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DYFAMED-BENTHOS, a long time-series benthic survey at 2347-m depth in the northwestern Mediterranean: general introduction

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Abstract

In 1990, a benthic component to the DYFAMED (dynamics of fluxes in the Mediterranean) program, the DYFAMED-BENTHOS survey, was established to investigate the possible coupling of benthic to pelagic processes at a permanent station in >2700 m water depth, 52 km off Nice, France. Surface sediment was first sampled at different periods of the year to assess the importance of the biological compartment (particularly metazoan meiofauna) and its relation to seasonally varying particulate matter input to the sea floor (estimated by measuring surface sediment particle size and porosity, as well as chloroplastic pigments, organic carbon, nitrogen and calcium carbonate contents). Beginning in 1993, surface sediment was sampled at an average interval of 1.4 months for over five consecutive years using multicorers. Biogeochemical techniques such as deployments of a free-vehicle benthic respirometer and a near-bottom sediment trap, along with analyses of sediment vertical profiles for dissolved oxygen, nutrients and dissolved metals in the porewater, were developed in conjunction with more extensive biological analyses to characterize the recycling of organic matter, and ultimately increase our understanding of the oceanic carbon cycle. This article provides the scientific background and motivation for the development of the on-going DYFAMED-BENTHOS survey, the general characteristics of the benthic site, as well as a detailed description of the sampling design applied from late 1990–2000. © 2002 Elsevier Science Ltd. All rights reserved.

1. Introduction

The deep-sea floor has long been regarded as a stable unchanging environment inhabited by sparsely dispersed organisms whose lives were sustained by constant drizzle of fine, mostly refractory particles from the euphotic zone. However, during the last decades, technical development of monitoring equipment and sampling gear (e.g., sequencing sediment traps, multicorers, and free-vehicle benthic respirometers), together with the proliferation of multidisciplinary research programs, has gradually changed this picture. Evidence has emerged that much of the deep-sea floor is linked to upper water column processes via variations in the flux of sinking particles on both a spatial and a temporal basis (in Gage and Tyler, 1991). Sediment-trap studies conducted in a number of oceanic areas have revealed distinct seasonal pulses of particles rapidly settling from the euphotic zone (e.g., Honjo, 1982; Takahashi,

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1986). Since the first evidence of mass sedimentation of surface-derived organic matter (phytodetritus) to the sea bed provided by time-lapse photography and sediment coring in the NE Atlantic (Billett et al., 1983), similar phenomena have been documented in other areas, extending from the Arctic (Pfannkuche and Thiel, 1987) to the Pacific (Beaulieu and Smith, 1998).

In the food-limited environment of the deep sea, seasonal cycles in surface-water primary production and subsequent sedimentation of particulate organic material to the bottom may initiate a response of the benthic community in terms of population growth. This response of the benthic community to fluctuating detrital influx has been addressed in a number of studies. However, the nature of the response observed in these studies largely depends upon the sampling design followed, and particularly on the methods employed. Indirect methods based on the measurement of biological rates (metabolism) or biomass-related biochemical compounds, either on-board (Graf, 1989; Pfannkuche et al., 1999) or in situ through deployments of benthic respirometers (e.g., Pfannkuche, 1993; Smith et al., 1994; Drazen et al., 1998), have shown a rapid reaction of the benthic community to seasonal sedimentation. This reaction was, however, in most cases restricted to the small size fraction of organisms in the benthic community, namely the bacteria and some protozoans (e.g., Pfannkuche et al., 1999). Direct evidence for population fluctuations in the deep sea is sparse, and direct methods often involve laborious sample processing and counting. Several of these studies have nevertheless shown that seasonal organic pulses may regulate the population dynamics of bacteria (Lochte, 1992), flagellates and some foraminiferans (Gooday and Turley, 1990; Drazen et al., 1998; Gooday and Rathburn, 1999), as well as the reproduction and growth of some metazoans in the macro- and megafaunal size ranges (in Gage and Tyler, 1991; Cartes, 1998). The response of the metazoan meiofauna, that are abundant in the deep sea (Tietjen, 1992), however, remains quite unclear, at least at the major taxon level (Pfannkuche, 1993; Gooday et al., 1996; Shimanaga and Shirayama, 2000). A possible reason for this is that because metazoans increase in abundance at a slower rate than bacteria and protozoans (Gooday et al., 1996), sampling resolution of earlier studies may have been inappropriate to encompass the different time-scales of response of the organisms that inhabit the sediment. Based on temporal coverage, these studies were of two kinds: (1) short-time series lasting no more than a year, generally including two sampling periods, i.e. before and after the pulse (Gooday and Lambshead, 1989; Lambshead and Gooday, 1990; Gooday et al., 1996), and (2) long-term discontinuous sampling and subsequent compilation of results from different years to form a composite annual cycle, thereby overlooking interannual variations (Pfannkuche, 1992, 1993; Soltwedel et al., 1996). In recent investigations, more attention has been paid to sampling resolution. For example, Shimanaga and Shirayama (2000) achieved up to 9 distinct sediment-sampling periods within the same year at a bathyal site in Japan. Unfortunately, although the abundance and biomass of metazoan meiofauna seemed to vary seasonally, the statistical significance of the fluctuations could not be established, possibly because food material was constantly available in this eutrophic environment.

