Mediterranean Marine Science

Vol 15, No 3 (2014)

Vol 15, No 3 (2014)

Biology and population dynamics of by-catch fish species of the bottom trawl fishery in the western Mediterranean

F. ORDINES, M.T. FARRIOLS, J. LLEONART, B. GUIJARRO, A. QUETGLAS, E. MASSUTÍ

doi: 10.12681/mms.812

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.812

Biology and population dynamics of by-catch fish species of the bottom trawl fishery in the western Mediterranean

F. ORDINES[1], M. T. FARRIOLS[1], J. LLEONART[2], B. GUIJARRO[1], A. QUETGLAS[1] and E. MASSUTÍ[1]

[1] Instituto Español de Oceanografía, Centre Oceanogràfic de les Balears, Moll de Ponent s/n, 07015 Palma de Mallorca, Spain
[2] Institut de Ciències del Mar (CSIC), Passeig Marítim 37-49, 08003 Barcelona, Spain

Corresponding author: xisco.ordinas@ba.ieo.es

Handling Editor: Konstantinos Tsagarakis

Received: 25 February 2014; Accepted: 20 July 2014; Published on line: 26 September 2014.

Abstract

The teleosts *Chelidonichthys cuculus*, *Trigloporus lastoviza*, *Serranus cabrilla* and *Trachinus draco*, are important by-catch species, in terms of landed biomass and commercial value, from the continental shelf bottom trawl fishery off the Balearic Islands (western Mediterranean). The main biological parameters of these species were calculated from monthly biological samplings, and were used along with three-year pseudo-cohorts (2008-2010) obtained from monitoring on-board of the bottom trawl fleet, to assess their exploitation level through Virtual Population Analysis (VPA) and Yield per Recruit (Y/R) analysis. Time series of fishery independent indicators based on MEDITS surveys data such as the evolution of the abundance and biomass, the distribution range, and the Conservation Status of Fish*b* (CSF*b*), were also analyzed.

All four species analyzed showed growth overfishing. The reductions of fishing effort required to reach the $Y/R_{F0,1}$ reference point were lower, 66-73% depending on the species, to those reported for the target species *M. merluccius* (87%), but higher than that reported for *M. surmuletus* (53%), in the study area in the period 2000-2010. The abundance and biomass, and the distribution range did not show any trend for the period 2001-2011, whereas the CSF*b* showed signs of recovery that may be due to the displacement of the trawl fishing effort from the shelf to the slope during the last decade. Our results underline the necessity of incorporating monitoring and assessment of by-catch species in fisheries management, given that their populations can show more pronounced overexploitation than target ones.

Keywords: By-catch fish species, biological parameters, fishing exploitation, fishery independent indicators, assessment.

Introduction

A large number of studies assess the main biological parameters and population dynamics of the most important species for fisheries. Moreover, the level of exploitation and status of some target stocks is periodically assessed, and this information can be used in the management of fisheries. During the last decades, the assessment and management of fisheries has progressively changed from a single-species to an ecosystem approach (Browman & Stergiou, 2004). The sustainability of marine ecosystems and fisheries requires avoiding the degradation of ecosystems, taking into account not only the target species for fisheries, but also the other components of the ecosystem (e.g. non-target species, vulnerable species, environmental conditions and trophic webs) and elucidating habitats critical to species for vital population processes (Pikitch *et al.*, 2004).

The Mediterranean Sea is characterized by high diversity, both at community and species level (Pérès & Picard, 1964; Fredj *et al.*, 1992; Bianchi & Morri, 2000), which is also reflected in the catch of its fisheries. This is particularly clear for the bottom trawl, highly multi-specific (Lleonart & Maynou, 2003) and with a large amount of by-catch of both commercial and non-commercial species and discards (e.g. Stergiou *et al.*, 1997; Moranta *et al.*, 2000). In this area, single-species approach to fisheries has mainly been focused on the target species, but very few studies have addressed by-catch ones (e.g. Farrugio *et al.*, 1993; Lleonart & Maynou, 2003; Moranta *et al.*, 2008). This is probably due to both the lack of biological data, and incomplete information about fishing exploitation of these species. That is the case of the bottom trawl fishery along the continental shelf, off the Balearic Islands (western Mediterranean), between 50 and 200 m depth, whose main target species are the striped red mullet (*Mullus surmuletus*) and picarel (*Spicara smaris*), and the cephalopod common octopus (*Octopus vulgaris*) on the shallow shelf, and the European hake (*Merluccius merluccius*) on the deep shelf (Palmer *et al.*, 2009). However, up to 67 species (57 fishes, 8 cephalopods and 2 decapod crustaceans) are commonly captured (Ordines *et al.*, 2006). Most of these by-catch fish species, with the exception of *Trachurus* spp., and large specimens of *Scorpaena* spp., *Lophius* spp., *Zeus faber* and *Lepidorhombus* spp., are sold together, in a mixed fish category (MFC) known as "morralla". This is common practice in some areas of the Mediterranean, allowing commercialization of species, which separately would have a low commercial value or could not even be sold on the fish market.

In Mallorca (Balearic Islands; Fig. 1), within the MFC, the teleost fishes *Chelidonichthys cuculus* and *Trigloporus lastoviza*, both belonging to the family Triglidae, and *Serranus cabrilla* and *Trachinus draco*, belonging to the families Serranidae and Trachinidae, respectively, are among the most important species (Ordines *et al.*, 2006). These species are also among the most important components of the demersal assemblages present on the continental shelf, *T. lastoviza* appearing almost exclusively on the shallow shelf (<100 m), *S. cabrilla* and *T. draco* having a wider bathymetric range including both the shallow and middle shelf down to 150 m, and *C. cuculus* being deeper distributed in the middle and deep shelf down to around 200 m (Massutí & Reñones, 2005). Despite their importance in demersal communities and fisheries in the Mediterranean, these species have received relatively limited attention, with the information remaining fragmented in most cases, while very few studies cover the main traits of the life history of these species (*C. cuculus*: Colloca *et al.*, 2003; *S. cabrilla*: Torku-Koc *et al.*, 2004; İlhan *et al.*, 2010).

Within the ecosystem approach to fisheries assessment and management, habitats are receiving increasing attention and the identification and mapping of some sensitive and essential fish habitats is now a mandate of the European Commission (Council Regulation EC 1967/2006). However, there is still poor knowledge on an important aspect of multi-specific fisheries, such as the level of exploitation of by-catch species. The present work aims to describe the main biological parameters of *C. cuculus, T. lastoviza, S. cabrilla* and *T. draco* and to assess the population dynamics and exploitation of these important by-catch species in the bottom trawl fishery off the Balearic Islands. The results obtained will contribute to the improvement of the biological knowledge of poorly studied fish species in the western Mediterranean and to the assessment of the bottom trawl fishery developed in the area.

Material and Methods

Sampling of the commercial fishery

The information on landings of the bottom trawl fleet operating off Mallorca was obtained from the official statistics facilitated by OP MALLORCAMAR, the fisheries producers of Mallorca. These data consist of daily sale bills, with the biomass and price of each commercial category by boat.

During 2008-2010, sampling of commercial catches was monthly, conducted on board commercial bottom trawlers from Alcúdia, Palma and Santanyí, three of the most important fishing ports in Mallorca (Fig. 1), whose fleet operates on the continental shelf. This sampling was developed within the Data Collection Framework (Commission Regulation EC Nº 1639/2001) and included information on the composition of the MFC (weight and number of individuals of each species gathered in this category), discards and landings, and the length frequency distribution of representative samples of *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco* (Table 1).

During 2001-2002, monthly samplings of the studied species were carried out, from commercial landings, at the laboratory, including individual total length (TL, to the nearest mm), total weight (TW), eviscerated weight (EW) and gonad weight (GW). All these weights were measured to the nearest 0.01 g. Sex and maturity were also determined from the macroscopic observation of the gonads, according to the maturity scale described in Brown-Peterson *et al.* (2011), and sagittal otoliths were removed (Table 1).

