p}(T^*_{z=0} - T_{z=\eta}) \tag{3.3}$$

where C_P is the specific heat capacity at constant pressure, T^* is the monthly Med6 climatology for surface temperature, and Q_t is the surface total heat flux. The total heat flux (Q_t) consists of the *solar radiation (Q_{sol}) minus the net long-wave radiation (Q_b) and the latent (Q_e) and sensible (Q_h) heat fluxes:*

$$Q_t = Q_{sol} - Q_b - Q_e - Q_h; \tag{3.4}$$

The heat flux components are calculated using the Reed formula (Reed, 1977) for the short-wave radiation flux (Q_{sol}) and the Bignami formula (Bignami et al., 1995) for long-wave radiation (Q_b). The latent (Q_e) and sensible (Q_h) heat fluxes are given by the bulk aerodynamic formulae using the Kondo scheme for the turbulent exchange coefficients (Kondo, 1975).

$$\begin{aligned} Q_b &= Q_b(T_a, T_o, C, rh) \\ Q_e &= Q_e(T_a, T_o, rh, |W|) \\ Q_h &= Q_h(T_a, T_o, |W|) \end{aligned} \tag{3.5}$$

where T_a is the air temperature, C is the total cloud cover, rh *is the relative humidity and W is the 10-m wind velocity modulus. The important concept is that T_o (the sea-surface temperature) comes from the model integration itself, while all the other meteorological parameters come from the 6-hour operational ECMWF analysis.*

For the salinity flux we consider:

$$K_h \frac{\partial S}{\partial z}\bigg|_{\eta=0} = S(E-P) + C_2(S^*_{z=0} - S_{z=\eta}) \tag{3.6}$$

where S is the monthly Med6 climatology of surface salinity, the evaporation rate E is expressed as the ratio Q_e/L_e, and precipitation P is obtained from monthly climatological values by Jaegar's and Legates (see e.g. Jaeger, 1976; Legates and Willmott, 1990).*

The numerical model output is expressed as a time-series of daily averaged currents, temperature and salinity fields for the five years. The fields for the GSA 15 area were extracted and expressed at each of 23 depths (1, 5, 7, 15, 30, 50, 70, 90, 120, 160, 200, 240, 280, 320, 360, 400, 440, 480, 520, 580, 660, 775, 925 m) at each model grid cell with a spatial resolution of 1/32 degrees. The model thus offers a very detailed picture of the area under study by providing a full three-dimensional array of currents, temperature and salinity updated every day. The fields were subsequently averaged over time to produce monthly averaged fields over the five-year period (2000–2004).

The fields are:
(i) temperature;
(ii) salinity;
(iii) U component (East–West, East positive) total velocity, and
(iv) V component (North-South, North positive) total velocities.

Each field is expressed at each of the 23 z-levels.

A Matlab application was constructed to visualize these fields. The application allows plotting of (i) single fields for a given month and depth, (ii) multiple fields in the form of subplots at selected months and depths.

It is important to note that the monthly averaging of the fields filters out all the short-term variability that is certainly relevant when analysing mesoscale processes. An idea on the daily variability of T, S and (U, V) in the area can be obtained by following the 3-hour forecast fields issued currently published by the Physical Oceanography Unit of the IOI–Malta Operational Centre (University of Malta) on www.capemalta.net\MFSTEP\results.html

Annex 3: Abundance Indexes calculated using MEDITS (spring) and GRUND (autumn) data

Biomass Index (BI) of the different taxonomic groups

Group	Year	Survey	Mean BI ± sd	Maximum
Total biomass	**2003**	MEDITS	646.4 ± 276.9	3143.8
		GRUND	499.9 ± 246.5	1757.2
	2004	MEDITS	946.4 ± 387.9	2666.8
		GRUND	758.7 ± 411.2	2576.7
Bony fishes	**2003**	MEDITS	405.1 ± 213.1	2468.1
		GRUND	305.5 ± 178.7	1442
	2004	MEDITS	637.1 ± 317.9	1896.1
		GRUND	522.5 ± 316.9	2004.4
Selachians	**2003**	MEDITS	143.0 ± 78.0	704.8
		GRUND	119.2 ± 62.4	471.6
	2004	MEDITS	199.6 ± 97.9	691.8
		GRUND	156.4 ± 81.5	501.0
Cephalopods	**2003**	MEDITS	64.8 ± 45.2	217.5
		GRUND	44.7 ± 36.3	259.4
	2004	MEDITS	49.6 ± 31.8	237.2
		GRUND	25.6 ± 20.9	132.3
Crustaceans	**2003**	MEDITS	32.6 ± 17.2	139.2
		GRUND	29.4 ± 8.9	89.9
	2004	MEDITS	59.2 ± 23.9	177.7
		GRUND	53.5 ± 32	238.7

