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Synthesis of Final Results
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Transfer of matter and energy on European continental margins

ABSTRACT

The EUROMARGE-NB Project is a contribution to the Mediterranean Targeted Project first phase, from 1993 to 1996. EUROMARGE-NB has developed a mesoscale strategy (over several hundreds of km) covering the whole Northwestern Mediterranean margins and deep basin. This is, to the best of our knowledge, the first experiment at such a scale. The strategy includes simultaneous long-term monitoring of physical and biogeochemical parameters on four key sites (Marseilles, Perpignan, Barcelona, North Baleares) by means of instrumented arrays, as well as quasi-synoptic cruises carried out regularly and covering the whole study area. Amongst the more outstanding results it is worth mentioning the unique data set gathered about deep circulation, suspended particulate matter (SPM) characteristics and dynamics (including the living and non-living components), particle fluxes and their relations to other environmental parameters, and the benthic response to such fluxes.

The circulation results confirm the role of the cyclonic regional circulation as a major dynamical factor along the Northwestern Mediterranean slopes, with two segment margins (Perpignan and Barcelona) exporting large quantities of particulate matter with a dominant lithogenic character, and relatively high primary production (Perpignan), and two other segment margins (Marseilles and Baleares) with weak exportation and particularly oligotrophic (Baleares). Particle flux patterns show an offshore decrease and a depth increase at a given location, with an along-slope increase downstream the general circulation. Consequently, total mass fluxes and fluxes of any constituents are progressively increasing from Marseilles down to Barcelona. The Baleares site shows the lowest fluxes of the entire system. Significant changes of total mass fluxes with time occur both on a short scale of a few weeks (flux peaks) and on a seasonal time scale (winter fluxes higher than summer fluxes), and are quite concomitant at the scale of the entire region. Due to the limited range of contents in various constituents (by comparison with the large range of total mass fluxes), fluxes of any constituents are almost totally controlled by the factors controlling total mass flux. This feature also applies to constituents which are derived from biological activity (e.g., organic carbon and opal) and budgets for such constituents cannot be constructed solely on a one-dimensional (vertical) basis.

Biogenic inputs to depth rely upon advective processes which transfer material from shallow sources (e.g., shelf waters) of either primary particles (e.g., newly formed) or resuspended material. The horizontal component dominates the transfer. Driving forces on fluxes are either external (e.g., river discharge of suspended sediments, storms) or
internal ones (e.g., circulation patterns of water masses, interactions with topography). The first group controls the amount of material which is injected into the water column, whereas the second one provides the routes along which transfer takes place. The exact importance of biological processes in this system remains relatively unknown. Meioabenthos quantitative patterns point out the peculiarities of the Balearic margin as well as the enrichment of canyon axis as compared to interfluves and therefore attests of the organic matter transfers at the continental margins. Being closely correlated with the POM collected in near-bottom particle traps, meiofauna abundance provides an interesting biological tool to assess organic matter fluxes at the sea-bed. However, macrofauna would also respond to other factors, like specific habitat requirements and mass-physical properties of the sediments.

The integration of various of the results obtained allows to the establishment of the Carbon budget in the key study sites, which could be extended to the overall study area.

**Key words:** Biogeochemistry, transfer, continental margin, suspended particulate matter, water circulation, particle fluxes, benthic response, Northwestern Mediterranean Sea.

**INTRODUCTION**

**Organization Of The Project And Scientific Objectives**

This contribution aims to provide the reader with a general background about the EUROMARGE-NB Project and its scientific results, which are hereby presented in a synthethic form.

The EUROMARGE-North Baleares (NB) Project, a component of the Mediterranean Targeted Project (MTP), has been conducted from the 1st of July, 1993 to the 31 of March, 1996 for a total of 33 months, by a multidisciplinary team formed by 12 partners and various subcontractors (see last page). The Project has been coordinated by the University of Barcelona (Spain) through the intermediation of the Foundation «Bosch i Gimpera. Main partners were, apart from the University of Barcelona, the «Laboratoire de Sédimentologie et Géochimie Marines» of the University of Perpignan (France), the «Observatoire Océanologique de Banyuls» (France) and the «Instituto de Ciencias del Mar» of Barcelona (Spain).

The aim of the EUROMARGE-NB Project is to understand, through a multidisciplinary study, the functioning of the Northwestern Mediterranean continental margin ecosystems. Special attention is given to the study of fundamental processes, in and between water column and sediment, which affect biogeochemical fluxes and material budgets.
The main objectives of the EUROMARGE-NB Project are:

A) To study and quantify the exchange biological, sedimentary and chemical processes occurring between the coastal domain and the open sea at the water column, sediment-water interface and surface sediment levels.

