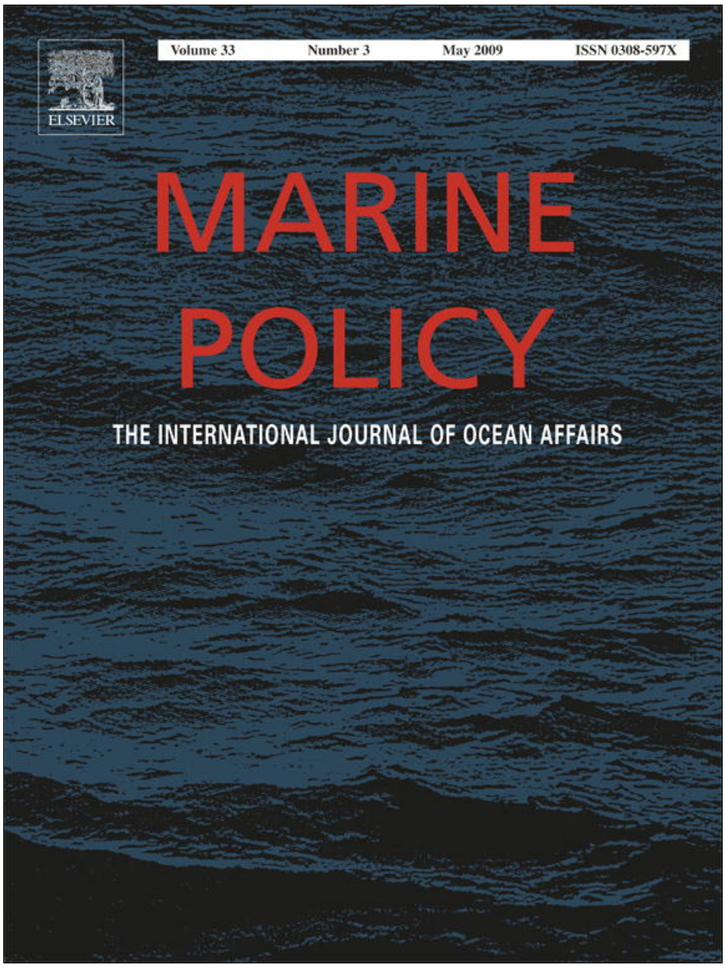
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Defining ecological indicators of trawling disturbance when everywhere that can be fished is fished: A Mediterranean case study

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ABSTRACT

Selecting indicators of the response of the benthic community to fishing effort restrictions is important for testing the efficacy of management actions that seek to minimise ecosystem degradation. Components of epifaunal communities are sensitive to trawling, and concordant measurements of trawling effort can be used to establish a link between response and impact variables. Trawling effort on Mediterranean fishing grounds can be assessed, but the lack of data from communities inhabiting these areas makes establishing the response–impact relationship difficult. This study addresses this challenge by investigating benthic communities from the NW Mediterranean subjected to a gradient of fishing effort, and confirms that indicators based on functional components of epibenthos can be a useful tool to describe the response of communities to disturbance across habitat types.

1. Introduction

The degradation that many marine ecosystems have suffered as a result of fishing, specifically bottom trawling [1], highlights the need for a more pervasive management of fishing activities. The current European legislation implies the establishment of ecosystem-based management plans and the monitoring of their effectiveness [2]. In this context, stakeholders want to quantify the outcome and predict responses to management actions, with the consequent need to define indicators of ecosystem status [3–6]. To achieve this, indicators of community disturbance that are sensitive to changes in pressure (i.e. fishing effort) must be selected. In order to predict response to changes in the fishing pressure (i.e., frequency and magnitude of disturbance) community indicators must be linked at the same spatial and temporal scales. This will help to determine the direct and indirect consequences of fishing disturbance that need to be fully understood to ensure that cost-effective indicators are applied to assessing the success of measures to sustainably manage fisheries.

The analysis of trawling disturbance on benthic communities needs adequate reference areas or defined gradients of disturbance, which are often lacking on coasts and continental shelves that have been subjected to extensive fishing [7,8]. This fundamental flaw in resources management, which has left no controls, limits the capacity to link benthic community variables with fishing effort [9–12]. Different responses to disturbance have been observed in different case studies, and each community might have a specific threshold beyond which recovery is no longer feasible. The effects of trawling are tightly linked to fishing frequency and intensity, environmental conditions and the ecological characteristics of the impacted community [13–15].