Although now recognized as imperative for the understanding of deep-sea temporal variability, comprehensive long benthic time-series at abyssal depths remain rare (Smith and Druffel, 1998; Rice et al., 1998). The relative inaccessibility of the deep sea and the resulting logistic and economic constraints, together with the lack of automated sampling and monitoring devices for the benthos, have always limited progress towards the extensive development of such studies.

An alternative was found at the French-JGOFS permanent station in the northwestern (NW) Mediterranean Sea. This deep-water site (>2300 m), which has long been recognized as a model area regarding its geographical and hydrological features, is relatively close to land and presents many of the characteristics of the open ocean with a strong surface seasonal signal. Since 1987, it has been the time-series station of the DYFAMED (dynamics of fluxes in the Mediterranean) program for long-term studies of biogeochemical cycles of carbon and associated compounds through the water column. In this context of well-documented water-column processes, a long benthic time-series, the DYFAMED-BENTHOS survey, was established in December 1990 to investigate benthic to pelagic coupling, and particularly benthic biological (with special emphasis on metazoan meiofauna) and biogeochemical responses to varying particulate organic matter inputs to the sea bed. This article that describes the general characteristics of the DYFAMED site and provides a detailed account on the benthic sampling design applied from late 1990–2000, is an introduction to the forthcoming reports on the benthic scientific results.

2. Study area

2.1. Location, topography, geology

The DYFAMED station is located in the NW Mediterranean, 52 km off Nice (France), in the central part of the Ligurian Sea, bounded to the north by the French coast, to the east by the Gulf of Genova (Italy), and to the south by the island of Corsica (France) (Fig. 1). The topography of the Ligurian Sea is characterized by a narrow continental shelf and a steep slope dissected by submarine canyons. The benthic site is centred around 43°24.61′N–7°51.67′E at a mean depth of 2347 m, and situated on the side of the lower median fan valley of a sinuous canyon that is directly connected to the outlet of the Var River. At the station, the terrain is rather smooth although not totally flat, with a maximum relief of 12 m over 4 km^2. The geological substratum is composed of Plio-Quaternary calcareous clay including many sand strata (Mulder et al., 1997). Recent surface sediments essentially derive from pelagic sedimentation that includes silty clay-size eolian dust particles originating from the Sahara desert (Molinaroli et al., 1993), and occasionally from turbidity flows.

