Regional Studies in Marine Science 15 (2017) 39–49

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Why long term trawled red algae beds off Balearic Islands (western Mediterranean) still persist?

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ARTICLE INFO

Article history:
Received 3 February 2017
Received in revised form 17 July 2017
Accepted 18 July 2017
Available online 27 July 2017

Keywords:
Fishing impact
Bottom trawling
Red algae beds
Peyssonnelia beds
Long term fishery
Western Mediterranean

ABSTRACT

The bottom morphology, the surface sediments and the epibenthic community of two adjacent areas within the fishing ground traditionally known as *Pesquera Rica* (Balearic Islands) were characterized using multibeam echosounder, van Veen dredge and beam trawl. Red algae beds predominate in both areas, but one has been exploited by trawling since at least 90 years ago, whereas the presence of natural barriers prevents this fishing activity in the other one. Comparisons between the two areas showed a biomass reduction of 46.8 and 39.3% of dominant red algae taxonomic groups Peyssonneliaceae and Corallinophycidae, respectively, in the trawled area (TA). Similarly, both mean abundance and biomass of most groups of fauna were higher in the not trawled area (NTA). N_{90} biodiversity index showed higher mean values of algae species in NTA than in TA (7.0 and 4.9, respectively), whereas no differences were detected neither for sessile nor for mobile fauna. SIMPER analysis showed that large species of both sessile and mobile epibenthic fauna (e.g. the ascidia *Polycarpa mamillaris* and the echinoderm *Spatangus purpureus*, respectively) presented higher abundance and contribution to within area similarity in NTA than in TA. In coincidence, these are the most abundant epibenthic species in the commercial hauls from the *Pesquera Rica*. The relatively low fishing effort and the gears used, addressed to avoid large catches of algae allowing longer hauls, may explain the subsistence of red algae beds in the Balearic Islands trawl fishing grounds. However, the detrimental effects shown here claim for urgent management measures aiming to preserve these beds.

1. Introduction

Nowadays, a large amount of scientific information gives evidence that bottom trawl fishing has a considerable negative impact on marine ecosystems. Bottom trawl gears scrape and plough the bottom, cause sediment resuspension, and extract and destroy the flora and fauna of the benthos (Jones, 1992). This results in a reduction of the biodiversity, biomass and production of the exploited bottoms, as well as changes in the structure of their benthic communities (Engel and Kvitek, 1998; Smith et al., 2000; Hiddink et al., 2006; Hinz et al., 2009).

Bottom trawling decreases the population of those species that, with their growth and/or action, can create habitats. These are known as *habitat engineers*, and are mainly sessile organisms with an important vertical development, but also include organisms that can modify the substrate (Jones et al., 1994). The loss of these organisms leads to benthic communities being dominated by infaunal organisms with a faster growth, and reduces the three dimensional structure complexity and productivity of benthic habitats (Engel and Kvitek, 1998; Jennings and Kaiser, 1998; Jennings et al., 2001; Coleman and Williams, 2002; Kaiser et al., 2006; Mangano et al., 2013). The most vulnerable to bottom trawl fishing mega-zoobenthos organisms, those with lower resilience and slower recovering rates such as corals, are the first to face a reduction of their populations or even disappearance from the exploited bottoms (Pitcher et al., 2000; Fossået al., 2002; Roberts, 2002). The slow-growing species of the flora, such as the free-living red calcified algae from the rhodolith beds undergo similar consequences (Bordehore et al., 2003).

The magnitude of the damage caused by bottom trawl gears to benthic communities depends not only on the intensity of the fishing activity, but also on the biological traits and the resilience of their species. Most of the available literature studying the effects of bottom trawling on biogenic habitats concludes that this fishing

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http://dx.doi.org/10.1016/j.rsma.2017.07.005
2352-4855/

activity causes severe damages, from which communities recover only on the long term, or even these damages can be irreversible. Particularly in those habitats built up mainly by slow growing species, such as rhodolith beds, deep corals or sponge bottoms (e.g. Fossået al., 2002; Barberá et al., 2003; Kaiser et al., 2006; Hogg et al., 2010; Basso et al., 2016).

The oceanographic conditions of the waters surrounding the Balearic Islands are advantageous for the presence of red algae beds. The absence of rivers in the Archipelago reduces the amount of terrigenous sediments. Consequently, the presence of muddy bottoms is very scarce in the coastal shelf. Most of the sediments of the continental shelf consist of sands and gravels with high percentages of carbonates (Acosta et al., 2002), usually of biogenic origin (Canals and Ballesteros, 1997). The absence of rivers also reduces the supply of nutrients, which makes the waters of the Archipelago more oligotrophic than those in the adjacent coast of the Iberian Peninsula and the Gulf of Lions (Estrada, 1996; Bosc et al., 2004). Both factors, the absence of terrigenous sediments and the oligotrophic conditions, favour the water transparency and allow the light to support the development of several facies dominated by red algae to almost 90 m depth (Ballesteros, 1992, 1994; Ordines and Massutí, 2009; Barberá et al., 2012a; Joher et al., 2015). At this depth, the red algae beds are exploited by the bottom trawl fleet, which in the Balearic Islands operate from 50 to 800 m depth (Palmer et al., 2009).

The red algae facies known as *Peyssonnelia* beds is frequently found in the detritic bottoms off Balearic Islands, particularly in the south of Mallorca and Menorca. It is characterized by high biomass of 'soft' species of the genus *Peyssonnelia* and also presents a large proportion of a mixture of the main morphological groups of rhodoliths described by Basso (1998) such as 'boxwork', formed by nodules of *Peyssonnelia rosa-marina*; pralines, mainly represented by *Spongites fruticulosus*; and unattached branches, mainly composed of *Lithothamnion valens* and *Phymatolithon calcareum* (Ballesteros, 1994; Ordines and Massutí, 2009; Ordines et al., 2011; Joher et al., 2015). Such beds show a high coverage and biomass, which can even be higher than those of shallow algae bottoms of the western Mediterranean (Ballesteros, 1994). The *Peyssonnelia* beds off southern Mallorca have been exploited by trawling since at least the first quarter of the twentieth century, when this type of bottom was already known by fishermen with the common name of *avellanó* (De Buen, 1934). Nowadays, these bottoms still include some of the most important trawl fishing grounds of the coastal continental shelf of the Balearic Islands (Ordines, 2015).

The aim of the present work is to assess the effects of long term bottom trawling on the *Peyssonnelia* beds off the southern coast of Mallorca Island. To do so, we developed an experimental sampling to compare the diversity, composition and density of the epibenthic flora and fauna in two adjacent areas, one subjected to high levels of trawl fishing pressure and one that has never been trawled. We also analysed the biomass of epibenthic and nekto-benthic species removed by commercial bottom trawling, quantified from a scientific sampling programme on board the fleet which operates in the study area.

2. Material and methods

The study zone was located between 45 and 60 m depth on the continental shelf off southern Mallorca (Fig. 1). Two areas were identified within the fishing ground traditionally known as *Pesquera Rica*: (i) a trawled area (TA); and (ii) an adjacent not trawled area (NTA). The characterization of the geomorphology of the seabed and the benthic communities of these areas was done during the two scientific surveys detailed below.

