Spatio-temporal variability of meiobenthic density in the Blanes submarine canyon (NW Mediterranean)

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Abstract

Meiofaunal density distribution was studied from 400 m to 1500 m depth inside Blanes submarine canyon (NW Mediterranean), and on the eastern open slope in autumn 2003 and spring 2004.

Our multidisciplinary approach allowed to study the hydrodynamics and sedimentary processes in the Blanes Canyon that characterize it as highly heterogeneous environment. Inside the canyon area, particle fluxes were higher than on the slope area, increased from autumn to spring and mostly consisted of lithogenic material. Moreover the canyon's locations experienced more intense bottoms' currents and sediment disturbance, being reflected in a greater variability of meiobenthic densities, both between stations and sampling times than on the open slope. No clear trends (e.g. declining densities) associated with increasing depths were observed.

Contrary in the open slope, current velocities were relatively lower compared with the canyon area and showed lower temporal variability. At the same time, the nutritional quality of the particle fluxes at deeper grounds were higher, probably allowing the meiofaunal densities not to change over time.

In conclusion, the meiobenthos in our system apparently showed a higher temporal variability, inside the canyon area, strongly affected by particle fluxes or erosive and sediment-mixing processes linked to current modifications induced by the canyon topography.

Keywords: Deep-sea meiofaunal density, Particle fluxes; Bottom current, Submarine canyon, Mediterranean Sea

1. Introduction

Deep-sea sediments have been traditionally characterized as physically stable environments (e.g. Sanders, 1968). However, most of our previous knowledge on deep-seas comes from regions with quiescent hydrodynamic conditions. More recent studies prove that near bottom flows clearly affect deep-sea sedimentary areas (Zúñiga et al., 2009, de Stigter et al., 2011; Kiriakoulakis et al., 2011; Martin et al., 2011; Masson et al., 2011). Consequently, there has been an increase in the interest for the consequences of physical reworking on deep benthic fauna (Thistle et al., 1991; Levin et al., 1994; Gage et al., 1995; Paterson and Lamshead, 1995; Levin et al., 2001; Guidi-Guilvard et al., 2009; Garcia et al., 2007; Bianchelli et al., 2010; Brewin et al., 2011; Ingels et al., 2011).

High current speed and energetic events have been recorded in the deep sea at different locations and settings. At the base of the Scotian Rise (North Atlantic, 4626 m deep), a high mean current velocity prevailed (Richardson et al., 1981), with periods of intense ‘benthic storms’ (Kerr, 1980) reaching 20 to 25 cm s⁻¹ at 10 m above the bottom and being able to erode the sediment (Weatherly and Kelley, 1983). The hydrodynamic regime is a primary structuring force for benthic organisms, and intense near-bottom currents ($\geq 15\text{--}20\text{ cm s}^{-1}$) which are able to redistribute bottom sediments, may strongly influence the nature of deep meiobenthic communities (Aller, 1997). At BIOTRANS (area 12, Northeast Atlantic; depth approx 4500 m), the deep mean flow was 3-5 cm s⁻¹, but 3 to 27 days long benthic storms reaching up to 27 and 40 cm s⁻¹ may occur (Dickson and Kidd, 1986; Klein and Mittelstaedt, 1992), having a remarkable impact on the benthic fauna. Water mass circulation and dynamics closely depends on the bottom topography, and therefore may be strongly affected by major features such as submarine canyons (Durrieu de Madron, 1994). Submarine canyons may deflect the incoming flow and deeply modify the local circulation (Flexas et al., 2008; Allen and de Madron, 2009). Inside the canyons, hydrodynamics are generally stronger and re-suspension or erosion events may occur at deep floors (De Stigter et al., 2007). A study by Mulder et al (2012) in the Gulf of Biscay showed that some canyons had no evidence of recent sedimentary deposits, associated with recorded current speeds up to 1 m s⁻¹. These canyons are clearly by-passing or erosive areas. In the southern part of the Bay of Biscay, recent turbidite are deposited since the magnitude of currents is much less. It also has been recently proven that dense shelf water in submarine canyons in the Gulf of

Lions triggered seasonal cascading events, a type of current driven solely by seawater density gradients, which may transport large amounts of water and sediment, reshape submarine canyon floors, and rapidly affect the deep-sea environment and its living resources (Canals et al., 2006; Palanques et al., 2006; Canals et al., 2010). This may be illustrated by the collapse of *Aristeus antennatus* fisheries in canyon areas of the NW Mediterranean after a cascading event, with an increase of juvenile catches from three to five years later (Company et al., 2008).

Moreover, canyons play an important role in deep-sea ecosystems by acting as preferential transport channels for organic particles and sediments from the shelf to the deep sea (Monaco et al., 1990; Heussner et al., 1996; Martín et al., 2006). Numerous physical processes, such as the suspended particulate matter dynamics and downward fluxes (Canals et al., 2006) are modified and generally resulting in large amounts of organic matter arriving at the seafloor in the canyons (Hickey, 1995; Martín et al., 2006; Garcia et al 2010) and available to benthic organisms.

Therefore the variable, often instable canyon systems' conditions affect benthic communities at different spatial and temporal scales (Cartes et al., 1994; Sardà et al., 1994; Danovaro et al, 1999; Garcia et al., 2007; Guidi-Guilvard et al., 2009; Bianchelli et al., 2010; Ingels et al 2011; Cunha et al 2011) resulting in a high patchiness in biodiversity and biological productivity and sometimes in increased biomass and abundance (Skiris and Djenidi, 2006; Koho et al. 2008, Ingels et al, 2009) with obvious influences on higher trophic levels too (Vetter and Dayton, 1998; De Leo et al., 2010). In Mediterranean deep-sea canyons only few quantitative studies on meiofauna have been carried out (de Bovée et al., 1990; Soetaert et al., 1991; Bianchelli et al., 2008; Lampadariou et al. 2009; Bianchelli et al., 2010) and rarely both spatial and temporal scales have been taken in consideration (Danovaro et al., 1999; Danovaro et al, 2000). The results don't allow to completely assess the relative importance of environmental factors in regulating communities in such complex systems.