B) To study material (suspended particles and sediments) and element (C, N, Si, P, metals and artificial radionuclides) cycling.

C) To study pelagic and benthic processes and their role in element cycling, which is specially important in view of the strong enrichment of the NW Mediterranean zone.

D) To verify the working hypothesis of a mid-slope depositional centre which mediates particle transfer to the deep sea.

E) To study the resulting sedimentation, integrated over time, as it bears witness to recent natural or induced changes. The continental margins which may subject to a terrigenous (Gulf of Lions and Catalonia margins) or carbonate sedimentation (Balearic Islands margin) lend themselves particularly well to the recording and interpretation of these changes.

The study area

The study area covers the northernmost part of the Western Mediterranean Sea, north of the Balearic Islands, and includes the otherwise named Gulf of Lions, the Catalan Sea and part of the Alfero-Provencal Basin (Fig. 1). This means that the Project operates at a mesoscale level. Most of the work has been carried out off the shelfbreak, on the continental slope and rise, from 200 to 2,400 m of water depth, with special attention to the mid-slope fringe, broadly from 500 to 1,200 m.

In the study area various types of continental margins exist. Very large shelves (60 to 120 km wide) appear on the Gulf of Lions and off the Ebro river mouth, while narrow shelves (less than 20 km wide) characterize the Balearic Islands. Shelves with intermediate widths characterize most of the Catalan margin, from the Ebro to the Gulf of Lions. The continental slope and rise environments are particularly developed in the Gulf of Lions, where a dendritic system of submarine canyons exists. In none of the other margin segments of the study area, submarine canyons are so developed. The Ebro slope is only incised by short gully-type canyons; the Catalan margin is cut by a few, tectonically controlled canyons, like La Fonera, Blanes and Foix, from north to south (Fig. 1). Finally, no canyons in strictu senso have been observed in the margin north of Mallorca and Minorca.

The entry of continent-derived sediment inputs determines the sedimentary type of the various margin segments, which have been classified as terrigenous (or siliciclastic), receiving heavy riverine contributions, carbonated, which lack of significant river inputs and hence most of the particle production is autochtonous, both pelagic and benthic, and mixed (Fig. 1). The Gulf of Lions and most of the Catalan margin, including the Ebro segment, are terrigenous, while the Balearic margin is carbonated. Mixed types appear only locally, as in the segment limited by La Fonera and Blanes canyons.
Other aspects which have been considered in the sectorisation and, as a consequence, in the definition of the field strategy (see below) of the various margin segments are primary productivity and anthropogenical influence. The Gulf of Lions and Catalan margins are much more productive and anthropogenically influenced than the oligotrophic margin north of the Balearic.

All the margins of the study area are swept by the Northern Current (or Algero-Provençal Current) which enters the study area from the eastern Gulf of Lions, contours the western Gulf of Lions and Catalan segments and goes back, towards the northeast, along the slope north of the Balearic (Fig. 1). This main circulation path is locally affected by the morphological irregularities, like canyons, of the various margin segments and, occasionally, by entries of surficial Atlantic waters through the west Balearic passages.

**Methodological approach, field strategy and instrumentation**

The methodological approach followed into EUROMARGE-NB basically includes:

1) The quantitative, simultaneous assessment of water masses, suspended particle standing stocks, and particulate fluxes over the entire margin system by means of a multidisciplinary approach (hydrology, nephelometry, biology, sedimentology).

2) The calculation of mass balances and budgets within the water column of significant biogenic constituents (POC, PON,...), trace elements and radionuclides.

3) The identification and understanding of the relation between energy supply and biological response of benthic communities.

In accordance to the features of the study area, which was selected because of the biogeochemically contrasted character of their various margin segments (see above), and to the scientific objectives to be addressed, an specific field strategy was adopted. This included the identification of four key sites to permanently monitor biogeochemical parameters, in combination with various synoptical regional and local oceanographic cruises.

