Assessing effects of a fishing protected zone on fish assemblages. Roses' bay case study (NW Mediterranean Sea)

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ABSTRACT

Protection zones provide an effective tool for fisheries management and biodiversity conservation. In fact, an increase in abundance, biomass and diversity within protected areas have been well documented. In this study we assess the no fishing effects in a Roses' fishing ground which was closed by fishermen in 2014, in order to protect the *Merluccius merluccius* recruitment. We conducted a comparative approach between inside and outside protected zone to evaluate changes in population density, biomass and diversity of the whole fish community. The size frequency distribution between inside and outside area was also studied to evaluate changes in population size structure for the most abundant species. In addition, for the target species, *Merluccius merluccius*, the sex ratio and the hepatosomatic index was analysed in both areas. The biological data were collected monthly on board trawl fishery vessels, inside and outside the protected area. Results indicate significant increases in all the studied parameters inside the protected area, mainly in biomass. Furthermore, the recruitment of the 6 most abundant species (observed as small-sizes individuals), including hake recruits, was found into the protected area. Also, large-sized individuals of these species were more frequent in this protected area. Our results suggest that the management measured adopted by Roses fishermen have a positive effects in the density, biomass and diversity of fish community, thus aiding recovery of fish stock. However, longer temporally sampling of fishery catches inside and outside the closure area is required in order to confirm the observed positive trends.

INTRODUCTION

Fishing protection zone

Marine protected areas (MPAs) are increasingly use as a tool to manage coastal ecosystems and fisheries (Marinesque et al., 2012; Fox et al., 2012). There are several definitions of marine protected areas. The following definition is used by the Technical Expert Group on Marine and Coastal Protected Areas (CBD, 2004): " Marine and Coastal Protected Area means any confined area within or adjacent to the marine environment, together with its overlying waters and associated flora, fauna, and historical and cultural features, which has been reserved by legislation or other effective means, including custom, with the effect that its marine and/or coastal biodiversity enjoys a higher level of protection than its surroundings". In Spain, MPAs were established by Law 42/2007 of 13 December on Natural Heritage and Biodiversity (Articles 29 and 32), as one of the categories of protected natural areas. In fisheries management, protected areas have a long history. In fact, measures such as area and time restrictions for ensuring the sustainability of a fish stocks or community (e.g. protection of adult spawning grounds or juvenile nursery areas), have been considered also as a MPA (FAO, 2011). The major benefits from protected areas are likely offered to the organisms which are heavily and directly affected by fishing pressure, as fishes (Micheli et al., 2004). Marine reserves can reduce impacts of fishing on benthic habitats, protected species and by-catch species, as well as on ecosystem structure and function. The positive impacts that 'not-take areas' have on adjacent areas enhancing local fisheries, through the emigration or spillover of exploitable fishes have also been documented (Francour, 1994; Halpern, 2003; Goñi et al., 2008; Harmelin-Vivien et al., 2008; Stelzenmüller et al., 2009).

Apart from MPAs, fishery managers have implemented other management measures such as, control of mesh size or size limit (Royal Decree Law 560/1995, dated 7 April), restriction of fishing gears (e.g. the trawling, one of the most important art in the Mediterranean fishing grounds are regulated by Royal Decree Law 1440/1999, dated 10 September) and closed areas and seasons. In the NW Mediterranean a collaboration between scientists from Marine Science Institute of Barcelona (ICM-CSIC), Fishermen's Association of Palamós and the Autonomous Government of Catalonia have result in the official publication in May 2013 of a management plan at local level regulating the fishing activities in the red shrimp fishing grounds of the port of Palamós and fishing capacity of its trawling fleet (Order AAA/923/2013, dated 16 May). The technical measures established by the plan include: fishery closure during two months in winter when juveniles are in the fishing grounds; use of a more selective mesh size (40 mm square instead of 50 mm diamond); reduction of the number of trawlers in the fleet.

This co-management project between stakeholders, resource managers, fishermen and scientists can serve as a model for other areas as Roses Bay that are trying to implement collaborative research and that research can greatly contribute to the realization of community based co-management of marine resources.

Fishery in Roses' Bay

Roses is one of the most important ports of the Catalan Sea. Roses' port is the second one in absolute terms of catches (total tons) and economic importance (total €) of Catalonia. In relative terms, is the fifth in kg/day*vessel and €/day*vessel of Catalonia. The fleet of Roses is composed of four different types of fishing gear and a total of 69 vessels:

1. Bottom trawls: 21 vessels.
2. Purse seines: 6 vessels.
3. Minor arts: 36 vessels.
4. Bottom longlines: 6 vessels.

The trawl fishery is the most important fishery in this port, both in terms of total catches (kg) and in their economic value (€) (Fig. 1).The main target species of the trawl fleet in Roses is *Merluccius merluccius*, which represent the 17,06 % of the total catches. Its economic importance has only briefly been surpassed by the red shrimp *Aristeus antennatus.*

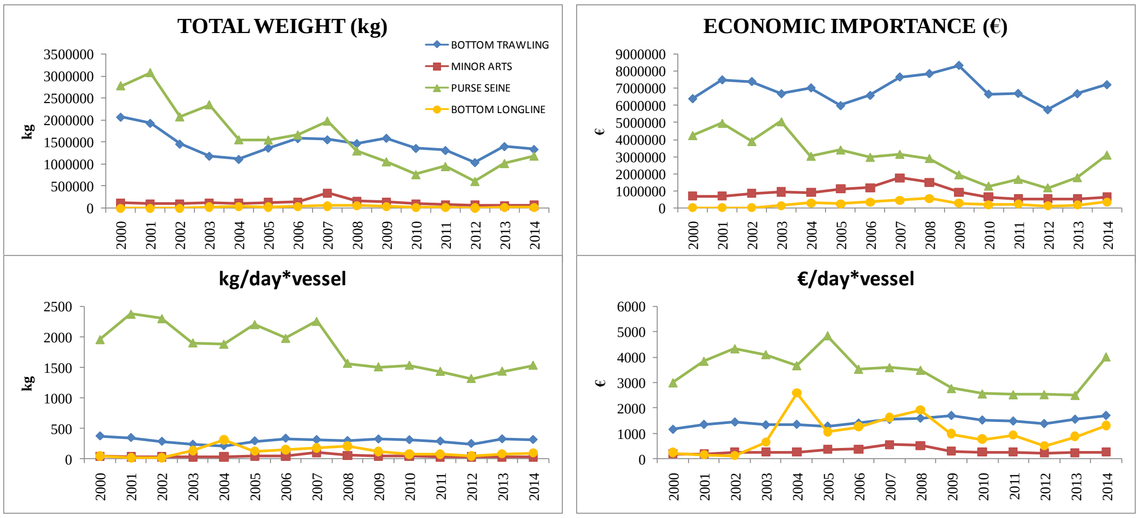

Fig. 1. Temporal variation of Roses' catches since 2000. Blue line: bottom trawling; red line: minor arts; green line: purse seines; yellow line: bottom longline.

