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Integrating the provision of ecosystem services and trawl fisheries for the management of the marine environment

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HIGHLIGHTS

- Ecosystem Service Providers (ESP) represented a link between function and services.
- ESP variability was mainly affected by sediment type and fishing effort.
- A DPSIR (Drivers–Pressures–State Change–Impact–Response) model is presented.
- The DPSIR aims to inform integrated management to ensure service provision.
- All socio-ecological system components are essential to adopt integrated management.

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ABSTRACT

The species interaction and their biological traits (BT) determine the function of benthic communities and, hence, the delivery of ecosystem services. Therefore, disturbance of benthic communities by trawling may compromise ecosystem service delivery, including fisheries' catches. In this work, we explore 1) the impact of trawling activities on benthic functional components (after the BTA approach) and 2) how trawling impact may affect the ecosystem services delivered by benthic communities. To this aim, we assessed the provision of ecosystem services by adopting the concept of Ecosystem Service Providers (ESP), i.e. ecological units that perform ecosystem functions that will ultimately deliver ecosystem services. We studied thirteen sites subjected to different levels of fishing effort in the Mediterranean. From a range of environmental variables included in the study, we found ESPs to be mainly affected by fishing effort and grain size. Our results suggested that habitat type has significant effects on the distribution of ESPs and this natural variability influences ESP response to trawling at a specific site. In order to summarize the complex relationships between human uses, ecosystem components and the demand for ecosystem services in trawling grounds, we adapted a DPSIR (Drivers–Pressures–State Change–Impact–Response) framework to the study area, emphasizing the role of society as Drivers of change and actors demanding management Responses. This integrative framework aims to inform managers about the interactions between all the elements involved in the management of trawling grounds, highlighting the need for an integrated approach in order to ensure ecosystem service provision.

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1. Introduction

Marine ecosystems provide a wide range of services that are essential for human well-being. (Beaumont et al., 2007; Townsend et al., 2011); however, the marine environment has been historically impacted by human activities (Jackson et al., 2001). Nowadays, both scientists and managers recognize that, in order to ensure the provision of ecosystem services for future generations, the broad range of human activities in our coasts and oceans must be subjected to an appropriate management (Levin and Lubchenco, 2008). Among the multiple human uses of our coasts and oceans, fisheries is acknowledged as being the principal source of disturbance that has historically and chronically altered marine ecosystems (Thrush and Dayton, 2002). Indeed, fisheries catches are declining world-wide (Pontecorvo and Schrank, 2014), implying that management strategies have failed to maintain sustainable ecosystems and to ensure the provision of the "fish for food" service.

Trawl fishing impacts cause the chronic modification of the ecosystem functioning (Bremner et al., 2003; de Juan et al., 2007). The alteration of ecosystem functioning is of high relevance for society as the services delivered by benthic ecosystems are the product of many interrelated functions (Townsend et al., 2011; Rees et al., 2012; Snelgrove

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et al., 2014). Moreover, benthic community structure does not only regulate ecosystem function of the sea floor, but also water column processes, e.g. nutrient fluxes that are positively related to primary production in the water column (Lohrer et al., 2004). Trawling disturbance may compromise the provision of food by overexploitation of target communities and degradation of benthic habitats (Jackson et al., 2001; Thrush and Dayton, 2002). Additionally, trawling activities might indirectly compromise many ecosystem functions (e.g. bioturbation and nutrient cycling) that are related with regulation and supporting services (MEA, 2005; Beaumont et al., 2007) but that might ultimately be related with the provision of food (e.g. productivity of fishing grounds). Therefore, in the fisheries context, the whole array of functional components of the seafloor should be considered under an integrated management approach (Rees et al., 2012), with conservation targets that go beyond the food provisioning service.

In order to adopt an integrated management approach, it is necessary to understand community dynamics under stress. To this aim, a functional approach based on Biological Trait Analysis (BTA) has proved useful (Bremner, 2008). Variation in functional components due to stress is linked to changes in BT, which are in turn linked to changes in the species composition (Bremner, 2008). The BTA has also been proposed as a useful framework to assess the provision of ecosystem services by biological communities (Bolam and Eggleton, 2014; Bremner et al., 2006a; Frid, 2011). Ecosystem services depend on functions performed by benthic communities (e.g. deep burrowing fauna increase the oxygen flow into the sediment, extending the total denitrification zone and stimulating nutrient cycling that is involved in the ecosystem regulating service (Lohrer et al., 2004; Beaumont et al., 2007)). But the estimation of the provision of ecosystem services normally addresses economic or social values (Beaumont et al., 2007; Boyd and Banzhaf, 2007) and rarely focuses on ecological measures (Kremen and Ostfeld, 2005, but see Townsend et al., 2011; Snelgrove et al., 2014). In this context, the concept of Ecosystem Service Providers (ESP) was proposed (Kremen and Ostfeld, 2005; Cognetti and Maltagliati, 2010) aiming to encompass a group of organisms sharing particular biological traits (BT) that were related with certain ecosystem functions and, ultimately, with the provision of services. Altogether, these links would determine the dynamics of the ESP; therefore, understanding these links would increase our knowledge on the relationships between ecosystem dynamics and service delivery.

