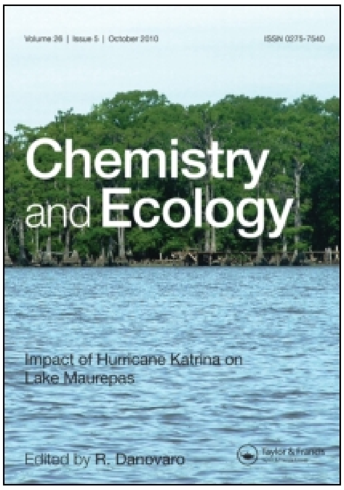


**Chemistry and Ecology**
Publication details, including instructions for authors and subscription information:
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**To cite this Article** Bianchelli, S. , Gambi, C. , Pusceddu, A. and Danovaro, R.(2008) 'Trophic conditions and meiofaunal assemblages in the Bari Canyon and the adjacent open slope (Adriatic Sea)', Chemistry and Ecology, 24: 1, 101 — 109
**To link to this Article: DOI:** 10.1080/02757540801963386
**URL:** http://dx.doi.org/10.1080/02757540801963386

*Chemistry and Ecology*
Vol. 24, No. S1, June 2008, 101–109



# Trophic conditions and meiofaunal assemblages in the Bari Canyon and the adjacent open slope (Adriatic Sea)

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(*Received 15 July 2007; final version received 1 October 2007*)

Due to their topographic features, submarine canyons are generally sites of intense shelf-slope exchanges of water and material, fuelling the deep basins with large quantities of sediment exiting from the continental shelf. In order to provide new insights about the role of submarine canyons in controlling the relationships between food availability and benthic biodiversity patterns along the continental slope, we investigated the quantity and the biochemical composition of sediment organic matter and the abundance of meiofaunal assemblages in the sediments along two different branches of a canyon and in an adjacent open slope located in the Bari margin (Adriatic Sea). Our results highlight that even twin branches within the same canyon may exhibit very large differences in the quantity, depth-related patterns and biochemical composition of sediment organic matter as well as of meiofaunal abundance. We also report here that the trophic relationships in the canyon sediments are tightly connected with the hydrodynamic conditions and that the steeper and the more flushed the canyon the more hostile environment for the benthos.

**Keywords:** submarine canyon; Adriatic Sea; organic matter; meiofauna

## 1. Introduction

Continental margins of the world oceans play a key role in the marine biogeochemical cycles [1–3]. They are characterised by the presence of many different geological characteristics, such as canyons, landslides, open slopes and trenches. Among these, canyons are deep incisions of the continental shelf and slope and dissect much of the European continental margin [4]. They range from relatively shallow systems of connected gullies, to deep and wide valleys [5].

Due to their topographic features, submarine canyons are generally sites of intense shelf-slope exchanges of water and material, fuelling the deep basins with large quantities of sediment exiting from the continental shelf [4,6–11]. Canyons also intercept and trap littoral drifts [12], thus acting as main drivers of the local sediment transport and deposition [13].

Recent studies pointed out that canyons are more active zones for the transfer of sediment and organic matter than the adjacent open slopes [8,14–16]. In this regard, it has been demonstrated that sediment transport through canyons and the adjacent areas is not constant or unidirectional,

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ISSN 0275-7540 print/ISSN 1029-0370 online

DOI: 10.1080/02757540801963386
http://www.informaworld.com

but it is characterised by cycles of resuspension and transport alternating with intervals during which the sediment accumulates on the seabed [5].

The presence of submarine canyons plays also a significant role in controlling biological processes of the adjacent area, influencing the structure and functioning of food chains, from phytoplankton to marine mammals [17]. Rapid, episodic flushing of canyons may mobilise large amounts of sediment carrying it to the abyss and overwhelming benthic ecosystems over a wide area [4,18,19].

In recent years, several studies reported that submarine canyons, locally characterised by high faunal biomass, biodiversity and presence of endemisms, have a great influence on the entire food chain and the concentrations of marine organisms [2,11,17,20–33]. Despite this, to date, only scarce information is available on the local trophic conditions [14–15] and on the biodiversity of meiofaunal assemblages of submarine canyons [34–38].

In order to provide new insights about the role of submarine canyons in controlling the relationships between food availability and benthic biodiversity patterns along the continental slope, we investigated the quantity and the biochemical composition of sediment organic matter and the abundance of meiofaunal assemblages in the sediments along two different branches of a canyon and in an adjacent open slope located in the Bari margin (Adriatic Sea).