The importance of *Merluccius merluccius* is extended to the whole of Mediterranean fisheries where catches increased until 1995 and then abruptly declined to less than a half. From 1995 to 2002 the total caught of hake decrease from 52.000 t/year to 21.000 t/year (FAO, 2005). The assessments of the status of the Atlantic Southern stock (Spanish and Portuguese waters) reveal a marked decline of the spawning stock biomass and this decline has been attributed to overfishing (ICES, 2006). The annual landings of *M. merluccius* in Catalonia, as well as in Roses, shows a decreasing trend in catch rates (Fig. 2). The stock is characterized by growing overexploitation with periodically higher recruitments periods (1998, 2002 and 2008) which ensure the sustainability of the stock at a low level of abundance.

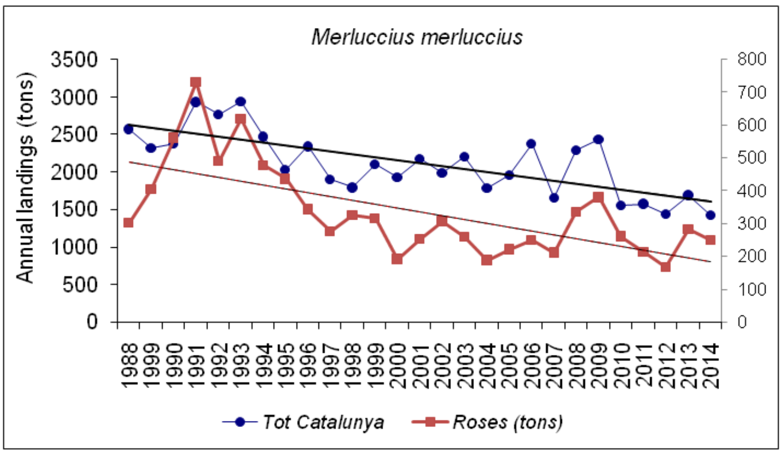

Fig. 2. Temporal variability in the annual landings of *M. merluccius* in Catalan Coast (blue) and in Roses (red).

In order to reduce the observed overfishing growth is necessary the reduction of the fishing pressure. For this reason the Fishermen's Association of Roses proposed the establishment of a temporal closure of a hake's fishing ground at 120 m depth. The fishing ground was selected by the fishermen based on one of the preferential recruitment area of the hake. The area was closed for a period of 7 to 10 months in 2013, coinciding with the period of settlement and growth of the one year old juveniles. Later, in February 2014 the fishing ground was closed permanently. The closure measure could have a double positive effect for the hake population. For one hand, it could favour the recruitment of hake because the recruitment peak occurs at these depths (i.e. 100-200 m depth) in spring and summer (Maynou et al., 2003). For the other hand, it could also protect the spawning females during the main peak of spawning at the end of autumn and beginning of winter (Recasens et al., 2008). Moreover, the protection could have had the same positive effects in all the species that lives associated with the hake, commercial and no commercial fishes, as for example *Scyliorhinus canicula*, *Lepidorhombus boscii* and *Capros aper* (Sanchez et al., 2003).

Aim of the study

Taking into account the previous considerations, the aim of this study is to assess if the protected area has any positive effect on the structure of the demersal fish community associated to *Merluccius merluccius.* The study is based on the comparison of the fish community structure between inside fishing closure area in Roses' Bay and outside. Moreover, some biological parameters of the target species *M. merluccius*, were analysed. The following specific aims that were addressed are:

1. To determine the spatial (inside and outside) variability of density (ind/km^2) and biomass (kg/km^2) values from fish assemblage associated with *M. Merluccius* fishery.
2. To compare several diversity index (i.e. Richness, Shannon index and Margalef index) of the fish assemblage studied.
3. To describe the size frequency distribution of the most abundant species and identity the effect of the closed area.
4. To calculate the sex ratio and hepatosomatic index of the target species *Merluccius merluccius.*

Our hypothesis is that density, biomass, diversity and size range will be higher inside of the non-fishing area than in the adjacent non-protected area. These differences were found previously by other authors in several studies carried out along the Mediterranean coasts (Garcia-Rubies and Zabala, 1990; Francoeur, 1994; Dufour et al., 1995; Harmelin et al., 1995; La Mesa and Vacchi, 1999; Garcia-Charton et al., 2004; Guidetti et al., 2005; Claudet et al., 2006).

MATERIAL AND METHODS

Study area

The protected area, called Z-3 by fishermen, has a surface of 69.55km^2. It represents the 2,7% of the Roses total trawl fishing grounds and is situated between 50-400 m depth (Fig. 3).

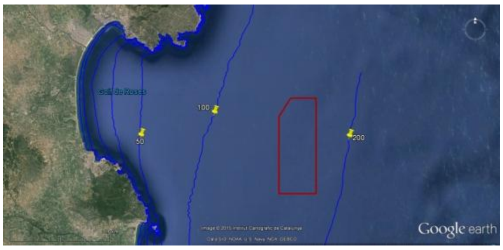

Fig. 3. Fishing ground Z-3 in red. Locations: 42º11’00/3º24’50, 42º09’50/3º23’50, 42º07’50/3º23’50, 42º05’00/3º23’50, 42º11’00/3º27’00, 42º09’50/3º27’00, 42º07’50/3º27’00, 42º05’00/3º27’00.

Sampling

The biological data were collected in the framework of the European hake (*Merluccius merluccius*) monitoring Pilot project conducted in the fishing grounds of Roses’ port from March 2015 to March 2016. The samples were obtained monthly on board two different commercial fishing vessels: ESQUITX (March) and CALANTU (from April to June). The Table 1 showed the characteristics of each sampling. In both vessels samples were obtained using a commercial fishing net (Otter bottom trawl, OTB) with the cod-end squared mesh size of 40 mm.

Table 1. List of the all the trawls conducted during the present study, indicating the data, location, bottom depth and swept area. The locations are classified in "I": inside the protected area; "O": outside the protected area.

Trawls	Loc.	Date	Depth (m)	Start			Finish			Swept area (km^2)
				Hour	Lat	Log	Hour	Lat	Log	
P01	I	17/03/15	131,7	8:11	42,1658	3,4122	10:00	42,0741	3,3948	0,17
P02	I	17/03/15	137,1	11:10	42,1608	3,4246	12:48	42,0740	3,4090	0,15
P03	I	17/03/15	136,8	14:07	42,1662	3,4330	15:52	42,0787	3,3917	0,17
P04	O	18/03/15	137,0	9:32	42,0434	3,3798	11:00	41,9766	3,3179	0,14
P05	O	18/03/15	133,5	12:06	42,0500	3,3804	13:40	41,9853	3,3111	0,15
P06	I	22/04/15	131,5	8:10	42,1767	3,4245	9:18	42,1200	3,4147	0,09
P07	I	22/04/15	133,1	9:40	42,1259	3,4077	11:16	42,0781	3,4039	0,10
P08	O	22/04/15	133,1	11:34	42,0819	3,3424	12:40	42,0173	3,3720	0,10
P09	O	22/04/15	130,7	13:10	42,0537	3,3791	14:20	42,1087	3,3876	0,09
P10	I	28/05/15	136,5	8:10	42,1020	3,4162	9:40	42,1057	3,4131	0,11
P11	I-O	28/05/15	135,9	10:04	42,1024	3,4044	11:07	42,0628	3,3949	0,08
P12	O	28/05/15	134,7	11:32	42,0555	3,3987	12:19	42,0263	3,3694	0,06
P13	O	28/05/15	133,2	12:40	42,0413	3,3781	13:26	42,0698	3,3977	0,06
P14	I	28/05/15	137,4	13:50	42,0996	3,4135	14:45	42,1398	3,4292	0,07
P15	I	23/06/15	144,3	8:15	42,1625	3,4239	9:30	42,0944	3,4063	0,10
P16	O	23/06/15	136,5	10:00	42,0947	3,4060	11:22	42,1495	3,3678	0,14
P17	O	23/06/15	134,0	11:45	42,0250	3,3971	12:45	42,0805	3,3911	0,10
P18	I	23/06/15	147,4	13:15	42,1051	3,6920	14:13	42,1652	3,4233	0,10