The aim of the RECS project, within which this study is framed, was to study the ecology of an important fishing resource, the red shrimp (*A. antennatus*), inhabiting the submarine Blanes Canyon area (Northwestern Mediterranean), in relation with environmental and biological variables. A multidisciplinary study was carried by simultaneous analysing meiobenthic data, as well as fishery, hydrodynamic and geological data (Sardà et al., 2009; Zúñiga et al., 2009). This implies that sampling sites were chosen to characterize different fishing grounds rather than the main canyon axis

and its adjacent open slope. The aim of the present paper was to study the variability in deep-sea meiofaunal distribution in the Blanes Canyon (BC) – and adjacent open slope system, in different locations and periods in terms of bottom morphology, hydrodynamics and particle fluxes. The following null hypotheses were tested: 1) meiofaunal communities of the hydrodynamically disturbed sediments from the BC area do not differ from those of the adjacent, more stable, slope area sediments. 2) deep-sea meiofaunal density do not change over time 3) meiofaunal density do not show depth-related pattern. Spatio-temporal differences are interpreted in the context of the prevailing environmental conditions such as sedimentary processes and current intensity. By unravelling meiofauna distribution and their relation with the environmental variability, on these important fishing grounds, we increase our insight in local and regional ecological processes to which the deep-sea meiofauna may contribute in a significant extent.

1.1 Regional setting

The Blanes Canyon (Catalan continental margin, NW Mediterranean) deeply cuts the continental slope in a NW:SE direction. Less than 4 km offshore, its head fits into the continental shelf at 60 m deep (ITGE, 1989; Díaz and Maldonado, 1990), being thus linked with the old riverbeds of the Tordera river and the torrential ephemeral streams of Blanes, Lloret and Tossa de Mar. The canyon width increases with depth, reaching a maximum of 20 km wide and apparently ending in the Channel of Valencia, at 2400 m deep (Canals et al., 1982). The structure of the canyon, similar to those of La Fonera (or Palamós) and Cap de Creus (all in the NW Mediterranean) is defined by fracture lines and was at least partially eroded under subaerial conditions (Canals, 1985; Amblas et al. 2006; Lastras et al. 2011). The cross-section of the BC is V-shaped along the upper course and U-shaped in the lower course, thus reflecting the prevalence of erosion and accumulation processes, respectively (Fig. 1). The canyon walls are clearly asymmetrical, while the western wall is highly steep the eastern wall is characterized by a milder slope and the presence of various gullies that connect the open slope with the canyon axis

The NW Mediterranean is characterized by a general cyclonic circulation along the continental slope, the so-called Northern Current (NC), forced by the entrance of Atlantic Water through the Gibraltar Strait (Millot, 1999). The NC is the main current flowing along the NW Mediterranean continental slope, and involves Atlantic Water

(AW) from surface to 300 m deep, Levantine Intermediate Water (LIW) up to about 600 m deep, and Western Mediterranean Deep Water (WMDW) down to the bottom. The NC has maximum velocities of about 30-50 cm/s at the surface, decreasing approximately linearly with depth to speeds of 3 to 5 cm·s⁻¹ at several hundred meters depth (e.g. Lapouyade and Durrieu de Madron, 2001); this velocity is maintained approximately to the bottom (e.g. Flexas et al., 2002; Flexas et al., 2008).

2. Materials and Methods

2.1 Sampling Stations

Eight stations (Fig. 1) were selected for this study. Rocassa was located at the canyon head (400 m deep) at 7 km from the coast and the Tordera river outflow. C1 and Sot were situated at the upper canyon close to the shelf break, and located in two depressions that connect the adjacent shelf to the canyon axis (600 m deep). C2 was located at the canyon axis at the depth of 1600 m, C3 was placed at the western canyon wall (900 m deep). C4 was located at the eastern canyon wall, in a plateau at the limit of the canyon with the adjacent eastern slope (900 m deep). Two stations outside the canyon, C5 and Barana, were located over the eastern slope at the depth of 1500 m and 800 m respectively.

2.2 Current meters and sediment traps

An array of 5 moorings (M1 to M5) equipped with a total of 5 pairs of PPS3 sequential-sampling sediment traps and RCM-7/11 current meters were deployed during two six-months periods in and out BC. In particular, M1 was located near Rocassa and C1 stations, M4 near C4, M2 was located at the middle canyon above C2, M3 over the western canyon wall near C3, and M5 outside the canyon near C5 (Figure 1). Each mooring line was equipped with Aanderaa averaging rotor current meters (RCM 7 & 8) at 250 m, at 600 m, one sediment trap placed 30 m above the bottom and another bottom current meter located 2 m below the trap. Moorings at M2 and M5 were an exception because the former had no device at 250 m, and the latter had no device at 600 m. Moreover M1 placed the upper current meter at 375 m. The employed sediment trap has a cylindrico-conical shape with a height/diameter ratio of 2.5 and a collecting area of 0.125 m² (Heussner et al., 1990). The rotating carousel bears 12 receiving cups,

and the sample collection interval ranged from 15 days to 1 month. Before deployment, all sediment traps were thoroughly cleaned. Once on board, receiving cups were filled with a 5% formaldehyde solution in 0.45 μ m-filtered seawater (buffered with sodium borate) for the purpose of slowing particle degradation and preventing swimming organisms from grazing and disrupting the collected particles. Upon recovery, the receiving cups were stored in the dark at 2–4 °C until they were processed. Following Heussner et al. (1990), swimmers (including all organisms that do not fall gravitationally through the water column) were removed to avoid error in the measured fluxes using a 1 mm nylon mesh to retain the largest organisms and to dislodge any trapped fine particles. Large aggregates, as part of the passive fluxes, were returned to the sample. The <1 mm swimmers were removed by hand under a dissecting microscope with fine tweezers. Then, to obtain several sub-samples of equal volume, a high-precision peristaltic pump was used. The total mass was determined gravimetrically. The replicates were filtered using pre-weighed Millipore cellulose acetate membrane filters (0.45 μ m pore size, 47 mm diameter), rinsed with distilled water to remove salts and excess formalin and dried to a constant weight at 40 °C over 24 h. The samples for the total and organic carbon and nitrogen were filtered through glass-fibre filters. The samples for the organic carbon analysis were first decarbonated with repeated additions of 10 μ l of 25% HCl (Fabres et al., 2002). Total and organic carbon and nitrogen were measured with an Elemental Analyser CE 2100 by sample combustion at oxygen atmosphere. Assuming that all the inorganic carbon was constituted by calcium carbonate, the organic matter ($\text{organic carbon} \times 2$) and the calcium carbonate $[(\text{total carbon} - \text{organic carbon}) \times 8.33]$ were calculated. Corg/Norg is expressed as an atomic ratio.

Time Weight Fluxes (TWF), derived from the sediment traps at M1 to M5, gave an indication of the sediment rate over the two sampling seasons. The average values of the fluxes of two months periods before the sediment corers collection were used in the analysis. Due to technical failure of the trap at M5, only data from M1-M4 were used to explain seasonal variability.

Current meter data used in the multivariate analyses cover the period of 60 days before sampling sediment cores, which were integrated to estimate the mean and the maximum current intensity values relative to the period before biological sampling. Near-bottom current meter data were available for the entire sampling period at M1, M2 and M5. Unfortunately, near-bottom currents were not available for bottom-current

intensities at M3 and M4 (900 m) relative to autumn 2003 and spring 2004. According to empirical orthogonal functions performed at site M4, intermediate currents were highly correlated with near-bottom currents during the first half of the experimental year (see details in Zúñiga et al., 2009). For that reason, we used time series recorded at the intermediate level (600 m depth) at both sites M3 and M4 (Fig. 2).