- **Continuous monitoring of major biogeochemical and physical parameters by in situ moored instrumentation at selected stations**

Moored instrumented arrays were deployed in four key study sites, from the entry to the issue of the system defined by the Northern Current (see above): I) the Planier Canyon, off Marseilles ("Marseilles site"), II) the Lacaze-Duthiers Canyon, off Perpignan ("Perpignan site", III) the Foix Canyon, south of Barcelona ("Barcelona site", and IV) northwest of Minorca, in the Balearic Islands ("Baleares site"). At each site, the instrumented arrays which included PPS3 Technicap particle traps and Aanderaa rotor current meters were deployed both in canyons and in the vicine interfluves, at 550 to 770 m ("shallow" stations) and 990 to 1350 m ("deep" stations) depth (Fig. 1 and Table 1). Moored transmissimeters were also deployed in the Barcelona site. In the Gulf of Lions, an additional intermediate array (Sète Canyon), situated between the Marseilles and Perpignan sites, was also deployed. In all, 12 permanent mooring stations were in
operation for at least one continuous year each, with sampling intervals of 15 days or 1 month depending on the particle trap model (Heussner et al., 1990 and 1996a). Recovery and redeployment of moored arrays were made every six months. The deep, canyon axis arrays of the four preferential sites included one particle trap/currentmeter pair about 30-35 m above the bottom, and a second pair, about 500 m above the bottom. The other arrays consisted of a single trap/currentmeter pair deployed at 30-35 m above the bottom (Table 1).

Approximately 6700 days of recording were performed at a sampling rate of a set of currentmeter measurements (velocity, direction, temperature, conductivity / pressure / transmission, leading to about 80400 two dimensional vectors) every two hours and a particle sampling every fortnight or month. Trap preparation before deployment as well as laboratory preliminary treatment of trap samples were performed according to state-of-the-art procedures (Heussner et al., 1990). The following parameters were currently analysed for all traps: total mass flux, organic and inorganic carbon, biogenic silica and refractory (lithogenic) constituents. They represent the major constituents of trapped particles. Determination of biogenic constituents (e.g., fecal pellets, coccoliths, diatoms) and analyses of biogeochemical compounds (e.g., sugars, amino acids, phenols), trace metals (e.g., Cu, Cd, Zn, Ni and Ba) and isotopic tracers (e.g., \(^{210}\)Po, \(^{210}\)Pb, C and Th isotopes) were also performed on selected samples (Sánchez-Cabeza and Canals, 1996). They were used to qualify the nature of collected samples, with the aim of tracing the sources and fate of settling particles within the water column.

- **Regional and local oceanographic cruises**

Twenty-three cruises, four regional or mesoscale, and nineteen local, have been performed during the 33 months span of the EUROMARGE-NB Project (Table 2). At all, they represent 253 days of work at sea. The specific objectives and summary reports of each of these cruises have been delivered to the MAST Programme as ROSCOP forms (Canals et al., 1994 and 1995).

These cruises have concentrated on water column, water-sediment interface and sediment investigations, together with the recovery; maintenance and redeployment operations of the moored arrays. Intensive field samplings and measurements have been carried out till 2400 m to provide information about the circulation, biogeochemical transfers and biological processes in the water column, geological processes at the sediment water interface, biogeochemical fluxes at the sediment water interface and sediment records.

Approximately 900 CTD casts have been recorded, some of them with transmissometer, fluorimeter and oxygen probes. ADCP underway measurements have been performed during two cruises. An approximate amount of 1100 water samples has been obtained from rosettes during CTD casts. Analyses included total suspended matter, size spectrum of seston, POC, trace metals and radionuclides. A number of other parameters have been also analysed (phenol compounds and carbohydrates, nutrients, chlorophyll,...) in a sub-set of stations (Sánchez-Cabeza and Canals, 1996).

Sediment samples have been collected using mostly a multicorer, but also box corers and gravity corers. Over 100 cores have been collected and analysed for a variety of
parameters such as biochemical parameters, paleoceanographic indicators, trace metals, radionuclides, etc. Also, 24 cores have been dated for $^{210}\text{Pb}$. Approximately 110 zooplankton net hauls have been performed (Sánchez-Cabeza and Canals, 1996).

Benthic samples have been taken using a multicorer and a box corer for meio- and macrofauna analysis, respectively. Benthic macrofauna has been also investigated by means of Sediment Profile Imagery, SPI (Rhoads and Germano, 1982). Parallel sampling was made for the study of granulometry and sedimentary particulate organic matter. Benthic metabolism in terms of oxygen consumption and CO$_2$ production was measured in situ with a free-vehicle automated lander (4 deployments) equipped with oxygen sensors and sequential water samplers.

A large amount of «non conventional» data were also collected during the project, such as high resolution seismic profiles, multibeam bathymetric profiles, deep-towed side scan images, vertical video profiles, acoustic reflection on marine organisms. Large volumes of surface water and atmospheric particles were sampled for radionuclide analysis.

RESULTS

Circulation

- Surface circulation at basin scale

The four key sites are under the influence of a common regional surface circulation that skirts the slopes of the Northwestern Mediterranean Basin: the Northern Current. The density-related flow (Fig. 2) and the current (ADCP) measurements (Fig. 3) reveal the position and structure of the regional slope current and the presence of frontal structures near the shelf-break.