A total of 18 bottom trawls were conducted, four for each sampling day, two inside of the protected area and two outside in a nearby place (Fig. 4) at similar depth, with the aim to compare within the same biological community. One extra trawl was conducted during March inside the protected area. The samples obtained during P11 (May) were not analyzed because swept area mixes inside and outside the protected area. In order to minimize the variability in the sampling, all the trawls were conducted at the same bathymetric range (130-144 m depth) in localities with similar sediment morphology and the same characteristics of the mesh (squared, 40 mm size).

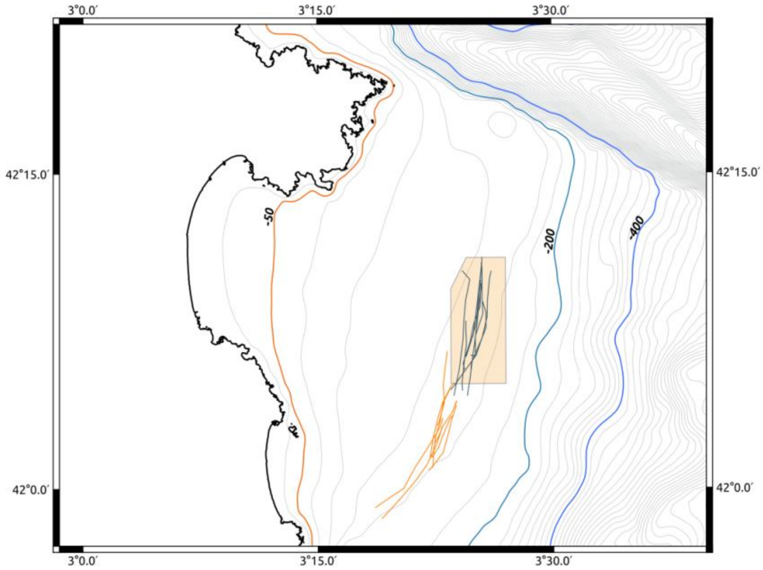

Fig. 4. Sampling trawls in the study area. Gray lines: inside the protected area; Orange lines: outside the protected area.

Biological data

For this study all the fish species captured were included in the analysis (commercial and non commercial species).

Commercial species: data of commercial fishes were collected on board (Fig. 5). Fishes were classified as species level, all individuals were counted to obtain the total abundance (nº individuals) and measured to total length (TL) in mm. For the species *Argentina sphyraena* standard length (SL) was measured because in most cases the tails of individuals were broken and for the analysis the sizes were converted to total length as follow: $\mathrm{TL} = a \times SL^b$. All the *Merluccius merluccius* individuals (or subsamples when the number of individuals was too high) were brought to the Instituto de Ciencias del Mar (ICM-CSIC). In the laboratory all individuals were measured to the nearest 1 mm total length (AL) and weighed to the nearest gram. Sex was determined by macroscopic examination of the gonad. All livers were weighed to the nearest 0,01 g and the hepatosomatic index (HSI) was calculated as follow:

$\mathrm{HSI} = {}^{\mathrm{Wh}}/_{\mathrm{Tw}} \times 100$ (Wh: liver's weight; Tw: eviscerate fish weight).

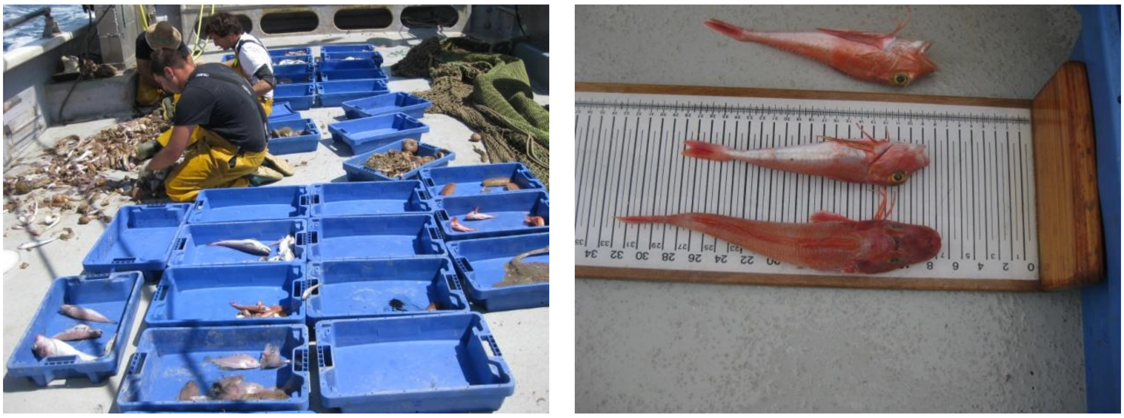

Fig. 5. Images of the sampling and on board collecting data.

Non commercial species: the subsamples of the non commercial fishes (or discard, Fig. 6) were taken on board and were analyzed in the laboratory using the same methodology described previously for the commercial species (number and length by species). Furthermore, all species were weighed to the nearest 0,01 g.

Fig. 6. Images of the work with the non commercial species in the laboratory.

Data analyses

Commercial and no commercial species were analyzed together. All samples were standardized to km^2 of swept seabed area, which was calculated from the vessel speed, average horizontal opening of gear doors and distance between the initial and final position of the gear on the bottom. As follow:

$$\text{Swept area} = \text{BT} \times \text{S} \times \text{H} \times 1852 / 10^6$$

Where BT was the average horizontal opening of the gear's doors (meters), S was the vessel speed (knots, 1 knot= 1852 m/h) and H was bottom time (hours).

Fish assemblage structure was defined for the two sampled localities (inside and outside protected area) by density (nº individuals/km^2) and biomass (kg/km^2). After, several diversity indices were calculated as follow:

Richness (S): total number of species

Shannon's diversity index (H') (Shannon and Weaver, 1949): $H' = -\sum_i \frac{n_i}{n} \ln \frac{n_i}{n}$

Margalef's richness index (Margalef, 1958): $(S - 1) / \ln(n)$

The significance of differences in species density and biomass between localities was determined using a Mann-Whitney *U* test. The significance of differences in species density and biomass between months was analyzed using one-way ANOVA test.

