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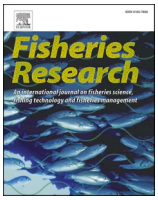

Discards reduction of non-commercial benthic species from a simple net modification

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ABSTRACT

The high discards rates of non-commercial benthic species is one of the main problems of the Mediterranean bottom trawl fishery developed on the continental shelf. The present work analyzes data from 22 bottom trawls, carried out in parallel by two commercial trawlers between 70 and 90 m depth on maërl beds off eastern Menorca (Balearic Islands). One vessel used an experimental trawl gear (EXP) equipped with a lighter and smaller groundrope in the mouth of the net, leaving a gap without net between the main groundrope and the secondary one. The other vessel used a trawl gear traditionally used by the fleet operating in the area (TRA), without that modification. Catches, discards and commercial yields between both gears were compared. Discarded biomass of non-commercial benthic species with EXP was reduced by half when compared to TRA, particularly for rhodoliths (54%) and ascidians (51%). The reduction of discarded rhodoliths is especially relevant in the Balearic Islands where sensitive habitats, such as maërl beds, are an important part of the benthic communities. The modification of the net, at the same time, does not imply a reduction of yields of commercial captures and can easily be implemented in any bottom trawl net. It is concluded that this could be an appropriate and plausible technical measure to improve the ecological efficiency and the sustainability of the Mediterranean bottom trawl fishery.

1. Introduction

Bottom trawling is one of the less ecologically efficient fisheries, due to its impact on ecosystems. The ploughing and scrapping of the seafloor by the fishing gear, the high proportion of discards and high consume of fossil fuel, and hence the emission of CO_2 into the atmosphere, are among the most important impacts of this fishery (e.g. Hall, 1999; Parker and Tyedmers, 2014; Pérez Roda et al., 2019). One of the main objectives of the new Common Fisheries Policy of the European Union (Reg. EU No 1380/2013), in line with the current Ecosystem Approach to Fisheries Management, is to mitigate the direct and indirect effects of bottom trawl fishing on ecosystems in order to achieve the sustainability of this fishery.

The bottom trawl fishery of the Mediterranean is highly multispecific (Lleonart and Maynou, 2003), with a large amount of by-catch of both commercial and non-commercial species and discards (FAO, 2016). In some areas such as the Balearic Islands, discards can represent up to 70% of the captured biomass (Carbonell et al., 1998; Ordines et al., 2006). Red algae beds are the fishing grounds with the highest discards rates of the bottom trawl fleet operating in the area. These discards are mainly composed of algae and non-commercial invertebrates (Ordines et al., 2006, 2017).

The lack of rivers runoff around the Balearic Islands favors the absence of terrigenous sediments and oligotrophic conditions. Both factors lead to a high transparency of the waters that benefit the presence of red algae down to 90−100 m depth (Ballesteros, 1992, 1994), forming the facies of *Peyssonnelia* and maërl beds, widely distributed on the shallow shelf and commonly overlapping with trawl fishing grounds (Farriols et al., 2017). These beds play an important role in structuring sedimentary communities on the continental shelf bottoms, increasing their diversity and macro-benthic secondary production (Ordines and Massutí, 2009). Maërl beds are considered sensitive habitats (Donnan and Moore, 2003), due to their fragility and slow regeneration and some of the rhodolith-forming species, such as *Lithothamnion corallioides* and *Phymatholithon calcareum*, are protected by the Habitat Directive and the Barcelona Convention. Moreover maërl beds have been protected by the Council Regulation (EC) Nº 1967/2006, concerning management measures for the sustainable exploitation of fishery resources in the

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Mediterranean Sea, which prohibits fishing with trawl nets above these beds. As a consequence, a great part of the shallow shelf of the Menorca Channel, declared Site of Community Importance (SCI) within Natura 2000 Network in 2015, was closed to trawling in 2016 (Fig. 1).