2.3 Sediment cores collection

At all sampling stations sediment samples were collected using a multicorer (core diameter 10 cm), which allowed to recover both undisturbed sediment and interstitial waters for meiofaunal extraction and physical and biogeochemical analyses (Table 1, Fig. 1). The cores were recovered during two cruises carried out in autumn 2003 (campaign RECS5, November) and spring 2004 (campaign RECS7, May) aboard the R/V Garcia del Cid.

2.4 Sediment analysis

During the spring campaign two replicate cores were collected at each station for sedimentological analyses. The topmost cm of the corers were sliced and stored in sealed plastic bags at 4°C. One in the laboratory, samples were dried at 50°C until constant weight was achieved. From each core two non-homogenized sub-samples of approximately 1 g each were used for grain size analysis by the use of a LS100 Coulter Counter. For these analysis, samples were treated with both 10% H₂O₂ and 1M HCl to remove organic matter and carbonates, respectively. Three main grain size categories were considered: i) sand (>63 µm), ii) silt (4–63 µm) and iii) clay (<4 µm). Total and organic carbon and nitrogen analyses were carried out with an Elemental Analyzer CE 2100 over aliquots (20–30 mg) of non-treated and 25% HCl-treated (to remove carbonates) sediment samples after homogenization with an agate mortar. Corg/Norg is expressed as an atomic ratio

2.5 Meiofauna

For meiofaunal analyses a total of 50 sediment cores were collected in autumn 2003 and spring 2004 in the BC and the eastern open slope area (Table 1, Fig. 1). During each cruises at least three independent replicates corers were collected at each of the eight sampling sites. Each core was divided on board into 1cm layers down to 3 cm sediment depth and preserved in 4% borax-buffered formalin (overlying top water was

combined with the 0-1 cm layer). In laboratory each sediment layer sample was filtered over a 250 μm and a 32 μm sieves, and the meiobenthos was extracted from the 32 μm fraction by the Ludox flotation method, stained with Rose Bengal, and counted under a binocular microscope (Giere, 2009). We checked for the presence of meiofauna taxa in the >250 μm fraction which was negligible (<10 individuals per sample of which the majority were polychaetes), rendering our samples equivalent to a 32-1000 μm size fraction. The > 250 μm fraction was sorted for macrofauna analysis and analysed separately. Meiofauna density was expressed as number of individuals per 10 cm^2 for each cm in order to study the vertical meiofaunal distribution or pooled for total meiofaunal density. In the present study meiobenthic communities were characterized based on the abundance of major taxa.

2.6 Statistical analyses

The spatial and temporal variability of the total meiofaunal abundance was investigated using an univariate analysis of variance, ANOVA, (Underwood, 1997) and Student–Newman–Keuls (SNK) post-hoc comparison tests (at $\alpha < 0.05$) were carried out when significant differences were encountered. A first analysis was performed in a full model that included two factors considered fixed and orthogonal: –Station” (8 levels: C1–C5, Rocassa, Sot, Barana), and –Season” (2 levels: autums vs spring). Variation in vertical profiles were similarly analysed considering separately replicate cores from each station and including two factors considered fixed and orthogonal: –season” (2 levels) and –sediment layer” (3 levels). Prior to analyses the homogeneity of variance was tested by Cochran’s test and data were appropriately transformed, if necessary. The analyses were performed using the GMAV 5 software (Univ. of Sydney, Australia).

PRIMER v6 & PERMANOVA+ software (Clarke and Gorley, 2006) was used for multivariate analyses. For these analyses, density data were organized into a sample vs major meiobenthic groups matrix. Non-metric multi-dimensional scaling (MDS) ordination was performed using the Bray–Curtis similarity measure, after Square root transformation of the data. In order to better characterize the samples the factor –location” was used. This factor groups the samples into 6 locations: Rocassa = canyon head, C1 and Sot = Upper Canyon, C3 = Western wall, C4 = Eastern wall, C2 = lower canyon, Barana and C5 = Open Slope (OS).

282 An analysis of similarities by randomization/permutation tests (ANOSIM) was
283 performed on the MDS results of samples grouped according to the relevant factors.

284 SIMPER analysis (Similarity Percentages–species contributions) was performed to
285 indicate the percentage contributions of each major taxa to the similarity within and
286 dissimilarity between groups of samples. ANOSIM and SIMPER analyses were also
287 performed on the rare meiofaunal taxa data excluding from the assemblages the four
288 most abundant taxa (Nematoda, Copepoda, Nauplii, Polychaeta).

289 Principal components analysis (PCA) was performed on a correlation matrix of the
290 environmental data, and a bi-plot used to describe the resulting ordination patterns of
291 samples. In the PCA correlated variables were removed. PCO (Principal coordinates
292 analysis) was performed on meiobenthic and on environmental data, vectors overlays
293 representing Spearman correlation between the ordination axes and the variables were
294 added in the plots.

295 In order to assess if environmental variables explained changes in meiofaunal
296 assemblages non-parametric multivariate multiple regression analyses, based on
297 Euclidean distances, were carried out using the routine DISTLM forward (McArdle and
298 Anderson, 2001).. The relationship between meiofaunal data and environmental
299 variables (e.g. current intensity and particle fluxes) was investigated for both the
300 seasons but only for the stations where mooring were present (C1, C2, C3, C4).

303 3. Results

304 3.1. Environmental and trophic conditions

305 3.1.1. Currents

306 Average speed ranged between 3.0 cm s^{-2} in autumn in M1 and 6.5 cm s^{-2} in spring M3.
307 Maximum current speeds were recorded in spring and varied between 38.6 and 14.8 cm
308 s^{-2} measured in M1 and M4 respectively (Fig. 2 and Fig 3B). Inside the canyon, current
309 speeds recorded in M1, M2 and M3 during spring were generally higher than in autumn
310 and in all these location sudden intensifications were recorded in the two months period
311 prior to the spring campaign with maximum current speed above 20 cm s^{-1} . Contrary
312 M4 showed lower variability in current speed among the two sampling periods and the
313 events of abrupt increases were less evident. M5 was out the main Northern Current

path (Flexas et al., 2008), showing less intense currents than the sites located inside the canyon (Fig. 2).