2.1. Bottom trawl fishing effort

Fishing effort have been estimated from the vessel monitoring by satellite system (VMS) data base of the bottom trawling fleet in the study area from 2006 to 2014. Data was filtered according to the methodology described in Farriols et al. (2015), in order to identify VMS positions of the vessels during fishing and to remove VMS signals from transits to fishing grounds or ports. Once the data base was depurated, in order to obtain a VMS density map, the VMS signals were assigned to a 0.01° resolution grid using Matlab R2013a.

Mean (± standard error, S.E.) annual fishing effort was calculated for the trawled area (TA) and expressed as fishing trips year^{-1} and fishing hours year^{-1}. The number of daily fishing trips was the sum of the number of boats fishing inside the area each day during a particular year. The number of hours of bottom trawl fishing per year was estimated multiplying per two hours the number of VMS, because they are recorded every two hours.

No VMS signals were detected in the NTA. In the whole *Pesquera Rica* fishing grounds, the number of daily fishing trips ranged from 287 to 452 per year between 2006 and 2014 (Fig. 2), equivalent to 926 to 1790 fishing hours/year and an average of 1356 ± 87 fishing hours year^{-1}.

2.2. Geomorphological and sediment characterization

Data used for the seafloor description was collected on board the R/V *Odón de Buen* during September 2009 using the Kongsberg EM3002D multibeam echosounder. The swath bathymetry and backscatter data recorded was processed using CARIS 9.0 and Federmaus 7.0 software. The resulting Digital Elevation Model (DEM) and the backscatter Digital Terrain Model (DTM) from swath bathymetry were compiled into a GIS in geo-database format in order to be managed, analysed and displayed using ArcGIS 10.1. The resolution of the DEM and the DTMs used for morphometric analysis was 10 × 10 m. Benthic Terrain Modeller (Wright et al., 2012), among other GIS routines, have been applied to obtain DTMs of slope (seabed slope in degrees), aspect (direction faced by the seabed) and the fine Benthic Position Index (BPI), which shows the cell relative elevation considering the bathymetry of the surrounding cells within a given distance.

Samples of surface sediments were obtained at eight sampling stations within the studied areas by using a 50 kg weighing van Veen dredge with a sampling surface of 30 × 30 cm (Fig. 1). Sediments were processed in order to obtain the percentage of the different granulometric fractions (gravel, sand, silt and clay) using the dry sieving method. Gravel was very scarce in our dredge samples, for this reason we used a ternary diagram, taking only into account the sand, silt and clay fractions (accounting for up to 99% of the sediment composition), to explore between-sample similarity in sediment composition. This analysis was carried out using the ggtern R package which produces a Shephard's diagram showing the distribution of the samples according to their granulometry.

2.3. Epibenthic characterization sampling

Data were collected in a survey developed during September 2014, on board the R/V *Francisco de Paula Navarro*. A total of 16 beam trawl samples were collected at daytime, 8 in TA and 8 in NTA (Fig. 1). The beam trawl used had horizontal and vertical openings of 2 m and 0.5 m, respectively, and a cod-end mesh size of 5 mm. A SCANMAR system was used to control the depth and the arrival and departure of the gear to the bottom. Beam trawl samples covered a surface between 50 and 120 m^2. In TA, the samples depth ranged between 50 and 59 m, with an average (± S.E.) of 54.7 ± 1.2 m,

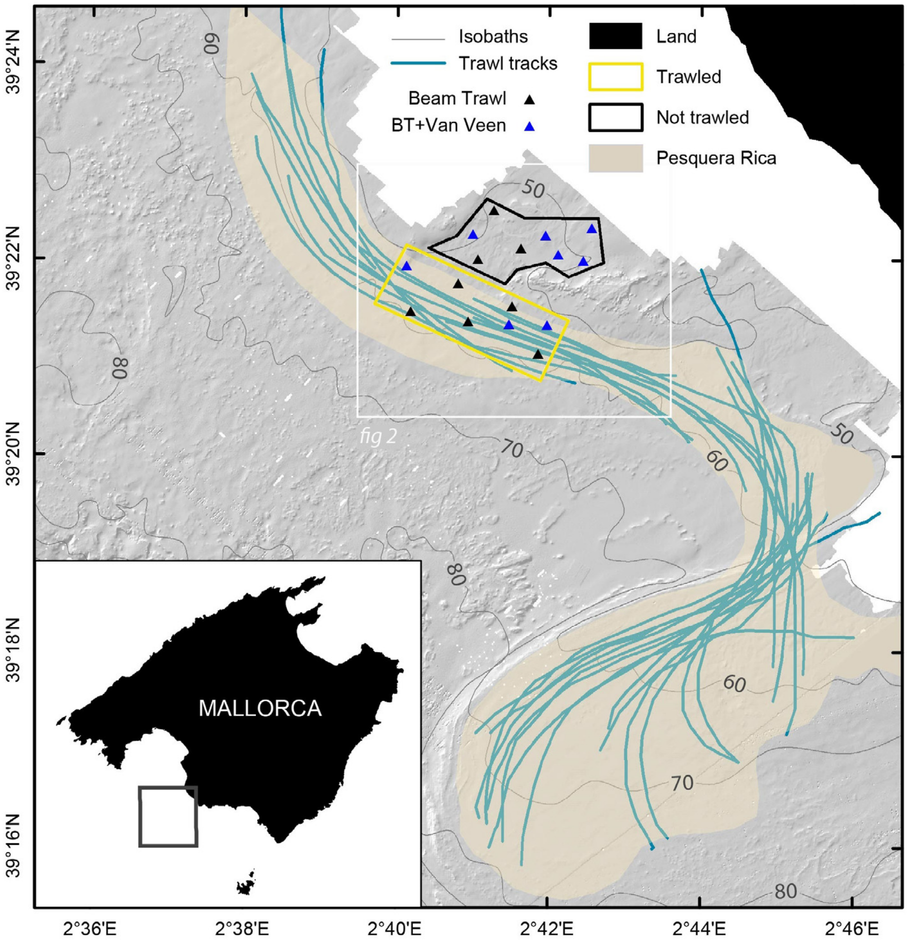

Fig. 1. Map of the study area showing the selected trawled and not trawled areas and the sampling stations where the beam trawl and Van Veen grab samples for the epibenthic characterization were collected. The bottom trawl fishing tracks corresponding to the commercial hauls analyzed in the Pesquera Rica fishing ground are also shown. White rectangle is the extent of Fig. 2. Isobaths are in m.

whereas in NTA it ranged between 46 and 54 m, with an average of 50.6 ± 1.2 m.

Samples were sorted to species level on board and unidentified specimens were preserved for further identification at the laboratory. Abundance and biomass of living organisms were standardized by species to 100 m^2. For the calculation of the abundance of colonial ascidians such as *Aplidium* spp. or cnidarians, a foot/colony was counted as one unit or individual. Most species of sponges appeared fragmented and could not be counted, thus only the biomass of sponges, but not their abundance, was calculated. The same was made for algae. In the case of calcareous algae only the biomass of living rhodoliths, including calcite, was taken into account.