Several studies have tried to define indicators of benthic community disturbance to be used as reference measures, but most have failed to quantitatively measure the effects of commercial trawling activities on communities [7,16] However, the possibilities for drawing general conclusions from the acquired knowledge derived from studies of trawling disturbance conducted to date have been generally underestimated [12]. Common patterns of community response to trawling have been detected, such as reduction of species richness or removal of those species most vulnerable to trawling disturbance [17], which should supply with valuable information for defining indicators.

Adequate indicators for the evaluation of ecosystem response to trawling must be both sensitive to gradients of fishing intensity and useful across a range of community types. To address this issue, an analysis based on a Mediterranean case study was developed to define which metrics of benthic communities within fishing grounds represent the degradation of these systems by trawling, and furthermore were sensitive to changes in effort patterns. This study proposes a methodology for defining

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ecological indicators based on existing research that is tested with available data from Mediterranean communities subjected to varying intensity of trawling. First, indicators of community disturbance have been defined (Section 2.1) and the trawling effort levels have been estimated as the pressure factor (Section 2.2). Subsequently, the relationship between the selected indicators and the pressure factor was established (Section 2.3), as a tool to both propose and evaluate management measures to minimise the degradation of benthic ecosystems in the NW Mediterranean.

2. Benthic community from a fishing ground: the NW Mediterranean case study

Non-target organisms within benthic communities of Mediterranean trawling grounds have been poorly studied, and there is no available data on diversity patterns related to trawling effort distribution. To develop an approach that related community indicators with the level of trawling effort, this study was focused on both information from the literature and data from benthic communities inhabiting trawling grounds. In a previous study conducted in the NW Mediterranean, the functional components of both a trawled and a relatively undisturbed community were compared, and results showed modification of the functional components of the benthic community [18]. The undisturbed site held higher densities of species with biological and functional traits predicted to be more vulnerable to trawling (e.g. sessile surface organisms or larger predators), and confirmed that these traits were reduced in commercially exploited trawling grounds, with the area dominated by small burrowing invertebrates. Other studies have similarly shown that trawling appears to enhance less vulnerable organisms such as small predators and scavengers, whereas more vulnerable organisms like large sessile and emergent filter feeders are generally eliminated from trawled areas [17,19–22]. Overall, these studies have defined general trends of the species' response to trawling disturbance that were mainly determined by their biological traits.

2.1. Indicators of community disturbance

Indicators must have three characteristics: they must be tightly linked in space and time with the disturbance factor, they must be easily recorded, and they must be clearly understood by stakeholders. Moreover, adequate indicators should be widely applicable, notwithstanding the area or community analysed [3,9,10,23,24]. However, the preliminary phase of development of appropriate indicators and the urgent need for including ecosystem considerations in marine resource management demands flexibility in the selection of indicators.

Metrics of the exploited stocks, such as landed biomass or average size of target species have been commonly analysed, and these indices can give valuable information on the state of the resource [25], but they miss the information related with non-target species and habitats [26–28]. Several studies have analysed the effects of trawling activities on communities of non-target species using a wide range of indices, such as diversity, size-spectra, life-history traits, stable isotopes analysis or trophic structure [29–34]. However, a disparity in responses depending on community type, environmental characteristics, trawling intensity, and other external factors emphasised the need to consider the ecosystem context of different fisheries.

Diversity indices have been touted as indicators of disturbance, as a high-diversity index is easily connected with a healthier community [32,35]. But the interpretation of results based on diversity indices can be difficult [16,29,31–34]. Two different communities can maintain similar species richness, but one might be composed of opportunistic species whereas the other one might exhibit the same number of species, but be composed of species more sensitive to trawling. These two communities would be functionally very different: a community composed of small opportunistic species would represent an impoverished community, homogeneous with poor habitat structure; whereas a community composed of more sensitive species, such as sessile and emergent fauna, with different trophic strategies, represents a more functionally diverse community with higher complexity of biogenic habitat structures [20,22,26,36–40].