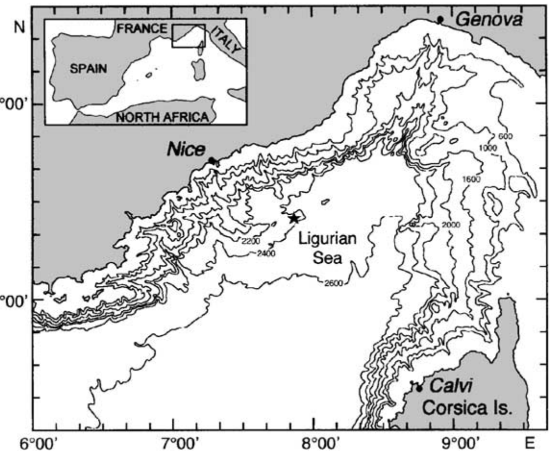

Fig. 1. Map of the Ligurian Sea in the NW Mediterranean, showing the location of the DYFAMED station (depth contours in metres).

2.2. Water column

2.2.1. Hydrography, productivity, particle flux

The primary hydrographic structure of the Ligurian Sea is the permanent cyclonic circulation, the Ligurian current, that flows southwestward along the French continental shelf, and tends to isolate the central part of the basin from lateral coastal influences (Béthoux et al., 1988). At all seasons except in winter, the sampling site is overlain with three main water masses (Tchernia, 1978): (1) the modified Atlantic water, which extends down to approximately 150 m depth; (2) the Levantine intermediate water that is generated in the eastern Mediterranean, and lies between approximately 150 and 600 m depth; (3) the western Mediterranean deep water, which is formed in winter in an area south of Toulon, and extends down to the bottom. In winter, instability due to strong dry and cold winds leads to the homogenization of the water column and the enrichment of the surface waters by subsurface nutrients essential for phytoplankton growth. Hence, the great seasonal variability in the hydrology, from winter mixing to intense summer stratification, results in varying trophic regimes in the upper water column, i.e. from mesotrophic conditions in late-winter–early-spring to oligotrophy from mid-summer through November (Marty et al., 2002). Annual primary productivity in the surface waters ranges from 86 to 232 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$

(measured from 1993 through 1999: Marty and Chiavérini, 2002) and exhibits strong interannual variability.

Fluxes of sinking particulate matter, measured at the DYFAMED station at 200 and 1000 m water depth since 1987, vary seasonally both in magnitude and composition (Miquel and La Rosa, 1999). They show marked peaks in winter through spring, followed by lower occasional secondary pulses in summer and autumn. Maximum fluxes almost always occur in winter (generally in February) as a result of both biological and physical (i.e. vertical mixing) processes (Miquel et al., 1994). In winter, the sinking particles are generally rich in diatoms (Marty et al., 2002). Particle fluxes also vary greatly between years, both in magnitude and timing. Annual mass fluxes at 200 m range from 14 to 40 $\mathrm{g\,m^{-2}\,yr^{-1}}$. They decline with increasing depth, and at 1000 m amount to 35% to 40% of the fluxes measured 800 m above (Miquel and La Rosa, 1999). It was anticipated that these different temporal signals, both seasonal and interannual, would be observed down to the seabed.

3. Benthic sampling design

The importance of sampling resolution in benthic/pelagic coupling studies has been stressed above. Therefore, one of the goals of the DYFAMED-BENTHOS survey was to achieve a sampling frequency high enough to match the reproduction cycles of the metazoan meiofauna that have a duration on the order of the month in shallow-water environments (in Giere, 1993). Another important point was that the sampling frequency should be such that both the recent particle deposition and the possible reactions of the metazoan meiobenthos could be monitored.

3.1. Sampling resolution, instruments

Surface sediment was sampled at 2347 ± 6 m depth for 10 years, from late 1990 through 2000. A total of 84 benthic cruises were performed, 61 of which were successful in collecting surface sediment (Fig. 2). Depending on sampling resolution and gear, the benthic survey was split into three phases.