2.4. Epibenthic characterization analyses

The mean biomass of the most important algae taxonomic groups and the mean biomass and abundance of the main taxonomic groups of epibenthic fauna was compared between TA and NTA using the Student's *t*-test. Due to the non normality of the distributions of biomass and abundance data, the bootstrap procedure was applied to calculate the means of random re-samplings of each of the main taxonomic groups of algae and fauna for these two parameters. Hundred bootstraps were done for each of the variables (taxons) studied in each area. The resulting mean values showed a normal distribution and could be then compared between TA and NTA using *t*-test.

The N_{90} diversity index, which has shown to be sensitive to the effects of fishing (Farriols et al., 2015), was used to compare the diversity between TA and NTA. This index follows the calculation of the Similarity Percentage analysis (SIMPER), using the Bray-Curtis similarity index, and applies a jack-knife re-sampling routine to calculate the mean and the variability of the number of species contributing up to the 90% of within-group similarity. The N_{90} results are given along with the result tables of the SIMPER analysis. The bootstrap procedure and the calculation of the N_{90} index were done using the R software, version 3.1.1.

The N_{90} was calculated for algae, based on biomass, and sessile and mobile fauna, based on abundance. Here, it was considered important to distinguish between sessile and mobile fauna species, due to the possibility of the latter ones to move to/escape from a trawled environment. The N_{90} values were compared between TA and NTA using the *t*-test. The cnidarians *Adamsia carciniopados* and *Calliactis parasitica*, and the sponge *Suberites domuncula*, were not included in the analyses of sessile fauna, because they always appeared loaded on the shells occupied by anomura crabs belonging to the Diogenidae and Paguridae families (mainly *Dardanus arrosor* and *Pagurus prideaux*) and, hence, their distribution is conditioned by the distribution of these mobile crustaceans.

2.5. Bottom trawl catches

Biomass and abundance of epibenthic and nekto-benthic organisms removed by the bottom trawlers during their fishing routine

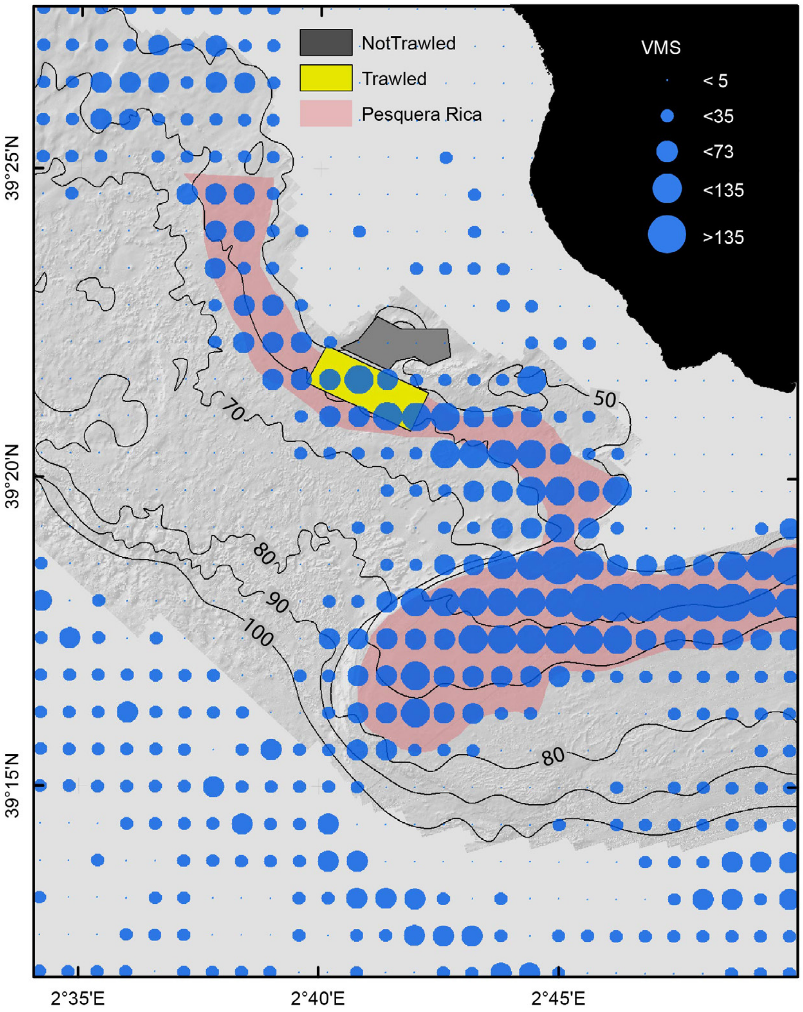

Fig. 2. Vessel monitoring by satellite system (VMS) density map based on VMS signals assigned to a 0.01° resolution grid. The trawled and not trawled areas studied are also indicated as well as the Pesquera Rica fishing ground. Isobaths are in m.

was quantified using data collected by scientific observers on board this fleet. A total of 24 commercial hauls carried out in the *Pesquera Rica* fishing grounds between 2010 and 2015 were analysed (Fig. 1). The data collected included position, boat speed and depth every 15 min during the hauls, along with the abundance and biomass of the retained and discarded catches. The duration of hauls analysed ranged from 60 to 147 min at a speed between 2.9 and 3.4 knots (on average (± S.E.) 3.2 ± 0.03 knots).

The living fraction of algae species were sorted by most abundant groups: Corallinophycidae, Peyssonneliaceae and Rhodomelaceae. The rest of algae were weighed together, with the exception of the large green algae *Codium bursa*, which was weighed separately. Fauna species were classified on board to the lowest possible taxon.

3. Results

3.1. Geomorphology and sediments

The study area was characterized by a rather flat seabed, with a gentle slope gradient (<1°). No relevant geomorphological entities were noticeable in this area, but two rocky outcrops and a bar showing a high reflective signal. Rocky outcrops are aligned with this 2 m high bar, which runs parallel to the coast line (Fig. 3(a)), representing a natural restriction to bottom trawl fishing activity.

Table 1
Sediment fractions (average percentage and standard deviation, indicated in brackets) in the trawled and not trawled areas, obtained from dry sieving of van Veen dredge samples.

Fraction	Trawled	Not trawled
Gravel	1.05 (0.81)	0.56 (0.87)
Sand	89.70 (5.93)	85.47 (5.88)
Silt	5.98 (4.08)	8.76 (4.08)
Clay	1.58 (2.21)	3.54 (2.69)

The two selected areas had a surface of around 300 ha each one. Depth ranged from 48.0 to 61.3 m and 44.4 to 56.8 m in TA and NTA, respectively (Fig. 3(a)). Slope mean values were low in both areas, 0.54° and 0.78° in TA and NTA, respectively (Fig. 3(b)), presenting a smooth slope facing southwest direction (Fig. 3(c); TA: 203.9°; NTA: 203.3°). The BPI analysis showed that the two sampling areas were very even (Fig. 3(d)).

The two areas have similar grain size distributions, with sands representing between 80% to 97% of the sediment sample weight. Silt, clay, and less than 2% of gravels complete the sediment (Table 1). A Shephard's diagram was created using only the three most important fractions. It did not show any grouping related to the two studied areas and all samples belonged to the sand class (Fig. 4).