The low selectivity and direct impact of bottom trawling on the seafloor have a negative effect on the benthic community structure, decreasing the abundance of vulnerable species and the presence of biogenic habitats (e.g. Smith et al., 2000; Hiddink et al., 2006; Ordines et al., 2017). In the Balearic Islands some experimental fishing pilot projects, aimed to improve the selectivity of the bottom trawl fishery, have been developed during the last decades. Changes in the geometry of mesh cod-end, from diamond to square (Guijarro and Massutí, 2006; Ordines et al., 2006) and the use of sorting grids (Massutí et al., 2009) have been tested. Lighter fishing gears and mid-water doors have also been tested to reduce the impact of bottom trawling on seafloor and benthic habitats and also in fuel consumption (Guijarro et al., 2017). Some of these technical improvements have been adopted by the trawling fleet of the Balearic Islands. For instance, the 40 mm square mesh cod-end was implemented in 2010 (Reg. EU No 1967/2006) and currently some trawlers use mid-water doors instead of traditional ones.

The main aim of this work is to test the effect of a modification of the groundrope of the bottom trawl net to reduce benthic discards in the maërl fishing grounds of the Balearic shelf. To do this, we have compared catches, discards and commercial yields between an experimental bottom trawl gear incorporating this technical measure and a bottom trawl traditionally used by the trawling fleet operating in the area.

2. Materials and methods

A pilot test at sea was developed to compare the performance of two similar bottom trawl gears working in parallel. Both gears used in the experiment are conventionally used by the trawling fleet of the Balearic Islands to operate on the continental shelf, but the groundrope of the net was modified in one of them.

2.1. Fishing gears and vessels

The experimental bottom trawl gear (EXP) was composed by a net of 55 m flotsam and 70 m groundrope, with polyethylene (PE) wings and polyamide (PA) netting in belly and cod-end, with a square 45 mm nominal size mesh cod-end of 3 mm twine thickness. This net was linked by 30 m bridles of PE headline and polypropylene (PP) footrope (⌀42), and 80 m steel and PP sweeps (⌀42) to mid-water doors Thyborøn 15VFS model, of 2 m^2 surface and 340 kg weight and to steel warp (⌀14). The linking between the doors and the sweep were made by a steel warp (⌀15) of 30 m length, with in-line chain ballast to ensure an optimal contact of sweeps and net to the bottom. In order to improve benthic species selectivity, the net had a main groundrope (⌀60) supporting the gear traction, with ballast leads and plastic rollers to separate it from the bottom, and a secondary shorter groundrope (⌀50) of 3 m length at the center of the main groundrope, without ballast leads and with one plastic roller mounted in the middle, leaving a gap of 1.5−2 m without net between both groundropes (Fig. 2).

The traditional bottom trawl gear (TRA) was similar to EXP, except for the length of flotsam and groundrope of the net (45 and 63 m, respectively), the length of bridles (40 m) and sweeps (160 m), as well as the type of doors, which were bottom doors EXPLORER model S1150, of 3 m^2 surface and 588 kg weight. The net had only one groundrope, equipped with ballast leads and plastic rollers, similarly to the groundrope supporting the gear traction in EXP.

These fishing gears were assessed with two commercial trawlers harbored in the Balearic Islands: F/V *Nueva Joven Josefina* (length 21.0 m, 44 grt, nominal engine power 150 hp) and F/V *Punta des Vent*

