Research papers

Infaunal community responses to a gradient of trawling disturbance and a long-term Fishery Exclusion Zone in the Southern Tyrrhenian Sea

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ABSTRACT

Historically the majority of Mediterranean trawl fisheries occur on the continental shelf with a smaller proportion focused on the shelf slope and deep sea areas. Understanding how trawl fisheries affect the wider ecosystem is an important component of the ecosystem-based approach to fisheries management. In this context the current study examined the impact of the otter trawl fishery on the infaunal communities found on the continental shelf and upper slope off the coast of Sicily and Calabria, Italy. A total of thirty six sites were sampled across a gradient of fishing intensity and from within a large bay from which trawling has been excluded for 22 years. Fishing intensities were ascertained post-hoc from vessel monitoring system data. Seabed characteristics of the sites studied were uniform across the continental shelf and slope areas that were studied, such that the only factor that varied was fishing intensity. The density index (DI) and total number of species (S) were significantly higher in the fishery closure area compared with other continental shelf sites. In particular, bioturbating decapod fauna occurred only within the fishery closure area. Fished sites were dominated primarily by burrowing deposit feeding worms, small bivalves and scavenging biota. In contrast, the response to fishing on the upper slope was less clear. This observation was treated with caution as the power to detect fishing effects was lower for the upper slope sites as a result of possible illegal fishing that had compromised two of the four replicate sites within the closed area. While the present study was able to quantify the effect of the demersal trawl fleet on the benthic infauna of the continental shelf, the effects of trawling on the upper shelf slope remain unclear and warrant further study.

1. Introduction

The direct physical effects of trawl disturbance on continental-shelf benthic communities are well understood for a range of fishing-gear types and in a variety of seabed habitats (Kaiser et al., 2006). However, the majority of these studies are focused on small-scale experimental manipulations whereas a much smaller number of studies have investigated the response of benthic fauna to trawling disturbance at the mesoscale of a fishing ground and across a gradient of trawling impact (de Groot, 1984; Dayton et al., 1995; Thrush et al., 1995; Auster et al., 1996; Jennings and Kaiser, 1998; Pauly et al., 1998; Hall, 1999; Norse and Watling, 1999; Kaiser and de Groot, 2000; Hinz et al., 2009). De Juan et al. (2011,

2012a) studied the effects of trawl disturbance in the North-Western Mediterranean Sea but suggested that such studies needed to be expanded to encompass a wider variety of systems in the Mediterranean in order to be able to draw consistent conclusions about the response of benthic communities to trawl disturbance in this region (see also Smith et al. (2000), Dimech et al. (2012).

The recent emphasis on the ecosystem-based management approach increased the need to understand the effects of anthropogenic disturbance on marine ecosystems that area associated with fishing activities so as to be able to introduce management measures that maintain the structure and functioning of marine communities (FAO, 2003; Sinclair and Valdimarsson, 2003; Browman and Stergiou 2005; Levin et al., 2009; Stelzenmüller et al., 2013). The establishment of ecosystem-based management plans and monitoring of the effectiveness of their implementation and the resulting outcomes are a mandatory requirement under current European legislation (Frid et al., 2005; FAO General Fisheries Commission for the Mediterranean, 2010). However, to

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date the implementation of Ecosystem-Based Fisheries Management (EBFM) in the Mediterranean basin has been hampered both by a lack of a good understanding of the ecological role of the species affected by fishing activities and by an inadequate knowledge of their distribution in relation to the distribution of fishing activities (Pikitch et al., 2004; de Juan et al., 2012b). The adoption of management actions at a regional scale is difficult due to the geophysical and political complexity of the Mediterranean basin (Cacaud, 2005). De Juan et al. (2012b) suggested that an EBFM approach in the Mediterranean Sea could be accomplished through the development of a management plan based on the establishment of marine spatial planning and the use of areas of the sea with varying levels of conservation.

To expand our understanding of the response of benthic communities in a data poor region (the Mediterranean) to trawling disturbance and, to provide suggestions for a sustainable use of marine resources in the context of EBFM, the present study aimed to quantify the responses of infaunal communities to a gradient of fishing intensities in the Southern Tyrrhenian Sea (Central Mediterranean Sea). A previous study in this location (see Mangano et al., 2013) highlighted differences in the biological traits composition of mega-epibenthic communities among areas subjected to different levels of fishing intensity but did not consider the effects of fishing on the infaunal component of the benthic community.

The present study was conducted from Cape Suvero (Calabria) to Cape Cefalù (Sicily) and focused on the infaunal communities associated with trawled muddy seabed habitats at a depth of between 50 and 400 m that encompassed the continental shelf and the upper shelf slope ecosystems. The responses of benthic infauna that experienced different amounts of trawling impact were studied by taking samples across sites in the Gulf of Sant'Eufemia (Calabria) and the Gulfs of Patti and Sant'Agata (Sicily). The fishing history for the previous twelve months at each site was ascertained a posteriori from the analysis of vessel monitoring system (VMS) data. Although it was impossible to reconstruct a historical trend in the response of the benthic communities to trawl disturbance, the availability of vessel monitoring system data for the trawl fleet enabled us to undertake a comparative study of the response of the community to the cumulative effects of fishing (Hinz et al., 2009). The vessel monitoring system (VMS) data enabled us to obtain high resolution quantitative

estimates of fishing activity at a relevant spatial scale (Bastardie et al., 2010; Lee et al., 2010; Lambert et al., 2012; Hintzen et al., 2012). VMS has become a critical tool that enables scientists to evaluate the footprint of fishing activity in the marine environment, in this regard, VMS data can support the assessment of fishing activity and marine spatial planning by providing a more detailed insight into the fishing effort and distribution (EC, 1997; Dinmore et al., 2003; Murawski et al., 2005; Mills et al., 2007; Lambert et al., 2012; Hinz et al., 2013). In particular, the study provides important insights into the distribution of fishing disturbance on the seabed in a central Mediterranean fishing ground, a necessary step to evaluate the relative impact of this activity on the natural environment and, particularly, to examine the effects of trawl disturbance on benthic communities.

The study utilises the presence of the Fishery Exclusion Zone of the Gulf of Patti (Messina) as a baseline against which to evaluate the effects of fishing on the seabed across an area that extended from the gulf of Sant'Eufemia on the west coast of Calabria to the Gulf of Sant'Agata, Sicily.