The preliminary phase comprised 12 cruises unevenly distributed between late 1990 and the end of 1992. After the first cruise, which was devoted to a general evaluation of the area, the survey started in April 1991 and surface sediment was sampled at an average interval of 29 days until the following November, mainly using a box corer. Because box corers are often inefficient at collecting the fluffy layer on the sediment surface (e.g., Bett et al., 1994), it was replaced by a *SMBA*

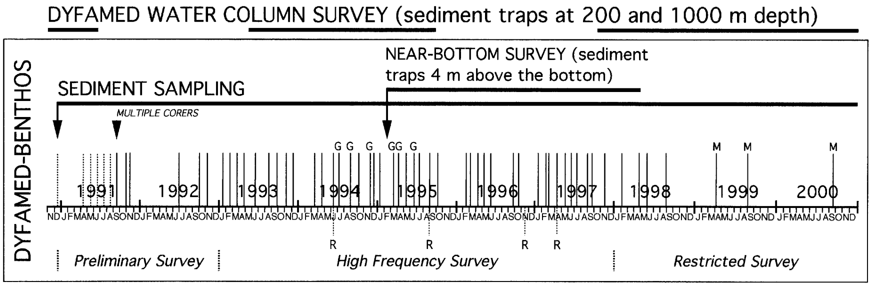

Fig. 2. Diagram of the DYFAMED-BENTHOS sampling design. Vertical bars represent the 61 benthic cruises carried out for 10 years, from late 1990 through 2000, and during which surface sediment was successfully sampled at a mean depth of 2347 m, using either a box corer (dashed bars) or a multicorer (solid bars). The program was split into three phases, depending on sediment-sampling frequency. Cruises including collaborations with geochemists (G) and microbiologists (M) are indicated. A free-vehicle benthic respirometer (R) was deployed on four occasions between 1994 and 1997, while sediment traps collected particles in close proximity to the bottom between February 1995 and April 1998 to supplement the information obtained from the upper water column DYFAMED survey that was moreover interrupted twice for a 2-year period.

multiple corer which was specifically designed to collect undisturbed sediment cores (Barnett et al., 1984). In 1992, after an interruption of more than 7 months when the research vessels were unavailable, only three cruises were achieved in the second half of the year. These first two years were considered as preliminary for three reasons: (1) the disparity in sampling devices, (2) the inadequacy of sampling frequency that did not allow a complete coverage of the four seasons, particularly the winter months when particle fluxes are maximum (see above), and (3) the interruption of the water column survey after the loss of the DYFAMED sediment trap mooring in mid 1991 (Fig. 2).

During the "high-frequency survey" that lasted 5 years, from 1993 through 1997, surface sediment samples were collected on 42 occasions at an average interval of 42 days (range = 6–129 days). Due to logistic constraints (bad weather conditions, corer damage), again the cruises were not evenly distributed within each year, although the seasonal coverage was this time greatly improved. During the 5-year period, all the months of the year but one were sampled at least three times (March, April and June were sampled all five times, December only twice) (Fig. 2). In November 1993, the *SMBA* multiple corer was itself replaced by a *Bowers and Connelly* Maxicorer, which is a similarly reliable multicorer, but smaller in overall size and thereby more convenient for deployments from vessels such as the R.V. *Professeur Georges Petit* and *Tethys II* (19.8 and 24.9 m long, respectively) from the "Institut des Sciences de l'Univers" (INSU). This multicorer, which is now manufactured by *Ocean Scientific International* ⟨http://www.oceanscientific.com⟩, has a hydraulically damped frame and a sediment sealing mechanism to ensure the extraction of an undisturbed sediment water interface and underlying sediment profile.