Therefore, indices that provide information on the functionality of the community, structure of the habitat and resilience of the overall ecosystem must be developed. Moreover, these indicators must be sensitive to gradients of trawling intensity in all habitat types. Based on the information acquired from the work described in [18], the present study proposes an indicator of fishing disturbance based on the functional traits of benthic organisms (e.g. average size, mobility or position on the substratum). The analysis based on functional traits summarises indicators that have been previously proposed and known to be sensitive to trawling activities, such as average size of organisms or abundance of vulnerable species. Moreover, the functional components of a community can be generalised over different areas, as similar ecological niches in different communities might be occupied by different species [41].

From a practical point of view, the collection of epifauna with a dredge is less time consuming and covers a larger area than the collection of infauna with grabs; epifaunal sorting and identification is also usually easier. The time-consuming methodology for surveying benthic infauna and identifying the collected organisms suggests that focusing on epifaunal organisms could be more cost-effective for monitoring management actions. Moreover, a methodology based on epifaunal samples could also be performed with non-destructive video or photograph image analysis [42].

In summary, a multiple measure based on functional components should provide more information on the ecosystem and reflect its vulnerability to trawling activities. These measures should be related to gradients of trawling intensity and reflect the ecosystem responses to disturbance.

2.2. Pressure factor: trawling effort

Mediterranean fisheries have a particular organisation, as trawling is controlled at a local scale and regulation is based on effort limits instead of total allowable catch (TACs) as in European countries bordering the North Sea [43–45]. In most Mediterranean countries the fishermens' association at each harbour records the daily activity of its fleet, controlling the hours each vessel spends out of harbour and its landings. This facilitates data gathering, and fishing hours per vessel can be recorded each day. The different fishing grounds where the fleet operates are defined by a set of preferential target species, so the analysis of landings indicates in which fishing ground each vessel has been operating. After selecting the vessels that have operated in the study area, the total trawling hours in that fishing ground can be estimated. The collection of this data permits estimations on the total trawling hours in a fishing ground per month, as a measure of trawling effort in the area [46,47]; nevertheless, this estimation of trawling effort assumes similar gear size and HP, which in the context of this Mediterranean fishery are controlled by establishing legal limits.

It can be argued that the frequency and intensity of effort is not evenly distributed over a fishing ground, and benthic communities vary at a much smaller scale [27,48]. However, to develop a study combining both variables it has been assumed that the surveyed benthos was representative of the whole area and that the fishing ground was evenly trawled. Adequate sampling must be undertaken to obtain sufficient replicated sites over the study area and represent the potential variability within the area [49]. Moreover, replicated areas subjected to gradients of effort intensity must be surveyed to directly link the effort level with an index of community disturbance.

2.3. *Evaluating the degree of trawling disturbance to functional components of communities*

This analysis must achieve a compromise between a simple procedure for easy monitoring and an accurate one to provide confident information on which to base management decisions. A complete analysis of the ecosystem functioning can be highly complicated, but the definition of a limited set of functional traits should provide sufficient information on community health. The proposed analysis is based on classifying the collected taxa into a list of functional traits, which is subsequently translated into functional components of the community as an index of community disturbance. These traits were easily attributable to each taxon with help from on-line databases or published literature.

The functional traits selected were based on current knowledge of the response of benthic fauna to trawling disturbance (Table 1). Position on the substratum is important in order to avoid direct contact with the gear, thus organisms on the surface are considered more vulnerable to trawling than burrowing fauna. The feeding type is related to the opportunism vs. selectivity of the organisms, with filter feeders highly vulnerable, whereas scavengers potentially benefit from trawling. The motility is defined at the scale of the fishing gear, thus sedentary fauna are not able to move from the disturbed area or escape from the action of the gear. Average size and life span are also defined at the scale of disturbance, and fauna with an average size larger than 5 cm and life span longer than 3 years were considered to be negatively affected by commercial trawling in the fishing ground. The category "other attributes" refers to any characteristic of the individuals that is either advantageous to sustained trawling impact, such as a hard shell or fast regeneration, or is sensitive to trawling, such as a fragile shell. See [18] for further discussion of these traits.