2. Materials and methods

2.1. Study area

The surveyed area extended from a depth of 50 to 400 m across an area of 800 km^2 that encompassed the Gulf of Sant'Eufemia on the west coast of Calabria (300 km^2) and the Gulfs of Patti and Sant'Agata on the northern coast of Sicily (respectively 240 and 260 km^2) (Fig. 1). The Gulf of Patti is a Fishery Exclusion Zone that has been closed to commercial trawling since 1990 (Regional Law N. 25/90). The fishing activity inside this gulf is restricted to artisanal fishing that extends over the continental shelf and upper slope and includes mainly highly selective static gears such as trammel nets and set gillnets. The Gulf of Sant'Eufemia and the Gulf of Sant'Agata are characterised by medium-large trawling fleets resulting in an intensive mixed demersal trawl fishery dominated by round fish (European hake, red mullet, *Pagellus* spp.), flatfish species (common sole, anglerfish *Lophius* spp.), several Crustaceans (Norway lobster, giant red shrimp, red shrimp, deepwater rose shrimp) and Cephalopods (shortfin squid,
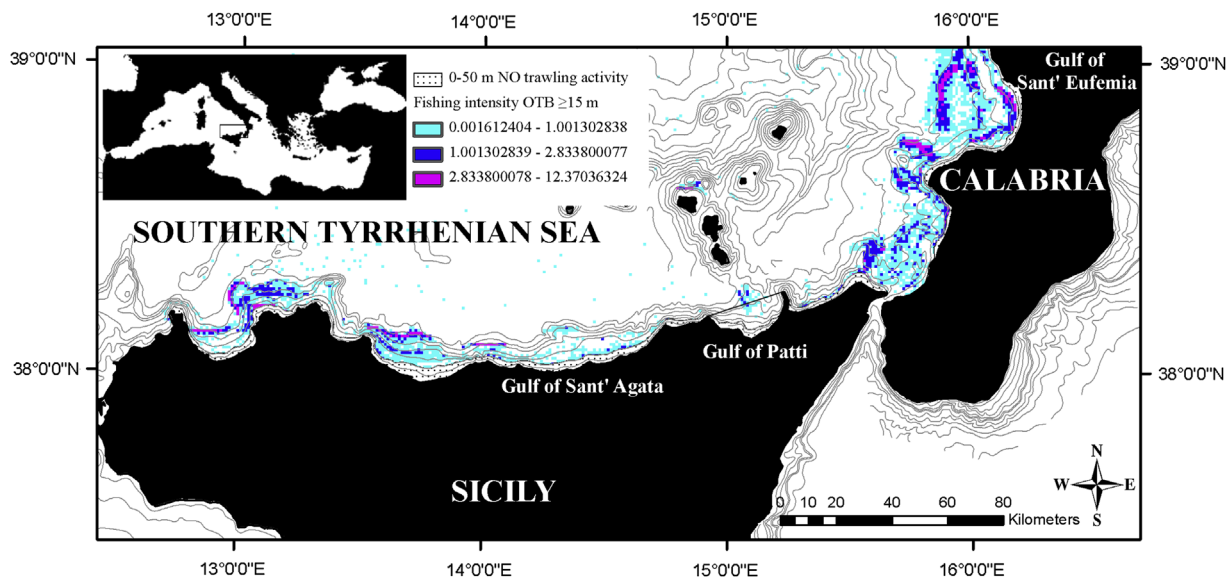

Fig. 1. Location of the study area and spatial distribution of sampling sites within the investigated fishing ground in the Southern Tyrrhenian Sea, Sicilian and Calabrian coasts, Italy. The three investigated gulfs are shown: Gulf of Sant'Agata, Patti and Sant'Eufemia. Fishing intensity (swept area year^{-1}) is shown with three ranges of fishing intensity and areas where no bottom trawling is permitted. Note: A black line in front of the Gulf of Patti represents the seaward limit of the Fishery Exclusion Zone that has been established since 1990. Code: OTB=Bottom Otter Trawlers.

Table 1
Summary of the abiotic environmental characteristics (mean $\pm$ 95% CI) measured at each sampling site on the continental shelf (50–200 m) and upper slope (200–400 m). Minimum and maximum fishing intensity values (swept area/year) were reported for each habitat in each gulf. Statistical tests for differences in the environmental metrics between the three Gulfs (SEu=Sant' Eufemia, Pat=Patti, SAg=Sant' Agata) were undertaken using either ANOVA (F) or Kruskal–Wallis (H) tests.

50–200	SEu	Pat	SAg	F/H	p
Depth	149.75 ± 38.65	127.88 ± 33.87	124.54 ± 31.50	$H=2.75$	0.253
Sand	8.63 ± 5.40	3.56 ± 4.73	6.62 ± 12.98	$H=3.56$	0.168
Silt	86.37 ± 7.30	92.45 ± 5.21	84.12 ± 13.47	$H=1.80$	0.406
Clay	4.86 ± 3.53	3.99 ± 1.26	9.27 ± 7.53	$F=2.06$	0.153
Mz (mean grain size)	6.20 ± 0.33	6.46 ± 0.26	6.43 ± 0.88	$H=5.92$	0.052
Fishing intensity min–max	0.931–6.368	0	0.032–0.367		
200–400					
Depth	308 ± 6.35	281.75 ± 44	317 ± 148.23	$F=0.16$	0.853
Sand	–	–	–	–	–
Silt	95.69 ± 1.40	96.16 ± 1.11	74.39 ± 22.93	$H=2.58$	0.276
Clay	4.31 ± 1.40	3.84 ± 1.11	25.61 ± 22.93	$H=2.58$	0.276
Mz (mean grain size)	6.51 ± 0.22	6.73 ± 0.14	7.10 ± 0.42	$F=4.19$	0.055
Fishing intensity min–max	0.933–2.982	0	0.096–1.180		

European squid, common cuttlefish), as well as artisanal fisheries (Mangano et al., 2013). In the last two decades both the Gulf of Sant′Eufemia and the Gulf of Sant′Agata have been described as overfished (Internal Report CNR, 1988; Greco et al., 1993; Greco, 1994). The only regulation imposed along the two fished gulfs is a ban on trawling in water shallower than 50 m as occurs for all Italian coastlines and elsewhere in the Mediterranean basin. All three Gulfs are characterized by very similar environmental variables (Table 1).

2.2. Sampling design

A total of 24 samples were collected in each of the three surveyed Gulfs, during July 2009, using a 70 l modified Van Veen grab with a sampling surface area of 0.25 m^2. In each Gulf, four transects approximately 5 km apart were sampled, with sampling sites stratified by depth zone (50–100, 100–200, 200–400 m). Two samples were collected at each of the sampling sites and these were merged together and the total number of individuals was standardised to a sampling surface of 0.50 m^2. A half litre sample of sediment was collected for particle-size determination. Percentage fractions of each sediment size-class category were dry sieved through a stack of ASTM-USA meshes. The silt and clay components were extracted by washing over a 63-μm mesh, and were subsequently separated using the column dispersion method (Buchanan, 1984). The descriptive dispersion index of mean grain size (Mz) was evaluated according to Folk and Ward (1957).