Sampling during scientific surveys

Data and samples were also collected from the MEDITS bottom trawl surveys, carried out annually

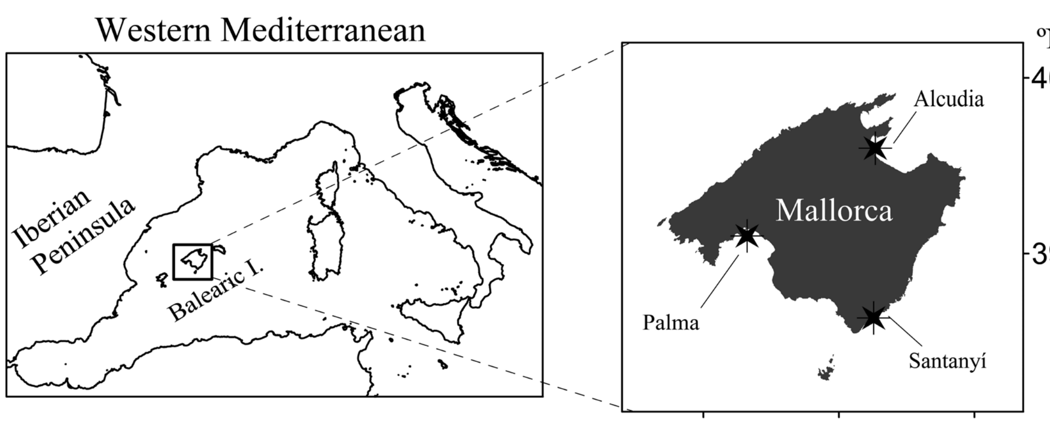

Fig. 1: Map of the study area (Mallorca; Balearic Islands; western Mediterranean) showing the three harbours considered: Alcúdia, Palma and Santanyí.

Table 1. Number of individuals sampled by data source and species.

Source	Sampling	*C. cuculus*	*T. lastoviza*	*S. cabrilla*	*T. draco*
On board (2008-10)	Length	3041	1134	2147	3485
Landings (2001-02)	Biological	261	542	553	595
	Otoliths	227	436	338	553
Surveys (2001-11)	Length	12718	4341	9561	7257
	Biological	1899	886	1985	1459
	Otoliths	646	663	743	652

since 2001 around Mallorca-Menorca during May-July, between 50 and 800 m depth. The sampling scheme, stratified considering four depth strata (50-100, 101-200, 201-500 and 501-800 m), and the gear used in these surveys were the same as those used throughout the Mediterranean in bottom trawl surveys since 1994 (Bertrand *et al.*, 2002). Hauls were conducted during daylight hours, with an effective duration of 20-60 minutes (net in contact with the sea bed), depending on the depth. The average towing speed was 2.8 knots. The arrival and departure of the net at/from the bottom, as well as its horizontal and vertical openings (on average, 16.4 and 2.8 m, respectively) were measured using a SCANMAR system.

A total of 467 experimental hauls were analyzed. In each sample, abundance, biomass and length frequency of the studied species were determined. Biological samples were also taken and saggital otoliths were removed to complete the biological data obtained from the sampling of the commercial landings (Table 1). Abundance and biomass were standardized to one square km, using the horizontal opening of the net and the distance covered in each haul.

Biological parameters

Length-weight relationships were established by power regression ($TW = \alpha * TL^b$) for sexes combined and using all the biological samplings available from both landings and surveys (Table 1). The reproductive period was assessed from the seasonal evolution of the gonadosomatic index (GSI) of females sampled within the monthly biological sampling carried out on samples of landings in the years 2001 and 2002, and females collected during the scientific surveys corresponding to that period (Table 1). The GSI was calculated as follows: $GSI=100*\frac{GW}{EW}$. The proportion of mature individuals (PL) for a given size class L during the reproductive period was used to calculate the vector of maturity by length class and the length at first maturity (L_{50} or length at which 50% of the individuals are mature) for sexes combined from the logistic curve: $PL = \frac{e^{(a+b*L)}}{1+e^{(a+b*L)}}$; to doso, all the individuals sampled either from landings or scientific surveys (in case that the surveys took place during the reproductive period) were used (Table 1).

All the otoliths collected either from landings samples or scientific surveys were taken into account to study the growth of the species (Table 1). Otoliths were immersed in a 50% mixture of glycerol-alcohol and the number of translucent rings was counted by two readers with a compound microscope using reflected light, following standard techniques (Morales-Nin, 1987). Readings not coincident between readers were repeated again and not taken into account for further analyses if an agreement was not met. Marginal increment analysis was used to verify the increment periodicity of the rings (Morales-Nin, 1992). Once the rings were considered to be annual, and taking into account the date of capture, the number of rings, their formation period and the spawning season, each specimen was assigned to an age class. The von Bertalanffy growth function (VBGF) was fitted to the observed length-at-age data according to the following expression: $L_t= L_{oo}\text{-}e^{-k(t-t_0)}$;where L_t is the total length at age t, L_∞ is the asymptotic length, k is the instantaneous growth coefficient and t_0 is the hypothetical age at which length is equal to zero.

All biological parameters were calculated using the INBIO package in R (Sampedro *et al.*, 2005), which implements the Gauss-Newton algorithm for non-linear least squares parameter estimation, and enables the calculation of their coefficients of variation (CV) by using a bootstrap routine.

The von Bertalanffy and the length-weight relationship parameters were used to calculate a vector of natural mortality (M) by age for each species. To do so, we used the PRODBIOM methodology (Abella *et al.*, 1997) based on the reciprocal M-at-age model proposed in Caddy (1991). This was considered a more suitable option than using a constant natural mortality due to the fact that a large part of the catches of the species analyzed were composed of individuals belonging to young age classes (see results), which are commonly subjected to higher natural mortality rates than older ones (Abella *et al.*, 1997).

Population dynamics and exploitation

The data obtained during monthly sampling on board the bottom trawl fleet was used to estimate the annual length frequency distributions of catches. For each species, only the ports and depth strata where they were well represented in the catches were considered. Thus, for *C. cuculus*, the fleet from Alcúdia operating on the deep shelf (100-250 m depth) was considered; for *T. lastoviza* the fleet from Palma and Santanyí operating on the shallow shelf (50-100 m depth) was considered; and for *S. cabrilla* and *T. draco* the fleet from Alcúdia operating on the deep shelf and from Palma and Santanyí operating on the shallow shelf were considered.

For the period 2008-2010, the species biomass composition of the MFC was calculated per year, port and strata in order to obtain the percentage of each of the studied species. These proportions, along with the amount of discards of each species, estimated from sampling on board, the annual length distributions and the total weight of landings of the MFC in Mallorca (obtained from the official statistics), were used to calculate the total annual biomass of catches by species, and the total number of individuals caught by length class. Pseudocohorts of each species were calculated as an average of the annual number of individuals caught by length class during the three-year sampling on board period. The population dynamics and exploitation of the studied species were analyzed by means of a Length Cohort Analysis (LCA), using the Virtual Population Analysis (VPA) on the mean length pseudocohorts, as implemented in the VIT software (Lleonart & Salat, 1992). This program was designed to analyze exploited marine populations, based on catch data, structured by age or size, and assuming a steady state of the population. The steady state is quite a restrictive assumption because it involves constant recruitment and mortality and a constant level of exploitation. Despite this, the analysis of length pseudocohorts has been commonly used to assess the state of Mediterranean exploited marine populations when lacking suitable historical data series allowing more standard VPA procedures based on catch-at-age data. Moreover, these approaches have frequently used mean length pseudocohorts obtained from different consecutive years (Demestre & Lleonart, 1993; Oliver, 1993; Aldebert & Recasens, 1996; Lleonart & Maynou, 2003; GFCM, 2014). Mean length pseudocohorts have also been considered to compensate for the effect of inter-annual variability in recruitment (Pallares, 1992; Aldebert & Recasens, 1996).

The fishing effort of the bottom trawl fleet in Mallorca during the period used to calculate the mean pseudocohorts was assumed to be constant. The number of boats was the same for all three years (34), with the same distribution among harbours (OP MALLORCAMAR), and no changes in the regulation of the bottom trawl fishery, and similar landings (see results).

The VPA applied to each species used a vector of M, the VBGF parameters and a terminal fishing mortality value (F_t, i.e. the value of fishing mortality for the last length class). Several values of F_t (0.1, 0.2, 0.3 and 0.4) were considered in order to investigate the sensitivity to such parameter. The maturity vector was also used to estimate the spawning stock biomass (SSB). A plus class was used when the number of individuals in one or several of the largest length classes showed a null value. Calculation of plus classes consisted in pooling the individuals of the remaining larger size classes. That was the case for *T. lastoviza* (24-26 cm), *S. cabrilla* (26-28 cm) and *T. draco* (29-33 cm). A Y/R analysis was carried out using the vector of fishing mortality (F) obtained from VPA, the length-weight relationship parameters and the length distribution of catches.

Fishery independent indicators

The average stratified abundance and biomass of the studied species were calculated from MEDITS data by multiplying the average standardized abundance (individuals/km^2) and biomass (g/km^2) of each stratum by its surface and dividing it by the total surface of all strata. Taking into account that the studied species are mostly distributed on the continental shelf, only the 50-100 m and 101-200 m sampling strata were taken into account. Trends of the stratified abundance and biomass during the time series (2001-2011) were analyzed by means of linear regression. The indicators distribution range and Conservation Status of Fish *b* (CSF*b*), elaborated within the context of the Marine Strategy Framework Directive (EU, 2008; IEO, 2012) were also calculated from MEDITS survey data.

