Discards regulation vs Mediterranean fisheries sustainability
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Linking trawl fleet dynamics and the spatial distribution of exploited species can help to avoid unwanted catches: the case of the NW Mediterranean fishing grounds

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Summary: With the full implementation of the landing obligation on 1 January 2019, In European waters it will become mandatory for the trawling fleet to land at port all catches of certain species because, according to Article 15 of the new European Common Fisheries Policy, the species subject to the minimum conservation reference size (MCRS) cannot be discarded. Additionally, since 2005, trawlers over 15 m in length are required to carry an onboard vessel monitoring system (VMS), which generates information on fleet dynamics. The objective of this work was to provide a tool for avoiding unwanted catches by integrating the catch study of trawlers operating in the port of Blanes together with VMS data. To achieve this objective, the catches of 40 hauls were monitored, sampled and analysed together with VMS data for the years 2012-2014 integrated in a geographical information system. The results show that specimens below the MCRS were often captured in crinoid aggregation habitats, bottoms with maërl and muddy bottoms that were identified as nursery habitats of commercial species, e.g. *Merluccius merluccius*, *Pagellus* spp. and *Mullus* spp. VMS data showed considerable fishing pressure on areas with maërl and muddy habitats during the recruitment periods of these and other commercially relevant species. Implementing spatial or seasonal closures in habitats where species regulated by the MCRS are subject to catches could be a useful tool for preventing unwanted catches.

Keywords: unwanted catches; northwestern Mediterranean; trawl fishery; discard; VMS; MCRS.

Vincular la dinámica de la flota de arrastre y la distribución espacial de las especies explotadas puede ayudar a evitar capturas no deseadas: el caso de los caladeros del Mediterráneo noroccidental

Resumen: Con la plena aplicación de la Obligación de desembarque a partir del 1 de enero de 2019, pasará a ser obligatorio para la flota de arrastre desembarcar en puerto todas las capturas de ciertas especies, que según el Artículo 15 de la nueva política pesquera común no pueden ser descartadas, ya que están sujetas a MCRS. Por otro lado, desde 2005, se requiere a los arrastreros de más de 15 m de longitud, llevar a bordo un VMS, que proporciona información acerca de la dinámica de la flota. El objetivo de este trabajo fue proporcionar una herramienta para evitar capturas no deseadas integrando el estudio de la captura de arrastreros que operan en el puerto de Blanes junto con datos VMS de la flota de arrastre. Para lograr dicho objetivo, las capturas de 40 lances fueron monitoreadas, muestreadas y analizadas junto con los datos VMS de los años 2012-2014 integrados en un Sistema de Información Geográfica. Los resultados muestran que se capturaron de forma notable especímenes por debajo de la MCRS en hábitats de agregación de crinoideos, fondos con presencia de maërl y fondos fangosos que fueron identificaron como hábitats de cría para especies como *Merluccius merluccius*, *Pagellus* spp. y *Mullus* spp. Los datos VMS mostraron una notable presión pesquera en hábitats fangosos y fondos con presencia de maërl durante los períodos de reclutamiento de estas y otras especies comerciales relevantes. El uso de cierres espaciales o temporales en hábitats sujetos a descarte de especies reguladas por MCRS podría ser una herramienta útil para evitar capturas no deseadas.

Palabras clave: capturas no deseadas; Mediterráneo noroccidental; pesca de arrastre; descarte; VMS; MCRS.

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INTRODUCTION

The European Commission defines discarding as the practice of returning unwanted catches to the sea, dead or alive, because they are too small, the fisherman has no quota, or certain catch composition rules apply. This practice has been recognized globally among the most important issues for fisheries management because it is considered a source of uncertainty in the assessment of commercial stocks and negatively affects biodiversity and community structure (Bellido et al. 2011, Tsagarakis et al. 2014).

The sustainable exploitation of marine ecosystems and their natural resources is one of the fundamental goals of the strategy of the European Union (EU) in the framework of research and development (Horizon 2020). For this purpose, the new Common Fishery Policy aims to reduce or avoid unwanted catches as much as possible and, if necessary, to maximize their utilization (non-human consumption) without creating a market for species with an MCRS (EU Reg. 1380/2013). It therefore aims to gradually eliminate discards from community waters.

The reasons for discarding are many and varied and can be driven by economic, sociological, environmental or biological factors (Damalas 2015). In the Mediterranean, total discards have been estimated at 18.6% of the total catch (Tsagarakis et al. 2014). However, bottom trawling is one of the least selective fishing methods (Sommer 2005) and the one with the largest discard of biomass production, accounting for an average of 32.9% of the total catch (Tsagarakis et al. 2014). This discard is less pronounced (<20%) in deep water trawl fisheries, where exploitation targets a single resource, *Aristeus antennatus*, which is exploited between 405 and 773 m (Sanchez et al. 2004). For this reason, in our work, red shrimp fishing grounds were not considered due to the low discard amount in this depth zone in comparison with other shallower fishing grounds and because this discard is mainly composed of non-commercial species (Gorelli et al. 2016) that do not fall under the landing obligation (Article 15 of EU Reg. 1380/2013)**.** On the other hand, previous studies in the Catalan Sea at upper slope depths (between 200 and 400 m) showed that *Nephrops norvegicus* trawl fishery discard rates can be considerable, and species with high commercial value, such as *N. norvegicus* and *Parapenaeus longirostris,* are discarded (Garcia-de-Vinuesa 2012). Lastly, trawl fisheries on the continental shelf typically target several species, such as the high-value *Stichopus regalis, Mullus* spp., *Loligo vulgaris, Merluccius merluccius* and *Lophius* spp. between 50 and 200 m, where the discarded percentage of the catch may be approximately 60% or higher (Durell et al. 2008, Sanchez et al. 2004, Carbonell et al. 2003).