Macrobenthic faunal organisms were extracted from the sediment after washing over a 0.5 mm mesh and thereafter preserved in 70% ethanol except polychaetes that were fixed with 4% buffered formalin. In the laboratory fauna samples were sorted and identified to the lower taxonomic level possible and the total number of each species was quantified and standardised.

2.3. Estimation of fishing intensity

VMS position, time, speed, and anonymous vessel identification data for bottom otter trawlers (OTB) in the territorial waters of the Southern Tyrrhenian Sea for the year 2009 were provided by the Italian Coast Guard (FMC—Fishing Monitoring Centre, Rome). Data included Italian vessels ≥ 15 m operating in the study area (European Commission (EC), 2003). Before analysis, data were screened to identify basic inaccuracies in vessel identity, position, speed and duplicate VMS records and records close to (within 1 km of) port were removed, along with erroneous position records allocated to land (Lee et al., 2010). Based on direct observations of fishing vessels operating in the study area and an analysis of the frequency distribution of the calculated speed

between consecutive VMS records, the calculation of fishing intensity was restricted to speeds > 2 and ≤ 4 knots (Piet et al., 2007; Lambert et al., 2012). The value zero was considered to indicate that vessels were anchored. All analyses were conducted using the VMStools package in R (Hintzen et al., 2012).

Fishing intensity was calculated for a 12-month period by estimating the area swept by point summation of VMS data on a grid cell size of 1 km $\times$ 1 km (Lambert et al., 2011). Point summation consists of summing the area swept attributed to each VMS point in a defined cell. The swept area was calculated by multiplying the time interval between positions, the fishing speed, and the spread of the gear. Otter trawls were assumed to be 89 m wide considering an average measure of horizontal door spread, HDS, for a conventional otter trawler operating on Mediterranean Sea. This measure was preferred to a more usual measure of horizontal net opening, as a result of recent observations of the impact on the seabed of two traditional otter nets operating on Mediterranean soft bottom fishing grounds (Sala et al. 2009; Sala and Lucchetti, 2012). The measure takes into account the horizontal surface of contact between the mouth of the net and the seabed but also includes a number of important points of contact such as ropes, chains and the two doors. All of these components of the gear have the potential to have a direct impact on macrofauna. Although this approach may result in an overestimate in the fishing activity we considered to be a conservative approach.

Fishing intensity was defined as the summed swept-area divided by the surface area of the cell (year^{-1}) and was calculated for a cell size of ca. 1 km $\times$ 1 km. The grid scale of analysis is important when fishing activity is used as a pressure indicator of the state of the environment (Lambert et al., 2012). The EU directives on the Data Collection Framework (DCF) and associated documentation define standardized indicators (Commission of the European Communities (COM), 2008; EC (European Commission), 2008a, 2008b) and recommend that the analysis VMS data should be based on grid cells of 3 km $\times$ 3 km. Nevertheless we preferred to use a smaller grid and hence to obtain a finer-resolution to reflect better the heterogeneity in fishing effort distribution. As grid size was defined in fixed kilometre units, longitude and latitude VMS position records were projected into the Universal Transverse Mercator (UTM) geographic coordinates system. The sum of the swept area in each 1 km^2 cell was represented with ArcGIS 9.3, giving the actual fishing frequency per annum (Figs. 1 and 2a–c).

2.4. Analysis of environmental characteristics

Prior to any analysis of the infaunal community data in relation to fishing activity, it was important to establish whether there
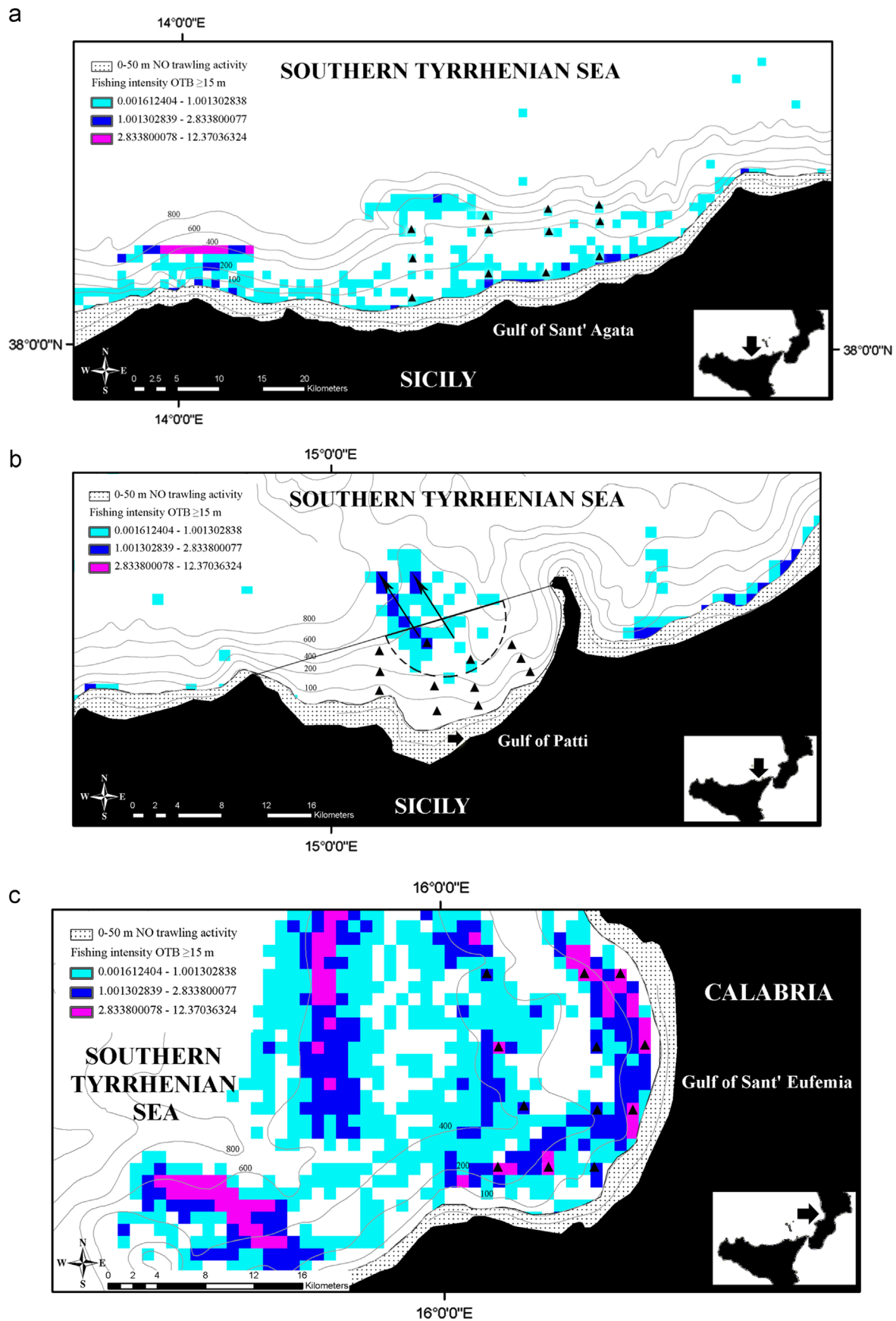
Fig. 2. Spatial distribution of sampling sites (black triangles) within each of the three investigated areas: (a) Gulf of Sant'Agata, (b) Gulf of Patti and (c) Gulf of Sant'Eufemia. The spatial distribution of fishing intensity (swept area year^{-1}) at a scale of 1 km² is also given. The stippled band represents the depth range between 0 and 50 m that is closed to otter trawl fishing activity. The black line delineates the seaward limit of the extension of the Exclusion Fishery Zone that has been established inside the Gulf of Patti since 1990; the thick black arrow indicates the position of Portorosa harbour; the two thin black arrows indicate the possible direction in which vessels fish illegally from inside of the area closure; the semi-circular dotted line is the extent to which illegal fishing could occur without detection from the VMS. Code: OTB=Bottom Otter Trawlers.