Total weight of species was calculated through length (TL)/weight (W) relationship as follow: $\mathrm{W} = a \times \mathrm{TL}^b$. The parameters *a* and *b* of *Phycis blennoides* were obtained by fish base of PROMETEO project (CTM2007-66316-C02/MAR), the parameters of *Raja polystigma* were calculated from the own data of the project (from individuals that were brought to the laboratory). For the other commercial species (n= 32 the parameters *a* and *b* were obtained from previous published data on *fishbase.org*. For the species that standard length was measured (i.e. *A. sphyraena*), standard length was converted to total length as follow $\mathrm{TL} = a \times S\mathrm{L}^b$: using our own data for the calculation of *a* and *b*.

The size frequency distribution for the most abundant species was plotted by localities and for each sampled month and the resulting variability was described.

RESULTS

Fish assemblage description

A total of 23.020 fish from 54 different species were caught. The species collected from the two locations (inside and outside) are compiled in Table 2. Number, density (individuals/km^2) and biomass (kg/km^2) data are reported per species in each area, with the exception of *Scorpaena loppei* and *Sarda sarda* that the biomass data were not available. The most speciose family was Triglidae (6 species), followed by Sparidae (5 species) and Scorpaenidae (5 species).

Inside the protected area, the number of species that were caught was higher than outside. A total of 51 species were found inside while outside 40 species were found. Of all species caught inside the protected area, 13 were found only in this area (*Raja polystigma, Aspitrigla obscura, Gobius niger, Pomatoschistus sp, Sarda sarda, Scorpaena loppei, Scorpaena notata, Serranus cabrilla, Solea vulgaris, Spicara flexuosa, Spondyliosoma cantharus, Sprattus sprattus, Trachurus picturatus* and *Trigloporus lastoviza*), while only three species were found exclusively outside the protected area (*Apterichtus anguiformis, Glossanodon leioglossus* and *Peristedion cataphractum*). The other 34 species were present in both locations.

The 7 most abundant species (frequency > 5%) represented 80,43% of total density, but only represented 62,36% of biomass. The target species *M. merluccius* represent the 14,63% and 15,89% of total density and biomass respectively, being the second more frequent species of the community, only below *C. aper* in density and *S. canicula* in biomass. The other most frequent species, in terms of density, were *A. sphyraena* (5,29%), *S. canicula* (14,04%), *T. trachurus* (5,05%), *C. aper* (20,08%), *L. boscii* (9,63%) and *L. cavillone* (11,72 %).

Table 2. Species list of the 54 species caught in this study and their species code. Mean values of its densities (ind/km^2) and biomasses (kg/km^2) in each sample area (inside and outside). Frequency is the percentage of the mean value of density. S= species number. The taxonomic list was obtained following the criterion of Nelson (2006). Species in red: species present only inside the protected area; species in blue: were present only outside the protected area.

SPECIES	CODE	INSIDE (S=51)			OUTSIDE (S=40)			FREQ
		Abundance	Biomass	Freq	Abundance	Biomass	Freq	
Order Carcharhiniformes								
Family Scyliorhinidae								
Scyliorhinus canicula	Scy_can	1.866	185,45	11,87	1.311	120,95	19,84	14,04
Order Rajiformes								
Family Rajidae								
Raja polystigma	Raj_pol	25	14,89	0,16	0	0,00	0,00	0,11
Order Torpediniformes								
Family Torpedinidae								
Torpedo marmorata	Tor_mar	16	0,57	0,10	4	0,40	0,07	0,09
Order Anguilliformes								
Family Ophichthidae								
Apterichtus anguiformis	Apt_ang	0	0,00	0,00	5	0,02	0,08	0,02
Family Congridae								
Conger conger	Con_con	56	24,76	0,36	10	3,90	0,15	0,30
Order Clupeiformes								
Family Engraulidae								
Engraulis encrasicolus	Eng_enc	95	0,98	0,60	175	1,92	2,65	1,16
Family Clupeidae								
Sprattus sprattus	Spr_spr	15	0,18	0,09	0	0,00	0,00	0,07
Order Argentiniformes								
Family Argentinidae								
Argentina sphyraena	Arg_sph	1.050	20,48	6,68	103	1,31	1,56	5,29
Glossanodon leioglossus	Glo_lei	0	0,00	0,00	5	0,02	0,08	0,02
Order Gadiformes								
Family Merlucciidae								
Merluccius merluccius	Mer_mer	2.268	154,34	14,42	1.004	30,21	15,18	14,63
Family Phycidae								
Phycis blennoides	Phy_ble	349	57,23	2,22	136	15,86	2,06	2,18
Family Gadidae								
Gadiculus argenteus	Gad_arg	15	0,02	0,09	81	0,36	1,23	0,40
Trisopterus capelanus	Tri_cap	293	8,46	1,86	102	2,86	1,54	1,77
Order Lophiiformes								
Family Lophiidae								
Lophius budegassa	Lop_bud	47	1,09	0,30	11	0,24	0,17	0,27
Lophius piscatorius	Lop_pis	137	119,13	0,87	57	41,89	0,86	0,87
Order Zeiformes								
Family Zeidae								
Zeus faber	Zeu_fab	4	2,99	0,03	2	0,15	0,03	0,03

SPECIES		INSIDE (S=51)			OUTSIDE (S=40)			FREQ
		Abundance	Biomass	Freq	Abundance	Biomass	Freq	
Order Scorpaeniformes								
Family Scorpaenidae								
Helicolenus dactylopterus	Hel_dac	163	7,96	1,04	5	0,53	0,08	0,78
Scorpaena elongata	Sco_elo	15	15,14	0,09	0	0,24	0,00	0,07
Scorpaena loppei	Sco_lop	178	-	1,13	0	-	0,00	0,82
Scorpaena notata	Sco_not	18	3,89	0,11	1	0,00	0,01	0,09
Family Triglidae								
Aspitrigla cuculus	Asp_cuc	25	2,45	0,16	65	5,22	0,99	0,38
Aspitrigla obscura	Asp_obs	3	0,20	0,02	0	0,00	0,00	0,01
Eutrigla gurnardus	Eut_gur	52	3,41	0,33	59	2,06	0,89	0,48
Lepidotrigla cavillone	Lep_cav	2.356	36,37	14,98	197	2,36	2,98	11,72
Trigla lucerna	Tri_luc	2	4,09	0,01	2	0,88	0,03	0,02
Trigla lyra	Tri_lyr	14	0,54	0,09	16	0,76	0,24	0,13
Trigloporus lastoviza	Tri_lac	1	0,22	0,01	0	0,00	0,00	0,01
Family Peristediidae								
Peristedion cataphractum	Per_cat	0	0,00	0,00	9	0,04	0,13	0,04
Order Perciformes								
Family Serranidae								
Serranus cabrilla	Ser_cab	16	0,19	0,10	0	0,00	0,00	0,08
Serranus hepatus	Ser_hep	11	0,27	0,07	15	0,23	0,22	0,11
Family Carangidae								
Trachurus picturatus	Tra_pic	3	0,35	0,02	0	0,00	0,00	0,02
Trachurus trachurus	Tra_tra	894	67,90	5,68	221	14,41	3,35	5,05
Family Sparidae								
Boops boops	Boo_boo	114	15,06	0,72	17	1,45	0,26	0,60
Pagellus bogaraveo	Pag_bog	55	1,84	0,35	24	0,83	0,36	0,35
Spicara flexuosa	Spi_flex	28	0,82	0,18	0	0,00	0,00	0,13
Spicara smaris	Spi_sma	42	0,61	0,27	5	0,09	0,08	0,22
Spondyliosoma cantharus	Spo_can	4	0,67	0,03	0	0,00	0,00	0,02
Family Mullidae								
Mullus barbatus	Mul_bar	132	9,36	0,84	114	7,05	1,73	1,08
Mullus surmuletus	Mul_sur	220	32,59	1,40	21	2,07	0,32	1,11
Family Blenniidae								
Blennius ocellaris	Ble_oce	3	0,12	0,02	13	0,29	0,20	0,07
Family Callionymidae								
Callionymus maculatus	Cal_mac	608	2,45	3,87	95	0,54	1,44	3,21
Family Gobiidae								
Gobiidae	Gob_spp	15	0,04	0,27	6	0,00	0,00	0,20
Gobius niger	Gob_nig	42	0,10	0,10	0	0,01	0,09	0,10
Pomatoschistus sp	Pom_sp	15	0,00	0,10	0	0,00	0,00	0,07
Family Scombridae								
Sarda sarda	Sar_sar	2	-	0,01	0	-	0,00	0,01
Scomber scombrus	Sco_sco	61	1,65	0,39	1	0,21	0,02	0,29
Family Caproidae								
Capros aper	Cap_ape	2.730	21,54	17,36	1.810	12,03	27,38	20,08