The capture of juveniles is one of the main reasons for discarding in the Mediterranean Sea (Bellido et al. 2017), and some vulnerable and highly productive Mediterranean zones (such as maërl beds or crinoid aggregations located on the continental shelf and slope) function as nursery areas and are negatively affected by this type of discard (Colloca et al. 2004, Barberá et al. 2003, Hall-Spencer et al. 2003). Maërl beds have been studied for decades, and they are particularly susceptible to physical disturbance (De Juan et al. 2013); although they are protected in Annex I of the Habitat Directive (EU Dir. 92/43/EEC), fishing pressure is still exerted on them (Demestre et al. 2017). However, crinoid aggregation ecosystems have been less studied (Colloca et al. 2004, Reale et al. 2005, Mangano et al. 2010), and unfortunately have no specific legal protection. Many of the commercial species habitually discarded by trawling operations in these ecosystems will soon be affected by the new European landing obligation.

In the European waters of the Mediterranean Sea**,** the management of bottom trawling is carried out mainly through fishing effort controls, which may not be an effective system for discard management (Damalas 2015). Trawl fishing is prohibited at less than 50 m depth, more than 1000 m depth and less than 1.5 nautical miles of the coast (EU Reg. 1967/2006); other restrictions include marine protected areas and temporal closures, which, in the case of the Spanish Mediterranean trawl fleet, are usually applied for one or two months per year. Technical measures include an MCRS for the main target species under Article 15 of EU Reg. 1380/2013, which specifies that animals below their MCRS should be landed at port. In addition, size regulations for nets are in place, specifying that 40 mm square-mesh net or 50 mm diamond-mesh net must be used for the cod-end (EU Reg. 1967/2006). In the Spanish Mediterranean control of the fleet, the number of hours and days at sea is limited, and since 2005, in European waters fishing vessels exceeding 15 m overall length must be equipped with a satellite-based vehicle monitoring system (VMS) (EU Reg. 404/2011) that, at least every two hours, provides data to the fisheries control authorities on the location, course and speed of vessels. This is one of the latest systems for controlling fishing effort adopted by European fleets operating in the Mediterranean Sea, where VMS has been proven to provide reliable information on habitat impacts (Hinz et al. 2013).

VMS together with other technical vessel data can be used to determine fishery fleet effort and its spatial and seasonal dynamics, which help identify the priority areas/seasons for management (Martín et al. 2014, Demestre et al. 2015). This knowledge, along with catch data, can be used to identify especially vulnerable or productive habitats in order to propose seasonal bans or enforce no-take areas to avoid unwanted catches below the MCRS.

Species covered under European legislation in the Mediterranean (Annex III of EU Reg. 1967/2006) include 20 fish, 4 crustaceans and 3 mollusc bivalves that are affected by MCRS. In addition, local level fishery control measures can often be more restrictive. Particularly in Catalonia, when taking into account European, national and local regulations, the number of species affected by size and/or weight regulations includes 34 fish, 5 crustaceans, 6 bivalves, 1 gastropod, 1 cnidarian, 3 echinoderms and 1 cephalopod (Generalitat de Catalunya 2015). Species only affected by local regulations are not subject to landing obligations, but

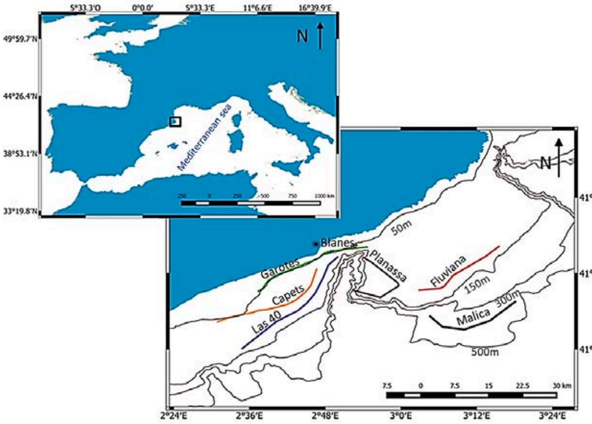

Fig. 1. – Study area indicating the six studied fishing grounds adjacent to Blanes port (northwestern Mediterranean).

when they are below the legal size or weight, they must be discarded and cannot be kept on board. Different regulations for a large number of species from the same fishery could involve an operational problem for fishing activities.

Considering the importance of the new European discard regulation, this work proposes to link VMS with discard catch data, paying special attention to the species regulated by MCRS, and at the local level for a representative trawling fleet from the port of Blanes, Catalonia (NW Mediterranean), in order to propose management measures that avoid or minimize unwanted catches.

MATERIALS AND METHODS

Study area

The study area is located in the northwest Mediterranean Sea, comprising five fishing grounds located in the vicinity of a submarine canyon that is frequented by the trawl fleet from the port of Blanes (Fig. 1).

Four of the fishing grounds chosen for the study are on the continental shelf, normally in the depth range of 54 to 145 m (Table 1). Uniquely, at Planassa, the depth reaches 530 m, as this fishing ground includes the northeastern edge of the Blanes canyon. The fifth fishing ground is located on the upper slope, between 196 and 494 m depth.

Data source

Between March 2016 and February 2017, sampling was carried out on four commercial trawlers in areas where discard activities were common. Generally, two field trips per month were carried out, one on the continental shelf where three vessels worked, and one on the upper slope where one vessel worked. It was attempted to completely cover the possible spatiotemporal variability at the fishing grounds worked by the Blanes trawl fleet, with the exception of the deepest fishing ground where *Aristeus antennatus* was the target species. Between 1 and 3 hauls were carried out on each fishing trip. In total, 40 hauls were analysed on board, from which biomass and abundance of commercial catch by species were recorded along with the biomass of regulated and unregulated discard.

From 23 hauls, between 7 and 10 kg of the discard fractions were randomly selected and transported to the laboratory, where the organisms were classified to the lowest possible taxonomic level. Abundance and biomass of each species were obtained, and the individuals regulated by MCRS or local regulations were measured.