- Deep slope currents

Deep currents along the continental slope, albeit much weaker than the surface flow, are likely to control the exportation of shelf material at depth. For that reason, current meter measurements, coupled to sediment trap measurements, were collected at the four experimental sites. With twelve moorings deployed in submarine canyons and on their adjacent open-slope, this current meter monitoring represents the first intensive follow-up of near-bottom and mid-depth slope currents in the Northwestern Mediterranean Basin. These observations complement deeper current measurements made within the same area during the SOFARGOS project.

Near-bottom currents appear to be strongly constraint by the local topography (Fig. 4). This is particularly obvious inside the canyons and to some extent in interfluve locations. This seems to validate some numerical experiments about the Neptune effect on the circulation in the Western Mediterranean (EUROMODEL Project). At intermediate depths the ellipses of variance are rather isotropic and do not indicate any marked topographic control. However, the mean currents follow the continental slope direction as the slope frontal currents of the zone do (Fig. 3).
The spectral analysis emphasize different dynamics for the across and along isobath components. The across-isobath component is dominated by inertial frequency motions and the along-isobath component presents a very intense peak at lower frequencies (2-10 days band). This spectra is seasonally variable and differs slightly from site to site. In general, it is observed that the low frequency band is stronger in winter. In summer, the energy increases towards the inertial band almost everywhere.

Eddy activity of currents is higher at deep levels than at mid-depth. The winter EKE increase, reported for surface currents by other studies made in the Ligurian Sea (EUROMODEL Project), is confirmed for the Marseilles, Barcelona and Baleares sites, where the Northern Current skirts the slope. The Perpignan site appears to be less affected by the fluctuations of the Northern Current, as this latter left the slope.

Suspended particulate matter: Distribution and composition

- Distribution of the suspended particulate matter

The simultaneous measurement of several optical parameters (transmission, scattering, fluorescence) offers an efficient tool to distinguish the organic and inorganic suspended matter. The profiles gathered during the various cruises (Fig. 5) show: i) a surface layer about 100 m thick linked to the thermocline, the high fluorescence values being due to phytoplankton biomass, ii) intermediate nepheloid layers, developing at shelf break or at mid-slope depths, concomitant with density gradients and probably due to resuspension, iii) the presence of a turbid bottom layer.

These observations confirm the following typology:

- The two extreme sites, Marseilles and Baleares, are characterized by an strong development of a surface nepheloid layer and a minor extension and concentration of intermediate nepheloid layers.

- The large development of surface nepheloid layers in the slope between Perpignan and Barcelona, particularly in the canyon axis.

- The central part of the Northwestern Mediterranean Basin is marked by the lack of a bottom nepheloid layer.

- Surficial and near-bottom spatial distribution of SPM concentrations are displayed at Fig. 6. Surficial SPM concentrates a) along a strip close to the Catalan continental margin, specially on canyon heads, and b) in an offshore zone between Marseilles and Minorca, caused by the NW wind forcing of the Northern Current (Thunus, 1995). Near-bottom SPM concentrations show a general decrease with respect to surface values and only the shelves with fluvial inputs (Barcelona and Ebro) present significant concentrations.

- Comparison of light transmission and the distribution of large particles

For the first time, the concentration of large particles has been measured in the Northwestern Mediterranean Basin with a marine snow camera during the EUROMARGE 95 cruise. The aim was to characterize the distribution and
concentration of large particles (aggregates), that are sought to be a major contributor to the downward particulate fluxes measured by sediment traps. Combined vertical profiles of these parameters were made at few hours intervals. They clearly reveal some common features (Fig. 7): i) peaks at the shelf break and mid-depth nepheloid layers, ii) seaward decrease of concentrations, and iii) variations between experimental sites. Unlike the Marseilles and Baleares transects, that show reduced large particle concentrations below the shelf edge plume, the Perpignan transect shows large concentrations of aggregates in the canyon head and within mid-depth layers in the lower canyon.

- **Particulate organic carbon and nitrogen**

  Figs. 8 and 9 show the surficial and near-bottom distribution of POC (wt %) and C/N relation. In the surface layer the high values of POC appear as spots along the continental margin. These maximums are inversely correlated with both SPM concentration and C/N relation. In the near-bottom layer, the maximum values of POC and C/N are situated in deep-basin locations, associated either to pelagic/degraded and/or bottom resuspension sources.