## 2. Materials and methods

### 2.1. *Study area and sampling*

The Bari canyon, located along the western coast of the Adriatic Sea, has two branches (B and C), emanating from a broad crescent-shaped head region on the shelf break, and is characterised by a marked asymmetry, with the right flank (southern) higher and steeper than the left flank (Figure 1). As a consequence, the steady-state contour-parallel bottom currents flowing along the South Adriatic slope from the north enters the canyon and interacts with its complex topography [39].

Sediment samples were collected in May 2006 using an oceanic box-corer operated on board the R/V Urania along the two main branches of the Bari Canyon (B and C) and in the open slope inserted in between. Replicate samples from independent box-corer deployments ($n = 3$) were collected from a total of 11 stations (from 196–908 m depth) (Figure 1). The coordinates of each sampling station in the branches B and C and in the open slope are reported in Table 1.

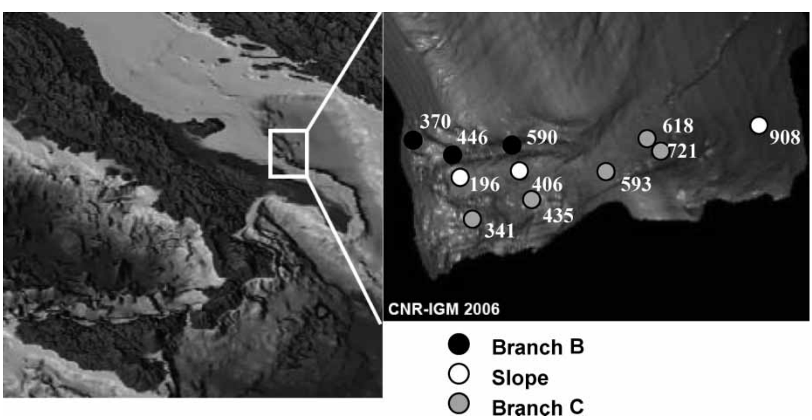


Figure 1. Study area and location of the sampling stations. Multibeam images are a courtesy of F. Foglini, G. Verdicchio and F. Trincardi (ISMAR, CNR, Bologna, Italy).

Table 1. Coordinates of sampling stations in the canyon branches B and C and in the open slope.

| | Station | Latitude (N) | Longitude (E) | Depth (m) |
|---|---|---|---|---|
| Branch B | S8 | 41° 22.10′ | 17° 06.70′ | 370 |
| | S5 | 41° 21.71′ | 17° 07.75′ | 446 |
| | S2 | 41° 20.63′ | 17° 11.02′ | 590 |
| Open slope | S7 | 41° 21.30′ | 17° 05.96′ | 196 |
| | S1 | 41° 20.08′ | 17° 10.32′ | 406 |
| | S11 | 41° 13.70′ | 17° 35.15′ | 908 |
| Branch C | S6 | 41° 19.07′ | 17° 05.15′ | 341 |
| | S4 | 41° 19.47′ | 17° 09.75′ | 435 |
| | S3 | 41° 18.18′ | 17° 12.51′ | 593 |
| | S10 | 41° 18.84′ | 17° 14.66′ | 618 |
| | S9 | 41° 18,43′ | 17° 15.61′ | 721 |

## 2.2. *Quantity and biochemical composition of sediment organic matter*

Chlorophyll-a and phaeopigment analyses were carried out according to [40]. Pigments were extracted (12 h at 4 °C in the dark) from triplicate sediment samples (about 1 g) each using 3–5 ml of 90% acetone as extractant. Extracts were analysed fluorometrically as such to estimate chlorophyll-a, and, after acidification with 200 μl 0.1 N HCl to estimate phaeopigments. Concentrations are reported as μg g dry weight $^{-1}$. Total phytopigments were defined as the sum of chlorophyll-a and phaeopigments.

Protein, carbohydrate and lipid sediment contents were analysed spectrophotometrically according to [41] and concentrations expressed as bovine serum albumin, glucose and tripalmitine equivalents, respectively. For each biochemical assay, blanks were obtained using pre-combusted sediments (450 °C for 4 h). All analyses were performed in 3 replicates on about 1 g of sediment for each sediment sample. Carbohydrate, protein and lipid sediment contents were converted into carbon equivalents using the conversion factors of 0.40, 0.49 and 0.75 μg C μg$^{-1}$, respectively and their sum defined as the biopolymeric organic carbon [42].