During the fishing trips, effective trawl time, initial and final position and speed during trawl (2.4-3.2 knots) were recorded. Technical vessel data such as gross tonnage (GT) and overall length were also recorded. Finally, distance between trawl wings was provided by previous measurements carried out by fishermen.

VMS data of the Blanes port trawl fleet for the years 2012, 2013 and 2014 were provided by the *Ministerio de Agricultura, Pesca y Medio Ambiente* (MAGRAMA) (Spanish Ministry of Agriculture, Fisheries and Environment).

Data analysis

Biomass (B) and abundance (AB) of discards by species were extrapolated to the total fraction of discards with the following formula:

$$\text{Species AB or B} = \\ = \frac{\text{AB or B (species sampled)} \times \text{AB or B (total discard)}}{\text{AB or B (discard sampled)}}$$

Discard and commercial species abundance and biomass were then standardized to hectares using technical vessel, cruise and catch data as follows:

$$\text{Species AB or B standardized} = \\ = \frac{\text{AB or B (species sampled)}}{\text{speed}\ \frac{\text{m}}{\text{s}} \times \text{SBW}(\text{m}) \times \text{HD}(\text{s})} \times 10000$$

where SBW is the mean distance between trawl wings and HD is the haul duration.

With the Primer 6.1.2 statistical program (Clarke and Gorley 2006), discard abundance by species and hauls were square-root transformed, and their Bray-Curtis similarity matrix was calculated. From this similarity matrix, a multidimensional scaling (MDS) plot was generated to visualize the ordination pattern between discards of the 23 hauls analysed.

Table 1. – Fishing grounds depth characteristics.

Fishing grounds depth characteristics	Capets	Fluviana	Las 40	Garotes	Malica	Planassa
Depth min (m)	70	93	83	54	195	85
Depth max (m)	113	144	102	107	493	530
Depth range (m)	42	51	19	52	298	444

Table 2. – Average (Av) biomass of catch fractions for each fishing ground studied.

Catch fractions (kg ha^{-1})	Capets	Fluviana	Las 40	Garotes	Malica	Planassa
Av. total catch	3.93	7.44	6.66	7.53	2.66	8.22
Av. commercial catch	1.27	1.42	1.79	1.68	1.97	1.83
Av. Regulated discard	0.36	0.13	0.51	3.54	0.14	0.30
Av. Unregulated discard	2.31	5.90	4.37	2.31	0.56	6.09
Av. Total discard	2.66	6.02	4.88	5.85	0.69	6.39

Table 3. – SIMPER discard analysis taking fishing ground as a factor, showing average similarity between hauls (Av. similarity) and with respect to species, average abundance in individuals per hectare (Av.Ab), average similarity contribution (Av.Sim), average similarity divided by standard deviation (Av.Sim/SD), similarity contribution in percentage (C) and accumulated similarity contribution in percentage (Cum) to the five species with the greatest contribution to similarity in each fishing ground.

	Av.Ab (ind. ha^{-1})	Av.Sim	Av.Sim/SD	C %	Cum %
Las 40-Capets Av. similarity: 39.54					
Ophiura texturata	4.02	6.11	2.45	15.46	15.46
Spicara smaris	1.52	2.8	4.5	7.08	22.54
Echinaster sepositus	1.29	2.07	4.27	5.24	27.78
Echinus melo	1.2	1.93	2.83	4.88	32.66
Boops boops	1.49	1.72	2.84	4.35	37.01
Planassa Av. similarity: 26.65					
Leptometra phalangium	19.1	5.77	1.15	21.65	21.65
Gracilechinus acutus	2.75	2.31	0.88	8.66	30.31
Capros aper	3.71	1.62	0.9	6.09	36.4
Echinus melo	2.61	1.32	0.89	4.95	41.35
Plesionika heterocarpus	3.39	1.15	0.41	4.31	45.67
Fluviana Av. similarity: 15.82					
Leptometra phalangium	45.39	6.54	0.83	40.07	40.07
Scyliorhinus canicula	2.71	1.97	2.55	12.43	52.5
Echinus melo	4.63	1.92	1.59	12.15	64.65
Spicara smaris	1.26	0.96	1.59	6.08	70.73
Calliactis parasitica	1.04	0.72	0.58	4.55	75.29
Malica Av. similarity: 57.90					
Nephrops norvegicus	1.93	8.29	3.32	14.33	14.33
Scyliorhinus canicula	1.62	6.63	1.57	11.46	25.78
Phycis blennoides	1.15	5.81	4.59	10.04	35.82
Arnoglossus rueppelli	0.99	4.65	5.44	8.03	43.85
Trigla lyra	1.16	3.72	1.56	6.43	50.28
Garotes Av. similarity: 33.11					
Boops boops	6.54	24.01	-	72.52	72.52
Pagellus erythrinus	1.21	3.7	-	11.17	83.69
Echinaster sepositus	0.56	2.14	-	6.45	90.14
Mullus barbatus	0.36	1.31	-	3.95	94.1
Spicara smaris	3.35	1.24	-	3.74	97.84

After MDS, similarity percentage (SIMPER) analysis was carried out with the non-transformed matrix to determine the relative contribution that discard species made to the similarity among hauls using fishing ground as a factor. Due to the protection figure of maërl, a deeper analysis was carried on one fishing ground with maërl presence, where the average abundance of hauls by species was calculated.

The seasonal size distribution of the regulated discard species was represented graphically with the R 3.4.3 statistical program (R Core Team 2017) to summarize it both temporally and spatially.

VMS together with GT data of 28 trawlers from Blanes active between 2012 and 2014 were used to estimate the spatial and seasonal distribution of fishing effort. The information from VMS data does not indicate whether a vessel is fishing, so a speed filter was applied to raw data taking into account only VMS positions with trawl speeds of less than 4 knots (Demestre et al 2015, Martín et al 2014). Duplicated positions were deleted, and then filtered and unduplicated VMS data sets were used to represent the fishing effort distribution on a grid with a cell size of 1 km^2, which offers a good resolution for the spatial characteristics of this fishery.