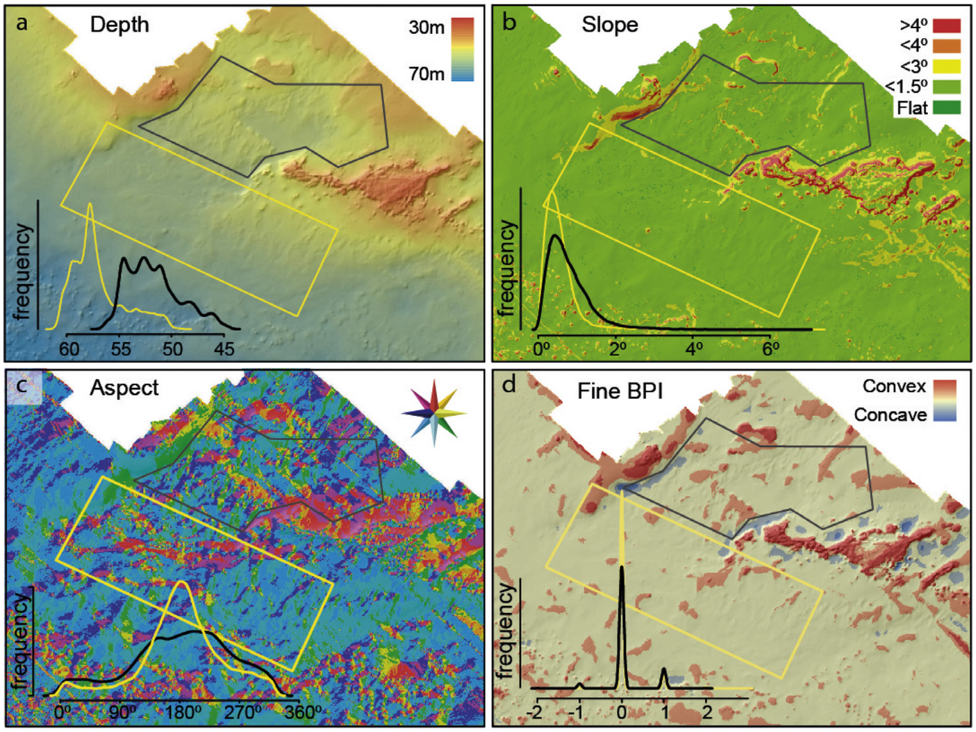

Fig. 3. Digital terrain models derived from swath bathymetry. Each subfigure includes two density functions, yellow and black for trawled and not trawled areas, respectively. (a) Colour coded seabed depth in m and enhanced by shade effect. (b) Seabed slope value in degrees. (c) Orientation of the seabed, where different colours indicate the direction faced by the seabed (N, NE, E, SE, S, SW, W and NW). (d) Fine scale Benthic Position Index shows where the seabed is convex or concave in relation to the surrounding area.

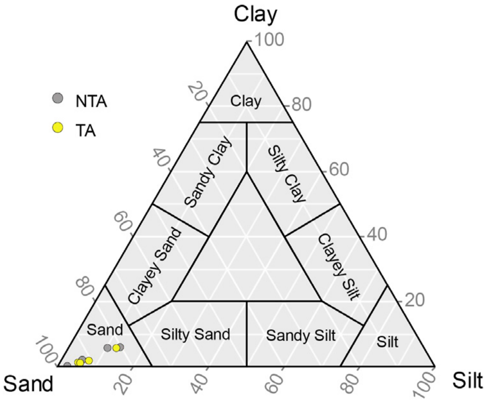

Fig. 4. Shephard's classification diagram showing the distribution of surface sediment samples according to their composition in sand, silt and clay. Yellow and grey dots represent samples collected in the trawled and not trawled areas, respectively.

3.2. Epibenthic communities

In both TA and NTA, the most important taxonomic groups of algae in terms of biomass were red algae species belonging to Corallinophycidae, Peyssonneliaceae and Rhodomelaceae. These groups showed significantly higher biomasses in NTA than in TA, as well as the pooled biomass of the rest of algae groups (Table 2; Fig. 5). It is remarkable that the presence of the green algae family Codiaceae, which only had one representative species in our samples, the large *Codium bursa*, was present in all samples of NTA, with a mean biomass of 1.17 ± 0.73 kg 100 m^{-2}, whereas it only appeared in 3 out of the 8 samples in TA, with a mean biomass of 0.06 ± 0.04 kg 100 m^{-2}. The rest of algal species represented less than 1% of the biomass and mainly belonged to red algae, with 23 different families, although some brown and green algae, with 6 and 4 families, respectively, were also present.

In both TA and NTA, the most important taxonomic groups of fauna in terms of biomass were the sponges, echinoderms and ascidians. The sponges showed a significantly higher mean biomass in TA than in NTA, whereas the rest of groups, except the crustaceans that did not show significant differences between areas, showed higher biomasses in NTA than in TA (Table 2; Fig. 5). The echinoderms showed the highest differences between areas with 0.25 ± 0.04 and 15.85 ± 0.54 kg 100 m^{-2} in TA and NTA, respectively.

In terms of abundance, the most important taxonomic groups were the echinoderms, crustaceans, ascidians and fishes. Except for crustaceans, which showed higher mean abundances in TA, and the ascidians that did not show significant differences, the rest of groups showed significantly higher means in NTA than in TA (Table 2; Fig. 5).

The N_{90} diversity index showed significant differences for algae, with a higher mean number of species contributing to the 90% of similarity in NTA (Table 2). The most important species in terms of contribution to similarity in TA was the Corallinophycidae *Lithothamnion valens*, whereas in NTA it was the Peyssonneliaceae *Peyssonnelia inamoena*. Except for the Rhodomelaceae erect red algae *Osmundaria volubilis*, the rest of algal species contributing to the N_{90} in TA also contributed to it in NTA, whereas *Peyssonnelia rosa-marina*, *Peyssonnelia harveyana* and the Corallinophycidae *Phymatolithon calcareum* only contributed to the N_{90} in NTA (Table 3).

Neither the sessile nor the mobile fauna showed significant differences in the N_{90} (Table 2). Regarding the sessile fauna, the ascidians contributed the most to the N_{90} index: the six species involved in TA were ascidians, whereas in the NTA five were ascidians and one was a cnidarian (*Alcyonium palmatum*). The most

Table 2

T-test comparisons of the mean biomasses (kg 100 m^{-2}) and, abundances (individuals 100 m^{-2}), and mean values of the N_{90} diversity index (in number of contributing species to the 90% within area similarity). Degrees of freedom were 195 in the t-test comparing biomasses and abundances and 14 for N_{90} comparisons. Other algae are specified in legend of Fig. 4.