were any potentially confounding variables. A Euclidian distance matrix of normalised environmental data was computed using the $\log(x+1)$ transformed abiotic habitat characteristics found at the individual sampling sites (using Primer v.6, Clarke and Gorley (2006)). A two-way Analysis of Similarity test (ANOSIM) was performed on depth (50–100, 100–200, 200–400) and location (three gulfs, SEu=Gulf of Sant'Eufemia, Pat=Gulf of Patti, SAg=Gulf of Sant'Agata). The environmental data used to compute the Euclidian distance matrix were: depth, mean particle size, percentage of sand, silt and clay. In order to account for any potential autocorrelation between the environmental variables and the distribution and intensity of the trawl fisheries, the correlation coefficients (Pearson's) were computed for each combination of environmental variable and fishing. If variables were found to be autocorrelated (i.e. rho $> =0.95$), one of the variables was removed from further analyses. Additionally, an ANOVA test was performed to ascertain whether there were significant differences in the environmental parameters among the three spatially distinct Gulfs.

2.5. Analysis of infaunal community

The analyses of infauna community data were undertaken using the PRIMER (v.6) software package. Species abundance data $(0.50\,\text{m}^{-2})$ were fourth-root transformed to down weight the influence of extremely abundant species, and clustered using the Bray–Curtis index of similarity. A multidimensional scaling ordination (MDS) plot was then computed from the resulting similarity matrix. A BIOENV procedure was undertaken, using a Spearman rank correlation coefficient, to explore which of the variables measured at each site (environmental variables and fishing intensity) best explained the multivariate relationship in the ordination of infaunal samples (Clarke and Ainsworth, 1993).

Differences in community composition and structure that were related to fishing intensity were tested using an Analysis of Similarity (ANOSIM) test. For this test, sites were grouped into fishing intensity categories. Fishing intensity was expressed as the number of times an area of seabed was swept area/year for each $1\,\text{km}^2$ cell and was grouped into three categories: 0 (Fishery Exclusion Zone, no fishing intensity), 1 (low fishing intensity 0.001–1.000 swept area/year), 2 (high fishing intensity 1.001–7.000 swept area/year). The three categories were grouped after checking the effective values of fishing intensity registered in proximity to each sampling site located along the study area (Fig. 2a–c). We adopted a categorical approach for our analysis to improve the statistical power to detect the effects of fishing. A Similarity Percentage (SIMPER) routine was used to determine which species contributed most to the similarity or dissimilarity for those sites that experienced the same (categorical) fishing intensity differentiated by habitat (shelf or upper shelf slope communities) (Clarke and Warwick, 1994).

The response of univariate community metrics to fishing intensity in both the shelf and slope habitats were tested separately with ANOVA, these metrics included: the total number of individuals per unit area (N), the total number of species per unit area (S), Species richness (d) together with two weighted structural indices Shannon–Wiener diversity (H') and Pielou's index of evenness (J'). All metrics were tested to see if they satisfied the assumptions required for ANOVA. Anderson–Darling and Levene's tests were used to test respectively normality and homogeneity of variance and the indices were $\log(x+1)$ transformed when necessary. The non-parametric Kruskal–Wallis test was performed on untransformed data when the assumptions were not met. A *post hoc* analysis of the difference between mean values was undertaken using Tukey's test to detect significant pairwise differences among the analysed factor. The same statistical approach was

adopted to examine the response of selected individual species to trawl intensity for both shelf and upper shelf slope habitats.

3. Results

3.1. Fishing intensity

The analysis of the distribution of fishing intensity from the VMS data demonstrated the non-random behaviour of the fishing fleet, which is presumably influenced by historical patterns of fishing performance and regulatory restrictions, as well as by the location of the fishing resources (Fig. 2a–c). In the Gulf of Sant'Agata fishing was mainly confined to coastal areas. The Gulf of Sant'Eufemia was subjected to a very patchy distribution of fishing intensity that had its highest concentration and intensity in proximity to the 100 and 600 m bathymetric lines that ran in parallel to the coastline. Inside the Fishery Exclusion Zone in the Gulf of Patti, the VMS data indicated that there was some evidence of limited infringement of the closed area which seemed to relate to a bathymetric feature (a protrusion of the deepest level of the slope) that extends offshore reaching a depth of 600 and 800 m. This feature is symptomatic of a canyon which is a habitat generally targeted by shrimp fisheries that are the most commonly practiced and profitable fisheries activity in this area.

In general, the highest values of fishing intensity were recorded on the continental shelf compared to the upper slope (Table 1). Within the continental shelf, the lowest values of fishing intensity occurred inside the Gulf of Sant'Agata, and varied from 0.032 to 0.367 swept area/year. The highest values of fishing intensity on the continental shelf occurred inside the Gulf of Sant'Eufemia, and varied from 0.743 to 6.638 swept area/year. The Gulf of Sant'Eufemia also had the highest values of fishing intensity for the upper slope, that ranged from 0.933 to 2.982 swept area/year, whereas the fishing intensity in the Gulf of Sant'Agata varied between 0.096 and 1.180 swept area/year.