The indicator of disturbance corresponds to the relative abundance of functional traits of the epifaunal community selected for the analysis. These can have a positive or negative response to disturbance, but collectively indicate community vulnerability to trawling. In order to develop a quantitative analysis, each functional trait (Table 1) was assigned a score depending on its vulnerability to trawling (i.e. low vulnerability 0, no response to disturbance 1, vulnerable 2 and high vulnerability 3: sessile 3, sedentary 2, motile 0) (Table 2). No organism was considered as being completely invulnerable to trawling, as the action of the gear would potentially impact all organisms inhabiting the bottom; therefore, the zero score has been assigned to those organisms considered as having low vulnerability to trawling. The collected taxa were classified based on the list of functional categories, and the scores of each of its categories were added so each taxon was assigned a score (e.g. an emergent, sessile filter-feeder, smaller than 5 cm, that is slow growing with no body protection would have an overall score of 14). This procedure takes into account the range of vulnerability traits exhibited by each community. High scores can be translated in a community with traits that were mainly vulnerable to trawling; in contrast a dominance of low scores was characteristic of a resilient community with traits that have low vulnerability to trawling. In order to translate organisms' abundances into indices a range of scores was defined, with each range representing a functional group defined by its degree of vulnerability. The summary of all community traits into groups reduces the error of assigning a wrong category to a species. A total of six groups that range from low to high vulnerability were defined: group 1, 0–3 scores; group 2, 4–6; group 3, 7–9; group 4, 10–12; group 5, 13–15; group 6, 16–18 (Table 3). The relative abundance of these groups, as the sum of abundances of all taxa classified in that group, is therefore a measure of community disturbance.

3. Indicator vs. effort gradient: a tool for fisheries management

A community indicator based on functional groups should positively or negatively respond to the different levels of trawling intensity (i.e. high abundance of G1–2 as an indicator of high intensity and G5–6 as an indicator of low disturbance; Tables 2 and 3). In order to analyse the response of community indicators to effort changes, benthic communities subjected to a gradient of trawling effort intensity were selected. In Mediterranean fishing grounds (the framework of our study), this objective was not easily achieved; however, four areas located in soft bottoms on the Spanish continental shelf have been previously analysed [50], and the collected data were used to test the community indicators.

Table 1
List of defined categories for the selected functional traits (included in the first row).

Position	Feeding type	Motility	Average size	Life span	Other attributes
Emergent	Filter feeders	Sessile	Small: <5 cm	Fast growth: <3 yr	Vermiform
					Fragile shells
Surface	Deposit feeders	Sedentary	Large: >5 cm	Slow growth: >3 yr	Hard shells
Burrowing	Predators	Motile			Protection in burrows
	Scavengers				Regeneration of damaged tissues

Table 2
Scores assigned to each category within the functional traits.

Scores	Position	Feeding	Motility	Size	Life span	Other attributes
0	Burrowing	Scavengers	Motile	Small <5 cm	Fast growth <3 yr	Hard shell, burrow, vermiform, regeneration
1		Deposit feeders				
2	Surface	Predators	Sedentary			No protection
3	Emergent	Filter feeders	Sessile	Large >5 cm	Slow growth >3 yr	Fragile shell

Scores range from 0, low vulnerability, to 3, high vulnerability to trawling activities.

Table 3
List of functional groups (G1–6) represented by a range of scores.

Functional group	Scores	Epifaunal species
G1	0–3	*Astropecten irregularis Bolinus brandaris Liocarcinus depurator*
G2	4–6	*Lesuerogobius suerii Sepietta* sp. *Trachythyone tergestina*
G3	7–9	*Acanthocardia echinata Anseropoda placenta Stichopus regalis*
G4	10–12	*Citharus linguatula Lepidotrigla cavillone Uranoscopus scaver*
G5	13–15	*Alcyonium palmatum Phallusia mamilata Smittina cervicornis*
G6	16–18	Large sponges or sessile cnidarians

Last column shows an example of Mediterranean epifaunal species included in each group.
No species from G6 were collected in the study area.

Study area: the area of study was located in the continental shelf off the Catalan Coast (NE Spain), corresponding to soft bottoms between 45 and 60 m depth (Fig. 1). The first sampling area was a muddy-bottom fishing ground off the Ebro Delta, including a heavily fished site (hereafter Delta-F) and a small portion of undisturbed seabed within the fishing ground (hereafter Delta-R) (described in detail by [18]). A second study area was located in and around the Medes Islands marine reserve to the north of the previous study area and characterised by sandy–mud sediments: one site located inside the reserve (hereafter Medes-R) and the other one outside it in an area where the fishing effort is relatively low (hereafter Medes-F).