SPECIES	CODE	INSIDE (S=51)			OUTSIDE (S=40)			FREQ
		Abundance	Biomass	Freq	Abundance	Biomass	Freq	
Order Pleuronectiformes								
Family Citharidae								
Citharus linguatula	Cit_ling	42	3,82	0,27	79	6,28	1,20	0,52
Family Scophthalmidae								
Lepidorhombus boscii	Lep_bos	1.430	45,87	9,09	731	19,98	11,07	9,63
Family Bothidae								
Arnoglossus laterna	Arn_lat	111	0,50	0,71	75	0,44	1,13	0,82
Family Soleidae								
Solea vulgaris	Sol_vul	1	0,44	0,01	0	0,00	0,00	0,01
Family Soleidae								
Microchirus variegatus	Mic_var	6	0,13	0,04	1	0,00	0,01	0,03
Monochirus hispidus	Mon_his	47	2,83	0,30	8	0,31	0,12	0,25
Family Cynoglossidae								
Symphurus nigrescens	Sym_nig	28	0,55	0,18	10	0,17	0,15	0,17

Density (ind/km^2) and biomass (kg/km^2) patterns

Density and biomass were higher inside the protected area than outside (Fig. 7A). The mean value of density inside was 15.724 ind/km^2 while outside only was 6616 ind/km^2. For the biomass, the mean value inside the protected area was 874,59 kg/km^2 while outside was 298,56 kg/km^2. The results of the Mann-Whitney *U* test (Table 3) showed that the differences in density and biomass between the protected area and the adjacent locality were significant ($p<0.05$).

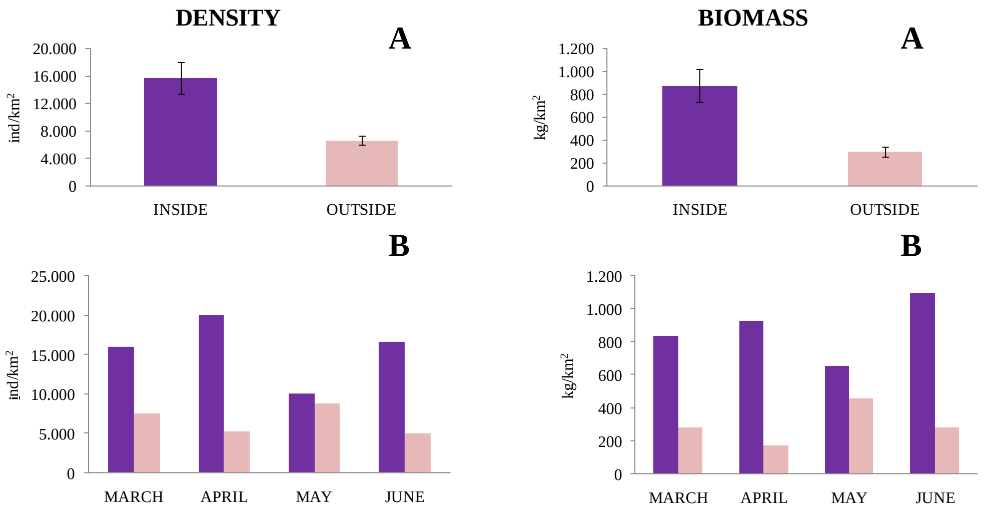

Fig. 7. A. Mean values of density (ind/km^2) and biomass (kg/km^2) inside the protected area (purple) and outside (pink). **B.** Mean values of density and biomass by months.

Figure 7B shows the temporal differences in density and biomass values between areas. Inside the protected area, density was highest in April (20.033 ind/km^2) while biomass was highest in June (1.097,5 kg/km^2). The lowest values for both parameters in the protected area were in May (10.067 ind/km^2; 653,2 kg/km^2). Outside the protected area, temporal variability was lower. Here, we found the higher density and biomass values in May (8.809 ind/km^2; 458,4 kg/km^2). The month with less density was June (4.982 ind/km^2) while for biomass was April (174,8 kg/km^2). The temporal differences in density between areas were significant (Table 3) in April and June ($p<0,05$). The temporal differences in biomass between areas were significant in all the months studied (Table 3).

Table 3. Mann-Whitney *U* test for density and biomass between the two areas. Significant p-values are indicated in bold numbers.

DENSITY	U	p
March	520	0,150
April	337	**0,043**
May	464	0,303
June	560	**0,002**
Mean	1.087	**0,011**

BIOMASS	U	p
March	390	**0,021**
April	290	**0,018**
May	332	**0,036**
June	563	**0,004**
Mean	912,5	**0,004**

In order to determinate if temporal variability was driving the observed patterns (e.g. higher density inside than outside), the density and biomass by months was analyzed.

The results of the ANOVA test showed that the temporal variation was not significant for density values ($F= 0,18$; $p= 0,91$) and not either for the biomass values ($F= 0,08$; $p= 0,97$).

The density and biomass of the most frequent species was compared between the two sampled areas (Fig. 8). For both parameters, inside the protected area the values were higher than outside for all the analyzed species. *A. sphyraena* and *L. cavillone* showed a clearly difference between areas showing the higher values of density (1.050 ind/km^2 and 1.356 ind/km^2 respectively) and biomass (20,48 kg/km^2 and 36,37 kg/km^2 respectively). In fact, the biomass of *A. sphyraena* and *L. cavillone* inside the protected area was more than 90% of the total biomass of these species. In contrast, these species outside the protected area showed very low values of both parameters (for A. *sphyraena* density= 103 ind/km^2, biomass= 1,31 kg/km^2; for *L. cavillone* density= 197ind/km^2, biomass= 2,326 kg/km^2). Although *M. merluccius* showed inside/outside differences in both parameters, the observed difference were more marked in terms of biomass (154,34/30,21 kg/km^2) than in terms of density (2.268/1.004 ind/km^2). The most abundant species inside and outside the protected area was *C. aper* (2730 ind/km^2 and 1810 respectively ind/km^2). In terms of biomass, *S. canicula* showed the highest value on the fish community studied (185,45 kg/km^2 inside the protected area and 120,95 outside). Moreover, this species showed the lowest difference between areas in both parameters, density and biomass.

