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Canyon effect and seasonal variability of deep-sea organisms in the NW Mediterranean: Synchronous, year-long captures of "swimmers" from near-bottom sediment traps in a submarine canyon and its adjacent open slope

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ABSTRACT

Numerous organisms, including both passive sinkers and active migrators, are captured in sediment traps together with sediments. By capturing these "swimmers", the traps become an extraordinarily tool to obtain relevant information on the biodiversity and dynamics of deep-sea organisms. Here we analyze near-bottom swimmers larger than 500 µm and their fluxes collected from eight near-bottom sediment traps installed on instrumented moorings deployed nearby Blanes Canyon (BC). Our data, obtained from November 2008 to October 2009 with a sampling rate of 15 days, constitutes the first year-long, continuous time series of the whole swimmers' community collected at different traps and bottom depths (from 300 m to 1800 m) inside a submarine canyon and on its adjacent open slope (OS). The traps captured 2155 specimens belonging to 70 taxa, with Crustacea (mainly Copepoda) and Annelida Polychaeta accounting for more than 90% of the total abundance. Almost half of the identified taxa (33) were only present in BC traps, where mean annual swimmer fluxes per trap were almost one order of magnitude higher than in the OS ones. Temporal variability in swimmer fluxes was more evident in BC than in OS. Fluxes dropped in winter (in coincidence with the stormy period in the region) and remained low until the following spring. In spring, there was a switch in taxa composition, including an increase of planktonic organisms. Additionally, we report drastic effects of extreme events, such as major storms, on deep-sea fauna. The impact of such extreme events along submarine canyon systems calls to rethink the influence of climate-driven phenomena on deep-sea ecosystems and, consequently, on their living resources.

1. Introduction

Deep-sea ecosystems represent the largest biome of the biosphere (> 65% of the earth surface). However, knowledge of their processes and biodiversity is still scant (Danovaro et al., 2010; Gage and Tyler, 1991), and the Mediterranean Sea is not an exception. Being one of the most intensively investigated marine areas of the world and having high rates of endemism, its deep-sea fauna still remains poorly known (Coll et al., 2010). During the last years, the number of studies has increased, but they often focus on a specific or limited number of taxa and are conducted in a limited spatial or temporal scale (Danovaro et al., 2010).

It is widely accepted that submarine canyons, especially those deeply indenting the continental shelf like Blanes Canyon (NW Mediterranean), have a very important role in channeling energy and matter from coastal areas to the deep ocean basin (Canals et al., 2013 and references herein). The downward particle fluxes and sediment accumulation rates inside canyons are generally higher than those recorded in the open slope (Palanques et al., 2008 and references therein). As a consequence of enhanced transport and fluxes, submarine canyons have a strong influence on deep-sea fauna (Company et al., 2008; Sardà et al., 2009), resulting in more productive and diverse planktonic and benthic communities in comparison to those found over open slopes (Vetter and Dayton, 1998; Gili et al., 1999; De Leo et al., 2010, Romano et al., 2013a) Processes generating advective fluxes canalized through the canyon, including large storms, river floods, dense

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shelf water cascading (DSWC) and trawling-induced resuspension (Martín et al., 2014; Pusceddu et al., 2014; Puig et al., 2012; Canals et al., 2006), have therefore strong impact in the functioning of deep habitats. In particular, DSWC has been related to drastic changes in the population dynamics of decapods and temporary fishery collapses (Company et al., 2008). The influence of increased downward particle fluxes caused by bottom trawling along the canyon flanks on benthic meiofaunal assemblages has been recently discussed in Román et al. (2016). However, the effects of shelf-originated phenomena on the ecology and variability of other deep-sea fauna and its trophic web is still a matter of discussion.

With the aim of establishing links between upper water column processes and deep-sea food webs, the use of sediment traps deployed at different depths in the water column may certainly provide useful information, not only on sedimentary but also on biological processes. Although sediment traps were mainly designed to study vertical particle fluxes and sedimentation processes, they also allow assessing their dynamics, composition and origin, as well as to infer their links with existing biogeochemical cycles (Baker and Hickey, 1986). Numerous planktonic and epibenthic organisms are habitually captured alive by the traps and then become fixed together with the sediments. However, the ability of sediment traps to collect organisms has often been questioned (e.g. in Knauer and Asper, 1989), and traditionally, marine geologists labeled them as "swimmers", considering them as contaminants to be removed from samples to prevent interferences in particle flux mass estimates. Conversely, contrasting opinions consider swimmers as legitimate parts of the particle flux (Silver and Gowing, 1991) having a relevant contribution to the total particulate organic carbon trapped (Steinberg et al., 1998). In turn, the presence of some organisms can also interfere with sediment characteristics. For instance, the pteropod-downward escape response artificially increased the rates of capture, leading to overestimate the aragonite flux as a result of shell dissolution (Harbison and Gilmer, 1986).