Fishing effort: the effort level was measured as trawling hours per month in the fishing ground. The effort was easily defined as the sites were located either in well-delimited fishing grounds or in marine reserves where trawling is prohibited. The total effort in each fishing ground was defined as very high in the Ebro Delta fishing ground (between 5000 and 7000 fishing hours/month in an area of 400 km^2) [46]; no trawling effort in the undisturbed area enclosed in the fishing ground, which due to its small area (2.7 km^2) will, however, be highly influenced by trawling activities in the surroundings; no effort inside the Medes Islands marine reserve, which has an area of 98 km^2 of integral reserve and 418 km^2 of partial reserve, and trawling has been restricted since the 1980s; and low trawling effort in the area adjacent to the reserve where occasional trawlers have been observed in the area (unpublished data). The four areas were classified in a gradient of trawling pressure, from high to low trawling disturbance: 1—Ebro Delta fishing ground (Delta-F), 2—undisturbed area within fishing ground (Delta-R), 3—area adjacent to the marine reserve (Medes-F), and 4—Medes Islands marine reserve (Medes-R).

Community indicators: epifaunal organisms were sampled with a 2 m beam-trawl, with a 1 cm mesh cod-end, performing a 15 min tow at three sites in the Ebro Delta study areas and five sites at the Medes Islands study areas (minimum sample size after [51]). The organisms were identified to species or genera, recording the number of individuals, and the collected epifaunal taxa were classified using the list of functional traits from Table 1. In order to define the community indices, the identified taxa were grouped based on their scores (Tables 2 and 3).

Multivariate analysis was used to relate the functional components with effort levels. The independent variable corresponds to fishing hours per month (in the area of fishing ground), and the response variable was the abundance of functional groups (G1–6, Table 3). Similarity between each pair of samples was calculated using the Bray–Curtis similarity index (PRIMER, [52]), and a non-metric multidimensional scaling ordination (MDS) was developed based on the similarity matrix. Afterwards, the indicators obtained at each of the sampled areas were correlated with the estimated effort in the area by a correspondence analysis; the ordination of samples was tested with χ^2 test, at $\alpha<0.05$ (SPSS v. 13).

3.1. *Response of community indicators to trawling intensity: a first approach*

Data was obtained from four conditions representing a gradient of trawling effort: a highly disturbed community from a fishing ground (Delta-F); a small undisturbed area enclosed in the fishing ground, and thus surrounded by high trawling effort (Delta-R); an area adjacent to the marine reserve with very low trawling disturbance (Medes-F); and the community inside the reserve that had not been disturbed by trawling (Medes-R). The proposed hypothesis predicts that the different effort intensities would cause changes in the percentage of abundance of the different functional groups.

The percentage abundance of each functional group relative to fishing effort (Fig. 2) showed progressive community degradation with fishing intensity: going from Delta-F with high abundance of G1, to Medes-R with dominance of G5. The groups indicative of important differences were the extremes, G1 vs. G5; those organisms characteristic of G6 (such as large and slow growth emergent sessile filter feeders, see Table 3) were not collected, as probably this group would represent the most pristine condition.

The samples collected at each of the four study areas were represented in an ordination plot (Fig. 3) based on the relative abundance of functional groups (G1–6). The MDS plot graphically represents the distance between the four areas based on the Bray–Curtis similarity of their community components (i.e. functional groups), with an ordination of the areas depending on their level of community disturbance, indicated by an arrow: from Delta-F with high effort to Medes-R with no effort. Therefore, communities from the Ebro Delta fishing ground (with high abundance of G1) were located in the opposite side of the graph in relation to the community from Medes Islands marine reserve (with high abundance of G5), whereas the fished area adjacent to the reserve (Medes-F) was in a middle position.