The fishing effort in each cell was estimated as follows:

$$\text{Fishing effort} = \sum_i \text{NVMS}_i \times \text{GT}_i$$

where NVMS_i is the number of VMS points of each vessel per cell in a specific month and GT_i is the GT value of each vessel. Both filtering and estimation were performed using the software QGIS 2.10.0 (QGIS 2015).

Finally, to study the most relevant links between fishing effort and regulated discards, the abundance and biomass of species with MCRS was calculated at particular fishing grounds and months and VMS data was plotted for these months and fishing grounds.

RESULTS

Catch characterization

A total of 45 species were found in the commercial catch, and 15 regulated species and 171 non-regulated

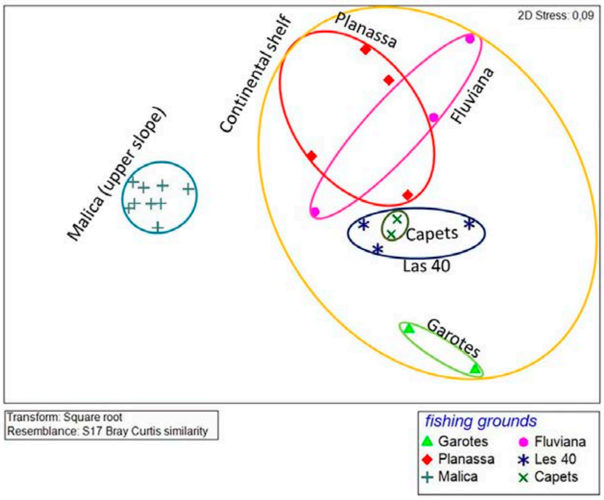

Fig. 2. – Discard MDS analysis; hauls and their occupied space are shown by fishing ground.

species were found in the discards. Table 2 shows the average biomass for each catch fraction from the fishing grounds studied.

Total discard characterization

The MDS discard analysis shows a clear difference between continental shelf and upper slope hauls. Garotes and Malica were separated from the other fishing grounds (Fig. 2). On the other hand, Planassa and Fluviana shared some space, and Capets was within the area occupied by Las 40. Due to the spatial overlap and the strong connection between Capets and Las 40 in the MDS analysis, it was decided to jointly analyse these two fishing grounds for the rest of the work.

In the SIMPER discard analysis, *Echinus melo* had an important presence in Las 40-Capets, Planassa and Fluviana, contributing 12.15% of the similarity among Fluviana samples (Table 3). A noteworthy finding was that *Leptometra phalangium* explained more than 40% of the similarity at Fluviana and more than 20% of the similarity at Planassa.

Boops boops explained more than 70% of the similarity at Garotes, where commercial species such as *Mullus barbatus* or *Pagellus erythrinus* were always discarded as well. Finally, *Nephrops norvegicus* was the discarded species with the highest percentage of similarity to Malica (14.33%).

Table 4. – Species abundance in Garotes hauls and their average (Av. Garotes), expressed in individuals per hectare.

Species	Garotes 1	Garotes 2	Av. Garotes
Boops boops	38.77	46.83	42.80
Maërl rhodoliths	43.56	0	21.78
Spicara smaris	40.80	0.10	20.45
Echinus melo	0	9.50	4.75
Octopus vulgaris	3.68	0	1.84
Pagellus erythrinus	0.92	2.14	1.53
Trachurus picturatus	2.61	0	1.30
Antedon mediterranea	0	2.38	1.19
Ophiotrix fragilis	0	2.38	1.19
Scomber scombrus	2.19	0.03	1.11

Table 5. – Abundance (ind. ha^{-1}) and biomass (g ha^{-1}) in each fishing ground of discard species regulated by Article 15 and species with local regulations. Ab, abundance; %Ab, abundance percentage; B, biomass; and %B, percentage of biomass.

		Garotes				Las 40-Capets			
		Ab	%Ab	B	%B	Ab	%Ab	B	%B
Art. 15 CE	*M. merluccius*	0	0	0	0	0.37	3.73	19.9	4.52
	M. barbatus	0.13	0.26	3.24	0.09	0	0	0	0
	P. bogaraveo	0.05	0.11	3.19	0.09	0.47	4.83	24.9	5.66
	P. erythrinus	1.53	3.13	84.54	2.39	0.54	5.57	33.5	7.61
	S. scombrus	1.11	2.27	77.21	2.18	0	0	0	0
	T. picturatus	1.30	2.67	89.01	2.51	0	0	0	0
	T. trachurus	0.02	0.04	0.60	0.02	2.95	30.1	108.5	24.7
	N. norvegicus	0	0	0	0	0	0	0	0
	P. longirostris	0	0	0	0	0	0	0	0
Local regulations	*T. capellanus*	0	0	0	0	0.52	5.29	6.33	1.44
	M. potassou	0	0	0	0	0	0	0	0
	L. budegassa	0.05	0.11	4.01	0.11	1.06	10.9	55.8	12.7
	L. piscatorius	0	0	0	0	0.46	4.71	32.96	7.49
	B. boops	42.8	87.7	2726	77.0	3.42	34.9	151	35.9
	O. vulgaris	1.84	3.77	552	15.60	0	0	0	0

		Planassa				Fluviana			
		Ab	%Ab	B	%B	Ab	%Ab	B	%B
Art. 15 CE	*M. merluccius*	1.22	17.1	12.1	5.81	1.81	18.1	10.6	4.30
	M. barbatus	0.24	3.42	10.43	4.99	1.38	13.8	27.5	11.2
	P. bogaraveo	0.72	10.1	40.1	19.2	0.32	3.15	28.8	11.7
	P. erythrinus	0	0	0	0	0	0	0	0
	S. scombrus	0	0	0	0	0	0	0	0
	T. picturatus	0	0	0	0	0	0	0	0
	T. trachurus	0.74	10.3	23.6	11.3	0.08	0.79	3.78	1.54
	N. norvegicus	0	0	0	0	0	0	0	0
	P. longirostris	1.21	17.0	6.00	2.87	0	0	0	0
Local regulations	*T. capellanus*	0.27	3.79	11.7	5.62	3.54	35.4	13.9	5.66
	M. potassou	2.46	34.5	97.7	46.8	0	0	0	0
	L. budegassa	0.17	2.39	3.65	1.75	0	0	0	0
	L. piscatorius	0.11	1.49	3.47	1.66	1.42	14.2	16.0	6.51
	B. boops	0	0	0	0	1.45	14.6	145.3	59.1
	O. vulgaris	0	0	0	0	0	0	0	0