Index	Group	Trawled		Not trawled		t-test	p
		Mean	S.E.	Mean	S.E.		
Algae biomass	Corallinophycidae	9.83	0.408	16.19	0.911	−6.9	***
	Peyssonneliaceae	10.21	0.255	19.20	1.023	−18.7	***
	Rhodomelaceae	1.75	0.199	2.54	0.368	−2.1	*
	Other algae	0.28	0.010	2.19	0.401	−3.9	**
Fauna biomass	Sponges	0.78	0.042	0.48	0.020	6.4	***
	Cnidarians	0.02	0.001	0.06	0.003	−10.5	***
	Annelids	0.01	0.001	0.04	0.002	−18.6	***
	Echinoderms	0.25	0.042	15.85	0.541	−30.2	***
	Crustaceans	0.11	0.005	0.12	0.005	−1.8	n.s.
	Molluscs	0.04	0.003	0.12	0.011	−7.1	***
	Ascidians	0.55	0.022	0.77	0.071	−3.5	***
	Fish	0.04	0.002	0.12	0.004	−19.5	***
Fauna abundance	Annelids	6.79	0.256	28.82	0.957	−22.3	***
	Cnidarians	12.47	0.431	23.69	0.894	−11.1	***
	Echinoderms	100.32	6.930	234.15	6.594	−13.1	***
	Crustaceans	135.75	2.586	121.37	3.237	3.3	***
	Molluscs	16.28	1.115	35.61	1.383	−11.2	***
	Ascidians	37.84	1.590	37.33	1.724	0.2	n.s.
	Fish	26.47	1.105	38.39	1.106	−7.5	***
N_{90}	Algae	4.88	0.134	7.00	0.202	−9.4	***
	Sessile fauna	5.75	0.267	5.50	0.202	0.8	n.s.
	Mobile fauna	17.13	0.62	17.50	0.40	−0.5	n.s.

Significant differences are indicated according to

[*] $p < 0.05$.

[**] $p < 0.001$.

[***] $p < 0.0001$.

Table 3

Similarity percentage table for algae, and sessile and mobile fauna in the trawled and not trawled areas. B (biomass, kg 100 m^{-2}); A (abundance, individuals 100 m^{-2}); std (standard deviation); Sim % (contributed within area similarity percentage); ΣSim % (cumulative Sim %).

Trawled area					Not trawled area				
Algae; Sim = 35.0	B	Std	Sim %	ΣSim %	Algae; Sim = 25.1	B	Std	Sim %	ΣSim %
Lithothamnion valens	5.9	3.6	33.4	33.4	*Peyssonnelia inamoena*	9.2	8.2	28.3	28.3
Peyssonnelia rubra	8.4	11.3	21.4	54.8	*Lithothamnion valens*	10.9	15.4	20.0	48.4
Spongites fruticulosus	3.9	3.2	19.4	74.2	*Peyssonnelia rubra*	10.6	15.5	17.5	65.9
Peyssonnelia inamoena	14.8	35.2	13.5	87.7	*Phymatolithon calcareum*	2.7	2.2	10.3	76.2
Osmundaria volubilis	2.4	3.3	6.8	94.6	*Peyssonnelia rosa-marina*	1.5	1.2	5.8	81.9
					Peyssonnelia harveyana	4.0	6.3	4.2	86.1
					Spongites fruticulosus	2.4	3.8	4.1	90.2
Sessile fauna; Sim = 32.8	A	Std	Sim %	ΣSim %	Sessile fauna; Sim = 12.8	A	Std	Sim %	ΣSim %
Aplidium nordmanni	25.1	32.3	43.1	43.1	*Polycarpa mamillaris*	32.2	55.5	49.2	49.2
Polycarpa mamillaris	7.9	5.7	31.1	74.2	*Aplidium elegans*	1.4	2.1	14.0	63.2
Aplidium elegans	2.9	3.0	6.9	81.2	*Botryllus schlosseri*	3.1	4.6	10.7	73.9
Ciona spp.	3.0	4.1	3.6	84.8	*Ciona* spp.	1.3	1.3	9.0	83.0
Pseudodistoma cyrnusense	2.6	3.4	3.6	88.3	*Ascidia mentula*	1.3	1.5	5.9	88.9
Ascidia mentula	1.5	1.9	2.8	91.1	*Alcyonium palmatum*	1.3	2.1	4.0	92.9
Mobile fauna; Sim = 25.7	A	Std	Sim %	ΣSim %	Mobile fauna; Sim = 30.8	A	Std	Sim %	ΣSim %
Ophiuridae	94.4	133.8	27.6	27.6	*Spatangus purpureus*	67.9	52.9	30.7	30.7
Pagurus prideaux	30.6	33.8	17.6	45.2	Ophiuridae	58.4	79.9	9.2	39.9
Inachus thoracicus	20.6	26.2	8.4	53.6	*Psammechinus microtuberculatus*	33.6	33.6	8.7	48.6
Psammechinus microtuberculatus	12.3	11.6	5.7	59.3	*Buenia* sp.	15.6	10.9	6.8	55.5
Eurynome aspera	12.9	13.8	5.0	64.2	*Pagurus prideaux*	22.6	25.7	6.7	62.2
Inachus dorsettensis	10.4	15.1	4.2	68.4	*Ophiura albida*	28.5	39.9	4.8	67.0
Ophiura albida	32.6	82.4	3.3	71.7	*Laetmonice hystrix*	19.0	23.9	4.4	71.4
Sphaerechinus granularis	4.9	6.0	3.2	74.9	*Paguristes eremita*	15.0	16.5	4.3	75.7
Inachus communissimus	11.2	17.3	2.3	77.2	*Sphaerechinus granularis*	12.7	14.6	3.0	78.7
Echinaster sepositus	3.5	3.0	1.9	79.1	*Dardanus arrosor*	6.2	4.9	2.0	80.7
Buenia sp.	4.4	7.2	1.9	81.0	*Eurynome aspera*	11.4	13.0	2.0	82.6
Gibbula magus	4.1	4.9	1.8	82.8	*Turritella turbona*	7.8	9.9	1.4	84.0
Anapagurus laevis	2.9	3.0	1.7	84.5	*Serranus hepatus*	7.5	12.3	1.4	85.4
Turritella turbona	4.6	5.7	1.6	86.0	*Anapagurus laevis*	7.5	11.1	1.2	86.6
Dardanus arrosor	2.5	1.9	1.5	87.5	*Macropodia rostrata*	4.6	4.7	1.1	87.7
Laetmonice hystrix	2.7	3.3	1.3	88.8	*Inachus thoracicus*	7.0	10.6	1.1	88.8
Pagurus forbesii	7.4	14.9	1.1	89.9	*Inachus dorsettensis*	5.4	7.2	0.9	89.8
Arnoglossus thori	1.7	1.7	1.0	91.0	*Ebalia tuberosa*	5.0	5.4	0.9	90.7