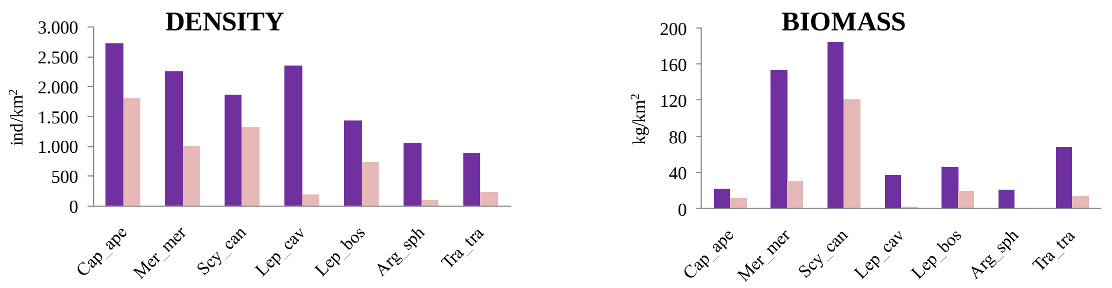

Fig. 8. Mean values of density (ind/km^2) and biomass (kg/km^2) of the 7 most frequent species. Purple bars: inside the protected area; Pink bars: outside the protected area.

Diversity

Some diversity indices were calculated. Species richness (S), Shannon's diversity index (H') and Margalef's richness index (Margalef) were higher inside the protected area than outside (Table 4). Both indices include the number of individuals as well as number of taxa.

The species richness (S) showed higher values inside the protected area along all the studied months showing its maximum value during June, when 37 different fish species were collected. In contrast, in the non-protected zone (outside) the minimum value was founded in April.

The Shannon index presented higher values inside the protected area than outside along all the sampled months, except in April when same value of Shannon index in both areas have found. Margalef index was higher inside than outside in all the samples except in June, when the calculated index was highest outside. In May, both diversity indices, Shannon and Margalef, showed a high marked difference between the protected area and the outside location.

Table 4. Values of the species richness (S), Shannon index (H') and Margalef index (Margalef) in each area per each month.

DIVERSITY	S		H'		Margalef	
	Inside	Outside	Inside	Outside	Inside	Outside
March	32,0	28,0	2,4	2,3	3,2	3,0
April	29,0	22,0	2,4	2,4	2,8	2,5
May	29,0	24,0	2,4	2,0	3,0	2,5
June	37,0	33,0	2,6	2,2	3,7	3,8
TOTAL	**51,0**	**41,0**	**2,6**	**2,3**	**5,2**	**4,5**

Size distribution

The size distribution as function of location (inside and outside) was analyzed for 6 of the 7 most frequent species (*Capros aper, Merluccius merluccius, Scyliorhinus canicula, Lepidotrigla cavillone, Lepidorhombus boscii, Trachurus trachurus*).

For all the species analyzed the sizes range were higher inside than outside (Fig.9). Smallest individuals were present inside the protected area. For most of the species, the largest individuals were also found only inside the protected zone except for S. *canicula* which showed similar density of largest individuals in both areas.

Inside protected area a right-skewed size frequency distribution was founded for most of the species comparing to the outside distribution size frequency, suggesting a higher concentration of small individuals in the protected area. For example, the maximum density of *C. aper* was found inside the protected area in individuals between size 60-65 mm (815,3 ind/km^2) while the maximum densities of the individuals collected outside was between 65-70 mm (521,1 ind/km^2). Similar results were founded in *L. boscii* where inside the protected area the maximum density was found in individuals between 60-65 mm (216,7 ind/km^2) while in the non protected area the peak was found between 140-145 mm size (112,8 ind/km^2). The target species *M. merluccius* showed a clear right-skewed size frequency distribution with a peak of small individuals inside the protected area. In contrast, outside, the size distribution was more homogeneous.

L. cavillone, T. trachurus and *S. Canicula* showed similar size distribution in both areas with higher values of density inside the protected area.

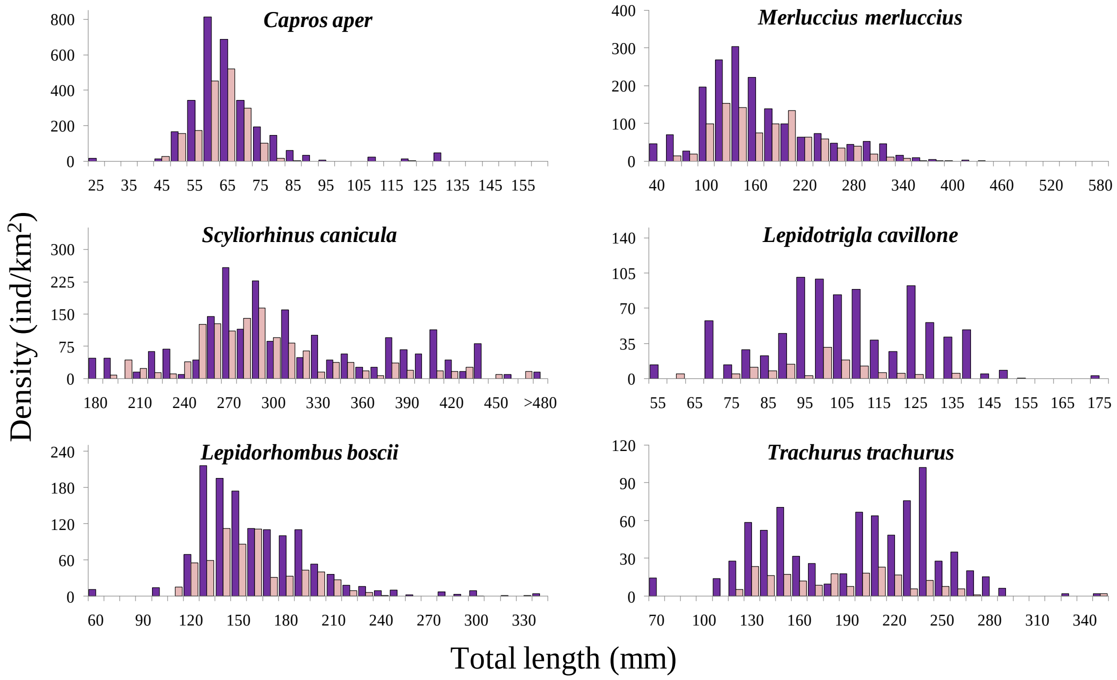

Fig. 9. Size frequency distribution of 6 analyzed species (mean values of density). Purple bars: individuals of the area protected; Pink bars: individuals of the non-protected area.