## 2.3. *Meiofauna*

For meiofaunal extraction, sediment samples were sieved through a 1,000-μm mesh, and a 20-μm mesh was used to retain the smallest organisms. The fraction remaining on the latter sieve was re-suspended and centrifuged three times with Ludox HS40 (density 1.31 gcm$^{-3}$) according to [43]. All meiobenthic animals were counted and classified per taxon, under a stereomicroscope and after staining with Rose Bengal (0.5 gl$^{-1}$). Since the analysis of soft-body organisms might be difficult in formalin-preserved samples, some fresh samples were analysed immediately after sampling, to identify characteristics of the different meiofaunal taxa.

## 2.4. *Statistical analyses*

In order to evaluate differences between stations, the entire data set was analysed by means of one-way analysis of variance. When significant differences were observed, a post-hoc Tukey's comparison test ($p = 0.05$) was also performed. Spearman-rank correlations were also carried out to ascertain possible relationships between the different biochemical variables and the meiofaunal abundance.

## 3. Results and discussion

### 3.1. *Quantity and biochemical composition of sediment organic matter*

Submarine canyons, because of the peculiar topography and nutrient supply, the vertical migration habits of species along their main axis, and the currents affecting their local hydrodynamic conditions, are typically characterised by enhanced productivity [33]. Thanks to these peculiarities, they have been also typically seen to act as conveyors of material towards the adjacent bathyal and abyssal plains [4]. In this study, such a distinctive feature was partially confirmed only in one of the two branches of the Bari canyon.

In branch B, the analysis of variance revealed significant differences between all sampled stations in the concentrations of all of the investigated biochemical compounds, with exception of proteins and biopolymeric C. In contrast with previous studies, the post-hoc analysis revealed also that in the branch B of the canyon concentrations of organic matter generally decreased with increasing water depth (Table 2). The ANOVA revealed significant differences in the concentrations of all of the investigated biochemical compounds also in the branch C of the Bari canyon, but the post-hoc comparison highlighted the presence of a significant peak in organic matter accumulation at intermediate depths (i.e. between 400 and 600 m depth; Table 2). As expected, a significant drop in organic matter content of the sediment was observed in the open slope sediments (Table 2).

Significant differences in the biochemical composition of sediment organic matter between the three investigated systems (i.e. the two canyon branches and the adjacent open slope) were also observed (Figure 2). In particular, the protein fraction of biopolymeric C increased with increasing water depth in the slope sediments, whereas in the two branches of the canyon higher protein fractions occurred at intermediate depths (between 400 and 600 m depth). Moreover, the



Table 2. Outputs of the one-way analysis of variance carried out to assess separately depth related patterns in all of the biochemical compounds measured in the sediments of the two branches of the canyon and the adjacent open slope. Reported are also the outputs of the post-hoc Tukey's test.

| Variable | MS | p-level | Tukey's text |
|---|---|---|---|
| | | A) Canyon branch B | |
| Phytopigment | 528.90 | <0.02 | 370 > [446, 590] |
| Protein | 0.04 | ns | ns |
| Carbohydrate | 0.27 | <0.0001 | 370 > [446, 590] |
| Lipid | 0.01 | <0.01 | [370, 446] > 590 |
| Biopolymeric C | 0.01 | ns | ns |
| Meiofaunal abundance | 129892 | ns | ns |
| | | B) Open slope | |
| Phytopigment | 12366.21 | <0.0001 | 908 > [196, 406] |
| Protein | 1.07 | <0.01 | [406, 908] > 196 |
| Carbohydrate | 0.41 | <0.02 | 196 > [406, 908] |
| Lipid | 0.04 | <0.003 | 908 > [196, 406] |
| Biopolymeric C | 0.15 | ns | ns |
| Meiofaunal abundance | 25037 | ns | ns |
| | | C) Canyon branch C | |
| Phytopigment | 3299.23 | <0.0001 | 341 > 618 > [435, 593, 721] |
| Protein | 1.00 | <0.0001 | 341 > [593, 618, 721] > 435 |
| Carbohydrate | 0.57 | <0.0001 | [721, 593] > 435 > 341 > 618 |
| Lipid | 0.03 | <0.0001 | 435 > [593, 618, 721] > 341 |
| Biopolymeric C | 0.52 | <0.0001 | 435 > [593, 618, 721] > 341 |
| Meiofaunal abundance | 94059 | <0.05 | [593, 618, 721] > [341, 435] |