The distribution range is based on geo-referenced presence/absence matrixes. The sampled area was divided into grids of 10x10 nautical miles. Then the percentage of grids in which the species were present, in relation to the total number of sampled grids, was calculated on an annual basis. With the objective of comparing the percentages between years, and taking into account both the random stratified sampling and changes in the number of sampled grids throughout the period analyzed, the annual percentages of appearance were standardized using:

$\%C_{+1} = \frac{c_{+i}/c_t}{c_{mi}/c_{max}}$; where C_{+i} is the number of grids where the species was present in year i, C_t the total number of grids in the whole area, C_{mi} the number of sampled grids in year i and C_{max} the maximum number of grids sampled any year. The temporal trend of $\%C_{+1}$ was analyzed by means of linear regression.

The CSF*b* measures the percentage of large individuals at community level in relation to an initial reference period. To calculate this indicator, we used the stratified standardized abundances by length class, calculated in the same way as explained above for total abundance and biomass. Then, at species level, we calculated: 1) the total abundance of large individuals (length $>0.5L_\infty$); 2) the mean abundance of large individuals in the first 3 years of the MEDITS time series (2001-2003); and 3) for the successive years, the proportion represented by the abundance of large individuals of each species in relation to the mean abundance in the first three years. For any given year, the CSF*b* indicator is calculated as the geometric mean of the relative abundance of the studied species. The temporal trends of CSF*b* and proportions of large individuals in relation to the reference period at species level were analyzed by linear regression.

Results

Catch and composition of the MFC

During the last decade, official annual landings of the MFC averaged 143 tons, which represents up to 6 and 5% of the total landed biomass and economic value obtained by the bottom trawl fleet, respectively (Fig. 2). The mean landings of the MFC were larger than those for the target species of the fishery, *M. surmuletus* (96 tons/year) and *M. merluccius* (82 tons/year), and barely less than that of *S. smaris* (157 tons/year), throughout the studied period. In terms of biomass, the most important species of the MFC category were *S. cabrilla* (17.4%), *T. draco* (17.1%), *C. cuculus* (13.2%), *Scorpaena notata* (9.0%), *T. lastoviza* (6.5%) and *Pagellus erythrinu*s (6.2%) (Fig. S1). Although these main species represented about 70% of the total biomass of the MFC, the rest of it is composed of a large number of species, up to more than 50 (Fig. S1, Supplementary file only on the on line version).

rest of the species showed similar life spans ranging from 0 to 5, 0 to 4, and 0 to 6 years for *C. cuculus*, *T. lastoviza* and *S. cabrilla*, respectively. The VBGF parameters and fitted curves are shown in Table 2 and Figure S3. The highest value of *k* corresponds to *T. lastoviza* (0.41 year^{1}) and the lowest one to *T. draco* (0.10 year^{-1}), while the values for *C. cuculus* and *S. cabrilla* were similar (0.17 and 0.18 year^{-1}, respectively).

Population dynamics and exploitation

The pseudocohorts of all the studied species showed similar ranges of total length: 11-26, 6-26, 8-28 and 9-33 cm for *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco*, respectively (Fig.4). The modes were located at 16 cm for *C. cuculus* and at 17 cm for the rest of species. An important proportion of the catches of the four species analyzed were composed of young individuals. In this sense, 69 and 68% of the catches of *C. cuculus* and *T. lastoviza*, respectively, consisted of individuals with a TL equal or smaller

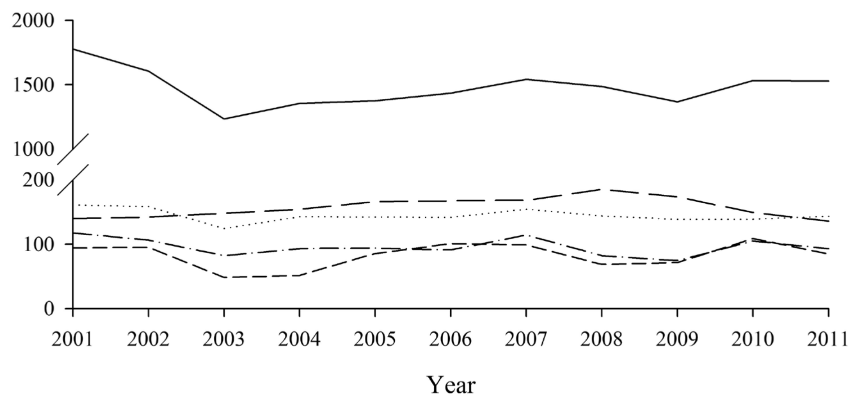

Fig. 2: Time series of the commercial landings (tons) of the bottom-trawl fleet off Mallorca for Total landings (continuous lines), *Spicara smaris* (dashed lines), MFC (dotted lines), *Mullus surmuletus* (dash-dotted lines), and *Merluccius merluccius* (short-dashed lines).

Biological parameters

The GSI along the year showed that the reproduction period occurs from January to April for *C. cuculus*, from March to June for *T. lastoviza*, from April to June for *S. cabrilla* and from June to October for *T. draco* (Fig. 3). The species with the largest L_{50} was *C. cuculus* (16.8 cm), whereas the smallest one was that of *T. draco* (14.4 cm). The L_{50} of *S. cabrilla* and *T. lastoviza* were 14.8 and 15.5, respectively (Table 2).

The length-weight relationship parameters are shown in Table 2. The otoliths showed the typical pattern for teleosts: alternations of translucent and opaque rings formed seasonally around an opaque nucleus. The seasonal evolution of the % of presence of opaque rings in the margin of the otoliths showed that the main deposition of this kind of rings occurs during the second quarter of the year for *C. cuculus* and *T. draco*, whereas for *T. lastoviza* and *S. cabrilla* it occurs during the last and first quarters of the year (Fig. S2). *T. draco* showed the longest life span, with age classes ranging from 0 to 9. The

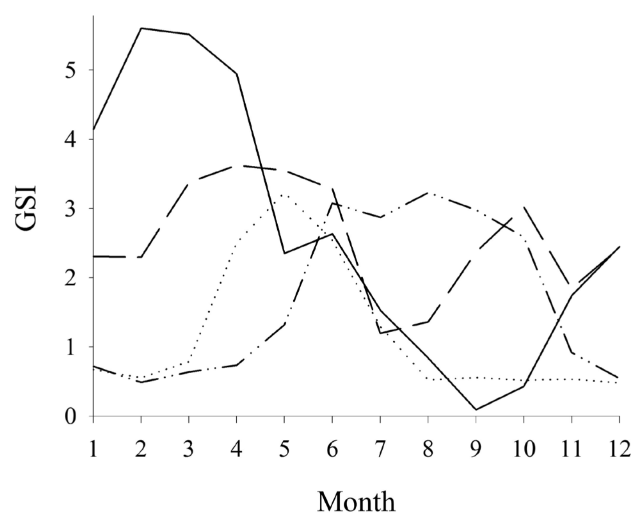

Fig. 3: Monthly evolution of the mean gonadosomatic index (GSI) of females for the studied species. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines.

Table 2. Parameters of the length-weight relationship ($TW = \alpha * TL^b$; TW in g and TL in cm); the von Bertalanffy growth function (VBGF; L_∞ in cm, k in year^{-1}, t_0 in years) and the maturity parameters (L_{50} in cm, L_{25}-L_{75} in cm) for the studied species and their associated coefficient of variation (*CV*).

Species	Length-weight		VBGF			Maturity	
	a (CV)	*b* (CV)	L_∞ (CV)	*k* (CV)	t_0(CV)	L_{50} *(CV)*	L_{25}-L_{75}
C. cuculus	0.005 (0.15)	3.196 (0.02)	37.6 (0.20)	0.176 (0.22)	-1.264 (0.15)	16.8 (0.01)	2.01
T. lastoviza	0.010 (0.13)	3.030 (0.01)	28.4 (0.05)	0.409 (0.12)	-0.007 (4.58)	15.5 (0.02)	4.99
S. cabrilla	0.014 (0.09)	2.903 (0.01)	38.8 (0.08)	0.173 (0.12)	-0.185 (0.32)	14.8 (0.01)	4.72
T. draco	0.005 (0.12)	3.075 (0.01)	42.3 (0.06)	0.101 (0.10)	-1.825 (0.09)	14.4 (0.05)	6.47

to that corresponding to 2 year-olds. In the case of *S. cabrilla* and *T. draco*, 43 and 48% of the catches, respectively, consisted of 3-year old or younger individuals (Fig. 4 and Fig. S3). The M vectors used as inputs for the VPA are shown in Figure 5. For the most abundant size classes of the species analyzed, the values of M varied between 0.13 for both *C. cuculus* and *T. draco*, and 0.21 and 0.29 for *T. lastoviza* and *S. cabrilla*, respectively.