3.1.2. Sediment cores and particle fluxes

In spring 2004 the sediments of the topmost centimetres were mainly fine-grained hemipelagic mud (Table 1), with high silt contents ranging between 63% (Rocassa and C1) and 57% (Barana). The sand content was higher at the canyon head (Rocassa), compared to the lower values (1-0.6%) at the upper canyon (C1 and Sot), and very low (<0.5%) at the other stations (Table 1). Cores at C2, C3, C4, and outside the canyon (Barana and C5) were also dominated by clay with the average value of 41% (Table 1). Mean grain size was $21 \pm 1 \mu\text{m}$ at the head of the canyon, and $11.3 \pm 0.6 \mu\text{m}$ at the upper canyon (averaging C1 and Sot) being greater than thus found in the other stations (7.8-10 μm).

The C/N values in the sediment ranged between 10.2 in Rocassa and lower values of 8.2 and 7.8 outside the canyon in C5 and Barana respectively.

Highest time weight fluxes (TWF) were recorded in the upper canyon (C1) in both seasons with a maximum total mass flux of $29.58 \text{ g m}^{-2} \text{ d}^{-1}$ in spring (Fig 3). Particle fluxes were lowest in C4 with the average value of $2.10 \text{ g m}^{-2} \text{ d}^{-1}$. Organic matter (OM) percentage of the settling particles varied from 1.97 to 4.19%, the highest contribution appeared in spring at C4. As overall the flux composition was dominated by the lithogenic fraction in all stations, ranging from 72 to 83% indicating the high influence of continental input (Fig 3).

3.1.3. Multivariate analysis of the main environmental descriptors

The first two axis of the PCA based on environmental variables regarding currents and sediment fluxes from C1-C4 stations accounted for 39% and 34% of the total variance, respectively (Fig. 4).

The first PCA axis was mainly defined by maximum current, N_{org} flux, and negatively by lithogenic %. The second PCA axis was mainly defined by N_{org} % and OM %, and negatively by TMF and $C_{\text{org}}/N_{\text{org}}$.

The ordination diagram (Fig 4) shows that C1 in spring was different from the other stations and characterized by the highest average values of TWF ($24.46 \text{ g m}^{-2} \text{ d}^{-1}$), C_{org} flux ($395.2 \text{ mg m}^{-2} \text{ d}^{-1}$), N_{org} flux ($41.0 \text{ mg m}^{-2} \text{ d}^{-1}$) and the highest maximum current

velocity (38.7 cm s^{-1}) (Fig. 3). In the other stations inside the canyon, C2 and C3, as well as in C1, the maximum current, the TWF and N_{org} flux presented higher values in spring than in autumn, consequently seasonality was evident in the ordination of these samples. Contrary, the eastern canyon location (C4 at 900 m deep) was characterized by more stable conditions with maximum current that did not vary considerably with season (Fig 3 and 4). Moreover C4 presented in the particle fluxes of both sampling periods the highest percentages of OM (3.7-4.2%) and N_{org} (0.2-0.5%) and the lowest values of $C_{\text{org}}/N_{\text{org}}$ ratio (4.2-9.0).

3.2. Meiobenthos

Total mean meiofaunal abundance (sum of the 3 cm layers) ranged from $25 \pm 3 \text{ ind. } 10 \text{ cm}^{-2}$ (C2) to over 717 ind. 10 cm^{-2} (Rocassa) in autumn, and from $367 \pm 143 \text{ ind. } 10 \text{ cm}^{-2}$ (C3) to $1500 \pm 88 \text{ ind. } 10 \text{ cm}^{-2}$ (C1) in spring (Fig. 5). Pooling the first 3 cm together, a negative linear correlation between total meiobenthic densities and depth was observed inside the canyon exclusively in autumn ($R = -0.98$, $p < 0.01$) (Fig. 5). The same trend was observed in nematode standing stocks in autumn (Ingels et al., this volume).

Considering the full set of data, total meiobenthic densities showed significant variations among “stations”, “seasons” and the interaction of the two factors (two-ways ANOVA, Table 2). Inside the canyon at the stations on the upper canyon (C1, Sot) and along the axis (C2) meiofauna reached higher density in spring (SNK test $p < 0.01$), and had lower to extremely low densities in autumn (Fig. 6). Contrary at the western wall (C3) the density in spring was significantly lower than in autumn (SNK test $p < 0.01$). Outside the canyon (Barana and C5) and in Rocassa, and C4 the density did not change significantly between seasons (Fig. 6).

Among stations, the density at the upper canyon (C1, Sot) in spring were significantly higher than in the other locations (Fig. 6). In autumn the only significant difference was found at the deepest station in the canyon axes (C2) that showed lower density than the other stations (Fig. 6, SNK test $p < 0.01$).

Densities decreased rapidly as going deeper into the sediment column, although the between-layer variability was less marked in the stations Sot-Travès, C4, Barana. The highest abundances always occurred at cm 1, except in Sot-Travès, in Barana during

autumn and in C3 and in C4 during spring where the density occurred at the first two centimeters was not significantly different (Fig. 7, SNK test $p>0.05$).

The structure of the meiobenthic assemblages in the canyon and in the open slope are illustrated in figure 8. We identified a total of 20 major taxa. Nematodes were always dominant (86-95%) (Fig. 8), followed by copepods (mainly harpacticoids and non-determined nauplii, 4-9%). Polychaetes were frequent but scarce (on average 1%). A total of 17 minor taxa (Kinoryncha, Tardigrada, Bivalvia, Ostracoda, Gastrotricha, Cladocera, Cnidaria, Halacaroidea, Holothuroidea, Isopoda, Loricifera, Pycnogonida, Rotifera, Sipunculida, Tanaidacea, Tubellaria) occurred occasionally and in very low numbers, on average these here defined "rare taxa" together represented <1% of total meiofaunal abundance.

ANOSIM results indicate that both "Season" and "Location" differences are significant (Table 3) and the MDS plot show a segregation of samples according to both factors (Fig 9A,B). The pair-wise test among locations (Table 3) show that meiobenthic community at the eastern wall (C4) do not differ significantly from the open slope as well as the head of the canyon that is not significantly different from the western wall. Similar trend was obtained when analyses of the structure on the meiofaunal assemblages was performed excluding the most abundant taxa (Nematoda, Copepoda, Nauplii and Polychaeta). Considering only the rare taxa, the ANOSIM revealed significant differences among locations and sampling times.

Moreover the Cluster analysis superimposed in the MDS plot (Fig 9A and Fig10A) segregate four main groups: I) lower canyon in autumn, II) western wall in spring, III) the rest of the samples except for the upper canyon in spring which is the group IV. In the MDS most of the higher taxa are decreasing in density from left to right (as well as from group I to group IV) (SIMPER, Table 4 and Fig. 10B). The group I (C2 in autumn) is very distant from the rest because is characterized by the lowest density for all the major taxa and for simplicity has been excluded from Figure 10.