		Malica				Total			
		Ab	%Ab	B	%B	Ab	%Ab	B	%B
Art. 15 CE	*M. merluccius*	0.22	3.55	5.41	5.12	0.72	4.42	9.60	1.06
	M. barbatus	0	0	0	0	0.35	2.13	8.24	0.91
	P. bogaraveo	0.09	1.49	8.42	7.97	0.33	2.02	21.1	2.32
	P. erythrinus	0	0	0	0	0.41	2.53	23.6	2.60
	S. scombrus	0	0	0	0	0.22	1.36	15.4	1.70
	T. picturatus	0	0	0	0	0.26	1.59	17.8	1.96
	T. trachurus	0	0	0	0	0.76	4.62	27.3	3.01
	N. norvegicus	4.27	69.8	46.1	43.7	0.85	5.21	9.23	1.02
	P. longirostris	0.76	12.4	5.52	5.23	0.39	2.40	2.30	0.25
Local regulations	*T. capellanus*	0	0	0	0	0.87	5.29	6.40	0.70
	M. potassou	0.32	5.26	10.6	10.1	0.56	3.40	21.7	2.39
	L. budegassa	0.41	6.64	13.4	12.7	0.34	2.07	15.4	1.69
	L. piscatorius	0.01	0.24	0.25	0.24	0.40	2.44	10.5	1.16
	B. boops	0	0	0	0	9.53	58.2	605.9	66.7
	O. vulgaris	0.04	0.62	15.8	15.0	0.38	2.29	113.6	12.5

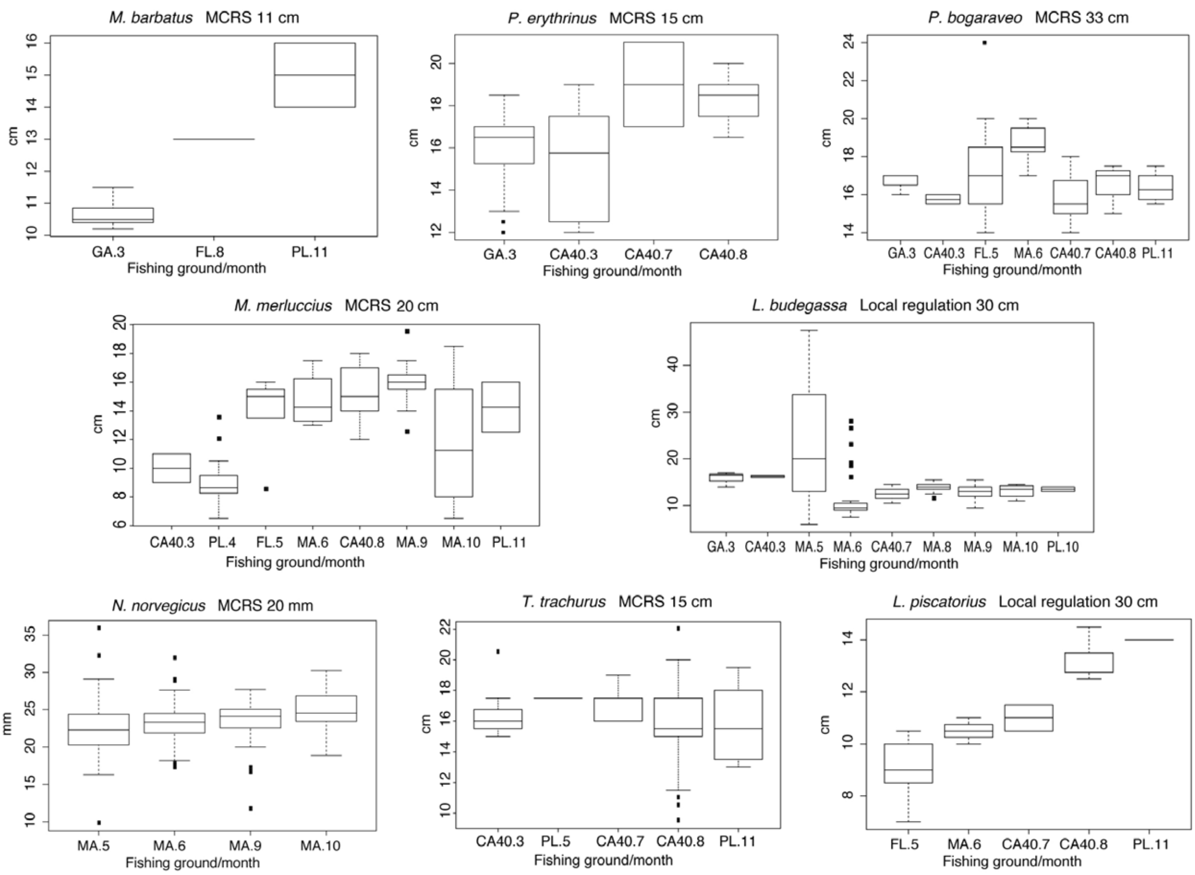

Fig. 3. – Monthly (in number) size distribution of the regulated species discarded from each fishing ground (Ga, Garotes; Pl, Planassa; Fl, Fluviana; CA40, Las 40-Capets; MA, Malica).