VPA results showed that the mean length and age of the catches were above the critical length and age of the estimated population at sea for all species (i.e. the length and age at which the population shows its maximum biomass, respectively). *C. cuculus* showed a critical length slightly lower than the L_{50}, whereas these values were quite similar for *T. lastoviza*. Both *S. cabrilla* and *T. draco* showed critical lengths higher than the L_{50} (Table 2 and 3). The SSB represented 24, 40, 56 and 58% of the mean annual biomass for *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco*, respectively (Table 3). The F by size class remained similar irrespective of the F_t that had been used (Fig.6). In this sense, the species showing the highest variability was *C. cuculus*, although these variations were low and appeared only for the largest and less abundant size classes. Among the species studied, the largest and smallest populations corresponded to *T.draco* and *T. lastoviza*, respectively (Table 3).

The Y/R analyses showed that, for all the studied species, the current Y/R was below the Y/R_{max} and $Y/R_{F0,1}$

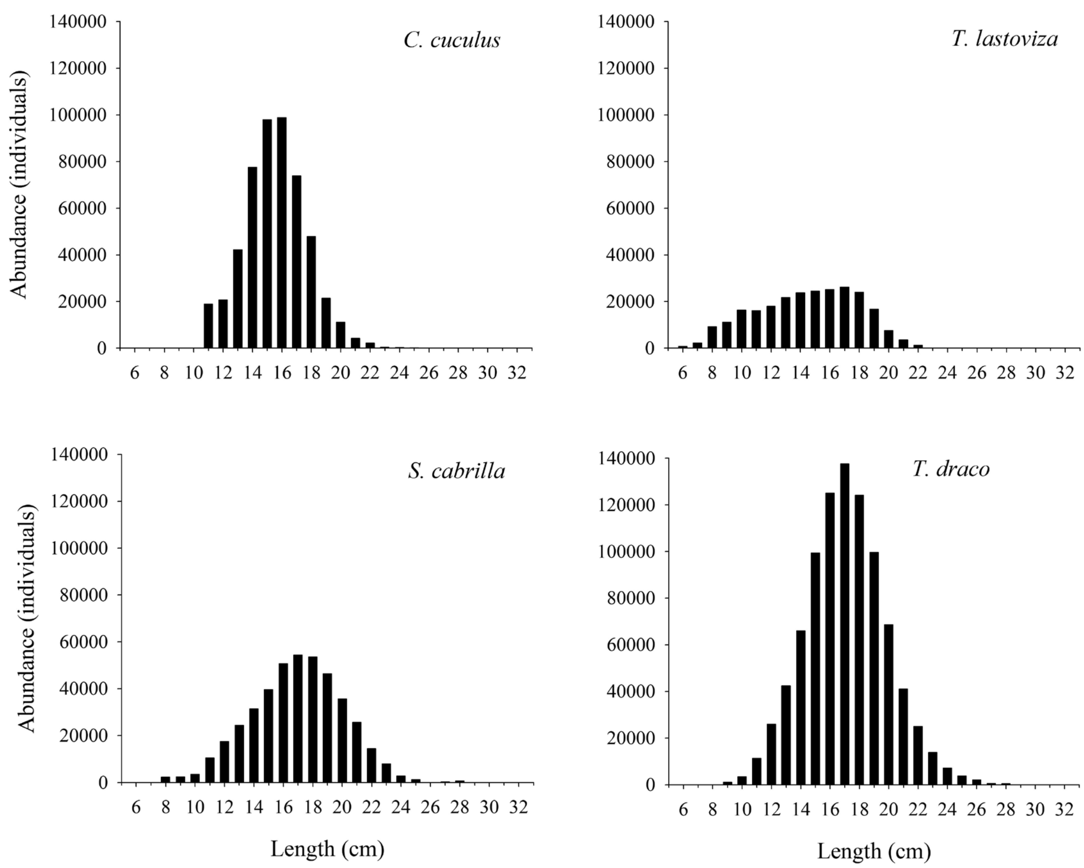

Fig. 4: Length frequency distribution of catches (pseudo-cohorts built with data collected between 2008 and 2010) for the studied species.

Table 3. Summary of the results of the Virtual Population (VPA) and Yield per Recruit (Y/R) analyses for the studied species. The value of terminal fishing mortality (F_t) used was 0.2 in all cases. Biomass is in kg; lengths in cm; ages in years; inputs, outputs and biomass turnover in %; Y/R in g; Φ is the effort factor; Φ_{max} is the Φ corresponding to the maximum Y/R; F is the fishing mortality.

		C. cuculus	*T. lastoviza*	*S. cabrilla*	*T. draco*
Catches					
Number		518107	248813	426724	899766
Biomass		19486	10405	26148	32787
Mean length		16.0	14.9	17.4	17.6
Mean age		1.92	1.90	3.3	3.56
VPA					
Mean annual number		708624	447500	1465689	3660410
Mean annual biomass		18444	9322	44600	67265
Recruits		672364	494891	995359	1837534
Spawning Stock Biomass		4400	3684	24997	38736
Mean length		14.1	11.3	13.1	13.6
Critical length		14.0	15.0	16.0	16.0
Mean age		1.43	1.30	2.28	2.88
Critical age		1.38	1.83	2.89	3.03
Total biomass balance (D)		22769	13585	40664	44704
Inputs	Recruitment	31.4	8.3	14.3	17.7
	Growth	68.6	91.7	85.7	82.3
Outputs	Natural death	14.4	23.4	35.7	26.7
	Fishing mortality	85.6	76.6	64.3	73.3
Biomass turnover		123.5	145.7	91.2	66.5
Global F		0.72	0.56	0.29	0.25
Y/R					
Current Y/R		29.2	21.2	26.4	17.9
Y/R_{max}		34.8	30.8	28.2	27.5
Φ_{max}		0.41	0.23	0.55	0.22
$Y/R_{F0.1}$		33.2	30.6	26.9	26.9
$\Phi_{F0.1}$		0.27	0.15	0.34	0.16
Virgin stock biomass		192024	590436	423841	2538665

(Table 3; Fig. 7).

Y/R_{max} could be achieved by reducing the current fishing mortalities of *C. cuculus, T. lastoviza, S. cabrilla* and *T. draco* by 65.2, 69.2, 71.8 and 72.5%, respectively. Slightly lower reductions of 66.8 and 69.4 for *C. cuculus* and *T. lastoviza*, respectively, and 73.1% for both *S. cabrilla* and *T. draco* are needed to achieve the reference point $Y/R_{F0,1}$ (Table 3). Compared to the virgin stock biomass, the mean biomass was low for all species, representing 10, 2, 11 and 3% for *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco*, respectively.

Fishery independent indicators

The time series of the average stratified abundance and biomass of the studied species showed an oscillatory behaviour in all cases but without a significant trend for any of them (Table 4, Fig. 8). The distribution range indicator did not show any significant trend for any of the studied species (Table 4, Fig. 9). The percentage of occurrence in sampled grids ranged from 10% in 2001 to 26% in 2011 for *C. cuculus*, from 10% in 2002 to 23% in 2011 for *T. lastoviza*, from 24% in 2004 to 31% in 2007 for *S. cabrilla* and from 32% in 2004 to 27% in 2005 for *T. draco*.

The CSF*b* showed an ascendant significant trend (R^2=0.47; t_6=2.66; p<0.05) during the period 2004-2011, taking values higher than those of the reference state in 4 of the 8 years considered (Fig. 10). Furthermore, regression analyses of the evolution of the proportion represented by the abundance of large individuals in relation to the reference period at species level showed an ascendant significant trend for all species except *T. lastoviza* (Table 4, Fig. 11).

Discussion

In the period analyzed, 2001-2011, the MFC had similar or even larger landings than those of the main target species on the shallow shelf, *M. surmuletus* and *S. smaris*, and the deep shelf, *M. merluccius*. The four species taken into account are important components of the MFC, representing a large percentage of the landed biomass of this commercial category (54%). Although there are two other species with similar importance, *S. notata* and *P. erythrinus*, the information on their length frequency distribution was too scarce to analyze their

Table 4. Results of the linear regression analyses of the time series of stratified abundance (A) and biomass (B), distribution range indicator (%C_{+i}) and the proportion represented by the abundance of large individuals in relation to the reference period 2001-2003 (%0.5L_∞). The value of the t-test testing for the significance of the slope is shown. Degrees of freedom are 9 for A, B and %C_{+i}, and 6 for %0.5L_∞.