3.2. Environmental characteristics of sampling sites

A cluster diagram (Fig. 3) and subsequent ANOSIM test showed that there were significant differences in the environmental variables among the three depth levels (ANOSIM, $R=0.239$,
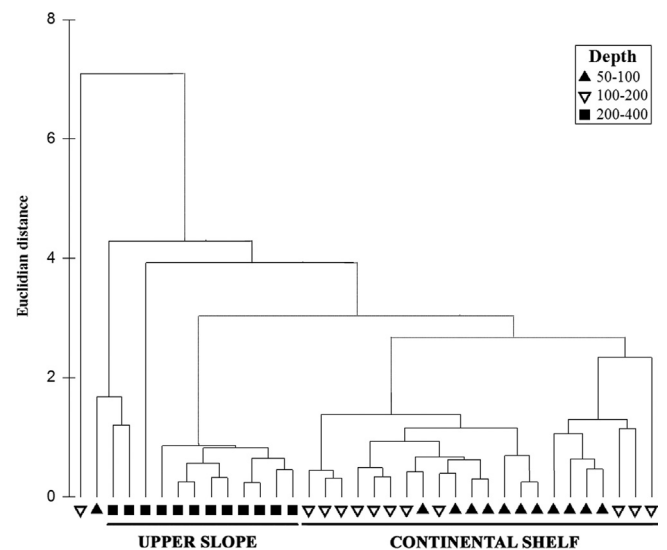

Fig. 3. Cluster analysis for the sample sites based on the environmental variables measured at each site. The main clusters of stations are divided into upper slope (200–400 m filled squares) and continental shelf (50–100, 100–200 m filled and open triangles respectively) sites.

$p < 0.001$). Pairwise tests indicated significant differences between depth levels 50–100 and 200–400 (ANOSIM test $R=0.396$, $p < 0.001$), 100–200 and 200–400 (ANOSIM test $R=0.219$, $p < 0.001$). As there was no significant difference between the two shallowest depth levels they were considered as a single 'continental shelf' category of 50–200 m cf the 200–400 m 'upper slope'. This pattern was consistent for all three Gulfs. In general, the finest fraction of sediments was highest on the slope where no sand fraction was present in the sediment (Table 1). Pearson correlations of environmental variables with fishing intensity within the continental shelf and upper slope habitats showed that there was no correlation between fishing intensity and the environmental variables (Table 2). The sand and silt fractions were correlated with median particle size in the continental shelf, whereas silt and clay fractions were correlated with the median particle size in the upper slope (Table 2). One pair of variables were autocorrelated but only in the upper slope sites, hence both were retained in the analysis.

3.3. Infaunal community

The BIOENV analysis with the infaunal abundance data for the continental shelf habitat showed that the ordination was best explained by the two variables percentage of clay and median particle size (Rho=0.342). The ordination of infaunal abundance data for the upper slope habitat was best explained by depth and percentage silt content (Rho=0.278). These low correlation coefficients indicate that other factors explain the patterns in the infaunal community data.

A one-way ANOSIM revealed that fishing had a significant effect on the species abundance data in the continental shelf (ANOSIM, $R=0.194$, $p < 0.05$) but not in the upper slope. For the continental shelf the pairwise tests showed that there was a significant difference only between the Fishery Exclusion Zone and the high fishing intensity range ($R=0.261$, $p < 0.05$). As fishing activity did occur (illegally) inside the EFZ, a second ANOSIM test was performed on the upper slope dataset allocating data from two of the EFZ to low and high categories of fishing intensity (Fig. 4). The two samples were located inside the central portion of the gulf nearest the boundary of the closure, in proximity to an area where VMS data analysis highlighted two different levels of fishing intensity (dashed line in Fig. 2b). Based on typical fishing speeds, it was estimated that it was possible for a vessel to transit from the nearest VMS record to the location of these sample sites and return without detection by the VMS. The ANOSIM test achieved once this change had been made showed a significant

effect on species abundance (ANOSIM, $R=0.549$, $p < 0.05$). Similarities among samples were visualised using Multi-Dimensional Scaling (MDS) (Figs. 4 and 5) and show how these two sample sites group most strongly with the fished sites outside the EFZ (dashed circle in Fig. 5). A SIMPER analysis highlighted those taxa that accounted for the differences between the different fishing intensity categories found on the continental shelf and the upper slope (Table 3). The average dissimilarly values between the three fishing intensity categories are reported in Table 4. The number of taxa that contributed to the average similarity was highest in the EFZ in the Gulf of Patti, in contrast to the sites subjected to the highest level of fishing intensity that were characterised by the presence of a very restricted number of taxa. In contrast, only three families of polychaetes contributed to the average of similarity in the EFZ on the upper slope. The average of dissimilarity was highest between the low and high categories of fishing intensity on the shelf and between the EFZ and the low level of fishing disturbance on the upper slope.

The overall macro-benthic community found in the fishing grounds along the study area was dominated by deep burrowing infaunal deposit feeders. The infaunal community at all sites was generally dominated by polychaetes of which the Maldanidae and Capitellidae were the most common families. The sub-surface feeding Maldanidae were found across all levels of fishing disturbance in both shelf and slope habitats. On the continental shelf,
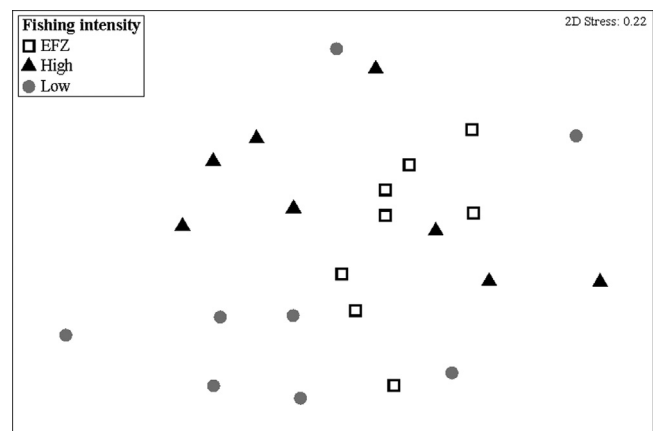

Fig. 4. Multidimensional scaling plot of infaunal abundance data for the sites sampled on the continental shelf (50–200 m). The stress value is high and suggests that there is some three dimensionality in the ordination such that the 2-dimensional plot does not represent well the significant differences that were ascertained from the ANOSIM test.

Table 2
Correlation analysis of physical environmental metrics and trawling intensity for the continental shelf (50–200 m), and the upper slope (200–400 m) areas. Pearson correlation coefficients are shown with p values in parentheses. The degrees of freedom were, d.f.=22 for the continental shelf and d.f.=10 for the upper slope. The asterisks indicate significant correlation ***$p < 0.001$. A Bonferroni correction was applied to account for multiple testing.