- **Major elements and trace metals**

  Suspended particulate material was analysed for major elemental composition: Cl, Si, Al, Fe, Mg, Ca, K, Ti, Mn, P, S and Ba, as well as for trace elements for a selected number of water stations: Cr, Co, Ni, Zn, Cu, As, Cd, Sn and Pb. In addition, complementary analyses were performed for the particulate organic carbon and nitrogen.

  The major element chemistry of the SPM in the Marseilles transect shows very clearly the plume of material derived from the shelf edge to be dominated by, excluding carbon, alumino-silicates and calcium. The phosphorous concentration, total and excess, appears not to correlate with the fluorescence; the greatest concentrations appear around the shallow depths.

  The Perpignan transect shows an area of sediment resuspension on the shelf and a plume of material derived from the shelf edge. Excess particulate silica is shown focused in two areas of surface waters. Organic phosphorous shows greatest concentrations on the shelf.

  The Baleares transect shows lower values of major elements than the other two transects and appears not to exhibit a shelf edge derived plume of material. Instead, a plume of material exhibiting higher aluminium and calcium figures was seen on the shelf-slope region. Total particulate silica concentrations are dominated by excess values and occupy the surface waters.
Biological production and processes in the water column

- Phytoplankton communities

Phytoplankton was analysed qualitatively by taxonomic identifications and quantitatively by estimation of cell biomasses from counts and biovolume calculations. The relative importance of three size classes: e.g. ultra-plankton (< 10 mm), nanoplankton (cell size between 10 and 20 mm) and microplankton (> 20 mm) was also determined.

Biomass profiles (Table 3) clearly show low values in surface waters (between 15 and 60 mg.m\(^{-3}\) or 1 to 5 mgC.m\(^{-3}\)), a maximum around 40 m depth (228 mg.m\(^{-3}\) or 18 mgC.m\(^{-3}\) in Perpignan at 40m) and very low values at 100 m (below 1 mgC.m\(^{-3}\)). Cell numbers decrease from surface to the bottom of the euphotic layer as surface waters are colonised by smaller cells living on regenerated nutrients. They take part to the microbial loop, while maximum biomasses correspond to microplanktonic forms growing in nutrient enriched waters. Because of the sampling season (summer), dinoflagellates were well represented and often dominant in the three sites. At the opposite, diatoms were abundant only in coastal samples. The relative importance of the different size fractions differs in detail from site to site, but ultra- and nanoplankton are usually the dominant fractions, except at the biomass maximum around 40 m. Coccolithophorids are better represented in Marseilles and Perpignan, and are localised in the lower part of the photic zone (maximum at 65m) at the Baleares site, but never are the main component of the Phytoplankton. The Perpignan site appears to be the richest, both in species number and in biomass values.

- Primary production

Primary production, estimated from «in situ» incubations with the Let-go apparatus at the three sites (Marseilles, Perpignan and Baleares) presents different structures and functioning systems, and displays a wide variability from coastal areas to open sea.

The Perpignan site (coastal area) is the richest with the highest production. Temperature stratification is less pronounced than in other sites. Chlorophyll and production maximal occur around 40 m and surface and subsurface layers are devoid of nutrients. The nitracline depth appears at 30m near the coast and sinks to 50 m in open sea waters. The Baleares site is most characteristic of oligotrophic conditions found in early summer. Nutrients are lacking in the first 50 m and a low chlorophyll maximum is found between 60 and 70m. This situation is not improved in its coastal part. The Marseilles situation is somewhat intermediate, with a weak chlorophyll maximum at 50m in the coastal area, found deeper in the open sea part. Primary production is high near the coast in surface waters, but low elsewhere. Finally, from results collected during the last three years on the Marseilles site, the new production of this area is estimated to approximately 50 to 60 gC.m\(^{-2}\).y\(^{-1}\).
- Zooplankton and micronekton

Zooplankton communities were studied through different biological parameters such as species identifications, direct counts, biomass estimations, food uptake and energetic budget. Zooplankton was collected in the surface layer (0-50 cm) with a neuston net (330 mm mesh size) and in the water column, with a WP2 net (200 mm mesh size) between 0 and 200 m.

Zooplankton abundances in the water column are strongly influenced by vertical migrations on a site, but also depend on the distance from the coast and on morphological depth profiles. In coastal areas, most of the zooplanktonic biomass is found in the first 100 m. Surface layers are heterogeneous as vertical migrations occur during the night and high concentrations of copepods are found in the neuston layer, specially in Perpignan and Marseilles where maximum biomasses are registered. Nocturnal biomass of neustonic organisms is frequently 4 to 10 times higher than the diurnal one. A marked feeding rhythm with a nocturnal maximum appears in copepods collected in neustonic in oceanic waters of the Perpignan area, characterized by the highest concentrations of Chla. Taxonomic composition is different at the Baleares site where chaetognaths, cladocerans and gelatinous organisms as well as fish eggs are much more abundant than in Perpignan and Marseilles where copepods are largely dominant.