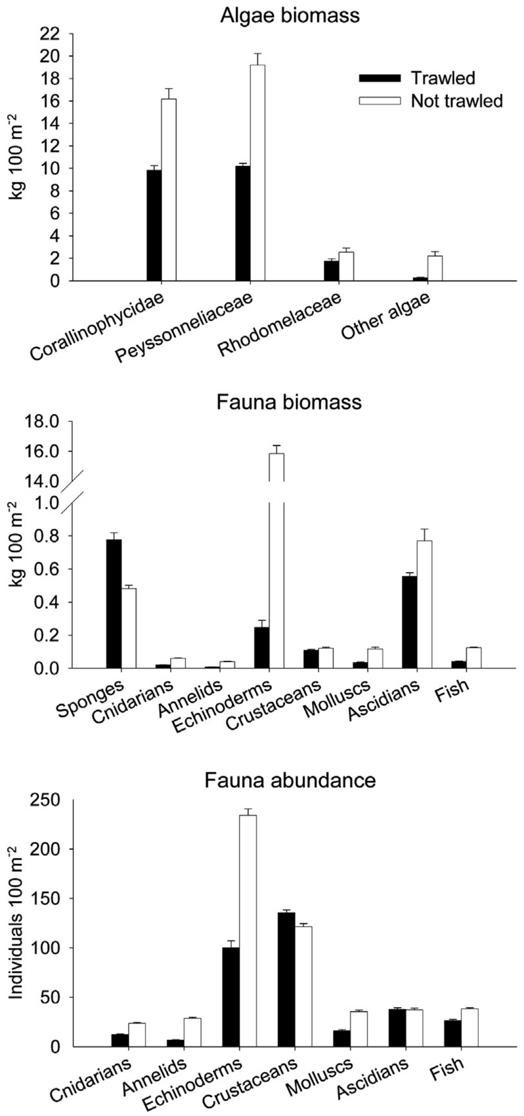

Fig. 5. Mean (±S.E.) biomass (kg 100 m^{-2}) of the main taxonomic groups of algae, and biomass and abundance (individuals 100 m^{-2}) of the main groups of fauna, obtained from beam trawl samples in the trawled and not trawled areas. Other algae include Arthrocladiaceae (3.9%), Caulerpaceae, Chordariaceae (0.9%), Codiaceae (1.2%), and representing <1% Dictyotaceae, Faucheaceae, Gracilariaceae, Halymeniaceae, Kallymeniaceae, Phyllophoraceae, Rhodymeniaceae, Sporochnaceae, Stypocaulaceae and Udoteaceae.

important species in terms of contribution to the similarity in TA was *Aplidium nordmanni*, which was the smallest ascidian species caught (averaging 0.5 g individual^{-1}; Table 3 and Appendix), but in NTA this species did not contribute to the N_{90}. On the other hand, among the most important species caught in NTA there were the largest ascidians *Polycarpa mamillaris* and *Botryllus schlosseri* (on average, more than 20 g individual^{-1}; Appendix).

In the case of the mobile fauna, in both TA and NTA most of the species were small invertebrates, except for fishes *Buenia* spp. and *Arnoglossus thori*, not usually exceeding more than 2 g individual^{-1} on average (Table 3; Appendix). The largest mobile epibenthic species, the echinoderm *Spatangus purpureus* (150 g individual^{-1} on average; Appendix), was the most important contributor to similarity in NTA, whereas it did not appear as a contributor to the N_{90} index in TA (Table 3).

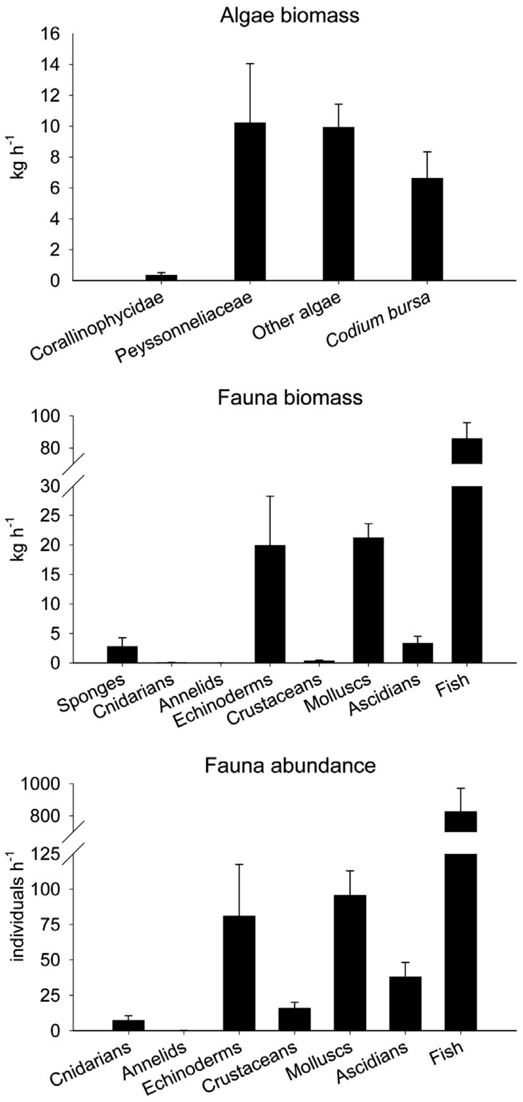

Fig. 6. Mean (±S.E.) catches of the commercial fleet operating in the *Pesquera Rica* fishing ground. In biomass (kg h^{-1} of fishing) for the main taxonomic groups of algae, and biomass and abundance (individuals h^{-1} of fishing) for the main groups of fauna. Other algae include undetermined algae species, mainly other red algae and Phaeophyceae.

3.3. *Bottom trawl catches*

Fishes were the most important group in the catches of the bottom trawl fleet operating in the *Pesquera Rica* fishing grounds (which includes the TA) in terms of both biomass and abundance, with 85.8 ± 9.9 kg h^{-1} and 825.9 ± 145.6 individuals h^{-1} (Fig. 6). This group was followed by mollusks (21.2 ± 2.3 kg h^{-1} and 95.7 ± 17.1 individuals h^{-1}), most of them commercial cephalopod species, echinoderms (19.9 ± 8.3 kg h^{-1} and 81.0 ± 36.4 individuals h^{-1}) and ascidians (3.3 ± 1.2 kg h^{-1} and 38.1 ± 10.1 individuals h^{-1}). The Peyssonneliaceae along with other algae (most of them soft non calcareous red algae as Rhodomelaceae) and the green algae *Codium bursa* dominated the algal catches, with average yields of 10.2 ± 3.8, 9.9 ± 1.5 and 6.6 ± 1.7 kg h^{-1}, respectively. Catches of Corallinophycidae averaged 0.3 ± 0.1 kg h^{-1} (Fig. 6).

The most abundant epibenthic sessile species were ascidians, especially *Polycarpa mamillaris*, *Botryllus schlosseri*, *Ascidia mentula*, *Molgula appendiculata*, *Phallusia mammillata* and *Microcosmus vulgaris*, which accounted for more than 75% of sessile fauna

Table 4
Abundance (A, individuals h^{-1} of fishing) and standard error (S.E.) of the main epibenthic species caught in the commercial hauls analysed from the *Pesquera Rica* (i.e. those representing more than 0.5% of the mean total abundance). In the case of fish and cephalopods, only the species appeared in the beam trawl samples were taken into account in order to centre these results on the epibenthic species. Σ%: Cumulative percentage in abundance.