Species	Parameter	*t*	R^2
C. cuculus	Abundance	1.36	0.08
	Biomass	1.68	0.15
	%C_{+i}	1.98	0.23
	%0.5L_∞	3.31*	0.59
T. lastoviza	Abundance	0.89	0.02
	Biomass	1.15	0.03
	%C_{+i}	2.18	0.27
	%0.5L_∞	0.68	0.08
S. cabrilla	Abundance	1.05	0.01
	Biomass	1.38	0.08
	%C_{+i}	-0.12	0.11
	%0.5L_∞	3.7**	0.65
T. draco	Abundance	1.34	0.07
	Biomass	1.94	0.22
	%C_{+i}	-1.14	0.03
	%0.5L_∞	2.94*	0.52

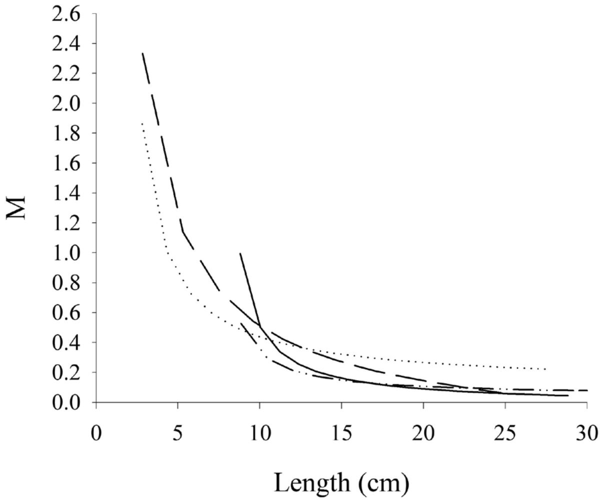

Fig. 5: Natural mortality (M) vector by length class for the studied species. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines.

population dynamics and exploitation state.

Similar biological traits have been found for the four demersal species considered in this study, *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco*. They live on the continental shelf, with L_{50} (14-17 cm) and a relatively short life span (a maximum of 4 years detected for *T. lastoviza* and

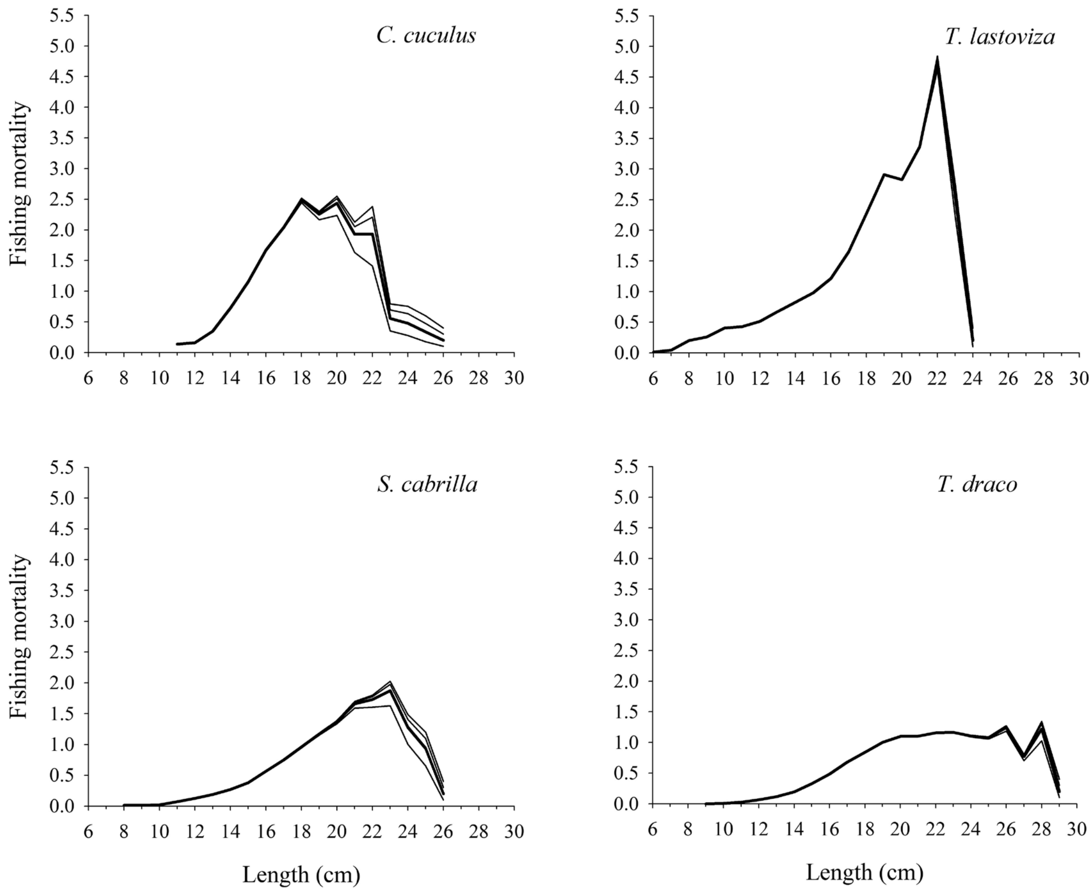

Fig. 6: Fishing mortality by length class for the studied species. Terminal fishing mortality (Ft) values of 0.1, 0.2, 0.3 and 0.4 were tested. The bold line represents the final value of Ft (0.2) selected for further analyses.

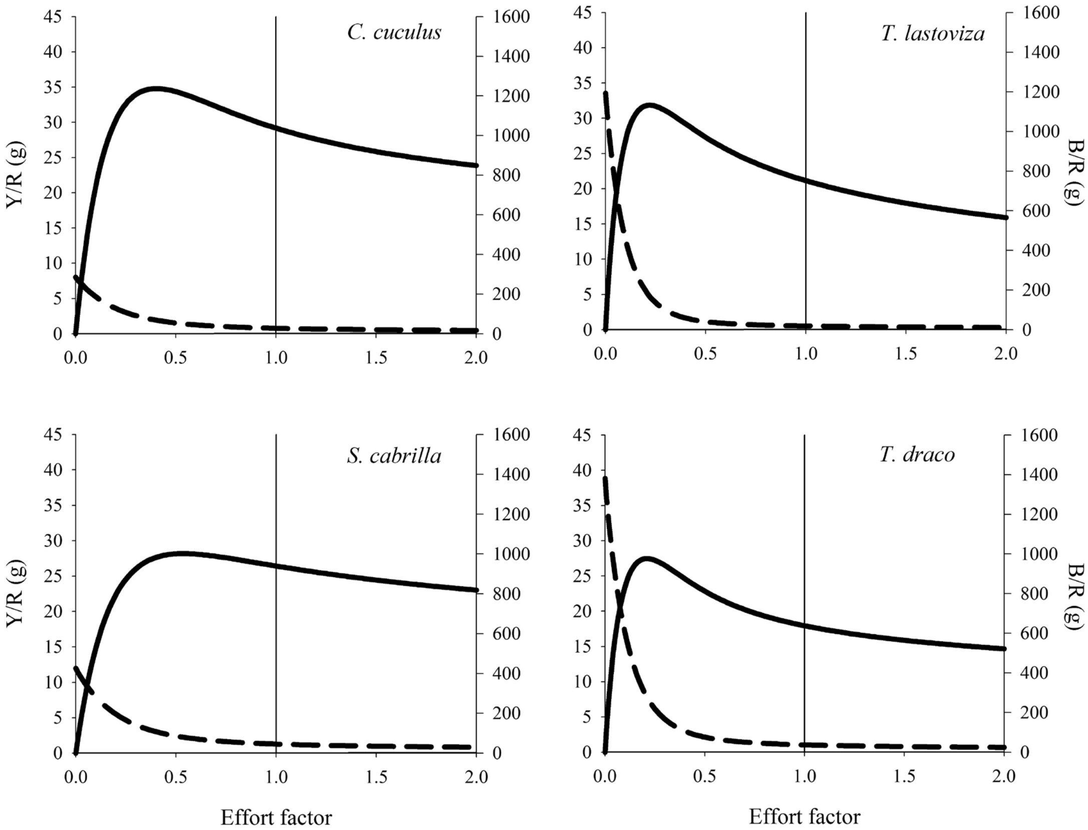

Fig. 7: Results of the Yield per Recruit (Y/R) analysis. The continuous line represents the Y/R and the dashed line the Biomass per Recruit (B/R) for the studied species The current effort factor (1.0) is shown with a line.