Species abundance at Garotes showed that the average abundance of maërl rhodoliths was one of the largest, with 21.78 ind. ha^{-1} (Table 4). The presence of maërl rhodoliths was located exclusively in the area corresponding to one of the two hauls carried out over a depth range of 54 to 70 m with rhodolith abundance of 43.56 ind. ha^{-1}. Other abundant species in the discards of the Garotes fishing ground were *Boops boops* and *Spicara smaris*.

Regulated discard characterization

From the total hauls analysed, we observed 15 discarded regulated species: 9 regulated by MCRS and 6 regulated locally by the Spanish or the Catalan government (Table 5). These species include 12 fish, two crustaceans and one cephalopod.

The locally regulated species *Boops boops* was the most discarded species, with a total of 58.21% abundance, well above the discarded percentage of other species, among which only *Trisopterus capelanus* and *Nephrops norvegicus* exceeded 5%. *Merluccius merluccius*, *Lophius budegassa* and *Trachurus trachurus* were discarded in all fishing grounds except one.

In Garotes, species regulated by MCRS such as *Pagellus erythrinus*, *Mullus barbatus* or *Pagellus bogaraveo* were discarded, although with a percentage of abundance much lower than *Boops boops,* which was discarded in 87.45% of cases. As in Garotes, the most discarded species in Las 40-Capets was *Boops boops*, which, like *Trachurus trachurus,* exceeded 30% of discarded abundance at this fishing ground. On the other hand, in Planassa, *Micromesistius potassou*, *Merluccius merluccius* and *Pagellus bogaraveo* were the most discarded regulated species, accounting for 34.46%, 17.08% and 3.42% of the abundance, respectively. In Fluviana, the discard of the MCRS regulated species *Mullus barbatus* and *Pagellus bogaraveo* accounted for close to 23% of the total biomass discarded. Finally, it is noteworthy that the most discarded species in Malica was *Nephrops norvegicus,* with 69.83% abundance and 43.67% biomass (Table 5). Regarding the size of the discarded regulated species, Figure 3 shows the size ranges of the eight species that were important in the study area because of their commercial interest. Only the genus *Lophius* is regulated at the local level. *Pagellus bogaraveo* was discarded in all fishing grounds due to its small size, and *Lophius piscatorius* and *Merluccius merluccius* were discarded for their small size in all fishing grounds except Garotes, where neither were discarded (Fig. 3). In addition, the fraction of *Lophius piscatorius* discarded grew over time, while *Merluccius merluccius* was discarded during all sampling months.

Nephrops norvegicus was discarded exclusively in Malica and showed an increase in the size of discarded individuals over time. *Mullus barbatus* and *Lophius budegassa* also showed an increase in size over time.

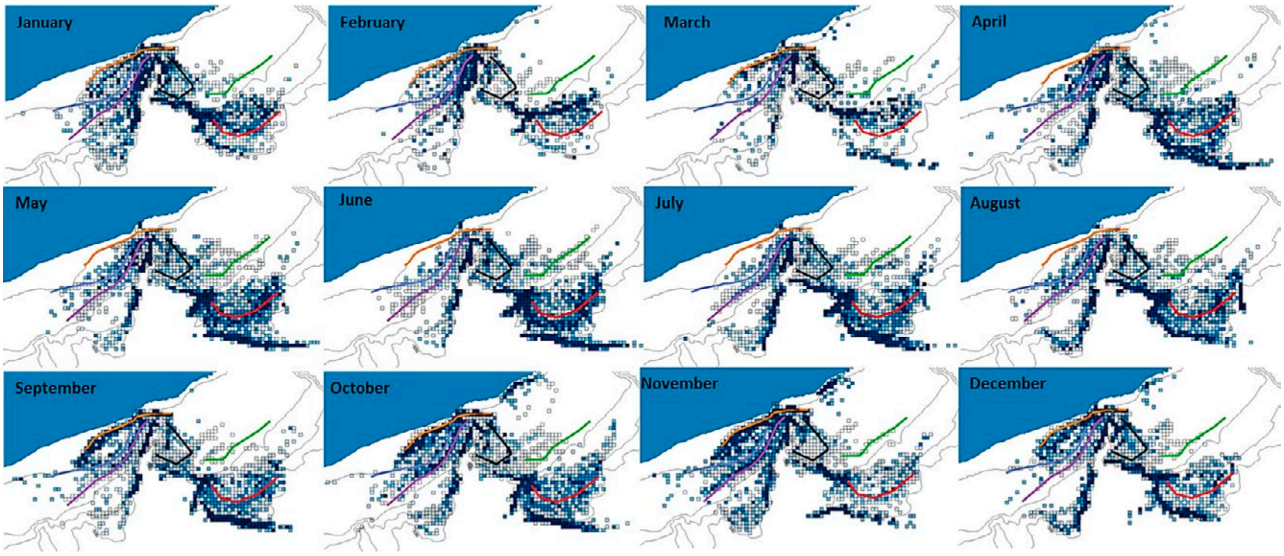

Fig. 4. – Monthly fishing effort estimates of the Blanes trawl fleet (2012-2014) and the locations of the fishing grounds studied (red, Malica; green, Fluviana; black, Planassa; purple, Las 40; light blue, Capets; and orange, Garotes).

Fishing effort dynamics

From 2012 to 2014 at the fishing grounds adjacent to Blanes port, trawl fleet dynamics were described, and the fishing effort was estimated per month for all fishing activity areas (Fig. 4).

The fishing ground Malica, located on the upper slope, endured intense fishing activity throughout the year, although fishing effort increased specifically in May and June. In Planassa and Fluviana, there was a fairly continuous fishing effort throughout the year, although it was less intense than in Malica. In addition, Fluviana was the fishing ground least frequently exploited by the fleet. Finally, Garotes, Capets and Las 40 showed a clear seasonal variation in fishing effort, with practically no fishing effort during some months of the year in Garotes. However, in September, there was a sudden increase in fishing effort at Garotes, which continued until December and then progressively decreased until April. Finally, Capets and Las 40 showed low but continued fishing effort throughout the year, except from July to November, when it increased significantly.