The results of the multivariate multiple regression analyses (DISTLM) conducted on the meiofaunal abundance in the C1-C4 stations of both season show that none of the environmental variables seems to significantly explain all meiofaunal variance. Although not significant, a trend may be present considering the variables: TWF, N_{org} flux, and Max CV that together explain 80% of the distribution.

4. Discussion

4.1. Meiobenthic densities in the Blanes canyon-slope area compared with other systems

Within the subtropical region, the highest deep-sea meiobenthic densities (up to 2,656 ind. 10 cm⁻²) were encountered along transects of the Iberian Peninsula and Northern Africa (Soltwedel, 2000). Lower meiofauna densities were generally reported for the Mediterranean Sea, but also pronounced regional differences are recorded. Soltwedel (2000) registered higher values (16–1414 ind. 10 cm⁻²) for the western and northern areas (Alborian Sea, Gulf of Lions, Ligurian Sea), than in the central and eastern parts (Ionian Sea, Aegean Sea) where meiofauna densities were lower (4–724 ind. 10 cm⁻²) and also decreased more rapidly with increasing water depth. This agrees with a decreasing gradient in meiofaunal density and biomass from the western Portuguese margin to the Central Mediterranean Sea recently encountered by Bianchelli et al. (2010). The meiobenthic densities in the BC- open slope area (513 - 735 ind. 10 cm⁻²) were comparable with previous Western Mediterranean records like those (383 - 743 ind. 10 cm⁻²) at a slope near Calvi (Corsica, Italy) (Soetaert et al., 1991) and at the northern Catalan margin (632.8 ± 128 ind. 10 cm⁻²) (Bianchelli et al., 2010). The regional differences may be explained by the variations in primary production rates and a subsequently varying trophic state between the north-western and eastern parts of the Mediterranean Sea (Soltwedel, 2000; Danovaro et al., 2008). As confirmed by satellite-derived figures, pigment concentrations in the upper water masses in north-western parts of the Mediterranean Sea are generally higher (up to 2.5 mg Chl_a m⁻³) than chlorophyll *a* concentrations (0.05 - 0.3 mg Chl_a m⁻³) in the Aegean Sea and the Ionian Sea waters (Crispi et al., 1998). Accordingly a decreasing eastward gradient in organic matter available to consumers in deep-sea sediments were encountered on a large regional scale (Gambi and Danovaro, 2006; Danovaro et al., 2008).

There are only a few quantitative studies on meiofauna in deep Mediterranean canyons (de Bovée et al., 1990; Soetaert et al., 1991; Garcia et al., 2007; Bianchelli et al., 2008; Bianchelli et al., 2010), however meiofaunal density recorded in the Blanes Canyon (25 – 1500 ind. 10 cm⁻²) were within the range observed for other submarine canyons. Lower densities, ranging from 20 to 220 ind. 10 cm⁻² at a depth from 300 to 5000 m, have been reported from the Nazaré Canyon, Portugal, (Garcia et al., 2007) but the authors used a bigger mesh size (48 µm) so they may have underestimated meiofaunal

density. Ingels et al. (2009) further demonstrated that densities are up to 100 times higher at other sites in the same canyon illustrating the high patchiness related to local sedimentary or erosive conditions induced by episodic disturbance events. Thiel (1975) recorded a higher density ranging between 1000 and 1,400 ind. 10 cm^{-2} from 750 – 1250 m deep near Gibraltar, while a maximum density of 1005 ind. 10 cm^{-2} was recovered in a Mediterranean canyon at 750 – 1250 m (Soyer et al., 1987a). Recently Bianchelli et al (2010) found meiofaunal densities ranging from 263 to 1484 ind. 10 cm^{-2} in the Nazare canyon (458 – 4363 m depth) and from 204 to 1391 in the Lacaze-Duthiers canyon (434-1497 m depth).

It is generally accepted that metazoan meiobenthos densities are much more variable on a small scale in the deep sea than in shallow waters. However, there is little information on the scale of this spatial variation and only a few studies consider possible causes' (Vincx et al., 1994). Biogenic structures such as burrows, depressions and mounds produced by the larger macrobenthos clearly influence the distribution of the meiobenthos on small scales, for example within box cores (Thistle and Eckman, 1988). Particulate organic matter is trapped occasionally by such structure. Opportunistic taxa, such as nematodes (Aller and Aller, 1986) may become unusually abundant early in the colonization of these patches, increasing variability in faunal composition within a sampling station (Grassle and Morse-Porteous, 1987). In this study, samples were sieved on a $250\text{ }\mu\text{m}$ sieve to retain the macrobenthic fraction. This fraction consisted exclusively of very small polychaetes with numbers never exceeding 10 individuals per core (Authors' unpubl. data). Furthermore no clear burrows or depression were encountered analysing the cores, moreover standard variation and differences among the sample replicas were smaller than differences among stations indicating that small scale variations of meiobenthic densities was not significant and the effect of patchiness was levelled out by the sediment core size (10 cm in diameter).

In the present study the first 3 cm of each core were analysed, and in general a decrease of meiofauna densities with sediment depth was encountered (Fig 7). This is in accordance with Soetaert & Heip (1990) which also commented that in general there is a decrease in meiofauna numbers with increasing sediment depth, although in some cases a maximum was found in deeper layers (Thiel, 1983). According to Thiel (1983), the food supply to the sediment surface determines why these organism are concentrated in the upper layer, although the increasing compactness of deeper layers (more difficult to penetrate) and the presence of macrofaunal organisms, mixing the sediment can

influence the general distribution. In this study however no important macrofaunal abundances and biomasses were encountered (see above).

4.2. Depth-density correlation

The decrease in meiobenthic densities with increasing depths has been postulated as a basic principle in deep-sea ecology (see Thiel, 1983 or; Tietjen, 1992 for a review).

Depth-related trends have been attributed to decreasing organic matter supplies (e.g. particulate organic matter fluxes) with increasing depth and distance from land (Thiel et al., 1987; Pfannkuche, 1993; Danovaro et al., 1995; Turley and Mackie, 1996; Gooday et al., 1996; Relexans et al., 1996; Soltwedel, 1997; Fabiano and Danovaro, 1999; Garcia et al., 2007, Garcia and Thomsen, 2008). However, it is important to remark that depth-density correlation may be modified by the presence of canyons as they induce modifications in the current regime and in biogeochemical processes channelling organic matter towards the deep basin (Bianchelli et al., 2010; Pusceddu et al., 2010). A direct influence of depth, in fact, seemed to be not much relevant in the Blanes Canyon area, as a significant negative regression of meiobenthic densities with depth was only found in autumn (Fig. 5). Density showed low variations on the slope area, although only two depths were sampled (e.g. Barana and C5 at 800 and 1500 m respectively). Conversely, spring densities were markedly more fluctuant along the canyon stations, and there was a remarkably absence of a relationship with depth. For instance, meiobenthos in Rocassa (400 m deep) was less abundant than at deeper stations (C1 and C2) in spring. This could be related with the preferential transport of sediments and particles toward the deeper stations along the main canyon axis as confirmed by the higher values of TWF (Fig 3 C) that may have driven the observed spring increase in meiofaunal density. Contrary the lower densities found in Rocassa, despite its proximity to the coast, may be due to eroding processes as showed by higher percentage of sandy disturbed deposits recorded in sediment corers (table 1).