The size of the preys ingested by zooplanktonic organisms varies from 8 to 30 mm. It seems that particles below 8 mm are not ingested, which would indicate that ultraplankton is not included in the trophic chain but is restricted to the microbial loop system. Analyses on metabolism show an omnivorous feeding activity of the zooplanktonic compartment, influenced by the availability of Phytoplankton preys and particle density. The grazing pressure varies between 9 and 100% in Marseilles where particle density is particularly low.

Micronekton is mostly represented by crustaceans but includes also some fishes. Euphausiid species as well as peracarides have also a nyctemeral activity and are good indicators of water masses with typical neritic and oceanic species. Crustaceans are more abundant in the Baleares site but Boreomysis artica (a pseudo-oceanic mysid) is found only in canyon axis, along the Marseilles and Perpignan transects. This species is well-known to accumulate at the upper slope and in canyon heads. Two species of cyclothone fishes have an identical distribution on the three transects and are limited to open sea areas.

The coastal part of the Marseilles site is characterized by the concentration of pelagic zooplankton. The Baleares site receives superficial waters of oceanic origin and advection is only visible for neritic species in the Perpignan and Baleares transects.

- Acoustic detection of living particles in the water column

Three size categories were detected by acoustic reverberation, according to emission frequency:

- 120 kHz allowed the detection between 0 and 150m of organisms which size is over 0,5 cm
- 38 kHz was used in the 0-250m water column for organisms larger than 1.2 cm
- 12 kHz selected organisms larger than 3 cm between 0 and 400 m.

Smaller organisms are present in the first 50 m, during day or night, but maximum densities occur during the night. Middle size organisms are found during day time in the water column in shallow waters and migrate near surface waters during the night. Large organisms are never found in coastal waters below 100 m. They stay in deep waters during day time and migrate in the 0-200m layer at night. A general trend is the migration of organisms towards surface layers between 18 and 22 h. The Perpignan site is characterized by a vertical stratification, absent in the Baleares site. The situation is opposite at these two sites for the spatial distribution of organisms: in the Perpignan area, organisms are concentrated during day time in open sea waters and at night in coastal waters, while in the Baleares site maximum biomasses are observed in coastal areas during day time and in open sea areas at night.

Very small particles (ultraplankton, below 10 mm) remain in the water column, except probably for some coccolithophorids, and are included in the microbial loop in a system based on regeneration. Larger particles (nanoplankton and microplankton) are at the basis of the food chain and are used as food preys for zooplankton. Their production, which depends on nutrient supply and water fluxes, is limited to the first 100m of the water column. Secondary producers are characterized by their mobility and migrations are generally associated with feeding activities. Size of organisms increases with depth, and larger animals, including adult fishes, are rather found in open sea areas.

Particle dynamics

- Stationarity of the particulate system

Repeated variability of the particulate structures. While the hydrological structure is usually stable over short intervals of time (Fig. 10), significant changes in the vertical distribution of particle may occur over the same lapse of time, especially in the head of the canyons. However, turbid structures observed at close intervals at one shelf station off Perpignan show a clear recurrence of the bottom nepheloid layer (Fig. 10). Moreover, a two year follow-up for one shelf and one slope station along the Perpignan transect also shows a seasonal recurrence of the turbid structures (Fig. 11). The main features are winter mixing, a frequent and coherent presence of a shelf bottom nepheloid layer and a shelfbreak-depth intermediate nepheloid layer. The permanence of these structures suggests that suspended particulate matter transport on the shelf occurs mostly near the bottom and is exported seaward as a shelf edge plume.

Particle residence times, inferred from the dissolved and particulate $^{234}$Th distributions, are fairly constant on the shelf (about 15 days) and variable at slope stations (between 2 and 125 days). Although the conditions were not stationary, these results suggest rather different exchange kinetics on the shelf and the slope environments. The residence time of dissolved thorium is lower in the organic layer and inorganic particles seem to settle more rapidly. A rough estimate of particle settling velocity gives results from 0.83 to 2.93 m·d$^{-1}$. 

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- Shelf-slope exchanges

Preliminary results of the 1993-1995 follow-up in the Gulf of Lions indicate a good link between the hydrological and nephelometric vertical structures and gradients on the shelf and slope. This relation highlights the influence of two major advective processes (cyclonic general circulation and winter dense water cascading) involved in the exportation of suspended matter from the shelf (Durrieu de Madron and Panouse, 1996).