Link between fishing effort dynamics and regulated discard

The fishing effort at Las 40-Capets was significantly lower in March than in July and August (Fig. 5).

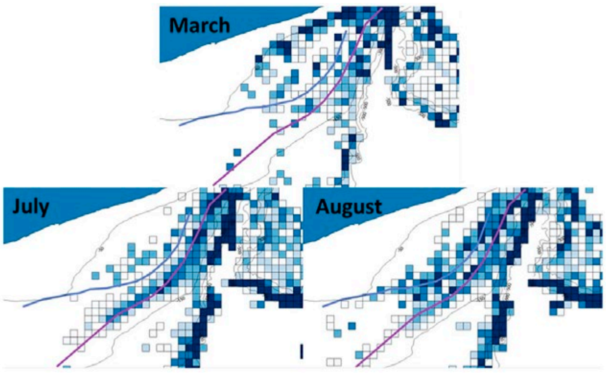

Fig. 5. – Fishing effort dynamics detail in Las 40-Capets for March, July and August.

Table 6. – Average biomass (g ha^{-1}) and abundance (ind. ha^{-1}) of species affected by the landing obligation for the months shown in Figure 5.

Las 40-Capets	Av. March		Av. July-August	
	Abundance	Biomass	Abundance	Biomass
Merluccius merluccius	0.41	3.68	0.34	30.72
Pagellus bogaraveo	0.09	0.004	0.73	41.47
Pagellus erythrinus	0.92	46.47	0.29	24.81
Trachurus trachurus	1.97	78.6	3.6	128.49
Total	3.39	128.75	4.96	225.49

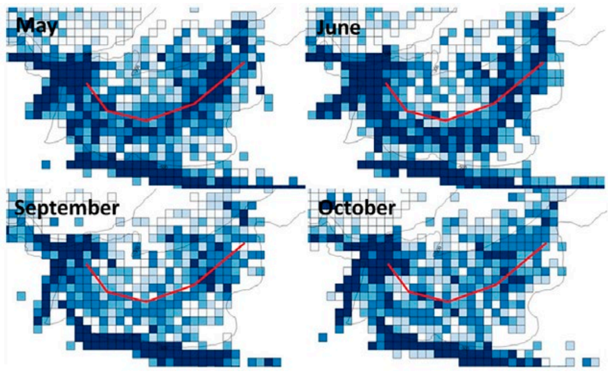

Fig. 6. – Fishing effort dynamics detail in Malica for May, June, September and October.

Table 7. – Average biomass (g ha^{-1}) and abundance (ind. ha^{-1}) of species affected by the landing obligation for the months shown in Figure 6.

Malica	Av. May-June		Av. September-October	
	Abundace	Biomass	Abundance	Biomass
Merluccius merluccius	0.07	1.35	0.52	10.14
Pagellus bogaraveo	0.14	12.62	0	0
Nephrops norvegicus	5.12	56.24	2.57	19.44
Parapenaeus longirostris	0.98	6.77	0.31	2.27
Total	6.3	76.99	3.4	31.85

This increase coincided with an increase in the regulated MCRS discard biomass, which was practically double that in March (Table 6). At the species level, it occurred with practically the same pattern. Most of the regulated species were discarded in greater numbers and biomass in July and August. This was the case for the target species *Pagellus bogaraveo*, of which only 0.004 g ha^{-1} were discarded in March, while in July and August, 41.47 g ha^{-1} were discarded.

In Malica, the total average discard biomass and abundance of regulated species was higher in May and June than in September and October (Table 7). For example, an average of 56.24 g ha^{-1} of *Nephrops norvegicus* was discarded in May and June, while an average of 19.44 g ha^{-1} was discarded in September and October, coinciding with a decrease in fishing effort in these last two months (Fig. 6).

DISCUSSION

The present work has analysed the captures of commercial trawl vessels, emphasizing the links between the discard fraction, specific species affected by the new European regulation on landing obligations and by local regulations, and the seasonal and spatial distribution of the fishing effort of the Blanes trawl fleet. Our final goal was to link these two types of information to propose measures that can help minimize or avoid unwanted catches.

Fishermen develop dynamic fishing strategies as an adaptive response to changes in resource abundance, environmental conditions and market or regulatory constraints (Martín et al. 2014). The Blanes fleet fishing effort showed two different behaviours: a continuous fishing effort in the canyon and upper slope zones, which corresponds to specialist behaviour on fishing grounds with *Aristeus antennatus* and *Nephrops norvegicus* as the target species; and a discontinuous fishing effort on most of the continental shelf fishing grounds, which corresponds to the generalist behaviour where there were several target species, such as *Merluccius merluccius*, *Mullus* spp., or *Lophius* spp. The knowledge of these dynamics is fundamental for the effective management of fisheries (Salas et al. 2004). Similar to the findings of previous works on the Blanes trawl fleet (Sanchez et al. 2004, Tsagarakis et al. 2014), this specialist or generalist behaviour was related to the discard amount, which was significantly higher on the continental shelf than on the upper slope (Table 2). Discard heterogeneity was also related to higher discard amounts, which were predominantly located on the continental shelf, with a similarity of between 15% and 40% (Table 3), while the most homogeneous fishing ground, located on the upper slope, showed less discard and an average similarity close to 60%.

Knowledge on the distribution of fishing activities should be followed by the characterization of the fished habitats (Demestre et al. 2000). Discard analysis by species revealed the existence of two especially productive but vulnerable Mediterranean habitats.