Continental shelf					
Factor	Depth	Sand	Silt	Clay	Mz (Φ)
Sand	0.067 (0.756)				
Silt	−0.058 (0.789)	−0.716 (0.001)***			
Clay	0.068 (0.752)	0.000 (1.000)	−0.381 (0.066)		
Mz (Φ)	0.752 (0.947)	−0.775 (0.001)***	0.805 (0.001)***	0.161 (0.453)	
Trawling intensity	0.236 (0.267)	−0.045 (0.836)	0.127 (0.554)	−0.155 (0.469)	0.060 (0.782)
Upper slope					

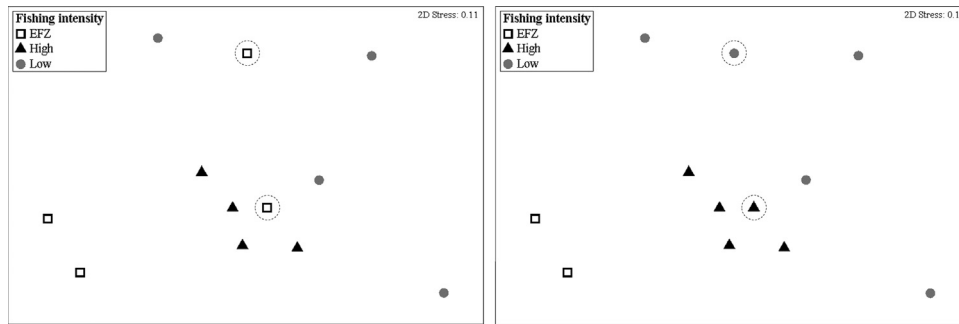| Factor	Depth	Silt	Clay	Mz (Φ)
Silt	0.372 (0.234)			
Clay	−0.183 (0.569)	−0.958 (0.001)***		
Mz (Φ)	−0.109 (0.737)	−0.811 (0.001)***	0.739 (0.006)**	
Trawling intensity	−0.000 (0.999)	0.216 (0.500)	−0.210 (0.513)	−0.489 (0.107)

Fig. 5. Multidimensional scaling plots of infaunal abundance data for the samples from the upper slope (200–400 m). Left MDS plot considering the four samples inside the EFZ as unfished. Right MDS plot considering two of four EFZ samples to be subjected to fishing activity. *Note*: dashed circles indicated the samples affected by possible illegal fishing activity.

Table 3
Output from the SIMPER analysis for the community data from the continental shelf and upper slope. Only those taxa that contributed 90% of the similarity are shown for sites within each of the different fishing intensity categories.

Continental shelf (50–200 m)	Av. Density $\sqrt{N}/0.5\ m^2$	Con. %	Code	Upper slope (200–400 m)	Av. Density $\sqrt{N}/0.5\ m^2$	Con. %	Code
EFZ				**EFZ**			
Average similarity: 35.63				Average similarity: 22.64			
Maldanidae	1.54	19.25	P	Capitellidae	1.28	71.89	P
Lumbrineridae	1.09	11.99	P	Spionidae	0.65	15.19	P
Cirratulidae	1.05	10.14	P	Maldanidae	0.89	12.92	P
Glyceridae	0.92	9.98	P				
Capitellidae	1.06	9.85	P				
Spionidae	1.02	7.63	P				
Nephtyidae	0.65	4.27	P				
Eunicidae	0.64	4.17	P				
Sternaspis scutata	0.88	4.01	P				
Alpheus glaber	0.59	3.64	C				
Oenonidae	0.47	2.33	P				
Jaxea nocturna	0.47	2.12	C				
Terebellidae	0.47	2.02	P				
Low fishing intensity				**Low fishing intensity**			
Average similarity: 17.12				Average similarity: 19.46			
Nucula sulcata	0.80	38.84	M	Maldanidae	1.22	75.07	P
Maldanidae	0.92	25.58	P	*Abra longicallus*	0.65	24.93	M
Terebellidae	0.45	8.37	P				
Eunicidae	0.45	5.34	P				
Phyllodocidae	0.45	4.70	P				
Abra alba	0.33	3.37	M				
A. glaber	0.30	3.07	C				
Amphinomidae	0.30	2.86	P				
High Fishing intensity				**High Fishing intensity**			
Average similarity: 25.29				Average similarity: 43.58			
A. glaber	0.87	15.89	C	Maldanidae	1.40	28.67	P
Oestergrenia digitata	0.87	15.89	E	*A. longicallus*	1.36	26.47	M
Sternaspis scutata	0.87	15.89	P	Capitellidae	1.15	13.85	P
Capitellidae	1.11	12.44	P	Terebellidae	0.89	13.14	P
Glyceridae	1.04	11.55	P	Eunicidae	0.65	5.41	P
Eunicidae	0.79	9.45	P	Nephtyidae	0.59	5.29	P
Maldanidae	1.24	9.45	P				

Fishing intensity categories were: EFZ=no fishing, Low=0.001–1.000, High=1.001–6.368 swept area/year. Abbreviation codes: Av. Density=number of individuals N/0.5 m², Con. %=percentage contribution to the overall similarity, P=Polychaetes, C=Crustacea, E=Echinodermata, M=Mollusca.

Table 4
Average of dissimilarity between the three fishing intensity categories EFZ, Low and High.

Average dissimilarity		
50–200	EFZ	Low
Low	79.68	
High	75.73	84.68
200–400	EFZ	Low
Low	84.94	
High	70.53	75.3

the density of Spionidae, Cirratulidae, Lumbrineridae, and the thalassinid shrimp *Jaxea nocturna* attained significantly higher abundances within the EFZ. Notably the polychaete family Poecilochaetidae together with some "rare species" as three decapod crustaceans, the two scavengers *Liocarcinus navigator* and *Ebalia tuberosa*, and the burrower *Callianassa subterranea*, three bivalve molluscs *Tropidomya abbreviata*, *Mendicula ferruginosa* and *Thyasira alleni* and the ophiuroid echinoderm *Amphiura filiformis* were collected exclusively from within the EFZ. In contrast, Glyceridae (mobile predatory polychaetes) were more abundant at sites subjected to high levels of fishing intensity.

Table 5
Kruskal–Wallis tests (*H*) and one-way ANOVA test (*F*) of the response of key species or taxa to different levels of fishing intensity within each of the different depth zones. A full list of species density with measures of error are given in supplementary materials.

	Taxa	df	H/F	p	Tukey's test
Continental shelf 50–200 m	Capitellidae	2	H=7.75	p=0.021*	EFZ > high
	Cirratulidae	2	H=9.98	p=0.007**	EFZ > high > low
	Glyceridae	2	H=6.44	p=0.040*	High > EFZ > low
	J. nocturna	2	H=6.55	p=0.038*	EFZ > low, high
	Lumbrineridae	2	H=7.20	p=0.027*	EFZ > high > low
	Spionidae	2	H=9.65	p=0.008**	EFZ > high
Upper slope 200–400 m	Capitellidae $Log_{10}(x+1)$	2	F=6.19	p=0.020*	EFZ > low < high
	Terebellidae	2	H=8.56	p=0.036*	High > EFZ

The ranges of fishing intensity were respectively: EFZ=no fishing, low=0.001–1.000, high=1.001–6.368 swept area/year.
Post-hoc multi-comparison Tukey's test results are presented, asterisks indicate *p* values ***$p < 0.001$.