The correspondence analysis (Fig. 4) represented the ordination of data in a 2-dimension graph. Dimension 1 (explaining 85% of variance; χ^2: 233.8, $p<0.001$) differentiated the communities from the marine reserve area and the Ebro Delta area, determined by abundances of G5 and G1–2. This could be translated into a disturbance direction, as more abundance of G5 in contraposition of G1 indicates a healthier community. Dimension 2 (explaining 9.3% of variance; $p<0.001$) was mainly defined by G4, and differentiated the reference areas, over 0 values, from the fished areas, bellow 0 values. However, this ordination of sites could also be explained by the different locations: Medes Islands marine reserve with sandy–mud sediments and Ebro Delta fishing ground with muddy sediments. This highlighted the need of further sampling areas subjected to different trawling effort intensities, to subsequently analyse an adequate sample size of benthic communities in a gradient of trawling effort.

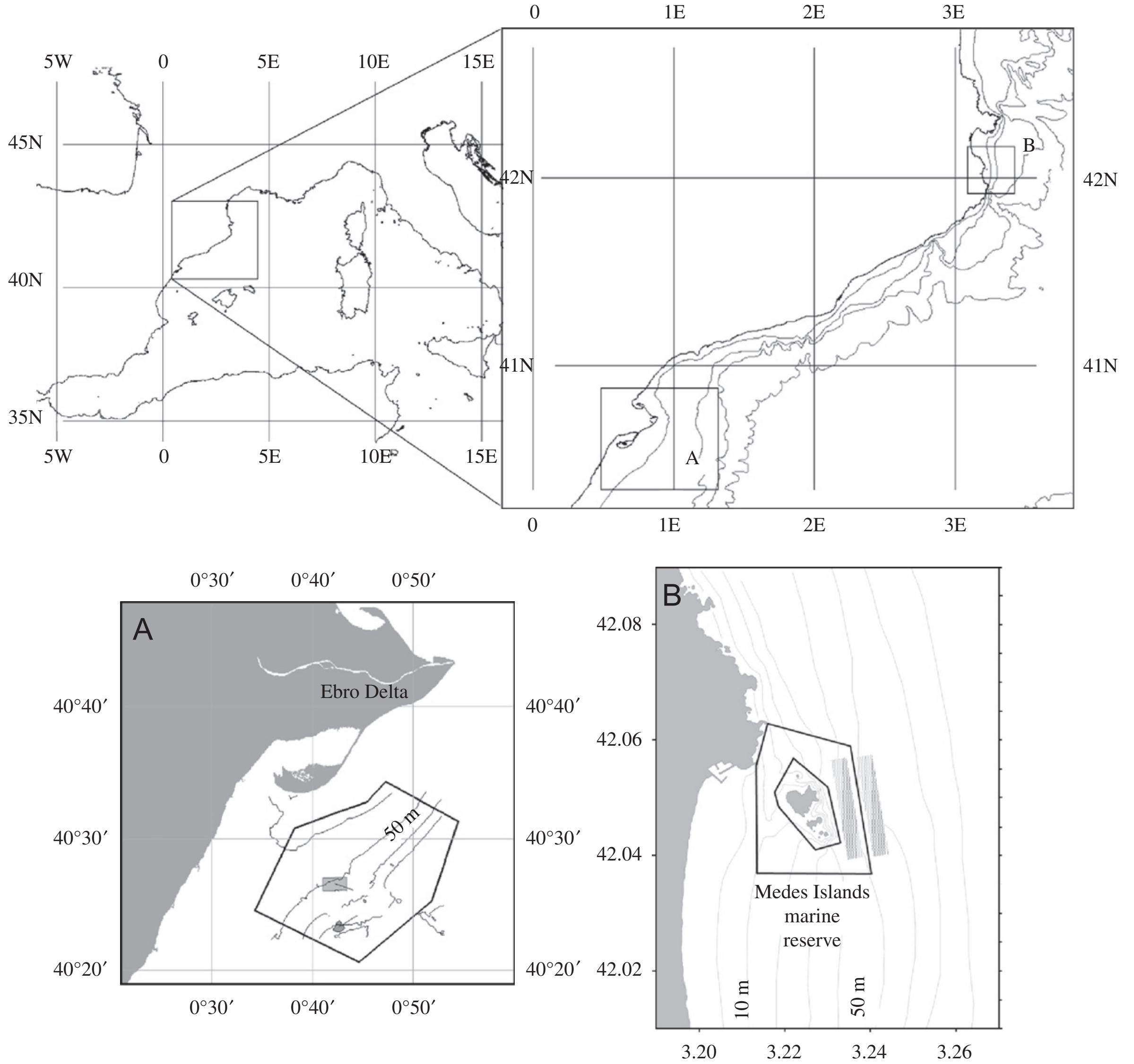

Fig. 1. Study area in the Catalan coast (NW Mediterranean): Ebro delta fishing ground (A, fishing ground encompassed by black line) and Medes Islands marine reserve (B, internal line encloses integral reserve and external line delimits partial reserve). Areas sampled in the fishing ground (A): disturbed area, Delta-F, and undisturbed area, Delta-R; areas sampled in marine reserve, (B): shadowed area inside (Medes-R) and outside the partial reserve (Medes-F).

4. Discussion

The negative consequences of trawling activities on ecosystems have been intensively studied over the last decades, but the potential for drawing general conclusions from these studies is underestimated. Common trends of community responses to trawling disturbance have been detected, and these trends can be interpreted with the knowledge we have on marine ecosystem structure and function [53].