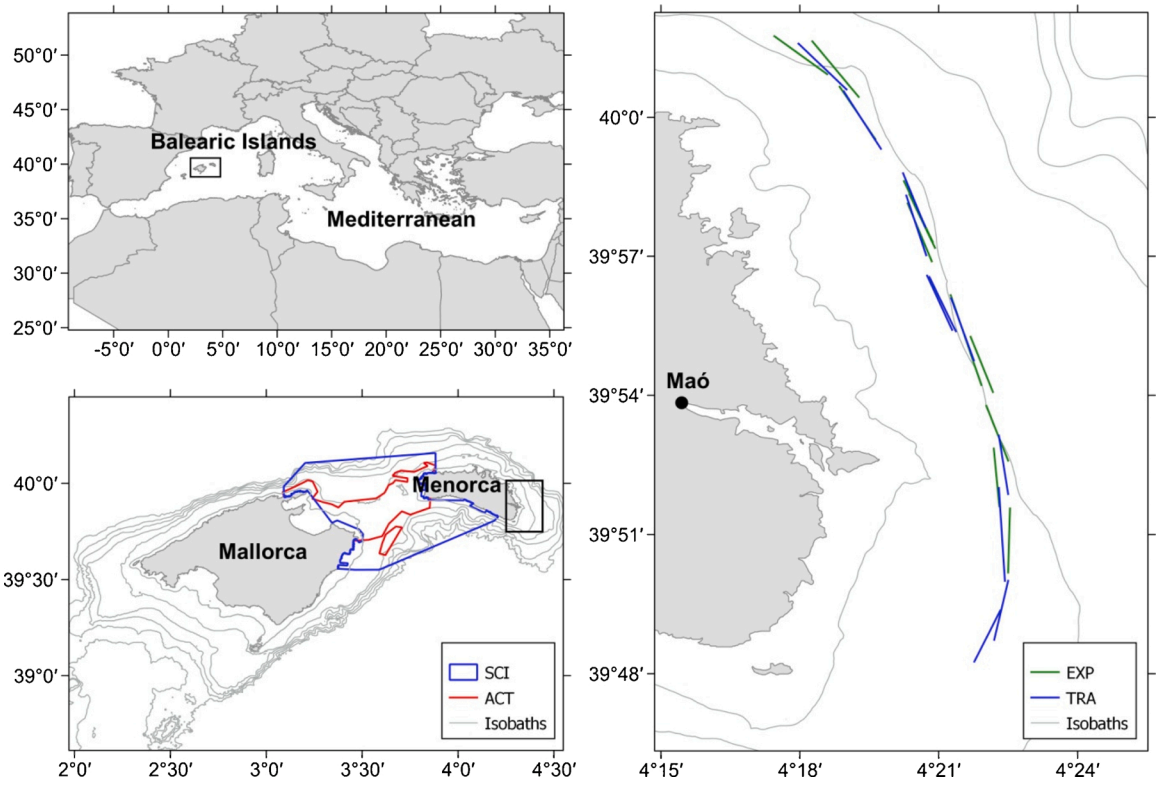

Fig. 1. Map of the study area (eastern Menorca, Balearic Islands, western Mediterranean), showing the Site of Community Importance (SCI) and the Area Closed to Trawling (ACT) in the Menorca Channel. Experimental bottom trawl gear (EXP) hauls analyzed are in green and traditional bottom trawl gear (TRA) hauls are in blue. Isobaths of 50, 100, 200, 400, 600 and 800 m are also represented (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

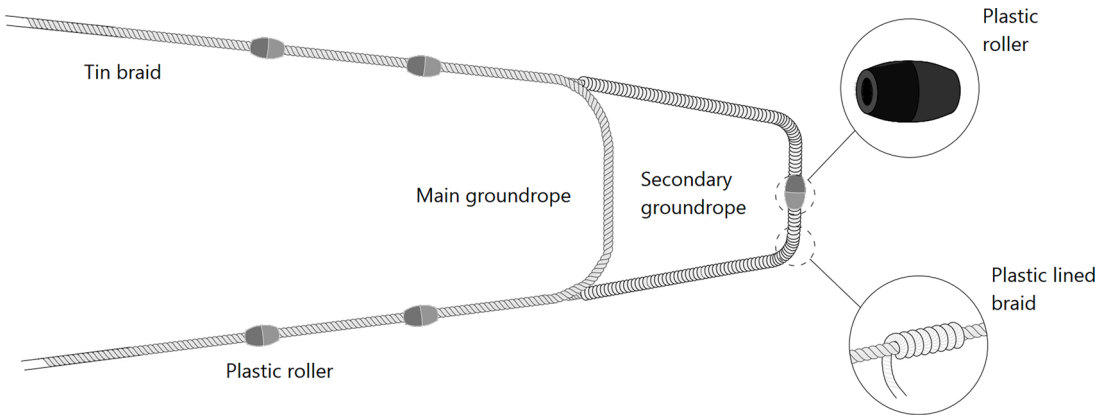

Fig. 2. Scheme showing a detail of the groundrope modification of the net in the experimental bottom trawl gear.

(length 22.5 m, 55 grt, nominal engine power 365 hp). In both vessels, the SIMRAD trawl monitoring ITI system was used to monitor the distance between the doors and their depth, and the horizontal and vertical opening of the net. This system was also used to monitor the arrival and departure of the gear to the bottom and hence the effective duration and the swept area of the hauls.