Sessile fauna	A	S.E.	Σ%
Polycarpa mamillaris	6.0	3.1	15.9
Botryllus schlosseri	5.2	3.6	29.6
Suberites domuncula	5.0	1.8	42.9
Ascidia mentula	4.6	1.7	55.0
Calliactis parasitica	4.1	1.8	65.9
Adamsia carciniopados	3.2	1.5	74.4
Phallusia mammillata	1.7	0.7	78.8
Microcosmus vulgaris	1.5	0.7	82.6
Ciona intestinalis	0.9	0.6	84.9
Tethya aurantium	0.8	0.4	87.1
Synoicum blochmanni	0.8	0.8	89.2
Aplidium spp.	0.8	0.5	91.3
Aequipecten opercularis	0.8	0.5	93.4
Microcosmus spp	0.8	0.4	95.4
Polyclinella azemai	0.6	0.5	97.1
Ascidia virginea	0.6	0.3	98.6
Axinella damicornis	0.2	0.2	99.2
Halocynthia papillosa	0.2	0.2	99.8
Mobile fauna	A	S.E.	Σ%
Sphaerechinus granularis	36.5	22.6	21.8
Spatangus purpureus	30.0	14.5	39.7
Scorpaena notata	27.0	5.7	55.8
Trigloporus lastoviza	12.6	3.6	63.3
Octopus vulgaris	11.0	2.7	69.9
Scorpaena scrofa	8.4	2.0	74.9
Serranus cabrilla	7.8	2.3	79.5
Pagurus prideaux	6.8	2.7	83.6
Dardanus arrosor	6.2	1.4	87.3
Echinaster sepositus	5.1	1.6	90.3
Scyliorhinus canicula	3.0	0.7	92.1
Inachus spp.	1.8	0.4	93.2
Hacelia attenuata	1.6	0.7	94.1
Serranus hepatus	1.3	0.9	94.9
Blennius ocellaris	1.2	0.7	95.6
Sepia officinalis	1.1	0.4	96.3

individuals. Regarding mobile epibenthic species, *Sphaerechinus granularis* and *Spatangus purpureus* were the most abundant ones (36.5 ± 22.6 and 30.0 ± 14.5 individuals h^{-1}, respectively) and accounted for almost 40% of the individuals, followed by nekto-benthic fish species such as *Scorpaena notata*, *Scorpaena scrofa*, *Trigloporus lastoviza, Serranus cabrilla* and *Scyliorhinus canicula*, the cephalopod *Octopus vulgaris* and the anomura crabs *Dardanus arrosor* and *Pagurus prideaux* (Table 4).

4. Discussion

The present work detected clear differences between the epibenthic communities of a frequently trawled area (TA) and a not trawled area (NTA). The close distance, and the similar geomorphology and sediment composition between the studied areas, rule out environmental variability as a plausible explanation for these differences, which can be clearly related to the impact of bottom trawling.

A reduction of algal biomass of 39.3 and 46.8% was detected for the main families of algae Corallinophycidae and Peyssonneliaceae, respectively, when TA was compared to NTA. Similarly, almost all main taxonomic groups of fauna, especially echinoderms, showed higher biomasses and abundances in NTA than in TA, with the exception of crustaceans and sponges, which showed higher abundance and biomass in TA than in NTA, respectively.

A lot of nekto-benthic species, including those fishes and cephalopods that are target of the bottom trawl fishery developed along the continental shelf, depend directly or indirectly on the production of the benthic communities, as they feed on benthic invertebrates or on preys that find their food resources in the benthic production (Konstantinov et al., 1985; Messieh et al., 1991). The periodical removal of these demersal resources by the trawling fleet may reduce their predator pressure exerted over the invertebrates. The crustaceans, particularly the small ones which do not appear in the trawl catches, may benefit from this predator reduction in TA. The "mallorquí" and "quadrat"-type bottom trawl nets currently used by the Balearic fleet to operate on the continental shelf (Ordines, 2015), are equipped with the 40 mm square mesh codends in force and a groundrope with plastic rollers, which reduce the contact of the net with the bottom, increasing efficiency to capture mobile nekto-benthic fishes and cephalopods, target of this fishery at this depth range, and decreasing the capture of non commercial benthic species, mainly algae, but also small crustaceans and other invertebrates. These unwanted catches have a negative effect on the yields of the fishery, by reducing the efficiency of the net and the time of the hauls, increasing the fuel consumption and the time required to sort the catches and even decreasing their profitability and quality.

By contrast, trawling has been reported to have negative and persistent effects on other benthic organisms such as the sponges, particularly those living in deep cold-water habitats, which suffer damages and important decreases in their abundance after the passage of a bottom trawl gear (Freese, 2003). However, in shallow waters of temperate seas this impact appears to be more ephemeral, recovering completely after relatively short periods (one year) without trawling (Van Dolah et al., 1987). The higher abundances in TA could be explained by this recovery capacity and the fact that the most important sponges caught by the trawl fleet exploiting the *Pesquera Rica* fishing grounds are the free-living species *Suberites domuncula* and *Tethya aurantium* (Table 4), which are discarded and appear to not suffer visible damages after they are caught (F. Ordines, personal observation).

The diversity of algae was also higher in NTA than in TA, whereas neither the sessile nor the mobile fauna showed any difference in diversity, although there are clear changes in the species contributing to the N_{90} index in these three groups. This can also be related to the catches of the bottom trawl fleet, because the most important family of algae and fauna species contributing to the N_{90} in NTA were in coincidence with the epibenthic species more present in the catches of the trawl fleet exploiting the *Pesquera Rica* fishing grounds. This is the case of Peyssonneliaceae algae, the ascidian *Polycarpa mamillaris* and the echinoderm *Spatangus purpureus*. Moreover, the fauna species seem to be replaced in the trawled area by smaller ones, with lower or null presence in the catches of the trawl fleet, such as the ascidian *Aplidium nordmanni,* usually smaller than 2 cm in diameter, or Ophiuridae echinoderms less than 3 cm diameter, which may escape through the codend of the nets used.

The important reduction in biomass of Corallinophycidae detected in TA cannot only be explained from the biomass removed by the bottom trawling. The estimated catches of these species in this fishery (∼0.3 kg h^{-1}) are almost negligible, taking into account the horizontal opening of the trawl nets used in the area (∼18 m) and the towing speed (∼3.2 knots), which is equivalent to a swept area of around 100 000 m^2 h^{-1}. The fishing pressure by the bottom trawl fleet in the *Pesquera Rica* fishing grounds has been estimated in 1357 ± 87 h year^{-1}, while the biomass of Corallinophycidae in NTA and TA are 16 and 10 kg 100 m^{-2}, respectively. For that reason, other factors should explain the reduction of Corallinophycidae algae in TA. In addition to the direct impact of trawl fishing through the extraction of algae, it should be considered an indirect impact. The passage of trawl gears can resuspend the sediments due to the contact of the otter doors, sweeps, groundrope and the net with the bottom (Durrieu de Madron et al., 2005). The burial of Corallinophycidae from the settlement of sediments has been reported as highly detrimental for these algae, causing high mortalities because light cannot reach the algae and the photosynthetic activity is stopped. In addition, the smothering due to the fine sediments coat may limit the gaseous exchange needed by the algae to survive (Wilson et al., 2004).