This study proposed defining the functional components of the epibenthic community, and the relative abundance of these components, as a measure of community disturbance. A methodology to estimate the trawling effort at the same scale as the community indicator was proposed based on the NW Mediterranean case study.

Epifaunal data were collected at four locations subjected to variable trawling effort, and results confirmed expectations in the response of community indicators to trawling disturbance. The highly trawled fishing ground was dominated by functional components with low vulnerability to trawling, which represented a homogenised community dominated by small organisms. In contrast, the Medes Islands marine reserve held a community with larger organisms and high abundance of emergent and sessile fauna, which overall increased community structure and likely benefited ecosystem functioning per se. Nevertheless, more data on communities subjected to variable effort should be included in such analyses to increase their generality. Even if a general model that predicts the response of indicators to different levels of trawling effort cannot be developed, the selection of these indicators is locally useful for monitoring the recovery of communities after the establishment of an ecosystem-based management plan.

From a fisheries perspective, the recovery of a disturbed community is necessary to maintain demersal resources, and from the ecosystem perspective, the recovery of communities from trawled continental shelves should allow for the maintenance of ecosystem function and contribute to ecosystem resilience [2,7]. Limitations to this study have been assumed, and the methodology must be generalised, analysing a wide range of areas subjected to gradients of trawling intensity. However, the most

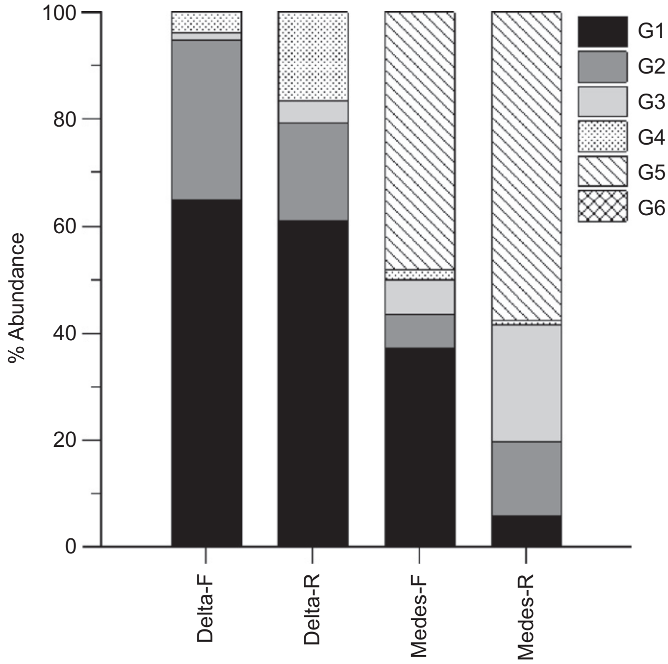

Fig. 2. Percent abundance of functional groups (G1–6) at each study area. Fishing ground: Delta-F and Delta-R; marine reserve: Medes-F and Medes-R.