During this period, a collaboration was developed with *Alexis Khripounoff* and his group from IFREMER (centre de Brest), and two other instruments were deployed at the DYFAMED benthic site. A free-vehicle benthic respirometer (model RAP-II, developed at IFREMER) was used to measure the sediment community oxygen consumption (SCOC) at the four seasons (June 1994, September 1995, November 1996, April 1997) (Fig. 2). Moreover, while the DYFAMED upper water column monitoring had resumed in May 1993 when the 200 and 1000-m depth sediment traps were replaced, an additional mooring supplied by *Khripounoff* was deployed starting from February 1995 to collect the particles in close proximity to the sea floor. It included three cylindro-conical baffled sediment traps, each with a collection area of 0.07 m^2, that were lined up in a rectangular frame. Each trap was equipped with five sequencing cups and collected particles, simultaneously, 4 m above the bottom (mab) so that the small scale (<1 m) horizontal variability of fluxes could be estimated from the 3×5 samples recovered per deployment. A total of 16 deployments (one of which failed to collect particles) were performed between February 1995 and April 1998 (Fig. 2). Sampling resolution varied between 5.5 and 21 days (generally around 14 days), and servicing was every 1.5–3.5 months. This mooring was furthermore equipped with an Aandera current meter that recorded current flow 12 mab until it broke down in June 1997. The DYFAMED-BENTHOS mooring was initially deployed to provide an estimate of the composition and flux of sinking particulate matter in close proximity to the bottom for comparison with both sea-floor processes and upper water column fluxes. This last point would allow assessing the magnitude of possible inputs from lateral advection and/or resuspension. A second loss of the DYFAMED mooring in September 1995, however, limited the upper water column/near-bottom comparison to two 6-month periods at the beginning and at the end of the near-bottom sediment trap survey (Fig. 2). During the subsequent 2-year interruption of the upper water column survey, the near-bottom traps served as a substitute and allowed the primary objective of the benthic program, i.e. to relate the changes in the benthic community to variations in particulate matter fluxes, to be maintained.

The intensive investigation carried out from 1993 through 1997 produced a large number of samples and data, some of which are still undergoing analysis. For this reason, from 1998 onwards, the DYFAMED-BENTHOS survey was lightened and restricted to occasional benthic sampling cruises at contrasting periods of the year (Fig. 2), mainly in early spring following the maximum particle pulses, and in late summer when fluxes are generally at their lowest. This “restricted survey” is still underway and should carry on for several years, as part of the long-term DYFAMED monitoring program (DYFAMED Observation Service).

3.2. Spatial distribution

The positions of the DYFAMED-BENTHOS moorings and corer casts are shown in Fig. 3. Shipboard positioning was carried out using differential global positioning system (DGPS) that can yield horizontal accuracies of 1–10 m. The near-bottom sediment traps and the benthic respirometer were deployed more than 1.5 km apart, and at least 700 m away from the coring site, to avoid any contamination from sediment resuspension when ballasts hit the bottom. Likewise, the DYFAMED upper water column sediment traps are always moored at least one nautical mile (1852 m) away from the coring site.

The study of temporal changes can be complicated by spatial heterogeneity. In the deep sea, where low food inputs may generate only moderate reactions of the benthic community, it may be particularly difficult to discriminate between the temporal and spatial components of population variability (Gooday and Rathburn, 1999). For this reason, in an attempt to minimise local variability, the coring site was restricted to a 200-m diameter circle centred around 43°24.61′N–7°51.67′E (Fig. 3). Of the 109 successful corer casts performed between late 1990 and 2000, over 75% were within that circle. Moreover, replicate samples are necessary to deal with spatial variability, so whenever possible (depending on weather conditions and ship time available) up to four corer casts were achieved on the same sampling period. On the same cruise, approximate distance from one corer to another varied between a minimum of 14 m to a maximum of 740 m, and most of the time it was much <200 m. Details of the corer positions and distances will be given in the forthcoming articles.