The fact is that sediment traps represent an extraordinarily useful tool to capture planktonic and benthopelagic organisms, especially in environments difficult to access, and to preserve them in good conditions. They provide complementary and relevant information to approach the biodiversity and dynamics of a wide range of deep-sea species. For instance, sediment traps are the only sampling method that can be used during long periods of sea-ice cover in the Arctic. Makabe et al. (2010) used them to demonstrate the existence of shifts in species composition related with the length of the sea ice cover period and nutrient availability. Sediment traps were also used to investigate the seasonal and interannual pattern of planktonic Crustacea in the Greenland Sea (Seiler and Brandt, 1997; Kraft et al., 2013; Nöthig et al., 2016). The observed differences between multi-net and trap samples in species composition and biomass allowed Seiler and Brandt (1997) to discuss on the significance of the abiotic influence of the sampling method vs. the biotic one caused by the active swimming behavior of some species into the traps.

Several studies focusing on swimmers found in sediment traps have been recently carried out in the Mediterranean Sea, mainly within the frame of geological studies. In terms of biodiversity, these studies lead both to the description of new species, genera, and even families, of cnidarians and polychaetes, as well as to the re-description of other species based on the analysis of new morphological features (Gili et al., 1998, 1999, 2000; Sardá et al., 2009, Sevastou et al., 2012). Others revealed that canyons in the North Western Mediterranean Sea host unique and specific hydromedusa populations (Bouillon et al., 2000; Gili et al., 1999, 2000). The relevance of these studies is high, specially considering that most of them were carried out in submarine canyons, where sampling with traditional devices is always difficult (Gili et al., 1999).

Sediment traps have seldom been used to approach biotic processes in the Mediterranean Sea. To the best of our knowledge, there are only two studies dealing with the temporal variability of deep-sea organisms caught in near-bottom sediment traps (Guidi–Guilvard et al., 2009, Danovaro et al., 2017). The first one provides relevant data on the temporal variations in organism fluxes and species composition of swimmers collected continuously during more than two years in a single station at the distal part of a submarine canyon, as well as on their relationships with environmental variables (Guidi-Guilvard et al., 2009). A more recent study (Danovaro et al., 2017) compares shallow and near-bottom zooplankton assemblages in three different geographical sub-basins of the Mediterranean Sea (Danovaro et al., 2017).

The fact that sediment traps provide simultaneous time series of both organisms and environmental data may be crucial for the understanding of processes controlling the changes in population structure of the target species. However, there are some obvious drawbacks in using sediment traps to study organisms. Among them, there is the difficulty to obtain replicates (which precludes the use of parametric statistics). Having this in mind, the amount of non-parametric options is fortunately far from negligible and should certainly allow scientists to go far beyond purely qualitative analyses with this kind of data, whose relevancy would otherwise be dismissed. Moreover there is a possible influence of behavior of the organisms in the captures (Harbison and Gilmer, 1986), which make difficult to compare data from trap-caught organisms with quantitative abundance data obtained by plankton nets. Nevertheless, comparing the simultaneous, synchronized and continuous swimmer fluxes obtained from different locations and depths allow us to gather new and important information on the spatial and temporal variability of zooplankton and benthopelagic fauna.

In this paper we present the first time series of "swimmers" collected continuously over one-year period in near-bottom sediment traps moored inside and outside a submarine canyon, which allowed us to analyze and correlate the variations in fluxes and composition of swimmers with the main environmental variables (currents, storms, and sediment composition) of the study area.

1.1. Study area

NW Mediterranean Sea shelves and slopes are carved by a variety of submarine canyons that densely incise the Gulf of Lions and the Catalan margins (Lastras et al., 2011). The largest one in the area is Blanes Canyon (Fig. 1), which measures 184 km in length, with a nearly N-S trending course in its shelf-incised section (the canyon head), followed by a meandering course with a flat-floored channel at the base of continental slope. The canyon reaches a maximum width of 20 km at its deepest part, where it turns to a W-E course before outflowing to the lower Valencia Channel at ca. 2600 m depth. The upper canyon is located at ca. 60 m depth and at ca. 4 km from the coastline where Tordera River reaches the sea (Amblas et al., 2006).

The Northern Current (NC) is one of the main sources of flow variability in the area, with deep flow intensifications inside and along the axis of the canyon related to the NC offshore displacements (Flexas et al., 2008; Jordà et al., 2013). The topography of the canyon walls plays a major role in current variability, with the unidirectional south

Table 1
Coordinates, distance of the traps from sea surface and seafloor, and number of samples recovered for each mooring; BC: Blanes Canyon; OS: SW open slope; mab: meters above bottom.

Station	*Latitude (°N)*	*Longitude (°E)*	*Trap depth (m)*	*mab*	*No of samples*
BC300	41.660	2.905	270	30	10
BC900	41.570	2.848	870	30	24
BC1200	41.521	2.847	1170	30	48
BC1500	41.458	2.882	1470	30	8
OS900	41.269	2.819	870	30	24
OS1200	41.219	2.815	1170	30	47
OS1500	41.150	2.897	1470	30	12
OS1500M	41.150	2.897	900	600	24
OS1800	41.081	2.969	1870	30	24