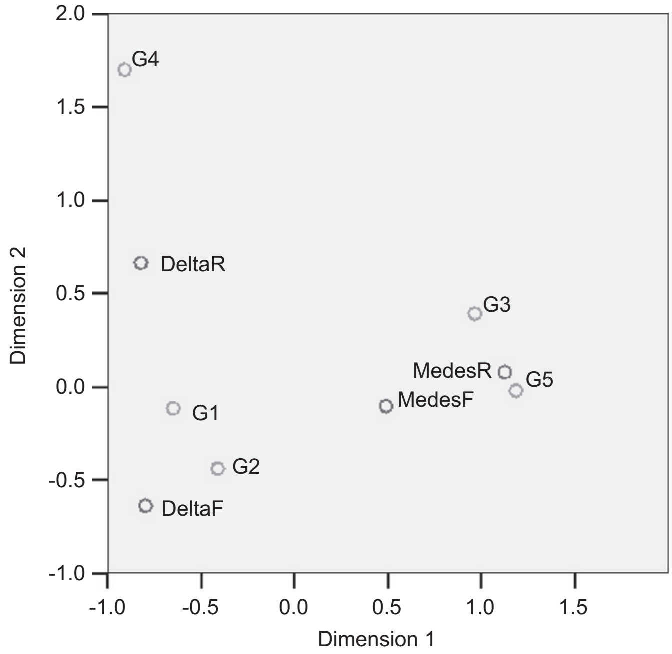

Fig. 4. Correspondence analysis based on the relative abundance of functional groups (G1–5, represented by grey open circles) within each community (Delta-F, Delta-R, Medes-R, Medes-F, represented by black open circles). Dimension 1 explains 85% of variance and 9.3% is explained by dimension 2.

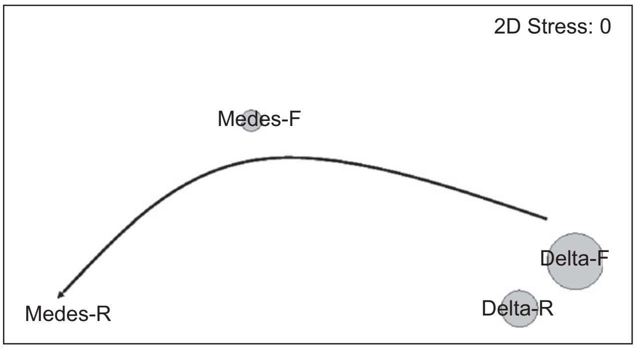

Fig. 3. MDS plot with distribution of the four communities (Delta-F, Delta-R, Medes-F and Medes-R), with the superposition of the relative effort intensity on each community: the size of the bubbles represents the disturbance intensity (large size: high intensity). The arrow indicates the disturbance direction for the communities.

important finding was that the data collected at the four different locations matched predictions on the response direction of the functional groups (i.e. G1 vs. G5). This community indicator would be useful for the management of ecosystems, and data from benthic communities subjected to different levels of trawling disturbance should be collected in order to determine community indicators based on functional components of each community. Therefore, to estimate the relative level of community degradation each obtained index should be established along a gradient of disturbance. The representation of benthic communities in a disturbance gradient would supply scientists and managers with valuable information, such as which areas are in priority for protection, or the effectiveness of restricting trawling activities in a fishing ground.

Ecosystems should not only be protected from further anthropogenic disturbance, but should also be returned to a less-altered state [26,54]. The definition of recovery trajectories is, however, difficult. An altered community may have been modified beyond a threshold from which recovery is no longer possible [55]. Moreover, community recovery is likely to be influenced by the context provided by both physical and biological characteristics, therefore it is difficult to simplistically generalise recovery patterns [56,57]. Recovery potential will depend on community traits, environmental factors, and the frequency and intensity of trawling disturbance that each community has been subjected to. In this context, recovery patterns should be generalised and allow establishing reference levels useful in the management of trawling and reduce disturbance. Research could focus on analysing the community degradation and the reversal of this process would guide us in identifying which community changes represent a positive response to protection measures.

Differences found between areas subjected to variable trawling effort confirmed predictions on the response of community indicators to trawling disturbance, and provided guidelines on changes caused by trawling that should be reduced to minimise disturbance on benthic ecosystems. Nevertheless, communities over the continental shelves must be systematically surveyed to define habitat characteristics, record community composition and diversity patterns, and identifying those fragile or more sensitive communities that might be in urgent need of protection; this is necessary in order to develop a direct correlation between effort levels and indicators of disturbance.

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