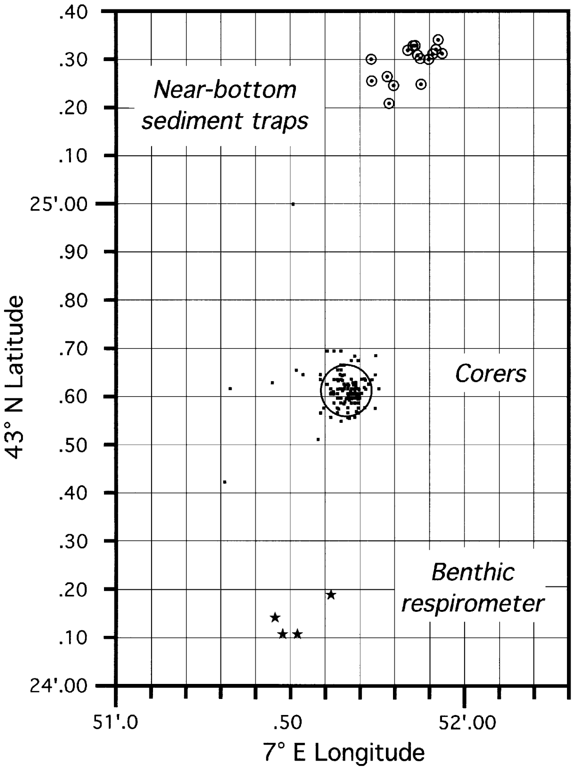

Fig. 3. Layout of the DYFAMED benthic station (2347-m mean depth) showing the positions of the 16 near-bottom sediment traps moorings, the four benthic respirometer moorings, and the 109 corer casts (small black dots) performed between late 1990 and 2000. More than 75% of the corer casts were within a 200-m diameter circle centred around 43°24.61′N–7°51.67′E. (distances can be calculated from: 1′ latitude = 1 nautical mile).

3.3. Sediment variables

On each cruise, a basic set of subsamples was obtained from the sediment cores in order to document both the recent particle deposit and the possible reactions of the metazoan meiobenthos.

Preliminary investigations at the DYFAMED benthic site showed that the most recent particles mainly occur in the upper 0.5 cm of sediment. Depending on the time of the year, this layer generally has a more or less pronounced grainy texture, and can become quite fluffy as detrital aggregates settle on the bottom. This layer was subsampled using 2-ml disposable syringes with the end cut off for subsequent analyses of: (1) physical characteristics, i.e. granulometry, porosity, microscopy observations, and (2) chemical composition, i.e. chloroplastic pigments (chlorophyll-*a* and its degradation products as an indicator of phytoplankton sedimentation), organic carbon, nitrogen and calcium carbonate concentrations. The subsamples were stoppered and stored refrigerated or frozen until analysis in the laboratory. Occasionally, subsamples also were taken for bacterial total counts using DAPI epifluorescence microscopy. Total metazoan meiofauna was subsampled to a sediment depth of 10 cm using 60-ml cut-off syringes with an inner cross-section area of 6 cm^2. Subsamples were preserved in borate-buffered formaldehyde (4% final concentration), stained with Rose Bengal and kept at ambient temperature until subsequent extraction of organisms larger than 40 μm using Ludox TM (in Higgins and Thiel, 1988). Since July 1994, additional samples have been taken to investigate gradients within the sediment column. On each cruise, from 1 to 2 Maxicorer sediment cores (75 cm^2 inner cross-section area) were sectioned horizontally into 0.5-cm-thick layers down to 1-cm depth and 1-cm-thick layers from 1 to 5 cm depth. Each layer was treated separately and subsampled for the above physical and chemical variables, while the rest of the sediment was preserved for metazoan meiofauna. Subsamples for physical and chemical variables were always taken from a homogenate of the corresponding sediment layer. Most of the routine sediment variables also were analysed in the near-bottom sediment trap samples.

Local variability also occurs at scales smaller than the intercorer distances reported above (e.g., Andrew and Mapstone, 1987), so on each cruise from 1 to 3 subsamples were taken from several cores of each corer cast. The Maxicorer can be equipped with up to 8 acrylic core tubes of inner diameter 9.8 and 60 cm long, and the intercore separation ranges from 17 to 68 cm. Within the cores, the adjacent meiofauna subsamples (i.e., 60-ml syringes) were approximately 3.5 cm apart (all distances are from the centre of the tubes). As a result, on each of the 42 "high-frequency survey" cruises, an average of eight total metazoan meiofauna subsamples were taken at three different spatial scales, i.e. the 10–100-m scale (between corers), the decimetre scale (within corer), and the centimetre scale (within core). A total of 336 subsamples were thereby collected for this sole variable over a 5-year period. Because of the time-consuming nature of meiofauna sorting, processing of this extensive collection is still under progress (65% of the corresponding subsamples have currently been worked up).