- Influence of the general circulation in summer

The general circulation was studied during two cruises made in summer 1994. The calm meteorological conditions during these cruises allowed us to evaluate the geostrophic circulation. The summer conditions are characterized by a strong density stratification. The nepheloid structures along the sections and on the entire shelf generally show either a mixed or a stratified turbid bottom layer associated with the density bottom mixed layer (BML). Most of the density profiles indicate that the BML is lighter than if the BML had been formed locally. This density anomaly suggests a downslope advection in the bottom layer and implies a seaward transfer of suspended matter. The bottom transport on the northern part of the shelf of the Gulf of Lions is likely to be driven by the cyclonic baroclinic circulation. Eventual detachment of this bottom layer occurs at the shelf edge, together with its isopycnal intrusion and dilution into the slope waters. On the south-eastern part of the shelf, the currents are mostly oriented across the shelf and have less effect on the cross-isobath bottom transport. Besides, the presence of a cold pool of bottom water, trapped in the depression located in the centre of the shelf and around which the cyclonic circulation flows, indicates that bathymetric features can hamper such bottom transport. However, exportation of suspended matter probably takes place where the currents leave the shelf, between the Marseilles and Perpignan sections.

- Influence of cascading of winter dense shelf waters

Winter dense water formation under the influence of evaporation and surface cooling is known to occur in the Gulf of Lions shelf. This water mass cascades from the shelf down to the slope until it reaches its buoyancy equilibrium at a few hundred meters deep. The influence of this winter downwelling on suspended matter exportation was studied during one cruise made in February 1995. Thermal and nephelometric profiles indicate the presence of mixed and cold water on the shelf. The spreading of this cold water layer is well traced over the slope environment between 100 and 200 m deep. The corresponding mid-depth maxima of turbidity and fluorescence reveal a rapid transfer of biogenic suspended matter from the shelf. This exportation is more intense on the Perpignan section, where the coldest bottom waters are observed, than on the Marseilles section. This enhanced southwestern exportation probably results from an increased dense water formation and spreading on the western shelf, linked to higher north-westerly winds frequency, the presence of wind-induced downwellings along the North-South Roussillon coast and, also, the westward transport of the cyclonic shelf circulation.
Numerical simulation of the particle transport

The knowledge acquired from the field observations in the Gulf of Lions area has been used to initiate the development of a particle-tracer model aimed at simulating the behaviour of the suspended matter on the continental margin and on the shelf area (Thunus, 1995). This approach takes advantage of the experience gained through the various applications of the PGCM (Prosper General Circulation Model), previously developed by the Oceane Group (Zuur, 1991).

The final objectives of the simulations are to locate the potential zone of accumulation/deposition of the suspended matter, and to identify the major processes and forcings to be considered in the analysis of its dispersion. A pragmatic approach is adopted, in order to avoid duplication and overlapping with the variety of nested and embedded hydrodynamic models which are presently under development in the area of the Gulf of Lions for other purposes. The long term goal here is to develop a rather user friendly, modular product, which do not requires prohibiting computer resources while correctly reproducing the major features observed or known to exist. Thus, the model is used as a tool to conduct general dispersion experiments, by injection of virtual particles at key locations, selected according to the field observations. Observed or modelled forcing (wind, flux of the Northern Current) are applied as drivers of the dynamics. The size and resolution of the domain, the settling velocities, the order of magnitude of the horizontal velocities as well as the available data determine the time scales which are relevant for such regional simulations. Special attention is paid to maintain a coherent ratio between the scales of the processes and the duration of the simulations. For instance, for particles having a residence time magnitude about 1 month in the water column and horizontal velocities of the order of 10 cm s\(^{-1}\), the appropriate spatial scale is about 260 km. Reciprocally, the size of the domain and the order of magnitude of the velocities determines the classes of particles which need to be included in the simulations. Fast settling particles deposit in the immediate surrounding of the sources, while very small, slow settling particle escape from the domain without settling significantly. The broad size distributions and the variety of particle's types (organic, mineral) makes it hopeless to calculate a precise spectrum of the settling velocities. To keep the model tractable, the particle population is actually characterized as a distribution of Stokes settling velocities. As the model is modular, such an standard distribution can be substituted at any time by any other settling velocities distribution either calculated or experimentally determined. By comparing the order of magnitude of the vertical velocities of the water with the Stokes' settling velocities, a rigorous resolution of the vertical velocities field appears to be of paramount importance in such simulations (Zuur, 1995). Indeed, the strong vertical gradients of the horizontal velocities may significantly modify the trajectories of particles according their settling velocities, and thus significantly promote their dispersion. Special attention is also paid to the critical problem of the open boundaries, in view of a future coupling with large scale hydrodynamical models.