First, in Garotes, an area with maërl rhodoliths was found. This could indicate that in the past, there was an active maërl bed that over time has been degraded as a result of fishing pressure. Although maërl is protected in Annex I of the Habitat Directive (EU Dir. 92/43/EEC), fishing pressure is still exerted on maërl habitat, here and in other Mediterranean areas (Demestre et al. 2017). In the western Mediterranean, maërl bottoms can reach 90 or 100 m depth (Basso 1996), and in Garotes, rhodoliths were found in the hauls carried out at lower depths, between 54 and 70 m (Table 4), where the fishing effort intensity was very low for five months out of the year (Fig. 4). However, there was a constant fishing effort in deeper areas of this fishing ground, between 80 and 107 m depth, where maërl rhodoliths were not found. It is possible that the maërl, due to its vulnerability to trawling (De Juan et al. 2013, Barberá et al. 2012), disappeared completely from deep areas of Garotes, surviving only in areas with lower fishing pressure. Second, areas with *Leptometra phalangium* crinoid aggregations were also found in two adjacent fishing grounds, Planassa and Fluviana. These fishing grounds showed the largest biomass of unregulated discards (Table 2), high heterogeneity (Table 3) and moderate but continuous fishing effort throughout the year. In the three fishing grounds where commercial species below the legal size (such as *Merluccius merluccius, Lophius* spp., and *Pagellus* spp.) were captured, catches showed that they function as nursery areas, as is confirmed in other studies (Hall-Spencer et al. 2003, Steller et al. 2003, Colloca et al. 2004).

A high similarity between the Las 40 and Capets fishing grounds is suggested by the close association of their hauls in MDS space (Fig. 2). Their discards were mainly composed of echinoderms such as *Ophiura texturata* and *Echinus melo* and the locally regulated fish *Boops boops,* but juveniles of several commercial species, such as *Merluccius merluccius* and *Pagellus bogaraveo*, were also found (Fig. 3), suggesting that these fishing grounds could also function as nursery areas for some commercial fish species.

Although in a higher bathymetric range, a previous study carried out in the Catalan Sea (Maynou and Cartes 2000) revealed a *Nephrops norvegicus* incidence of 1.8 ind. ha^{-1} for the total catch. In our work *Nephrops norvegicus* discard had a considerable incidence in Malica, where with 4.27 ind. ha^{-1} it was the most discarded species, mainly due to its small size. This commercial species is regulated by an MCRS and avoiding the capture of small individuals is imperative to improve fishery management (Méhault et al. 2016). In addition, Norway lobster showed good survival potential in several studies (Campos et al. 2015, Méhault et al. 2016), and this species could be exempt from the landing obligation because of its high survival (Article 15 of EU Reg. 1380/2013). Sorting methods to improve the survival of the discards of this species in the Mediterranean should be adopted, such as sorting tables to expedite discard activities (Garcia-de-Vinuesa et al. 2017).

The discarding behaviour of the Blanes trawler fleet is related to the biology of some species regulated by

MCRS. The period of greatest reproductive activity of many Mediterranean commercial fish species, such as *Merluccius merluccius, Mullus barbatus, Mullus surmuletus, Pagellus bogaraveo, Pagellus erythrinus* and *Trachurus trachurus,* occurs between late spring and late autumn (Recasens et al. 2008, Tsikliras et al. 2014, Carbonara et al. 2015), and there was a significant increase in fishing effort in autumn and winter at several of the continental shelf fishing grounds studied, corresponding with the season of recruitment of these animals. This was the case for Garotes, where the fishing effort increased from September to April and discarding increased significantly in March for *Mullus barbatus, Pagellus erythrinus* and *Pagellus bogaraveo* (Fig. 3) below the MCRS. In Las 40 and Capets, two species of the genus *Pagellus* plus *Merluccius merluccius* and *Trachurus trachurus* were discarded mainly because they did not reach the MCRS (Fig. 3), and the total discarded biomass of these regulated species at the end of summer was practically double that in March (Table 6). On the other hand, in Malica, the smallest individuals of *Nephrops norvegicus* were discarded almost three times more often between May and June, when fishing effort increased, than in September and October (Table 7). Finally, although there was no significant seasonal change in fishing effort at fishing grounds with crinoid aggregations, MCRS-regulated species such as *Mullus barbatus, Merluccius merluccius, Pagellus bogaraveo* and *Trachurus trachurus* were discarded, the last three below their MCRS. Due to the costs in time and money that the landing obligation entails, one of the expected positive consequences can be the increased interest of fishermen in avoiding areas where unwanted species are caught, thus improving fishing efficiency (Vilela and Bellido 2015).

Species regulated at the local level that are also commercially important include those of the genus *Lophius* spp. which comprise two target species in the region that were discarded in all the fishing grounds studied (almost always under the local minimum legal size) and *Micromesistius poutassou, Trisopterus capelanus* and *Octopus vulgaris*, which are accessory species to the Blanes trawl fleet. *Boops boops* was the only non-commercial regulated species that we found, and it was the most discarded species.

CONCLUSIONS

The joint study of catch focusing especially on the discard fraction and fishing effort dynamics provides a useful tool for improving the management of trawling fisheries and particularly for avoiding unwanted catches. The presence of maërl in Garotes together with the large discard rates and the obligation to land six species affected by MCRS suggests that this area could be a good candidate for establishing a permanent no-take zone to avoid the problem of unwanted catches and prevent further habitat degradation. Additionally, it is demonstrated that, as in Garotes, fishing effort on Las 40 and Capets increased during recruitment months for commercial species affected by the landing obligation. Thus, carrying out seasonal closures in these fishing grounds is recommended, and although no seasonal pattern was found in the behaviour of the fleet in fishing grounds with crinoid aggregations, seasonal closures could be carried out during the recruitment season of discarded species regulated by MCRS such as *Merluccius merluccius* and *Mullus barbatus* or species regulated locally such as *Lophius* spp. to avoid unwanted catches. These closures would be more beneficial in late spring or summer, but not in February, as has already been adopted in the area by internal agreement among the fishermen. Also, de *minimis* exemption could be applied for hake and red mullet, up to a maximum of 7% of the total annual catches in 2018 and 6% in 2019 (EU Reg. 2017/86) in all fishing grounds, but this would only be a short-term solution.

Finally, in Malica, the possibility of reducing fishing effort in the months in which smaller individuals of *Nephrops norvegicus* were discarded should be studied, particularly in the months of May and June.

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