* $p < 0.05$ Post-hoc multi-comparison Tukey's test results are presented, asterisks indicate *p* value.
** $p < 0.01$ Post-hoc multi-comparison Tukey's test results are presented, asterisks indicate *p* value.

Table 6
Results of the one-way ANOVA and Kruskal–Wallis tests, for tests of the response of univariate community metrics (based on abundance data) to variations in fishing intensity set as a factor.

Continental shelf 50–200 m

	d.f.	F	p	Tukey's test
Density Index (DI) $Log_{10}(x+1)$	2	7.27	p=0.004**	EFZ > low, high**
Total number of species (S) $Log_{10}(x+1)$	2	5.40	p=0.013*	EFZ > low, high**
Species Richness	2	3.20	p=0.061	–
Shannon's index (H′)	2	3.23	p=0.060	–
	d.f.	H	p	Tukey's test
Pielou's index (J′)	2	5.59	p=0.061	–

Upper slope 200–400 m

	d.f.	F	p	Tukey's test
Density index (DI)	2	1.44	p=0.287	–
Total number of species (S) $Log_{10}(x+1)$	2	5.87	p=0.023*	High > low, EFZ*
Species richness (d) $Log_{10}(x+1)$	2	5.56	p=0.027*	High > low, EFZ*
Shannon's index (H′)	2	5.38	p=0.029*	High > low, EFZ*
	d.f.	H	p	Tukey's test
Pielou's index (J′)	2	0.46	p=0.648	–

***$p < 0.001$ Post-hoc multi-comparison Tukey's test results are given, asterisks indicate *p* value.
The ranges of fishing intensity were respectively: EFZ=no fishing, low=0.001–1.000, high=1.001–6.368 swept area/year.

* $p < 0.05$ Post-hoc multi-comparison Tukey's test results are given, asterisks indicate *p* value.
** $p < 0.01$ Post-hoc multi-comparison Tukey's test results are given, asterisks indicate *p* value.

Only organisms belonging to two families of polychaetes showed significant differences in the upper slope. Subsurface deposit feeding Capitellidae had significantly higher densities within the EFZ and highly exploited sites. The surface deposit feeding Terebellidae reached the highest density in proximity to the higher levels of fishing intensity (Table 5). Orbinid polychaetes were found only inside the EFZ on the upper slope.

On the continental shelf the gross community metrics revealed that the density index (*N*) and the species richness (*S*) were significantly different across the different categories of fishing intensity. The indices showed the same trend with the highest values found in the EFZ in the Gulf of Patti (Table 6, Fig. 6). The other three indices of species diversity, Shannon's and Pielou's, were similar at all sites. In the upper slope, three of the univariate diversity indices were significantly different (the total number of species (*S*), the species richness (*d*) and the Shannon's diversity) (Table 6, Fig. 7). For all three indices the highest values were recorded at the higher level of disturbance.

4. Discussion

The present study considered the response of benthic infaunal communities to a gradient of fishing disturbance within the continental shelf and upper slope where demersal otter trawling in the Mediterranean is most intense (Dimech et al., 2008; de Juan et al., 2009; Mangano et al., 2013). The sites sampled during this study were originally chosen without reference to VMS data, thus the analysis of VMS data was retrospective in this respect and explains why the distribution of sites among different intensities of fishing disturbance and depth zones was not balanced. Nevertheless, given the paucity of such studies that examine fishing effects at the scale of the fleet, we propose that the present study provides some valuable insights into the effects of otter-trawling in the Mediterranean basin. The evaluation of fishing intensity measures using VMS data offered the opportunity to define an accurate gradient of trawling impact and thereby to detect with a great precision the degree of disturbance on infaunal communities from fishing ground, as underlined by the differences obtained after comparing the infaunal community from the EFZ and the less trawled areas in the continental shelf. The improved accuracy for estimating fishing effort at a small scale using VMS data was also evident in the upper slope where, the spatial distribution analysis of fishing intensity inside the EFZ helped us to infer that illegal fishing may have occurred within the closed area (Hinz et al., 2013).

As highlighted in previous experimental and short-term studies on this type of habitat in the Mediterranean Sea, the fauna was
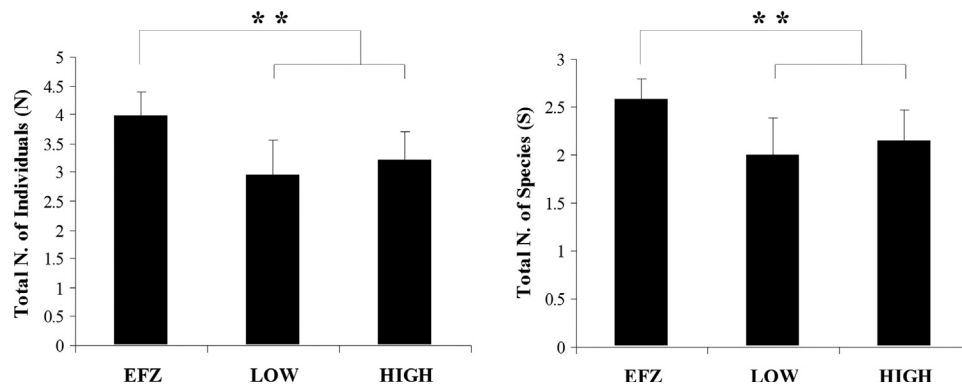
Fig. 6. Mean (± 95% CI) total number of species (S) and total number of individuals (N) along a gradient of fishing intensity from zero, inside the EFZ, to the highest level of exploitation along the continental shelf. The data are shown as Log_{10} (x+1) transformed values. Significant differences are indicated by **$p < 0.01$. Plots correspond to significant results from the ANOVA test (Table 5).
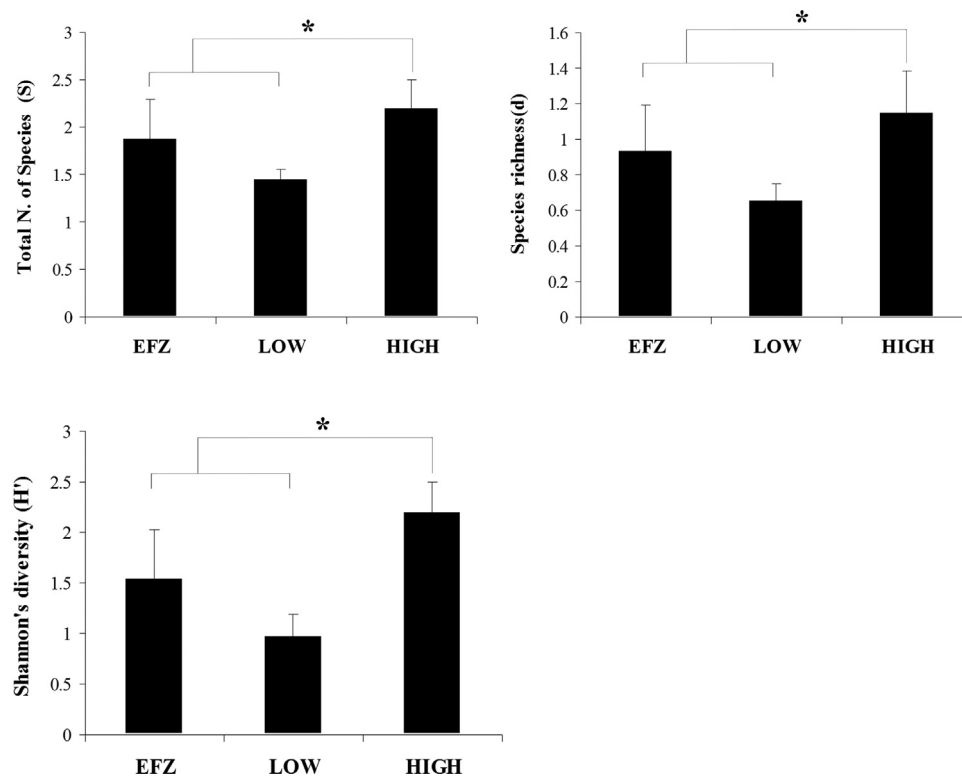