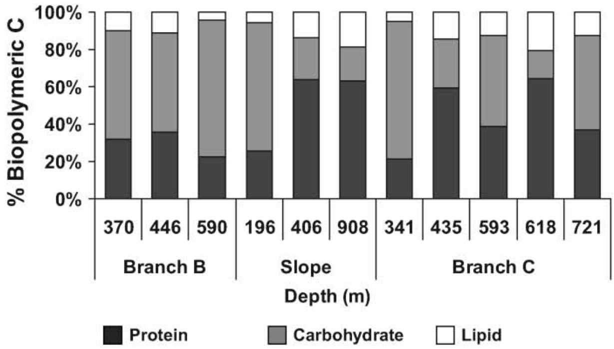


Figure 2. Biochemical composition of sediment organic matter in the Bari Canyon (Adriatic Sea).

biochemical composition of sediment organic matter displayed significant differences between the two canyon branches. In fact, while the sediments of the branch B were generally characterised by the overall dominance of the carbohydrate fraction (on average of all of the stations 62%, followed by 30% proteins and 8% lipids), the sediments of the branch C displayed a co-dominance of the protein and carbohydrate fractions (on average of all the stations 44 and 43%, respectively, followed by 13% lipids). These differences are likely to be related to the different hydrodynamic features conditioning the bottom of the two different branches of the Bari Canyon and imply rather different trophic conditions for the benthos.

The Bari Canyon appears markedly asymmetric with the right hand (southern) side higher and steeper than the left-hand one [44]. As a consequence, the cold-dense bottom waters formed on the Adriatic shelf through winter cooling enter the Canyon system with low sediment. The active erosion on the upper portions of either the B or C branches suggests that cascading currents flushing the upper trunk of B tend to over-bank towards the right and spill over into canyon C. This trend is clearly evident by comparing the quantity of sediment organic matter deposited in the three different systems at similar depths. From such a comparison, it clearly emerges that the branch C acts as a conveyor of organic loads derived from the branch B and the open slope. At about 400 m depth, the three systems also exhibited significant differences in the biochemical composition of organic matter deposited at the sea bottom. In particular, the branch B, as a result of the prevailing flushing conditions, was characterised by lower organic loads of poorer quality

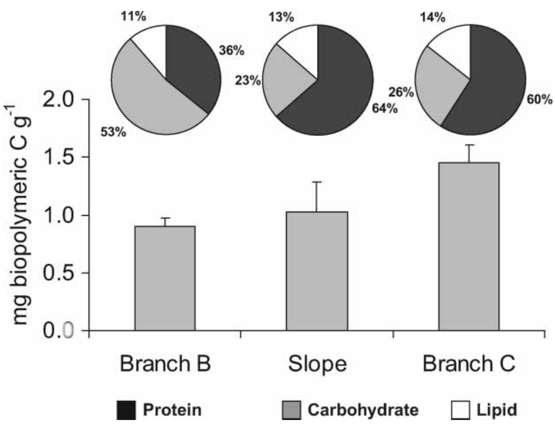


Figure 3. Changes in quantity and biochemical composition of sediment organic matter in the Canyon Bari system at about 400 m depth.

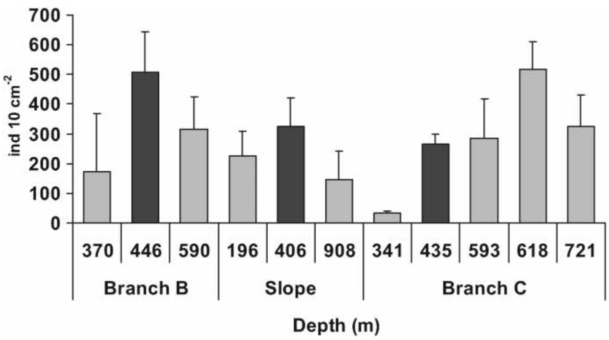


Figure 4. Meiofaunal abundance in the Bari Canyon systems. Reported are average of $n = 3$ replicates ± standard deviations.

(i.e. lowest protein fraction), when compared with the sediments of either the open slope and branch C (Figure 3).

Our results highlight that even twin branches within the same canyon may exhibit very large differences in the quantity, depth-related patterns and biochemical composition of sediment organic matter. The differences observed between the two branches of the Bari Canyon and the adjacent open slope were also compared with the meiofaunal abundance.