Target Species: Biomass Index (BI), Density Index (DI) of Young of the Year (YOY) and Density Index of Adult Females (AFE)

Species	Index	Year	Survey	Mean ± std	Maximum
Mullus barbatus	**BI**	**2003**	MEDITS	14.5 ± 25.3	224.5
			GRUND	6.9 ± 12.3	110.8
		2004	MEDITS	22.2 ± 34.1	236.4
			GRUND	10.5 ± 16.9	91.0
	DI YOY	**2003**	MEDITS	18.5 ± 83.6	969
			GRUND	56.2 ± 130.8	1952
		2004	MEDITS	169.6 ± 393.8	2979
			GRUND	1.3 ± 3.6	28
	DI AFE	**2003**	MEDITS	42.4 ± 67.7	552
			GRUND	60.9 ± 106.3	878
		2004	MEDITS	214.1 ± 350.5	2235
			GRUND	124.9 ± 223.7	1551
Merluccius merluccius	**BI**	**2003**	MEDITS	32.3 ± 16.7	114.2
			GRUND	37.5 ± 23.3	224.8
		2004	MEDITS	48.9 ± 19.3	173.4
			GRUND	45.3 ± 51.7	231.9
	DI YOY	**2003**	MEDITS	151.6 ± 173.8	1273
			GRUND	359.5 ± 419.9	4007
		2004	MEDITS	199.8 ± 357.5	3962
			GRUND	301.2 ± 500.5	3794
	DI AFE	**2003**	MEDITS	31.2 ± 26.6	205
			GRUND	42.6 ± 22.9	167
		2004	MEDITS	53.3 ± 25.1	242
			GRUND	56.9 ± 43.2	327
Parapenaeus longirostris	**BI**	**2003**	MEDITS	16.9 ± 17.3	138.2
			GRUND	13.2 ± 11.2	89.8
		2004	MEDITS	27.9 ± 20.7	138.7
			GRUND	35.5 ± 36.3	188.5
	DI YOY	**2003**	MEDITS	704.3 ± 1441.8	14759
			GRUND	662.8 ± 1067.6	6467
		2004	MEDITS	866.8 ± 1066.9	10575
			GRUND	784.0 ± 1177.0	11847
	DI AFE	**2003**	MEDITS	568.6 ± 499.7	3534
			GRUND	453.6 ± 393.4	2239
		2004	MEDITS	1155.4 ± 928.9	6268
			GRUND	2154.3 ± 2500.7	13787

Species	Index	Year	Survey	Mean ± std	Maximum
Raja clavata	BI	2003	MEDITS	20.7 ± 25.9	208.2
			GRUND	17.7 ± 17.5	136.1
		2004	MEDITS	31.4 ± 35.4	429.7
			GRUND	20.1 ± 17.2	126.9
	DI YOY	2003	MEDITS	1.1 ± 2.5	42
			GRUND	4.1 ± 6.7	84
		2004	MEDITS	0.2 ± 0.6	10
			GRUND	1.9 ± 5.2	73
Raja miraletus	BI	2003	MEDITS	6.1 ± 13.7	86.1
			GRUND	3.6 ± 4.7	42.4
		2004	MEDITS	6.5 ± 13.9	113.9
			GRUND	5.3 ± 7.3	47.7
	DI YOY	2003	MEDITS	-	-
			GRUND	2.5 ± 4.4	58
		2004	MEDITS	11.4 ± 30.6	234
			GRUND	5.5 ± 11.2	84

MEDSUDMED

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