These results suggest that spring events such as storm-induced turbidity currents and increase in particle transport due to for example dense shelf water cascading may have affected the meiobenthic community. Contrary in autumn under less dynamic conditions the generally observed negative relation between depth and meiofauna is maintained.

4.3. Canyon vs Open Slope

In previous studies it was observed that food availability and meiofauna density in canyons are generally higher compared with equally deep stations lying between canyons (de Bovée, 1987; Soyer et al., 1987b; Soetaert et al., 1991; Garcia and Thomsen, 2008; Martin et al., 2006; Koho et al., 2008; Ingels et al., 2009). In the BC-slope area density inside the canyon were not always higher than in the adjacent slope. This pattern was only found in spring when the densities at the upper canyon (C1 and Sot) and on the main axis (C2) were higher than those at the open slope (C5 and Barana). Comparing the deepest stations, C2 and C5, respectively at 1600 m depth along the main canyon axis and at 1500 depth at the eastern open slope, the meiofauna inside the canyon showed a wide range of variation from 25 ± 3 ind.10 cm⁻² in autumn to 965 ± 181 ind.10 cm⁻² in spring, while density outside the canyon did not change significantly among the two seasons (average 602 ± 99 ind.10 cm⁻²). These results are consistent with the expectation that inside the canyon greater disturbance and dynamism may affect the meiobenthic fauna (Thistle and Sherman, 1985; Aller, 1989; Thistle et al., 1991; Levin et al., 1994; Gage et al., 1995; Paterson and Lambshead, 1995; Aller, 1997; Garcia et al., 2007). Inside the Blanes Canyon, in fact, we recorded an instable and variable hydrodynamic activity, high velocity bottom currents (Fig. 2) together with higher particle fluxes and organic matter, increased food resources available to benthic consumers that may be responsible of the wide variation in meiofaunal density.

Contrarily, C5 was not affected by the canyon dynamics. In fact, current speed did not vary significantly among both periods. Unfortunately, the sediment trap at C5 did not function, but measurements obtained during the first half of the project showed that the particle flux recorded at the open slope (C5) was $5.42 \text{ mg m}^{-2} \text{ d}^{-1}$, i.e. three orders of magnitude lower than that recorded in the same period at the canyon stations (Zuñiga et al, 2009). Moreover, sediment profile analysis showed that in C4 and C5 sediments were unaltered, and that sedimentation, mainly hemipelagic, happened at relatively low rate (Zuñiga et al 2009). According to these results the station at the open slope may support and maintain more stable meiofaunal density.

4.4. Temporal variability

Beyond the continental shelf, seasonal trends in meiofaunal densities are not commonly observed (Gooday, 2002; Kalogeropoulou, 2010). Our results evidence that deep-seafloor and meiofauna in the locations inside the canyon do not conform with the

paradigm of stable deep-sea ecosystem and communities not affected by changes over time. In our system, fluxes and the overall dynamics seem to be very influenced by the presence of the canyon and are subjected to high variability throughout the year. Inside the canyon especially at the stations C1, C2 and C3, strong current intensifications occurred from early March 2004 (Fig 2), and particle fluxes recorded in spring were higher than in autumn (Fig 3). Zuñiga et al (2009) showed that energetic events recorded inside the BC were concomitant with increases in particle fluxes and were clearly related to major Tordera River discharges (Fig. 3 and Fig. 10 in Zuñiga et al 2009). Moreover the TWF peaks observed in spring occurred relatively close to a strong dense shelf-water cascading event in the Gulf of Lion, which may have also affected the Blanes Canyon re-suspending and transporting material stored on the shelf along the Cap de Creus Canyon toward the deep basin (Palanques et al., 2006, 2009). Indeed, in March 2004 a cascading event leading to local winter intermediate water formation took place in BC and may also be responsible for down-canyon transport of large amounts of sediment and particles (Zuñiga et al 2009).

Our results show that meiofaunal densities in the locations along the preferable pathway of water cascading and sediment fluxes, seem to respond to the high environmental variability over time. In the sites C1 and C2, in fact, meiofaunal density is significantly higher in spring than in autumn and this is consistent with a coincident increase in organic matter fluxes.

The sediment inside the canyon is characterized by refractory particulate organic matter ($C_{org}/N_{org} \approx 8-10$) proceeding from advective fluxes like the intense Tordera river input but also from the resuspension and sediment falls of older and degraded organic matter (Fig 3H). Despite the fact that the organic matter was refractory, the amount of organic matter channelled along the canyon axis was so large, especially at the upper canyon (OM flux $790 \text{ mg m}^{-2} \text{ d}^{-1}$), that it was likely responsible for the subsequent increase in meiofaunal density. In agreement with our results, few previous studies demonstrated that deep-sea meiofauna responds to organic matter inputs (Thiel et al., 1987; Pfannkuche, 1993; Relexans et al., 1996; Gooday et al., 1996; Soltwedel, 1997; Danovaro et al., 1999; Fabiano and Danovaro, 1999; Galeron et al., 2001; Gutzmann et al., 2004), even over a time scale of days (Aller, 1989). Increasing meiofaunal biomasses seemed to be associated to increases in particle flux rates at depths ranging from 5,000 m to 8,000 m (Tietjen, 1989) and a similar relationship was found in a NW Mediterranean canyon (Danovaro et al., 1999). In the northern Gulf of Mexico,

meiobenthic densities were clearly higher inside than outside the canyon and also declined with depth, this being likely caused by the constant particle inflow of the Mississippi river (Baguley et al., 2006).

In the BC, autumn and spring samples separated in the MDS plot (Fig. 10a), likely due to the increasing meiobenthic densities in spring in all the stations except for Rocassa and C3.

Along the western wall (C3) the variability in meiofaunal density and the absence of a higher value in spring may be interpreted as a consequence of unstable sedimentary conditions. The study of sedimentary accumulation rate carried out by Zúñiga et al (2009) revealed that C3 were affected by erosion processes and the whole sediment core (upper 30 cm) was disturbed. Erosive processes and strong events may have affected the western wall and the head of the canyon (see above) and flushed the canyon sediments. It has either mechanically removed the organisms or disturbed them inhibiting their settlement and growth.