### 3.2. *Meiofaunal assemblages: Comparison between canyon and open slope sediments*

To date, the available data relative to meiofauna in submarine canyons are very scant. Previous studies carried out in the Gulf of Lions (Western Mediterranean Sea) [37,45–46] and the Gulf of Mexico (North-West Atlantic) [38] indicated that along the main canyon axis the meiofaunal abundance was generally higher than in the adjacent open slope. Another study carried out in the Gulf of Lions showed that there was 2 to 3-fold variation in meiofaunal abundances at similar depths, whereas there was 10 to 15-fold variation in abundances over the entire depth range studied [35]. Local variations were also observed between the main axis and the sides of the canyon along a cross-transect in the Lacaze-Duthiers canyon (Gulf of Lions, Western Mediterranean) [34].

In the Bari canyon, the ANOVA revealed significant differences in the total meiofaunal abundance only along the canyon branch C (Table 1), where the post-hoc analysis revealed that meiofaunal abundance increased with increasing water depth (Figure 4). It is noticeable that the post-hoc comparison showed that the values of meiofaunal abundance in the station at 341 m depth in the branch C were significantly lower of those in all other stations. This is attributable to the presence at that station of high-speed bottom currents as highlighted by the presence of a dominant gravel sediment fraction (data not shown).

Differently from what was observed for the sediment organic matter quantity and biochemical composition, comparing the three systems at 400 m depth no significant differences in meiofaunal abundance were observed (Figure 4). Moreover, the depth-related patterns in meiofaunal abundance were not associated with the patterns in organic matter quantity and biochemical composition. However, significant relationships between total meiofaunal abundance and biopolymeric C concentrations in the sediment were observed separately in the two canyon branches, but not in the open slope (Figure 5). The slopes of the linear curves fitting the relationship between organic matter quantity (in terms of biopolymeric C contents) and the meiofaunal abundance clearly increased with increasing steepness of the bottom profiles moving from the branch B, to the branch C and the open slope. Such a tendency suggests that the relationship between meiofaunal abundance and the food available in the sediment becomes tighter and tighter as the

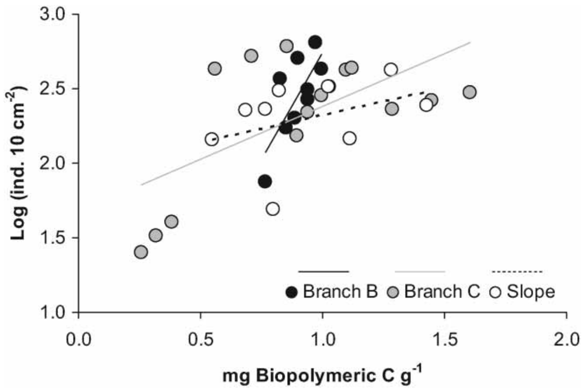


Figure 5. Relationships between organic matter quantity (in terms of biopolymeric C contents) and meiofaunal abundance (log transformed) in the two branches of the Bari Canyon and the adjacent open slope.

hydrodynamic forcing increases. In branch B sediments, where the flushing conditions continuously impoverish the trophic resources available for the benthos nutrition, small differences in the quantity of sediment organic C are related to large changes in the meiofaunal abundance. As the hydrodynamic conditions become progressively less intense, as in the canyon branch C and in the open slope, the relationship appears progressively less relevant. This result indicates that the trophic relationships in canyon sediments are tightly connected with the hydrodynamic conditions and that the steeper and the more flushed the canyon the more hostile environment for the benthos.

Recent investigations have pointed out that many canyons can be subjected to severe flushing conditions following cold waters cascading events and gravity flows, which might episodically determine a dramatic removal of material and organisms from the upper canyon layers to the adjacent bathyal and abyssal plane [5,19]. Although our data represent a simple snapshot of the conditions within the Bari canyon, the results of the present study suggest that also this canyon is exposed to such episodes. Our hypothesis is confirmed by a recent study that demonstrated that the branch C of the Bari canyon, where hard grounds and corals are encountered, is flushed by currents characterised by reduced turbidity [44].



## Acknowledgements

This study was conducted in the framework of the project HERMES (Hot-spot Ecosystem Research on the Margins of European Seas; Contract No. GOCE-CT-2005-511234-1). We are grateful to F. Trincardi (CNR, Italy) for the help in addressing our knowledge of the local geological setting and his courtesy in providing us with high definition maps of the Bari canyon. Thanks are due to the crew of the R/V Urania and to D. Zeppilli and M. Mea for sampling.

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