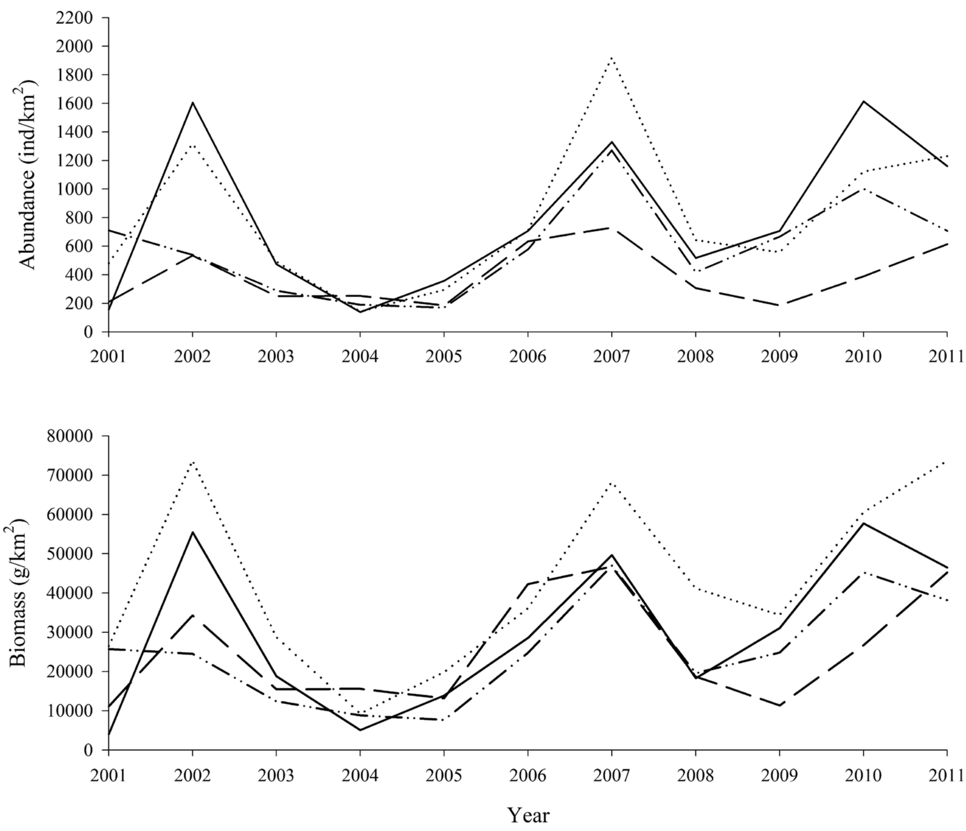

Fig. 8: Temporal evolution of the average stratified abundance and biomass for the studied species obtained from MEDITS surveys data. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines. Linear regression analyses did not show any significant trend, neither for abundance nor for biomass, for any of the studied species.

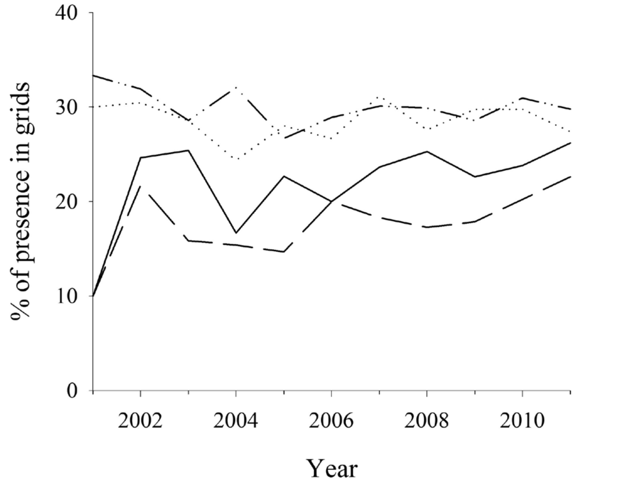

Fig. 9: Temporal evolution of the distribution range (% of presence in grids) for the studied species obtained from MEDITS surveys data. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines. Linear regression analyses did not show any significant trend, neither for abundance nor for biomass, for any of the studied species.

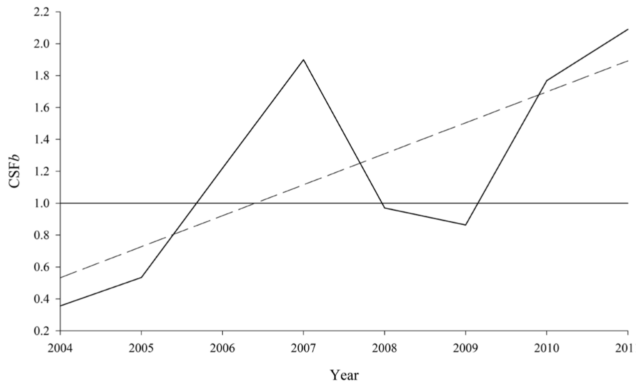

Fig. 10: Temporal evolution of the Conservation Status of Fish *b* (CSF*b*) obtained from MEDITS surveys data. The horizontal line indicates the reference state. The discontinuous line represents the linear regression of CSF*b,* which shows an ascendant significant trend (R^2= 0.47; p<0.05).

9 years for *T. draco*), and are important components of the demersal communities from the continental shelf off the Balearic Islands, both in abundance and biomass (Massutí & Reñones, 2005; Ordines & Massutí, 2009). Despite the importance of these species as by-catch for the bottom trawl fishery in the Balearic Islands, little is known about their biology and, unlike target species, their exploitation levels have not been previously assessed. In fact, there are few studies addressing the most important traits of the biology of these species in both the Mediterranean and the Atlantic, especially in the case of *T. lastoviza* and *T.draco* (Table S1). Moreover, the values of the parameters of growth and maturity gathered from the literature available may present differences even if we reduce the scope to the Mediterranean, e.g. the k and L_{50} of *S. cabrilla*

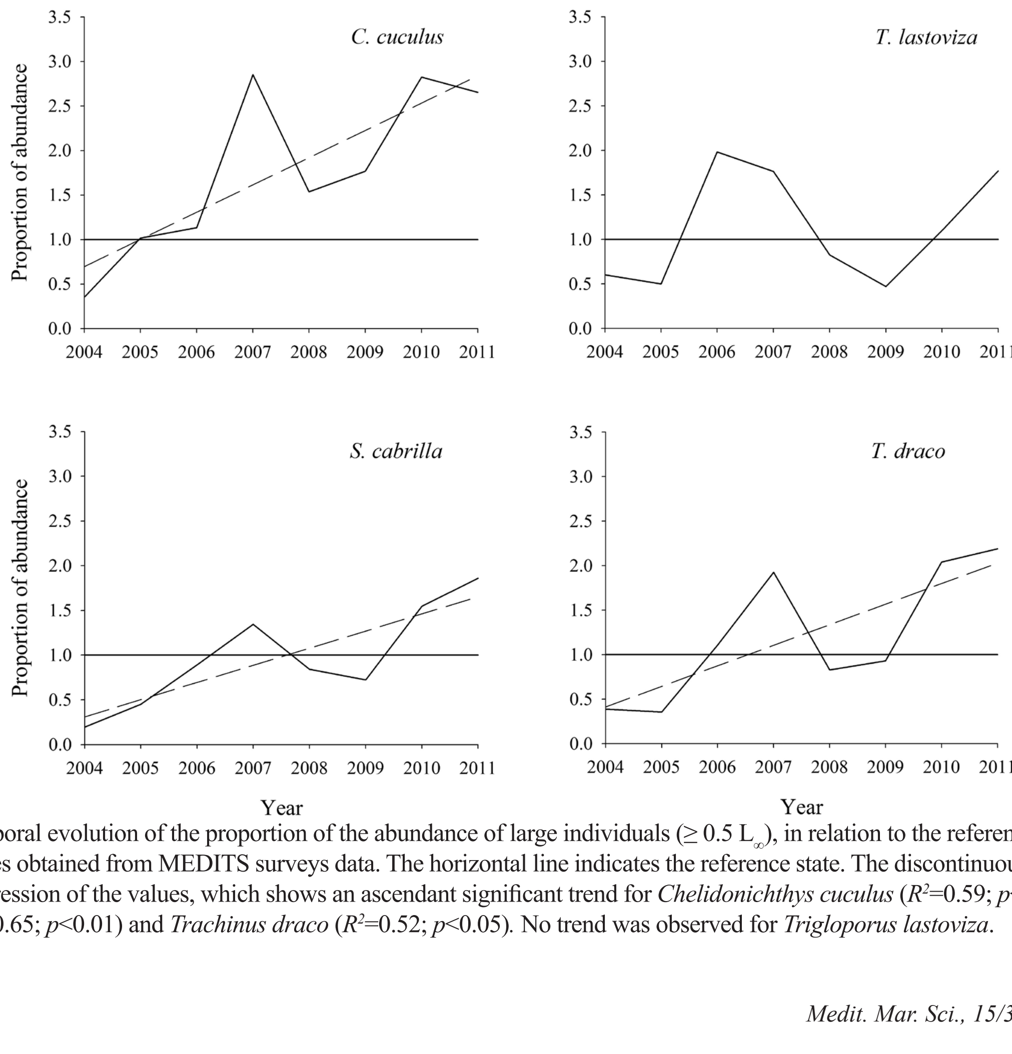

Fig. 11: Temporal evolution of the proportion of the abundance of large individuals (≥ 0.5 L_∞), in relation to the reference period for the studied species obtained from MEDITS surveys data. The horizontal line indicates the reference state. The discontinuous line represents the linear regression of the values, which shows an ascendant significant trend for *Chelidonichthys cuculus* (R^2=0.59; p<0.05), *Serranus cabrilla* (R^2=0.65; p<0.01) and *Trachinus draco* (R^2=0.52; p<0.05). No trend was observed for *Trigloporus lastoviza*.

vary from 0.1 to 0.4 years^{-1}, and 10 to 15.2 cm in standard length, respectively (Table S1). In general, the values of the main biological parameters calculated in the present work are similar, or fall within the ranges of the values calculated in previous studies. This was not the case for the von Bertalanffy *k* parameter for *T. lastoviza*, available only from Tunisia where it is lower (0.13 years^{-1}) (Boudaya *et al.*, 2010; Table S1) than that reported in the present work (0.41 years^{-1}), and the larger values of L_∞ for *S. cabrilla* and *T. draco* reported for the Balearic Islands.