2.2. Experimental fishing

A survey was developed from 17th to 19th September 2019 on traditional fishing grounds of the continental shelf eastern Menorca (Balearic Islands) between 70 and 90 m depth (Fig. 1). The two vessels carried out parallel hauls of 30 min of effective duration during night hours, the F/V *Nueva Joven Josefina* using EXP and the F/V *Punta des Vent* using TRA. During the hauls, geographic position, depth, speed and fuel consumption were registered every 5 min, as well as data of the fishing gear obtained from the ITI system. Experimental conditions were the same for both F/V, with the only exception of the fishing net modification in EXP.

The sampling was similar in both vessels and followed the routines usually made by the commercial fishing fleet. First the crew separated the commercial capture from discards and classified the landings into commercial categories. Then the scientific observers on board separated and classified the discards by species or taxonomic group. All categories or species were counted and weighed separately.

2.3. Data analysis

Data from 22 hauls, 11 for each fishing vessel working in parallel, were analyzed. In each haul, total catch in weight, catch of the most important commercial species and categories, total discards and discards of main taxonomic groups were standardized to one km^2, by calculating the area swept by the net using the distance covered in each haul and the horizontal opening of the net while it was in contact with the bottom. These parameters were obtained from the ITI system. The average values of these parameters, as well as the taxonomic composition of discards, were estimated by type of fishing gear. Species with a pelagic behavior (e.g. *Spicara smaris*, *Centracanthus cirrus* and *Trachurus* spp.) were excluded from these analyses. The list of species captured by each fishing vessel is included in the Supplementary material.

Student-t test was applied to test for differences in catch yields by type of fishing gear. We compared yields of total catch, commercial species and categories and discards, as well as the percentage of commercial and discard yields from total catch. Redundancy analysis (RDA) was used to assess differences in catch composition of commercial categories and taxonomic groups discarded by type of fishing gear. Monte Carlo free-distribution permutation based test was used to assess the significance. Differences in yields of main commercial categories and main taxonomic groups discarded by type of fishing gear were also tested. Prior to the use of the t-test, Shapiro-Wilk test was applied to check for normality. When this assumption was not met, a Kruskall-Wallis non-parametric test was applied. All these analysis were carried out in R statistical software (R Core Team, 2019).

3. Results

The 22 trawl hauls carried out yielded 843 kg of commercial catches and 966 kg of total discards. The commercial species or categories caught were comprised of 20 fishes and 5 cephalopods, which represented 87 and 13%, respectively, in terms of biomass. The most important commercial species or categories were *Mullus surmuletus* (23% of biomass), *Scyliorhinus canicula* (15%), *Raja* spp. (12%), Mixed fish category 1 (called Morralla; 10%), *Serranus cabrilla* (9%), the category Octopus (6%), *Scorpaena scrofa* (5%) and *Loligo vulgaris* (5%). The most important taxonomic groups of discards were rhodoliths (59%), echinoderms (14%), fishes (11%), ascidians (6%), Porifera (4%) and soft algae (3%).

No significant differences between gears were detected for the total (EXP: 1482 ± 100 kg/km^2; TRA: 2156 ± 355 kg/km^2; Kruskall-Wallis: $p > 0.05$) and commercial catches (EXP: 819 ± 67 kg/km^2; TRA: 846 ± 131 kg/km^2; Student *t*-test: $p > 0.05$). However, there were differences in discards, with significant lower values with EXP compared to TRA (662 ± 54 and 1309 ± 238 kg/km^2, respectively; Kruskall-Wallis: $p < 0.05$).

RDA showed a significant effect of type of gear on the overall catch biomass of commercial categories (variance explained = 21%, $p < 0.05$). Significantly larger average yields were detected for *S. scrofa* (Kruskall-Wallis: $p < 0.05$), *Pagellus* spp. (Kruskall-Wallis: $p < 0.01$) and *Illex coindetii* (Kruskall-Wallis: $p < 0.05$), when using EXP (Table 1). Regarding discards biomass, the type of gear explained up to 22% of the variance ($p < 0.05$), with significantly larger average yields for ascidians (Kruskall-Wallis: $p < 0.05$) and rhodoliths (Kruskall-Wallis: $p < 0.01$) when using TRA, and larger yields for soft algae when using EXP (Kruskall-Wallis: $p < 0.01$; Table 2).