In C4 and in the open slope the increase in spring density was not statistical significant and the seasonal stability in meiofaunal density may reflect the less dynamic environments. In C4 the particle flux was overall lower than at the canyon stations and did not increase in spring. The origin of the settling particles could more likely be pelagic as suggested by relatively higher organic contents (OM %) and higher quality of organic matter recorded in spring fluxes ($\text{Corg/Norg} = 4.12$). The spring increase in the quality of organic matter may reflect the biogenic material and may have been evident on the wide eastern wall, as well as in the open slope. Contrary inside the canyon area the organic matter resulted more diluted by the high lithogenic fraction associated to the river discharge (Zúñiga et al., 2009). Together with the relatively quiet currents and the slow sedimentation process, this could explain the apparent temporal stability in meiobenthic density supported in C4 and in the adjacent open slope (C5 and Barana). However we have no information on the time slot between the sampling periods and we cannot fully confirm the continuous stability.

4.5 Variability within the Blanes Canyon

The drivers inside the canyon are various, and all related to the more intense dynamics comparing to the open slope, particular in terms of hydrodynamic activity, erosion processes, sediment transport and deposition rates. The BC clearly alters the

bottom current circulation pattern, producing different environmental conditions depending on the location within the canyon stations. Consequently, a local variability in physical environment of the uppermost sediments, and thus, of the meiofauna, was recorded. The sediment characteristics and particle fluxes, in fact, differed among the stations. N_{org} flux, maximum current velocity, and TWF and C_{org}/N_{org} and OM %, were among the major components defining the PCA variability (Fig 4).

These variables could contribute to explain the spatial and temporal differences in meiobenthic densities in the canyon area. An increase in spring meiobenthic densities was recorded along the main axis, coinciding with a large increase in organic matter fluxes.

At the head of the canyon and on the western wall meiofauna seemed to be modulated by sediment eroding and mixing processes due to changes in current patterns induced by the canyon topography. The canyon's head, Rocassa, was characterized by higher percentage of sandy disturbed deposits indicating that the sediments were exposed to strong currents producing eroding processes. The sediment core profile and ^{210}Pb analyses reveal that also C3 at the western wall is often affected by erosion processes (Zuñiga et al, 2009). During periods of maximum flow intensity like those recorded in the period before the spring campaign, the head of the canyon and the western wall might be subjected to currents able to erode the topmost sediment layer or to cause sediment slumps. In these canyon locations, as it has been previously found in rigorous hydrodynamic environments, the result of erosion and disturbance events are likely to be associated with passive transport and removal of the meiofauna (Soltwedel, 2000, Palmer, 1988). This could explain the overall low meiofaunal densities found in Rocassa and in C3, especially during spring, which was preceded with a more intense current activity compared to autumn. Our results agree with previous studies in the Nazaré canyon that indicated that lower density in the upper and middle part of the canyon may be due to local high-velocity currents, unstable and more disturbed sedimentary conditions (Garcia et al. 2007; De Stigter et al. 2007).

The present study confirms that multidisciplinary studies are crucial in order to characterize complex systems like deep sea canyons. There is much that we do not know about meiofaunal processes including recruitment and settlement. More studies are needed, like direct measurements about the distances at which meiofauna may be transported or dragged. Future studies should be designed to quantify the threshold of

current speed that produces sediment erosion and meiofaunal removal and that allows meiofaunal settlement/re-entry.

Conclusions

Meiofaunal densities at the Blanes area confirm partly the general pattern recorded in Mediterranean canyons where higher numbers are found compared to equally deep stations in the adjacent slope areas (de Bovée, 1987; Soyer et al., 1987b; Soetaert et al., 1991; Koho et al, 2008). However, the pattern was not consistent over time. A spatially differentiated physical alteration of the uppermost sediments, and thus, of the meiofauna density, may be related to altering of the current regime especially in the canyon area. This is reflected in differences in sediment characteristics and sedimentation processes between the canyon and adjacent slope resulting in variable meiofauna densities between sampling periods in the canyon area.

A direct influence of depth seemed to be less relevant as the meiobenthic densities decline with increasing depth or distance from the coast only appeared in autumn. For the canyon area this could be explained, apart from the current regime, also by the seasonal change in particle fluxes. Inside the canyon area, densities seemed to be modulated and strongly affected by sediment eroding (particularly Rocassa and C3) due to increase in current velocity especially in spring and by temporary high fluxes of refractory organic matter (C1 and C2). Contrarily the slope area was characterised by lower currents and slower and stable sedimentation processes. In comparison the particle fluxes on the open slope is lower but the quality higher, whereas meiobenthos densities do not present significant variations with time.

In summary, meiobenthic densities distribution both in space and time are influenced by specific environmental conditions (e.g. particle fluxes and currents). Thus, caution is required when considering different and heterogenous locations and environment variability inside canyons and when comparing specific results of the BC-slope area with other systems.

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Table 1. Location, depth of sampling stations and sediment characteristics from corers collected in spring 2004. Mean grain size (MGS) and granulometric composition (percentage of clay, silt and sand) are given for the top centimetre of the cores. Mean values of total carbon (TC) and total nitrogen (TN) contents, C_{org}/N_{org} atomic ratios from sediment cores are also shown for each stations.

Station	Latitude	Longitude	Depth (m)	% Clay	% Silt	% Sand	MGS (μm)	% Sed TC	% Sed TN	C_{org}/N_{org} Sed
Rocassa	41°36'29''N	02°50'35''E	400	28.4	62.6	9	21	4.2	0.1	10.17
C1	41°30'94''N	02°55'01''E	600	35.6	63.5	0.9	11.6	3.7	0.1	8.97
C3	41°54'60''N	02°48'19''E	900	41.1	58.9	0.1	7.9	3.6	0.1	8.31
C2	41°22'34''N	02°51'04''E	1600	41	58.9	0.1	8.7	3.6	0.1	8.94
C4	41°19'30''N	02°57'10''E	900	42.1	57.9	0.1	7.8	3.8	0.1	8.94
Sot	41°29'20''N	03°00'54''E	600	38.9	60.5	0.6	10.9	3.9	0.1	8.97
Barana	41°22'40''N	03°22'08''E	800	42.4	57.2	0.4	10	3.9	0.1	8.17
C5	41°20'06''N	03°12'54''E	1500	40.5	59.1	0.4	8.4	4	0.1	7.76

Table 2. ANOVA performed on total meiofaunal abundance in all the sampling stations and in two seasons. df: degrees of freedom, SS: sums of squares, MS: means of squares, ** $p < 0.01$, n.s no significant difference ($p > 0.05$)

Source	df	MS	F	<i>P</i>
Stations (ST)	7	273089.4	17.01	**
Season (Se)	1	1128656	70.31	**
ST X Se	7	287373.1	17.9	**
Residuals	32	18490.33		
Cochran's C				n.s

Table 3 Dissimilarity in the total meiofaunal assemblages and in rare taxa composition among seasons and locations. Results of ANOSIM global tests and SIMPER analysis . ANOSIM test: two-way crossed analysis with “Season” and “Location” factors. Including pairwise comparison tests to investigate the interaction factor Season x Location. Avd Dis: average dissimilarity, ** = $p < 0.01$, * = $p < 0.05$, ns = not significant.