Within the framework of the General Fisheries Commission for the Mediterranean (http://www.gfcm.org), the traditional single-species approach based on target species has predominated in the assessment of demersal fisheries, focusing mainly on M. surmuletus and M. merluccius (e.g. GFCM, 2012). The management of these fisheries, based on this approach, would also benefit by-catch species and habitats because by reducing the excessive fishing mortalities of target species to sustainable levels the pressure on the rest of the components of the ecosystem would also decrease (Mace, 2004). However, not all of the affected species are equally resilient. A clear example is that of the elasmobranches, which are a usual by-catch species of demersal fisheries in the Mediterranean (Guijarro *et al.*, 2012) and are considered highly vulnerable due to their k-selected life-history strategy, characterized by slow growth, late attainment of sexual maturity, long life spans and low fecundity (Stevens *et al.*, 2000). The different resilience of the species involved in a fishery could lead the most vulnerable components of the ecosystem to collapse if fishery management only takes into account the assessment of target species and they are among the most resistant.

Our results show that the main by-catch species of the trawl fleet operating on the continental shelf off the Balearic Islands must be considered as overexploited. The reduction in fishing effort required to reach the $Y/R_{F0,1}$, considered as a reference point for management targets for sustainable fisheries (GFCM, 2014), is lower (67-73%, depending on the species) to that required in the case of *M. merluccius* ($Y/R_{F0,1}$=87%), but higher than that required for *M. surmuletus* ($Y/R_{F0,1}$=53%) for the period 2000-2010, the two target demersal species periodically assessed in the area (GFCM, 2012). Hence, reducing the fishing effort on the shallow shelf in order to achieve the $Y/R_{F0,1}$ of *M. surmuletus*, would not suffice to achieve the same target for the by-catch species studied here, especially for *T. lastoviza*, *S. cabrilla* and *T. draco*, whose largest parts of their populations live on the shallow shelf, as is also the case for *M. surmuletus* (Massutí & Reñones, 2005). It should be noted here that the mentioned reference points made our results comparable to those of the periodically assessed species. However, as is the case of *M. merluccius*, whose population of largest individuals is considered to be not fully available to the trawl fishery (Caddy, 1993), some of the species assessed in the present work may also share this characteristic. This could be the case of *S. cabrilla*, a species present in most of the habitats of the continental shelf, including rocky bottoms (Fischer *et al.*, 1987) not available to trawling. Hence, the population of *S. cabrilla* could be in a better state, or be more resilient to the trawling fishing pressure than suggested by the present assessment, which is restricted to the bottom-trawl fishery.

The fishery-independent indicators allowed completion of the fishery-dependent single species assessment. The data available for the by-catch species studied forced us to use VPAs based on pseudocohorts, yielding results that do not include any information of the trend of the state of the populations. This was supplied by the fishery-independent indicators. The average stratified abundance and biomass and the distribution range showed that the studied species are stable, while the Conservation Status of Fish indicator (CSF*b*) showed an overall positive trend, indicating a certain recovery. These results are in agreement with those obtained from the initial evaluation of the implementation of the MSFD in the study area (IEO, 2012), where most of the biodiversity indicators applied to fish species showed a Good Environmental State in the Balearic Islands. In the specific case of the CSF*b*, the reported trend of this indicator in the MSFD was almost identical to that reported here. Although the analyses for the MSDF included a higher number of fish species, according to Massutí & Reñones (2005), most of these species are mainly distributed on the continental shelf (41%, i.e. *C. cuculus*, *M. surmuletus*, *Pagellus erythrinus*, *Scorpaena scrofa*, *S. cabrilla*, *T. draco* and *Zeus faber*) or on both the continental shelf and upper slope (41%, i.e. *Helicolenus dactylopterus*, *Lepidorhombus boscii*, *M. merluccius*, *Peristedion cataphractum*, *Raja clavata*, *Trygla lyra* and *Scyliorhinus canicula*), whereas only 18% were species typically distributed on the slope (i.e. *Galeus melastomus*, *Micromesistius poutassou* and *Phycis blennoides*). During the last decade, the trawl fleet operating in the Balearic Islands has displaced its fishing effort from the shelf to the slope, targeting the economically most valuable demersal resource in the area, the red shrimp *Aristeus antennatus* (Hidalgo *et al.*, 2009). This seems to be already positively affecting fish populations of the shelf. This is the case for the elasmobranch community living on the shelf bottoms of the study area, showing slight recovery during the last decade, which has not been observed for the same community on the slope (Guijarro *et al.*, 2012).

Although the time series of the average stratified abundance and biomass did not show any clear trend, all the species analyzed showed a similar pattern of oscillations. Similarly, inter-annual fluctuations have also been detected for other species in the same study area, both on the shelf and the slope (Quetglas *et al.*, 1998; Carbonell *et al.*, 1999; Quetglas *et al.*, 2013). While these fluctuations were attributed to meso- and large-scale climatic indices in the case of species with broader age structure and longer life span, global scale indices seemed to influence the populations of species with a narrow age structure and short life span, especially species inhabiting the continental shelf (Quetglas *et al.*, 2013). Although the short time series available for the present study prevents further analysis, the similarity in the pattern of oscillations among the species analyzed suggests that it may also be the result of a similar response to climatic forces.

Our results may allow us to be more optimistic about the future of demersal species living on the continental shelf of the Balearic Islands, despite the fact that this may be at the expense of species living on the slope. However, they also underline the necessity of incorporating monitoring and assessment of by-catch species in fisheries management, given that their populations can show more pronounced overexploitation than target ones (in our case *M. surmuletus*). In the progressive change from single-species management to an ecosystem approach to fisheries (Browman & Stergiou, 2004) undertaken by the European Common Fisheries Policy for the Mediterranean in order 'to protect and conserve living aquatic resources and ecosystems' (Council Regulation EC 1967/2006), the "traditional" single-species assessment techniques will still be needed and fit perfectly, as long as their scope expands beyond the main target species.

Acknowledgements

We would like to thank very much: Aina de Mesa and Susana Ruiz who carried out the on board sampling of the bottom trawl fleet of the Balearic Islands during the period 2008-2010; all participants in the MEDITS surveys from 2002 to 2011; the MEDER, DEMO, EVADEM, EVADEMED and BADEMECO projects, financed by the IEO and, as of 2007, by the EU; and the EU Data Collection Program for co-funding.

References

Abella, A., Caddy, J.F., Serena, F., 1997. Do natural mortality and availability decline with age? An alternative yield paradigm for juvenile fisheries, illustrated by the hake *Merluccius merluccius* fishery in the Mediterranean. *Aquatic Living Resources*, 10, 257-269.

Aldebert, Y., Recasens, L., 1996. Comparison of methods for stock assessment of European hake *Merluccius merluccius* in the Gulf of Lions (Northwestern Mediterranean). *Aquatic Living Resources*, 9, 13-22.

Bertrand, J.A., Gil de Sola, L., Papaconstantinou, C., Relini, G., Souplet, A., 2002. The general specifications of the MEDITS surveys. *Scientia Marina*, 66, 9-17.

Bianchi, C.N., Morri, C., 2000. Marine biodiversity of the Mediterranean Sea: situation, problems and prospects for future research. *Marine Pollution Bulletin*, 40, 367-376.

Boudaya, L., Neifar, L., Rizzo, P., Badalucco, C., Bouain, A., Fiorentino, F., 2010. Age and growth of *Chelidonichthys lastoviza* (Bonnaterre, 1788) in Tunisia. *Rapport de la Commision Internationale pour l'Exploration Scientifique de la Mer Méditerranée*, 39, 458.