The percentage of commercial yields referred to total catch, were significantly higher using EXP than TRA (55% and 39%, respectively; Student *t*-test: $p < 0.001$). On the contrary, the percentage of discarded yields were significantly lower using EXP than TRA: 45 and 61%, respectively (Student *t*-test: $p < 0.001$). Similar results were obtained regarding discarded rhodoliths, which represented 23% using EXP and 36% using TRA (Student *t*-test: $p < 0.001$).

4. Discussion

Bottom trawling is one of the less sustainable fisheries in the Mediterranean. On one hand, its target resources show a high level of

Table 1
Mean yields and standard errors (±SE) of main commercial categories captured (kg/km^2) with the experimental (EXP) and the traditional (TRA) trawl gears. P-values of the Kruskall-Wallis (KW) or Student *t*-test (T-test) are also presented: (*) $p < 0.05$; (**) $p < 0.01$; (***) $p < 0.001$; (ns) not significant. The species composition of these categories is shown below.

Commercial categories	EXP		TRA		Statistics	
	Mean	±SE	Mean	±SE	Test	p-value
TELEOSTS						
Lophius spp.[1]	17	6	9	6	KW	ns
Mixed fish 1[2] (called Morralla)	71	14	100	19	T-test	ns
Mixed fish 2[3] (called Sopa)	19	10	32	9	KW	ns
Mullus surmuletus	165	26	214	48	KW	ns
Pagellus spp.[4]	42	16	11	10	KW	**
Scorpaena scrofa	58	20	24	21	KW	*
Serranus cabrilla	60	19	98	28	KW	ns
Zeus faber	32	13	18	13	KW	ns
ELASMOBRANCHS						
Raja spp.[5]	97	27	117	39	KW	ns
Scyliorhinus canicula	126	29	120	34	T-test	ns
CEPHALOPODS						
Illex coindetii	20	4	9	3	KW	*
Loligo vulgaris	38	14	39	12	KW	ns
Octopus[6]	53	14	37	9	KW	ns

[1] *Lophius budegassa* and *Lophius piscatorius*.
[2] Morralla: *Serranus cabrilla*, *Trachinus draco*, *Chelidonichthys cuculus*, *Chelidonichthys lastoviza*, *Scorpaena notata* and *Citharus linguatula*.
[3] Sopa: *Scorpaena scrofa*, *Pagellus erythrinus*, *Pagellus acarne*, *Scorpaena porcus* and *Trachinus radiatus*.
[4] *Pagellus erythrinus* and *Pagellus acarne*.
[5] *Raja clavata*, *Raja brachyura* and *Raja polystigma*.
[6] *Octopus vulgaris* and *Eledone cirhosa*.

Table 2
Mean yields and standard errors (±SE) of main taxonomic groups discarded (kg/km^2) with the experimental (EXP) and the traditional (TRA) trawl gears. P-values of the Kruskall-Wallis (KW) test are also presented: (*) $p < 0.05$; (**) $p < 0.01$; (***) $p < 0.001$; (ns) not significant.

Taxonomic group	EXP		TRA		Statistics	
	Mean	±SE	Mean	±SE	Test	p-value
Fishes	80	13	122	43	KW	ns
Cephalopods	5	2	3	2	KW	ns
Molluscs	12	5	5	2	KW	ns
Crustaceans	8	2	11	3	KW	ns
Echinoderms	70	13	216	143	KW	ns
Ascidians	35	11	71	14	KW	*
Porifera	38	15	43	12	KW	ns
Bryozoans	0.5	0.3	0.2	0.2	KW	ns
Cnidarians	0.3	0.1	0.9	0.3	KW	ns
Rhodoliths	358	51	784	155	KW	**
Soft algae	36	10	11	3	KW	**

overfishing, as consequence of the high fishing mortality exerted and an inadequate selectivity pattern for these species (Colloca et al., 2013). On the other hand, it shows a high percentage of discarded biomass, composed by species of commercial interest (small-sized or damaged specimens) and the rest being species of low or no economic value (Machias et al., 2001; Sánchez et al., 2004).