Fig. 7. Response of the total number of species (S), Species richness (d) and Shannon's diversity index (H′) (± 95% CI) along a gradient of fishing intensity from zero, inside the EFZ, to the highest level of exploitation along the upper slope. The data are shown as Log_{10} (x+1) transformed values. Significant differences are indicated by *$p < 0.05$. Plots correspond to significant results from the ANOVA test (Table 5).

generally impoverished, even the area where no fishing disturbance had occurred for several decades (Pranovi et al., 2005; Smith et al., 2000; de Juan et al., 2007; 2011). The presence of impoverished communities characterised by the reduction in the total number of species and density in the most highly exploited areas (Smith et al., 2000), confirmed that the infaunal communities were negatively affected by fishing disturbance.

In general the fished areas of seabed were dominated by a relatively homogeneous community of sedentary vermiform subsurface deposit feeders (Maldanidae) and, opportunistic organisms such as scavenging carnivores (Glyceridae) were more characteristic of sites that experienced the higher values of fishing disturbance. In contrast, fragile particle feeders (reef-forming tube-worms as Spionidae) and fragile bioturbators (J. nocturna and Alpheus glaber) were mainly present only inside the EFZ area.

Both multivariate community analyses and univariate community metrics changed with the level of fishing disturbance on the continental shelf. However, on the upper slope the community responses to fishing disturbance were evident only for univariate community metrics (Table 6, Fig. 7). The lack of such a clear response to fishing disturbance within the upper slope areas may be due a lack of statistical power due to the confounding effects of illegal fishing activity at the sample sites adjacent to the boundary of the Fishery Exclusion Zone inside the Gulf of Patti. This latter hypothesis is supported by the vessel monitoring system data analysis that showed the presence of fishing activity within the EFZ that could have extended to encompass the area from which the upper slope samples were taken. Both of the sampling sites that were located closest to confirmed VMS records within the EFZ had community structures that were most similar to areas of the

upper slope subjected to either low or high levels of fishing disturbance (Fig. 5).

The response of the infaunal community on the upper slope to fishing disturbance is perhaps not intuitive, however a recent study in the Mediterranean demonstrated that demersal trawling leads to significant transport of organic material and sediment off the continental shelf and down the slope (Puig et al., 2012). As otter trawling disturbs the upper layers of sediment this leads to the remobilisation of labile organic material. If the latter is transported down the slope then this would represent a subsidy to biota that feed on organic material (Aller, 1982; Hall, 1994; Hill et al., 1999; Thrush et al., 2008; Palanques et al., 2001). The consequent increase in the availability of organic matter in the sediment may result in an increase in deposit feeders and their associated demersal fish predators (Frid et al., 2000). This may explain why the Terebellidae are more common on the upper slope. Most of the species collected in these areas are subsurface motile burrowers with a more robust body structure and moderate vulnerability that may be located below the depth of penetration by the fishing gear (e.g. the bivalve *Abra longicallus*) (Philippart, 1998; Ramsay et al., 1998; Smith et al., 2000; Brown et al., 2005). In contrast, in the absence of fishing, fragile subsurface organisms, such as the sedentary deposit feeding Cirratulidae and Spionidae, were more abundant in the EFZ together with bioturbating decapod crustaceans and fragile sedentary surface feeding ophiuroids as *A. filiformis*. The notable absence of bioturbating fauna in fished areas of the seabed indicates the potential for a loss of some ecosystem functions that maintain the structure and oxygenation of muddy sediment habitats (Reise, 1981; Fenchel, 1996; Widdicombe et al., 2004). The loss of such organisms would presumably lead to changes in habitat complexity and community structure (Jennings and Kaiser, 1998).

Interestingly this study focused not only on the continental shelf but also on the upper slope for which the impact of trawling remains little studied despite the importance of this area of seabed to the fishing fleet in the Mediterranean basin. The magnitude of the response of benthic infaunal communities to otter trawl disturbance was much more pronounced in the continental shelf compared with the upper slope. Although the finding for the latter may in part be due to an issue of statistical power, this area of seabed appears to be naturally impoverished in terms of faunal diversity. If this holds true, then demersal fishing impact may be much less pronounced in this habitat compared with others.

5. Conclusions

The present study highlights the important role that areas closed to fishing perform by acting as baselines against which communities subjected to fishing disturbance can be compared. Such comparative areas allow a robust assessment of the magnitude of the response of communities to fishing disturbance which could form the basis of developing a management regime to reduce such effects. Soft bottom ecosystems remain poorly studied although they are considered among the most productive, providing habitats for many exploited commercial species with high economic value (Hinz et al., 2009; de Juan et al., 2009; Dimech et al., 2012). The access to VMS data proved an invaluable tool to provide insights into the potential confounding effects of illegal fishing in some areas of the EFZ, and thereby informed the interpretation of the results.

Given that the Fishery Exclusion Zone of the Gulf of Patti has been in place for 22 years, although there are significant and clear differences in benthic community composition on the continental shelf compared with surrounding fished areas, there is sufficient overlap in the community structure to suggest that recovery could be relatively rapid within fishing grounds in the event that demersal fishing were to be removed from an area.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.csr.2013.12.014.

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