	Total meiofauna				Rare meiofaunal taxa			
	Sample statistic	ANOSIM Permutation Used	Significance level	SIMPER Avg. Dis (%)	Sample statistic	ANOSIM Permutation Used	Significance level	SIMPER Avg. Dis (%)
Two-way ANOSIM								
Season	0.529	9999	0.01%	**	0.3	9999	0.01%	**
Location	0.539	9999	0.01%	**	0.46	9999	0.01%	**
Pairwise test								
Head, Upper	0.652	9999	0.04%	**	20.1	0.652	9999	0.02%
Head, Western wall	0.14	350 ^(a)	18.3%	ns	17.9	-0.114	350	83.4%
Head, Lower	0.656	350 ^(a)	1.10%	**	35.7	0.277	150	8%
Head, Eastern Wall	0.471	840 ^(a)	1.30%	**	17.2	0.314	840	7.1%
Head, OS	0.506	9999	0.01%	**	18.9	0.395	9999	0.7%
Upper, Western wall	0.284	9999	4.2%	*	20.1	0.396	9999	0.9%
Upper, Lower	0.892	9999	0.02%	**	36.0	0.826	3024	0.03%
Upper, Eastern Wall	0.455	9999	0.30%	**	16.9	0.386	9999	0.4%
Upper, OS	0.699	9999	0.01%	**	19.9	0.671	9999	0.01%
Western wall, Lower	0.722	100 ^(a)	2%	*	35.5	0.416	100	1%
Western wall, Eastern Wall	0.599	560 ^(a)	1.4%	*	20.0	0.531	560	1.6%
Western wall, OS	0.485	7056 ^(a)	0.40%	**	20.0	0.556	7056	0.1%
Lower, Eastern Wall	0.371	560 ^(a)	3.8%	*	24.2	0.178	168	20.2%
Lower, OS	0.633	7056 ^(a)	0.20%	**	30.3	0.425	2352	1.7%
Eastern Wall, OS	0.213	9999	6.7%	ns	14.2	0.221	9999	8%

Table 4 Percentage contribution from SIMPER analysis in the dissimilarity among groups.

	Average Density (ind. 10 cm ⁻²)			
	<i>Group I</i>	<i>Group II</i>	<i>Group III</i>	<i>Group IV</i>
Nematoda	21.4	347.4	642.8	1274.3
Copepoda	1.6	10.0	21.5	47.8
Nauplii	0.6	6.6	11.7	27.4
Polychaeta	0.6	2.6	7.1	12.7
Kinoryncha	0.0	0.2	1.4	3.8
Tardigrada	0.2	0.0	0.9	0.3
Bivalvia	0.0	0.3	0.3	0.6
Cladocera	0.0	0.0	0.1	0.6
Rotifera	0.5	0.0	0.2	0.0

Caption of Figures

Figure 1. Overview of the Blanes canyon and the sampling stations. The greyscale indicates the depth gradient.

Figure 2. Time series of bottom current speed (cm s^{-1}) recorded at the mooring M1 (600 m), M2 (1600 m), M3 and M4 (600 m) and M5 (1500 m). Spring and autumn cruises are marked by grey bars. Dotted areas describe the two-months period considered before each cruise when mean and maximum current velocities were calculated. When for technical reason a full set of data was not available, a shorter period was used (* = six days before the cruise, ** = 40 days before the cruise)

Figure 3. Principal physical and biogeochemical descriptors at the different sampling stations along the Blanes canyon. A) average current velocity recorded in M1-M5 over a period of two months prior to the sampling campaigns. B) maximum current velocity over a period of two months prior to the sampling campaigns. C) MGS: mean grain size of the first cm of sediment cores. D) TWF: time weight flux, E) Norg Flux: total organic nitrogen flux F) Lithogenics %: weight percentage of lithogenic sediment trap matter, G) OM % weight percentage of organic sediment trap matter, H) $C_{\text{org}}/N_{\text{org}}$: organic carbon/nitrogen weight ratio of sediment trap matter. D-H) Descriptors measured by sediment taps M1-M4. The absence of bars means no data available.

Figure 4. Plot of the PCA based on the most influent biochemical and physiographic variables. Sample label in the plot refers to “name of the station_season” where R5 = autumn, R7 = spring.

Figure 5. Pattern of total meiofaunal densities (as sum of the first three centimetre sediment layers) with depth in (a) autumn and in (b) spring. Open symbols represent stations on the open slope and the full symbols those inside the canyon. Regression line was fitted among stations inside the Blanes Canyon, $n = 6$, $p < 0.01$.

Figure 6. Seasonal fluctuations of total meiofaunal density within the Blanes canyon and the Open slope (statistical notation over each point deals with comparison between

seasons in every station, * $p < 0.01$; ns not significant; dotted circle indicates that in autumn C2 < all other stations; dotted rectangle indicates that in spring C1 > Sot > Rocassa = C2 = C4 = Barana = C5 > C3. SNK test $p < 0.01$)

Figure 7. Meiobenthic densities (ind $\cdot 10 \text{ cm}^{-2}$) from the first three one-centimetre sediment layers at each station. Statistical notation deals of comparison among layers. Please note there were always significant dereference (SNK $p < 0.01$) between layers with the exception of the notation in the figure. Continuous line refers to comparison among autumn values, discontinuous line comparison among spring values.

Figure 8 Meiofaunal community structure: a, c) total meiofauna; b, d) rare taxa (after removal of the dominant taxa: Nematoda, Copepoda, Nauplii and Polychaeta) at all the sampling stations. a, b): Autumn; c, d): Spring. Numbers above the bars in (b) and (d) represent total density (ind 10 cm^{-2}).

Figure 9 MDS plots based on total densities of the mayor meiobenthic groups: (a) showing the segregation between location and season and with superimposed 80% similarity groups from cluster analysis. and (b) showing the segregation between seasons. In this plot the extremely low autumn density at C2 (group I) has been omitted to improve the quality of the representation.

Figure 10 a) MDS plot (C2 excluded) based on total densities of the mayor meiobenthic groups (averaging among replicates corers) and b) PCO diagram with vectors representing correlation of rank Spearman > 0.6 between taxa groups and axes.

Figure 1
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Figure 2

Figure 3

Figure 4

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Figure 7

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Figure 9

1 **Figure 10**

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