On the other hand, socio-ecological links must be accurately defined if we aim to achieve an integrated management approach and this requires appropriate methodological tools (Daily et al., 2009). The DPSIR framework (Drivers–Pressures–State change–Impact–Response) has been proposed as a systems-based approach that captures key relationships between society and the environment, note the tight link with the ecosystem service concept. Moreover, the DPSIR is regarded as a philosophical context for structuring and communicating policy-relevant research about the environment to non-scientists (Mangi et al., 2007; Atkins et al., 2011).

The principal aim of this study is to understand how commercial trawling compromises the delivery of ecosystem services, through changes in functional components of the benthic ecosystem. The specific goal is to assess the variability of ESPs under different environmental conditions and subjected to variable trawling intensity. We analyzed the functional components of benthic communities as surrogates for ecosystem functions from 13 sites located in fishing grounds in the Mediterranean. These sites were subjected to different levels of trawling effort. Variability in BT across sites could be linked to i) trawling activity ii) local environmental factors or iii) area location. Through this approach we discuss if these factors drive ecosystem function variability in our study area and how this could ultimately compromise the delivery of ecosystem services. Finally, management implications for the variability of ecosystem services are discussed in a socio-ecological context under the DPSIR framework, highlighting the importance of benthic ecosystem service conservation to sustain healthy fisheries.

2. Materials and methods

2.1. Study areas and site characterization

Six areas were selected in the Mediterranean Sea to carry out this study: 3 in the coast of Spain (Cap de Creus-CC, Ebre Delta-D and Cabo de Palos-CP), two in Italy (Ligurian Sea-L and Adriatic Sea-A) and one in Greece (Ionian Sea-I) (Fig. 1). Fishing effort was estimated in these areas based on information gathered from fishermen interviews and from registers of landings recorded by the fisheries associations. This allowed us to estimate fishing effort as GT*days at sea/month. Four of the study areas (CC, CP, I, L) were further divided in 2–3 sites that were identified as being subjected to different levels of fishing effort (Low or no effort, Medium and High) based on the fishermen information previously obtained (Fig. 1, Table 1). Sites with "Low", "Medium" and "High" effort were defined within each area and are not comparable among areas (e.g., site H in CC was not comparable to site H in CP; these were relative values).

All the study sites had an area of 2–4 km^2 and showed homogeneous sediments and communities (Demestre et al., 2008; de Juan et al., 2013). The sites were located on soft bottoms in the continental shelves between 40 and 80 m, where commercial trawling is performed. The CC area included a no-take Marine Protected Area (CCL). The L, I and D areas had muddy bottoms (over 90% of mud); CC and A areas had sandy-mud bottoms; and the CP area was characterized by maërl protruding within sandy-mud bottoms (de Juan et al., 2013; Table 1).

Subsequently, during the experimental cruise, a different approach for fishing effort estimation was carried out using side-scan sonar surveys (SSS). Trawl doors alter the structure of the sediments, with scars that can be up to 20–30 cm depth. These scars on the sediment show high reflectivity tracks on the SSS images (Lucchetti et al., 2012). Thus, the SSS images allow the estimation of trawl mark density on the seafloor. Density was obtained considering the total length of the trawl marks per site area (trawl tracks density/km^2) (see de Juan et al., 2013 for further details) (Table 1). This approach was consistent in all study areas; therefore, the obtained effort values could be compared across sites and areas.

2.2. Data collection

All samples were collected in early summer (June–July) of 2003 for D and A and 2009 for the other areas. The sampling protocol was consistent across areas. The potential influence of this 6-year gap between sampling periods was tested with multivariate analysis of benthic community composition (using PRIMER 6 & PERMANOVA, see Section 2.4). A MDS analysis for the whole data set was done based on Bray–Curtis similarity index, and results showed no structure in relation with the sampling year. The distribution of samples was mainly influenced by environmental variability.

The epifaunal community was sampled with an epibenthic dredge that had a 2 m iron-frame aperture and a 1 cm cod-end. Six samples were randomly collected in each site, the dredge towed for 15′ with a constant speed of 2.3 knots. A SCANMAR device was attached to the dredge to ensure continuous contact with the seabed. Due to bad weather conditions, only three replicates were collected in CCL site and two in IL site. Epifaunal organisms were generally identified to species and the number of individuals and biomass for each species was recorded and standardized to 1000 m^2.

Three to five Van Veen grabs were randomly collected in each site. The surface sediments from grab samples were retained for the analysis of grain size and carbon content. Grain size was analyzed with laser diffraction (using Horiba La-950v2 particle size analyzer). Total carbon (TC) was analyzed using a TruSPec Leco analyzer. After removing the inorganic carbon from the sediment sample using HCL vapors, the sample was reanalyzed to obtain the total organic carbon (TOC). These data were not available for A study area (Table 1).

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