In the course of the study, two additional collaborations provided supplementary information on the geochemical and microbiological environments of the DYFAMED benthic site. The first collaboration was with *Christophe Rabouille* and *Marion Gehlen* from the Laboratoire des Sciences du Climat et de l'Environnement (LSCE) in Gif-sur-Yvette, who studied the porewater chemistry of 21 cores taken between July 1994 and June 1995 ("G" in Fig. 2), and established profiles of porewater nutrients and metals (NO_3^-, $Si(OH)_4$, Mn^{2+}, Fe^{2+}) and dissolved oxygen down to a depth of 10 cm in the sediment (procedures are described in Gehlen et al., 1997). The second collaboration, with *Armand Bianchi* from the Laboratoire de Microbiologie Marine (LLM) in Marseille, started in April 1999 ("M" in Fig. 2) and is still underway, to examine the role of aquatic and sedimentary microflora in the degradation of particulate organic matter. Bacterial numbers and biomass, as well as potential heterotrophic activities are measured in the overlying water and sediment column of Maxicorer cores collected at contrasting periods of the year ("restricted survey", see above), following the procedures detailed in Tholosan and Bianchi (1998).

3.4. Physical disturbance

The situation most relevant to the study of the effects of food availability on population dynamics would be an environment where this driving force highly prevails so that its effects are not confounded by those of any other factor. In this sense, the deep sea is an ideal setting. It is relatively stable in terms of its physical and chemical environment (i.e. temperature, salinity), while the seasonally varying downward flux of organic matter derived from surface production represents, most of the time, the only source of temporal fluctuations. Nevertheless, although much of the deep sea is physically tranquil, several investigations have shown that some regions, at times, may experience intense bottom-current activity, and that the resulting physical disturbance of the surface sediment may have substantial effects on the benthos (e.g., Aller, 1989; Thistle et al., 1991) and totally override food-dependent relationships (see Guidi-Guilvard and Buscail, 1995). During the DYFAMED-BENTHOS survey, bottom physical disturbances of two different kinds were identified on two occasions.

In early November 1994, very heavy rainfalls generated an exceptional flood of the Var River that produced a hyperpycnal current intense enough to transport clay-size minerals tens of kilometres from the river mouth (Mulder et al., 1997). These authors calculated that particles could have travelled as far as the lower median fan valley of the Var Canyon, on the side of which the DYFAMED benthic site is located. This was clearly confirmed during the corresponding DYFAMED-BENTHOS cruise 3 weeks after the flood, when the cores were overlain with a $\approx$0.5-cm-thick unconsolidated layer of very fine foreign sediment. Apart from this event, which has a theoretical return period of 50–200 years (Mulder et al., 1997), however, no other significant evidence of disturbance by turbidity flows was observed during the 10-year duration of the benthic survey.

Bottom-current meter records (12 mab) are available (A. Khripounoff, personal communication) from the first 12 deployments of the near-bottom sediment traps mooring at the DYFAMED benthic site. Bottom currents were variable, but net flow was from the southwest to the northeast, parallel to the coastline and opposite to the surface Ligurian Current. In all deployments, from February 1995 to June 1997, more than 37% of the individual records showed a current speed less than the stalling speed of the rotor ($2.47\,\mathrm{cm\,s^{-1}}$), and only 2.45% of the values were greater than $10\,\mathrm{cm\,s^{-1}}$. All but one value $>10\,\mathrm{cm\,s^{-1}}$ were recorded in 1996, mainly in the month of April when daily averaged current speeds of $11–18\,\mathrm{cm\,s^{-1}}$ occurred for 2–4 consecutive days at time intervals of 2–7 days. Except during the summer, the rest of 1996 appeared somewhat more quiescent, as in 1995 and 1997. During the 28-month bottom-current survey, a total of four "benthic storms" (see Aller, 1989) with peak velocities between 13 and $21\,\mathrm{cm\,s^{-1}}$ were identified, and they were all confined to April 1996. In the absence of a longer bottom-current record, it is difficult to draw conclusions about the frequency of such events, although from the general appearance of the surface sediment on the cores as well as the currently available sediment-data set, one would tend to argue that this area is nevertheless, most of the time, relatively tranquil.