Difference in the recruit temporality was found for the 6 species studied (Fig. 10). The recruits of *L. cavillone* (55-60 mm) appeared during March while the recruitment of *M. merluccius* (40-80 mm), *S. canicula* (180-200 mm) and *L. boscii* (60-70 mm) was found in April. *C. aper* recruits (25-35 mm) were observed with low frequency in May in both areas, while in June recruits were present only inside the protected area. On June recruits of *T. trachurus* (70-80 mm) were found.

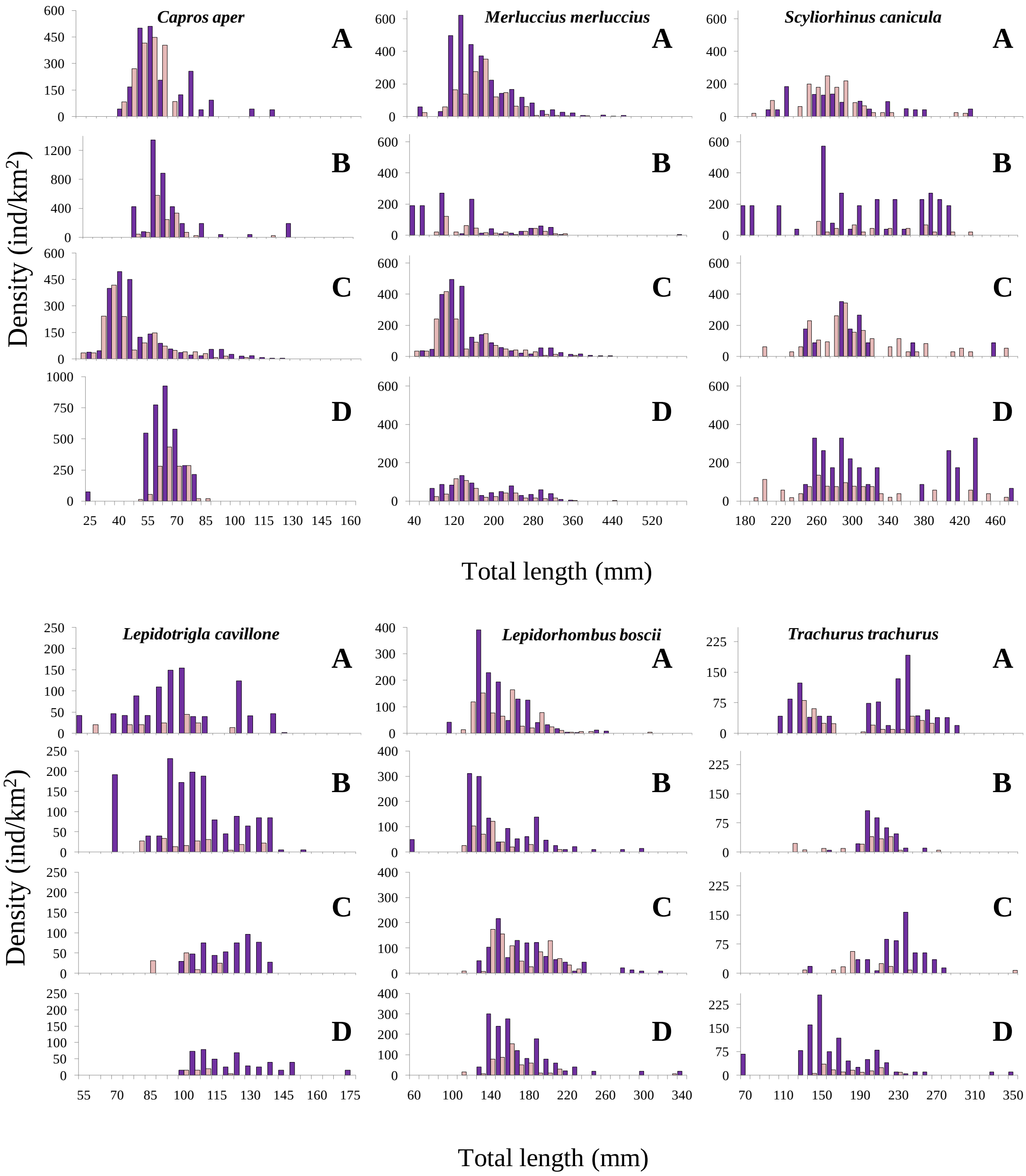

Fig. 10. Size frequency distribution of the analyzed species by month, A: March; B: April; C: May; D: June (mean values of density). Purple bars: individuals of the area protected; Pink bars: individuals of unprotected area. Density of *Capros aper* is in different scale for each month.

Merluccius merluccius: case study

Specific results for the target species *M. merluccius* as a case study were obtained. The sex ratio of *M. merluccius* was analyzed for both areas, inside the protected area and outside. Immature individuals were defined as the small individuals with undifferentiated gonads. The sex proportions for each location are shown as percentages in Table 5. In both areas females were predominant; the overall sex ratio was 1:0,73 for females' vs. males. Inside the protected area the sex ratio was 1:0,77 while outside the proportion of males was lower, 1:0,67. The difference between the protected area and outside in sex ratio was significant (chi-square= 5,74; p= 0,017).

Table 5. Percentage of females and males over total mature individuals captured of *Merluccius merluccius* by each sampling location, inside and outside the protected area.

Location	Inside	Outside
Male (%)	43,57%	40,21%
Female (%)	56,43%	59,79%

The size-frequency distribution of males and females was analyzed (Fig. 11). In each location, the largest individuals were females and the smallest individuals (110-130 mm) were males. The largest females (570-590 mm) were found inside the protected area.

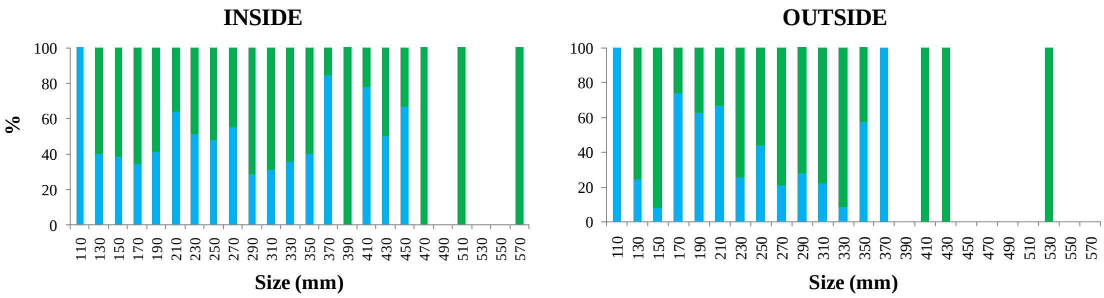

Fig. 11. Length distribution of *Merluccius merluccius* by sex ratio proportion, inside and outside the protected area. Green bars: females; blue bars: males.

Figure 12 showed the results of the hepatosomatic index (HSI). HSI increase following a temporal pattern, minimum values were found in March and increase progressively until June, when the maximum values of HIS were found. Similar values of HSI between the two areas were found for all the individual analysed, males and also females.