The differences between the yields of Corallinophycidae obtained using the beam trawl and those from the bottom trawl fleet indicate that fishermen may only skim the bottom with the trawl net, as it has been already pointed out by Borg et al. (1999) in Maltese rhodolith beds. However, the resuspension of sediment caused by bottom trawl gears and its settlement on the Corallinophycidae represents a severe threat for these slow growing algae species (Bosence and Wilson, 2003). This seems to be the most plausible explanation for the biomass reduction observed for these algae group in our study area. Although rhodoliths and gravel are close related, as dead rhodoliths and their fragments become a part of the gravel, in our case, the red algae beds studied showed a low content in gravel (less than 2%) which may be due to the typical micro-scale patchy distribution of rhodoliths (Barberá et al., 2012a, b; Savini et al., 2012; Sañé et al., 2016). In fact, particles that can be easily resuspended by the bottom trawl passage predominated in the studied areas, where the most important fraction was sand (composing up to around 90% of the sediments), but also with presence of silt and clay (representing around 7% and 12% of the sediments in TA and NTA, respectively). The impact of sediment resuspension and its settlement would not affect Peyssonneliaceae species, because they are adapted and even have affinity for bottoms located in calm areas with presence of fine sediments and even mud (Pérès, 1985). In any case, and although these species grow faster than Corallinophycidae (Bordehore et al., 2003), in the TA, Peyssonneliaceae showed higher biomass reduction than Corallinophycidae with respect to the NTA (47% and 39%, respectively), probably because of the larger amounts of Peyssoneliaceae removed by trawlers (averaging 10 kg h^{-1}).

The negative effects of bottom trawling on benthic communities are well known (see Introduction and references therein), and the red algae beds are not an exception. The bottom trawling has been considered one of the most important threats to rhodolith beds, dominated by red calcareous algae, particularly in the Mediterranean where they are not subjected to direct extraction for industrial uses (Barberá et al., 2003; Basso et al., 2015). However, the few studies on the effects of bottom trawl in Mediterranean rhodolith beds have shown contradictory results. On one hand, a comparative study between a protected rhodolith bed and a rhodolith bed subjected to high bottom trawl frequency in the Iberian Peninsula coast revealed clear negative effects of this fishing activity, including a reduction in the coverage and size of rhodoliths, and a decrease of the faunal biodiversity in the trawled area (Bordehore et al., 2003). On the other hand, a study of the impact of bottom trawl on Maltese rhodolith beds showed higher abundance and size of rhodoliths in an area subjected to low intensity bottom trawling when compared to a not trawled area (Borg et al., 1999). Similarly, recent studies in rhodolith beds of the Menorca Channel (Balearic Islands), reported a significant positive correlation between rhodolith coverage and bottom trawl effort, and no correlation between this effort and biomass of rhodoliths (Moranta, 2014). In that area, differences in size and morphology of rhodoliths between different levels of bottom trawling effort were detected, but only for the two most abundant rhodolith species, *Spongites fruticulosus* and *Lithothamnion corallioides* (Barberá et al., 2012b). In fact, these works conclude that bottom trawl effort is not the main factor explaining the differences in the epibenthic communities of the Menorca Channel, particularly in the case of the habitat structuring species, mainly red algae, which were better explained by depth, mud content and current velocity than by bottom trawl effort.

The relatively low bottom trawl fishing effort in the Balearic Archipelago, compared to adjacent areas in the Iberian Peninsula (Quetglas et al., 2012) and the trawl fishing routine, that tries to avoid large amounts of algal catches (e.g. fishing at higher speed and/or using lighter footrope in the net to avoid an excessive scratch of the gear in these bottoms), may be the reasons supporting the long term coexistence of red algae beds and the trawl fishery. This overlapping has also been demonstrated in other areas of the Balearic shelf, as the Menorca Channel (Barberá et al., 2012a), and seems to be widespread along the whole Archipelago (Ordines and Massutí, 2009). However, despite the red algae beds still persist in the Balearic Islands bottom trawl fishing grounds, our results have shown that this activity has clear detrimental effects on this community, and highlight that even when carried out at relatively low intensity, bottom trawling reduces the abundance and biomass of most epibenthic organisms, both algae and fauna.

For these reasons, it is urgent to adopt management measures aiming to preserve red algae beds off Balearic Islands and to make compatible, as long as possible, this habitat protection with the sustainability of the trawl fishing activities. To do that, it is necessary to elaborate detailed cartographies of benthic habitats and fishing grounds for the whole Balearic shelf, allowing the detection of other areas in conflict, in which management plans will be developed and implemented. These plans should include not only spatial planning measures, trying to separate protected habitats and trawl fishing activities, but also technical measures in the bottom trawl gears trying to reduce the direct and indirect impacts of this fishery on the benthic communities and the seafloor. It must be also highlighted that one of the widespread red algae beds in the Archipelago (rhodolith beds) is considered a sensitive habitat, which has been catalogued as a protected habitat by the Council Regulation (EC) N° 1967/2006, of 21 December 2006, concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, which prohibits fishing with trawl nets above rhodolith beds. Moreover, the soft red algae communities, as the *Peyssonnelia* beds, can act as Essential Fish Habitats for the demersal resources exploited by the trawl fishery off the Balearic Islands (Ordines and Massutí, 2009; Ordines et al., 2009, 2015; Ordines, 2015). There are more than enough scientific reasons, therefore we must move from words to deeds.

Acknowledgements

Surveys at sea in 2009 and 2014 were carried out within the project DRAGONSAL (Caracterización del Ecosistema Bentónico de la Plataforma costera del area comprendida entre sa Dragonera, cap de ses Salines y Cala Figuera (Mallorca)), co-funded by the Instituto Español de Oceanografía and the Balearic Islands government. Analysis of the data has been done within the framework of the projects DRAGONSAL and LIFE-IP INTEMARES "Integrated, Innovative and Participatory Management for N2000 network in the Marine Environment" (LIFE15 IPE/ES/000012). We would like to thank very much all the scientific staff and the crew participating in the sampling at sea.

Appendix

Mean weight and standard error (S.E.) of the epibenthic species collected in the beam trawl samples.

Species	Mean weight	S.E.
Alcyonium palmatum	0.79	0.52
Anapagurus laevis	0.08	0.03
Aplidium elegans	5.07	2.41
Aplidium nordmanni	0.57	0.33
Ascidia mentula	20.74	9.07
Botryllus schlosseri	27.84	16.74
Ciona spp.	4.04	1.57
Arnoglossus thori	2.10	0.99
Buenia jeffreysii	0.11	0.02
Dardanus arrosor	1.98	0.77
Ebalia tuberosa	0.52	0.23
Echinaster sepositus	7.81	3.76
Eurynome aspera	0.18	0.04
Gibbula magus	0.71	0.40
Inachus communissimus	0.37	0.17
Inachus dorsettensis	0.42	0.13
Inachus thoracicus	0.61	0.15
Laetmonice hystrix	0.67	0.18
Macropodia rostrata	0.08	0.05
Ophiura albida	0.59	0.57
Ophiuridae	0.16	0.07
Paguristes eremita	0.27	0.10
Pagurus forbesii	0.14	0.06
Pagurus prideaux	2.33	0.50
Polycarpa mamillaris	23.83	5.65
Psammechinus microtuberculatus	0.61	0.32
Pseudodistoma cyrnusense	1.55	0.80
Serranus hepatus	1.12	0.99
Spatangus purpureus	190.89	48.54
Sphaerechinus granularis	10.53	7.78
Turritella turbona	1.36	0.42

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