Browman, H.I., Stergiou, K.I., 2004. Perspectives on ecosystem based approaches to the management of marine resources. *Marine Ecology Progress Series*, 274, 269-303.

Brown-Peterson, N.J., Wyanski, D.M., Saborido-Rey, F., Macewicz, B.J., Lowerre-Barbieri, S.K., 2011. A standardized terminology for describing reproductive development in fishes. *Marine and Coastal Fisheries: Dynamics Management and Ecosystem Science*, 3, 52-70.

Caddy, J.F., 1991. Death rates and time intervals: Is there an alternative to the constant natural mortality axiom?. *Reviews in Fish Biology and Fisheries*, 1, 109-138.

Caddy, J.F., 1993. Some future perspectives for assessment and management of Mediterranean fisheries. *Scientia Marina*, 57, 121-130.

Carbonell, A., Carbonell, M., Demestre, M., Grau, A., Monserrat, M., 1999. The red shrimp *Aristeus antennatus* (Risso, 1816) fishery and biology in the Balearic Islands, Western Mediterranean. *Fisheries Research*, 44, 1-13.

Colloca, F., Cardinale, M., Marcello, A., Ardizzone, G.D., 2003. Tracing the life history of red gurnard (*Aspitrigla cuculus*) using validated otolith annual rings. *Journal of Applied Ichthyology*, 19, 1-9.

Demestre, M., Lleonart, J., 1993. Population dynamics of *Aristeus antennatus* (Decapoda: Dendrobranchiata) in the northwestern Mediterranean. *Scientia Marina*, 57, 183-189.

EU, 2008. Report of the Ad Hoc Meeting of independent experts on Indicators and associated data requirements to measure the impacts of fisheries on the marine ecosystem. *Commission Staff Working Paper*, 32 pp.

Farrugio, H., Oliver, P., Biagi, F., 1993. An overview of the history, knowledge, recent and future research trends in Mediterranean fisheries. *Scientia Marina*, 57, 105-119.

Fischer, W., Bauchot, M.L., Schneider, M., 1987. *Fiches FAO d' identification des espèces pour les besoins de la pêche. (Révision 1). Méditerranée et mer Noire. Zone de pêche 37. Volume II. Vertébrés.* FAO, Rome, pp. 761-1530.

Fredj, G., Bellan-Santini, D., Meinardi, M., 1992. État des connaissances sur la faune marine Méditerranéenne. Spéciation et biogeographie en Mer Méditerranée. *Bulletin de l'Institut océanographique*. Monaco, 9, 133-145.

GFCM, 2012. *Report of the fourteenth session of the Scientific Advisory Committee*. FAO Fisheries and Aquaculture Report, No 1001 ,44 pp.

GFCM, 2014. *Report of the SCSA Working Group on Stock Assessment of Demersal Species (WGSAD)*. Bar, Montenegro, 28th January-1st February 2014.

Guijarro, B., Quetglas, A., Moranta, J., Ordines, F., Valls, M. *et al.*, 2012. Inter- and intra-annual trends and status indicators of nektobenthic elasmobranchs off the Balearic Islands (northwestern Mediterranean). *Scientia Marina*, 76, 87-96.

Hidalgo, M., Massutí, E., Guijarro, B., Moranta, J., Ciannelli, L. *et al.*, 2009. Population effects and changes in life history traits in relation to phase transitions induced by long-term fishery harvesting: European hake (*Merluccius merluccius*) off the Balearic Islands. *Canadian Journal of Fisheries and Aquatic Sciences*, 66, 1355-1370.

İlhan, D., Akalin, S., Tosunoğlu, Z., Özaydin O., 2010. Growth characteristics and reproduction of comber, *Serranus cabrilla* (Actinopterygii, Perciformes, Serranidae), In the Aegean Sea. *Acta Ichthyologica et Piscatoria*, 40, 55-60.

IEO, 2012. *Estrategia Marina. Demarcación Marina Levantino-*

Balear. Parte IV. Descriptores buen estado ambiental. Descriptor 1: Biodiversidad. Evaluación inicial y buen estado ambiental.Instituto Español de Oceanografíahttp://www.magrama.gob.es/es/costas/temas/estrategias-marinas/IV_D1_Levantino-Balear_tcm7-207252.pdf. (Accessed 25/02/2014)

Lleonart, J., Salat, J., 1992. *VIT. Programa de análisis de pesquerías*. Informes Técnicos de Scientia Marina, 168-169, 116 pp.

Lleonart, J., Maynou, F., 2003. Fish stock assessments in the Mediterranean: state of the art. *Scientia Marina*, 67, 37-49.

Mace, P.M., 2004. In defence of fisheries scientists, single-species models and other scapegoats: confronting the real problems. In: Browman, H., Stergiou, K.I. (Eds), Perspectives on ecosystem-based approaches to the management of marine resources. *Marine Ecology Progress Series*, 274, 269-303.

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

Morales-Nin, B., 1987. *Métodos de determinación de la edad de los osteíctios en base a estructuras de crecimiento*. Informes Técnicos de Investigación Pesquera, No 143, 30 pp.

Morales-Nin, B., 1992. *Determination of growth in bony fishes from otolith microstructure*. FAO Fisheries Technical Paper No. 322, 51 pp.

Moranta, J., Massutí, E., Morales-Nin, B., 2000. Fish catch composition of the deep-sea decapod crustacean fisheries in the Balearic Islands (western Mediterranean). *Fisheries Research*, 45, 253-264.

Moranta, J., Quetglas, A., Massutí, E., Guijarro, B., Ordines, F. *et al*., 2008. Research trends on demersal fisheries oceanography in the Mediterranean. p. 9-65. In: *Biological Oceanography Research Trends*. Mertens, L.P. (Ed), Nova Science Publishers, New York.

Oliver, P., 1993. Analysis of fluctuations observed in the trawl fleet landings of the Balearic Islands. *Scientia Marina*, 57, 219-227.

Ordines, F., Massutí, E., Guijarro, B., Mas, R., 2006. Diamond vs square mesh codend in a multi-species trawl fishery of the western Mediterranean: effects on catch composition, yield, size selectivity and discards. *Aquatic Living Resources*, 19, 329-338.

Ordines, F., Massutí, E., 2009. Relationships between macro-epibenthic communities and fish on the shelf grounds of the western Mediterranean. *Aquatic Conservation:Marine and Freshwater Ecosystems*, 19, 370-383.

Pallares, P., 1992. *Comparacion de los resultados de la aplicacio de técnicas de anilisis de poblacion virtual sobre distribuciones de edad y distribuciones de tallas con aplicaciones a la evaluacion de stocks explotados de diferentes grupos taxonomicos*. Ph.D. Thesis, Universidad Complutense Madrid, 173 p.

Palmer, M., Quetglas, A., Guijarro, B., Moranta, J., Ordines, F. *et al*., 2009. Performance of artificial neural networks and discriminant analysis in predicting fishing tactics from multispecific fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, 66, 224-237.

Pérès, J.M., Picard, J., 1964. Nouveau manuel de bionomie benthique de la mer Méditerranée. *Recueil des Travaux de la Station Marine d'Endoume*, 31, 1-137.

Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R. *et al*., 2004. Ecosystem-based fishery management. *Science*, 305, 346-347.

Quetglas, A., Alemany, F., Carbonell, A., Merella, P., Sánchez, P., 1998. Biology and fishery of *Octopus vulgaris* Cuvier, 1797, caught by trawlers in Mallorca (Balearic Sea, Western Mediterranean. *Fisheries Research*, 36 (2-3), 237-249.

Quetglas, A., Ordines, F., Hidalgo, M., Monserrat, S., Ruiz, S. *et al*., 2013. Synchronous combined effects of fishing and climate within a demersal community. *ICES Journal of Marine Science*, 70 (2): 319-328.

Sampedro P., Saínza M., Trujillo V. 2005. *A simple tool to calculate biological parameter's uncertainty. Working Document in Workshop on Sampling Design for Fisheries Data*. 82 pp. ICES CM 2005/ACFM:11, Pasajes, Spain.

Stergiou, K.I., Politou, C.Y., Christou, E.D., Petrakis, G., 1997. Selectivity experiments in the NE Mediterranean: the effect of trawl codend mesh size on species diversity and discards. *ICES Journal of Marine Science*, 54, 774-786.

Stevens, J.D., Bonfil, R., Dulvy, N.K., Walker, P.A., 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. *ICES Journal of Marine Science*, 57, 476-494.

Torcu-Koc, H., Türker-Cakir, D., Dulčić, J., 2004. Age, growth and mortality of the comber, *Serranus cabrilla* (Serranidae) in the Edremit Bay (NW Aegean Sea, Turkey). *Cybium*, 28, 19-25.