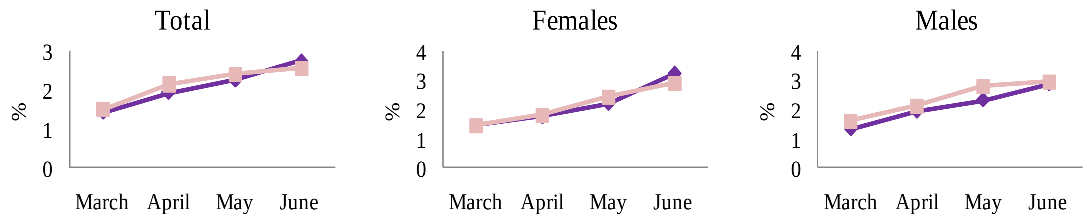

Fig. 12. Hepatosomatic index of all the individual analyzed (a), males (b) and females (c) by month.Purple lines: inside the protected area; pink lines: outside the protected area.

DISCUSSION

The closure of areas to fishing and establishment of MPAs can effectively increase the yield by increasing recruitment and reducing fishing mortality (Gell and Roberts, 2003). Similarly, the results from the study conducted in the 'no take' area of Roses showed that the measures adopted by fishermen have positive effects on fish populations. In the Mediterranean, the majority of MPAs are designed to protect rocky littoral areas and the effects in these zones are largely studied (e.g. Benedetti-Cecchi et al., 2003; Garcia-Charton et al 2004; Claudet et al. 2006, Sahyoun et al., 2012). In the Catalan Sea there are not protected areas on the shelf, in the zone where fishermen usually works. Thus, this is the first evaluation study of an MPA created as a management tool to protect the recruitment of hake (*Merluccius merluccius)*, one of the most important commercial species for the trawl fisheries in the Mediterranean Sea.

The analysis of density and biomass of the most frequent species in this study showed that the differences in both parameters between inside and outside the protected area are much higher in commercial species (*Merluccius merluccius*, *Lepidotrigla cavillone, Lepidorhombus boscii* and *Trachurus trachurus*) than in non commercial ones (*Scyliorhinus canicula* and *Capros aper*). Moreover, some commercial species are presented exclusively in the protected area. This is the case of *Raja polystigma*, an endemic species of the Mediterranean Sea. The minimum size at which this species is mature appears to be close to its maximum size (60 cm). Thus, this species is more sensitive and would not be able to "escape" fishing exploitation (Ferretti et al., 2005). The presence of vulnerable species as *Raja polystigma* exclusively in the protected area suggest that the close area could act as refuge for vulnerable species as has been also found for other species (García-Rubies and Zabala 1990; Pastor et al., 2009).

In contrast, the most abundant non commercial species analyzed, *S. canicula* and *C. aper* showed lower difference in density and biomass between the protected area and the surrounding non protected area. The lower effect of the protection in this species could be caused by the high survival rate of the species. Most of the individuals of this species are returned to the sea shortly after being captured and thus can survive. In fact, in the Western English Channel beam trawl fisheries, *S. canicula* exhibited a very high survival rate of 98% (Revill et al., 2005).

The increase of diversity indexes inside the protected areas has been studied previously in other places (Helpern 2003, Russ et al 2004, Stelzenmüller et al 2009). The results of the present study confirm the positive effects of non-fishing area in terms of richness, Shannon index and Margalef index showing, in general, higher values inside the protected area than outside. Similar results of diversity were described in a comparative study conducted by Garcia-Rubies and Zabala (1990). These authors found higher values of mean richness and Shannon index inside than outside the protected area.

The size frequency distribution showed similar pattern that the one observed for density and biomass. Commercial species showed marked differences between the two studied areas (inside and outside) while non commercial species (*C. aper* and *S. canicula*) presented the lowest difference between areas. Outside the protected area, the size distribution of some of the commercial fishes studied (i.e. *Lepidorhombus boscii* and *Trachurus trachurus*) showed a slight reduction in their medium sizes. This is a characteristic of species under fishing pressure (Colloca et al., 2013). The absence of fishing pressure inside the protected area would also justify the presence of the largest individuals in this area. Larger sizes could have positive effects in the reproduction for two reasons, in one hand, the presence of larger individuals guaranteed that all of them are overcome the first maturity size. In the other hand, in most of marine fish species there is a positive relationship between the length and total fecundity (Murua et al., 2003), like *Merluccius merluccius* (Recasens et al., 2008). Although the results are still preliminary, the presence of larger females inside the protected area could suggest that this non-fishing area could act as preference spawning site for several species as has been found in other areas (Gell and Roberts, 2003).

The present study showed a recruitment period of the most frequent species during the sampling months. *Lepidorhombus boscii,* showed its maximum of juveniles in April in agreement with the results found previously by Sanchez (2003). The recruitment peak of *Merluccius merluccius* and *Lepidotrigla cavillone* was founded in spring as have been also described on the literature (Tortonese, 1970; Recasens et al., 1998)

The recruitment peaks of the species analyzed occur with different intensity and with different temporality. This fact could be a strategy for minimize the competition for the food resources between the juveniles of the different species, especially in the oligotrophic Mediterranean Sea. However, these results were obtained based on 6 months of sampling, thus, are still preliminary and all year around data will be need in order to determine the preference recruitment periods of the species.

The European hake (*Merluccius merluccius*) is among the main target species of the Mediterranean demersal fisheries (Gucu and Bongel, 2011) and is the target species of the fishery that we analyzed in the present study. In agreement with the results obtained for the other commercial fishes analyzed in the present study, hake showed higher values of density and biomass inside the protected area than its adjacent ground. The results also showed that the smaller and the larger individuals were inside the protected area. The results of the sex ratio are in agreement with other studies that reported that the females developed larger body size than males (Recasens, 1992; Recasens et al., 1998). The total number of females was higher inside the protected area than outside. The positive relationship between size and batch fecundity suggested that the closed area could favors the spawning capacity of the species. Designation closed area that protect that protect a proportion of spawning stock biomass, especially the larger individuals, could ensure the robustness of the fishery under environmental or anthropogenic perturbations (Johnson and Sandell, 2014). Temporally, the hake recruits present their maximum abundance in April (Recasens et al., 1998; Maynou et al., 2003; Abella et al., 2005). Hidalgo et al (2008) evidence a strong correlation between the abundance of recruits of *M. merluccius* and the phytoplankton pigment concentration recorded in the area one and two months before.

The Hepatosomatic Index (HSI) gives us information about energy reserves and it is important for the population success because it has a large influence on growth, survival and reproduction (Shulman and Love, 1999). The progressively increment in HSI from March to June suggested the increasing role of the liver as an energy store for reproduction in hake which occurs in summer (Lloret et al., 2008)

Finally, we should remark that this study was conducted in the framework of a pilot project with one year of duration. For the present study we use the data collected during the first four months of the sampling. Thus, the complete annual sampling cycle of fishery catches inside and outside the closure area will be required in order to confirm the observed positive trends of the closed area on the Mediterranean fish community.

CONCLUSIONS

The results of the present study exemplify how a fishing protected area induces significant changes in the fish assemblages that inhabit the area. The benefits of non fishing are evident for the whole fish community. However, the results showed that the commercial species were more positively affected by the measurement. Specially, *Merluccius merluccius*, the target species of our study area, showed an increase on its density, biomass and size range inside the protected area. For this reason, we suggest that a no-take zone in the Mediterranean shelf could be an appropriate management strategy in order to increase the viability of over-exploited species and the associated ecosystem.

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