Most studies developed to mitigate the problem of sustainability of bottom trawl fisheries have been only aimed at incrementing the length of first capture of target species. To do that changes in mesh size and shape, mainly in the cod-end (e.g. Bahamon et al., 2006; Sala and Lucchetti, 2011; Gorelli et al., 2017) but also in the extension piece of the net (Sola and Maynou, 2018), and the introduction of sorting grids (Sardà et al., 2005; Sala et al., 2011; Vitale et al., 2018a) have been tested. Although some works have also analyzed the effect of these technical measures on commercial catches and discards (Stergiou et al., 1997; Sala et al., 2011; Vitale et al., 2018b), studies focused on the reduction of discards of non-commercial benthic species, through improving selectivity of trawl nets, are still scarce. In the Balearic Islands Guijarro and Massutí (2006), Ordines et al. (2006) and Massutí et al. (2009) have assessed the effect of a change of mesh shape in the cod-end and the introduction of sorting grids on catch composition, commercial yields and discards rates.

Our results are in line with other studies showing a reduction of discards of benthic species in trawl fisheries modifying the groundrope of the net (e.g. Broadhurst, 2020; Kynoch et al., 2015). However, this is the first study developed in the Mediterranean, where trawl fleets operate in a great variety of habitats, causing a high percentage of non-commercial species discarded, some of which are macro-invertebrates (Demestre et al., 2018). In this context, the results obtained in the present paper are especially relevant, because a simple modification of the groundrope of the bottom trawl net allows reducing up to 50%% of the discarded biomass of non-commercial benthic species, mainly rhodoliths and ascidians. These are large and heavy species which must be detached from the seafloor by the main groundrope, but due to their weight, they fall to the bottom before the arrival of the second groundrope, lighter and with less contact to the bottom than the main one, which only retains a half of them. By contrast, this secondary groundrope retains most commercial species, even those with a more benthic behavior such as octopuses or skates, probably because their swimming capacity can allow them react to the pass of the main groundrope and remain separated from the bottom until the arrival of the secondary one.

The reduction of discarded rhodoliths is not trivial in the Balearic Islands, where sensitive habitats such as maërl beds are an important part of the benthic communities (Ordines and Massutí, 2009). The mapping of the spatial distribution of the benthic habitats in the Menorca Channel (Barberá et al., 2012) was determinant to protect these habitats. However, the rest of the Balearic shelf, where the presence of rhodoliths has been detected on coastal detritic bottoms (Ordines and Massutí, 2009), has not been mapped yet and, therefore, their distribution is still unknown. The modification of the net assessed in the present study, could be an appropriate and plausible technical measure to reduce the impact of the bottom trawl fishery developed on the continental shelf of the Balearic Islands until detailed cartographies of their benthic habitats are available. This is necessary for a spatial management that allows the implementation of Habitat Directive, Barcelona Convention and the Council Regulation (EC) Nº 1967/2006 to protect maërl beds.

The catch rates of its main demersal resources, *Octopus vulgaris*, *Mullus surmuletus* and *Loligo vulgaris* (Palmer et al., 2009) estimated with both fishing gears were similar, showing that fishing efficiency is not compromised by this modification. It is important to highlight this result, because fisheries innovations are only accepted by fishermen if the economic losses are negligible. Moreover, the reduction of non-commercial benthic species in the catches, should improve the quality of landings. The lower amount of rhodoliths in the cod-end can produce less friction with the specimens of commercial species, avoiding the loss of scales and pigmentation. Besides these important improvements in discards and commercial captures, the groundrope modification offers the advantage that can be implemented in any bottom trawl net by the net maker. So the cost of the new design is low and the manipulation of the net does not differ from that of traditional ones.

The modification of the groundrope tested in this work, jointly with the use of semi-pelagic doors which efficiency was already tested (Guijarro et al., 2017), should be additional to the spatial management for the protection of maërl beds, which implementation began in 2016 with the prohibition of trawling in much of the Menorca Channel. The implementation of both technical measures that reduce the impact of bottom trawling could start in the areas of the SCI of the Menorca Channel still open to trawling, where there are maërl beds with low

coverage and coastal detritic bottoms with rhodoliths (Barberá et al., 2012). Afterwards they should be extended to the whole Balearic shelf, meanwhile its detailed mapping of benthic habitats and fishing grounds is not available, to protect maërl beds and other detritic bottoms with rhodoliths, through spatial planning measures, as those applied in the Menorca Channel.

CRediT authorship contribution statement

M. Teresa Farriols: Methodology, Formal analysis, Writing - original draft. **Francesc Ordines:** Investigation, Methodology, Writing - review & editing. **Enric Massutí:** Investigation, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fishres.2021.105985.

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