4. Conclusion

The 10-year DYFAMED-BENTHOS survey represents one of the longest continuous time-series study of a deep-sea soft-bottom area in the world ocean. Moreover, it is the first time that metazoan meiofauna has been sampled at such a high frequency (mean 1.4 months) over such a long period of time (five consecutive years) in the deep sea. This study has produced a tremendous amount of samples and data, some of which are still undergoing analysis. To date, only one article (Gehlen et al., 1997) based on the geochemical changes in the sediment column following the November 1994 flood, has been published. Nevertheless, other results are now ready for final interpretation and subsequent publication. They cover a wide range of topics including:

- The variations in timing, amount and composition of the particles settling on the seabed and their subsequent burying within the sediment column;
- The short- and long-term reactions of the meiobenthic community to particle input, including immediate responses such as emergence of some harpacticoid copepods, and delayed

Table 1
Environmental characteristics and metazoan meiofauna abundance at the DYFAMED benthic site. All sediment variables were measured from subsamples of cores from 1 to 3 corer casts performed on 25 different dates between 1993 and 1995. Physical and chemical variables as well as total bacteria were measured in the top 0.5-cm layer of sediment (values are expressed as a percentage of sediment dry weight unless otherwise indicated). Metazoan meiofauna abundance was counted in the top 10-cm layer of sediment.

	Mean	Range	No. of subsamples	No. of cores
Bottom water				
Temperature (°C)[a]	12.7	—	—	—
Salinity (‰)[a]	38.4	—	—	—
Oxygen (ml l^{-1})[b]	4.7	4.6–4.8	—	—
Surface sediment				
Silt-clay fraction (%)	94.40	80.65–99.08	69	58
Porosity (%)	74.25	56.04–83.45	228	93
Organic carbon (%)[c]	0.58	0.47–0.76	98	62
Nitrogen (%)[c]	0.062	0.050–0.095	52	46
Calcium carbonate (%)[c]	40.79	35.77–43.20	77	53
Chloroplastic pigments (μg cm^{-2})	0.802	0.360–1.556	238	95
Total bacteria ($\times 10^7$ cm^{-2})	2.02	1.34–2.83	21	7
Metazoan meiofauna				
(individuals 10 cm^{-2})	380	133–770	170	75

[a] Tchernia (1978).
[b] Khripounoff (personnal communication).
[c] Analysed by R. Buscail and A. Khripounoff.

responses such as population growth of the nematodes;

- The short- and long-term effects of physical disturbance (of depositional nature in the case of the flood, and erosional nature in the case of the benthic storms) on the sediment column and its inhabitants;
- The establishment of carbon flux budgets based on porewater profiles and in situ measurements of the benthic community respiration.

While the Mediterranean Sea may not be typical of the world ocean owing to its high bottom-water temperature and salinity, most of the sediment data measured at the DYFAMED benthic site are on the order of those usually reported for deep-sea environments (Table 1). Even the metazoan meiofauna abundances, which are high for the deep Mediterranean (see Fig. 5 in de Bovée et al., 1990), compare well to abundances reported for equivalent depths in the eastern Atlantic (see Fig. 2 in Tietjen, 1992). Although close to land (which is a definite advantage, considering ship-time cost), this benthic site is generally not influenced by lateral inputs as confirmed by the near-bottom sediment-trap survey. Bottom disturbance events such as those previously reported for other deep-sea locations, only occurred on two occasions during the survey, moreover providing unexpected opportunities to study their effects on the benthic community. In the end, this relatively accessible station presents a number of open-ocean characteristics in surface-water as well as bottom-water processes, and provided a unique opportunity for the achievement of a comprehensive long-term study of the biologically driven temporal variability in the deep sea.

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