The first series of simulations carried out to date address the effect of events of wind forcing and their influence on the transport of particle at time scale of weeks to months. The initial and boundary conditions are inferred from the GHRR seasonal climatological maps obtained by the inverse method. Virtual sources of particle are considered near the Rhone river outlet, on the continental shelf and along the continental margin in order to
estimate their dispersion (Fig. 12). The comparison between the seasonal situations confirms an enhanced exportation of the suspended material at the southwestern limit of the Gulf of Lions, a fact which is in agreement with the cascading effect of the SPM observed during the Suivilion experiment (Durrieu de Madron and Panouse, 1996). In the next future, the model shall be improved by adding resuspension and particle transformation modules while preserving its modular structure.

Particle fluxes: Temporal and spatial variability of total mass fluxes

Among the various studies necessary to improve our knowledge on the role of the oceans in the global cycling of CO₂, those dedicated to the mechanisms controlling particulate transfer in marine systems occupy a central position. On continental margins, biological, physical and geochemical processes distribute and inject large quantities of land-derived and/or surface-produced particulate matter to depth and ultimately to sediments (Monaco et al., 1990a; Biscaye and Anderson, 1994). The study of such processes passes through the ability to quantify and chemically assess downward fluxes of settling particles. Sediment traps are currently the only existing tool which allow such measurements and they are, for that reason, of paramount importance into the EUROMARGE-NB project.

The Northern Current, flowing along-slope from the northeast to the southwest, represents the major dynamical feature of this region (cf. Chap. 4.1) and is believed to be the main driving force controlling, over the entire NW Mediterranean margin, the water column distribution of suspended particles, the «source-term» of particle fluxes (Durrieu De Madron et al., 1990; Monaco et al., 1990a, b).

The range of observed fluxes of settling particles in the different sites of the Northwestern Mediterranean slopes is large, both in time and space. Total mass fluxes cover a broad range of values (almost 2 orders of magnitude) from approximately 1 mg m⁻² d⁻¹ to almost 50 g m⁻² d⁻¹ (Fig. 13). Nevertheless, fluxes exhibit similar temporal trends between the different experimental sites. Flux peaks are observed on several occasions, approximately during the same periods of the year and for all traps (e.g., canyon heads, canyon axes and open slopes): in October-November 93, February-March and May-July 94.

On a seasonal scale, total mass fluxes are higher during winter, a feature summarized by the seasonally weighted means of Fig. 14. Winter mean fluxes are generally 2-3 times higher than summer means for most traps. The only noteworthy differences concern: (i) the canyon axis and open slope traps off Marseilles and the Baleares where the seasonal differences are more pronounced, the winter means being up to 10 times higher than the summer means; and (ii) the near-bottom axis traps off Perpignan and Barcelona for which the seasonal means are reduced or equal.

Annual mean mass fluxes are closer to each other and cover a range of only 3 orders of magnitude from a minimum of 86 mg m⁻² d⁻¹ (Baleares) to a maximum of 17165 mg m⁻² d⁻¹ (Barcelona), the latter value being a biased annual estimate since it represents only summer values.

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These general features strongly suggest that temporal patterns of particle transfer on the Northwestern Mediterranean margin are largely controlled by factors (dynamical and/or climatic) that concern the mesoscale (several hundreds of km).

In terms of spatial variability, the experimental strategy allows to address flux variations at different scales. At the local scale (x * 1 - 10 Km), total mass fluxes decrease in the across-slope direction, from the canyon head down to the 1000 m mooring sites. Fig. 15 summarizes this general trend for the 4 mean sites. Mean annual fluxes are normalized to the mean flux of the 500 m.a.b trap in the canyon axis at mid-slope. In the near-bottom traps, fluxes markedly decrease downcanyon. Furthermore, fluxes at 35 m.a.b within the canyon axis are higher than on the open slope, except for the Marseilles site where the opposite is found. This situation confirms previous findings in the same region where fluxes measured within the canyon axis were 2 times higher than on the adjacent open slope (Radakovitch, 1995; Monaco et al., in preparation) and underlines the channelling effect of canyons which act as conduits for the transfer of particles to deeper parts of the slope. The fact that the Marseilles site reacts differently could be related to the shallower depth of deployment of the interfluve set with respect to the one in the canyon axis (750 vs. 1100 m). The interfluve set will receive therefore slightly more settling material from the shelf and upper slope. Finally, mean fluxes increase with depth at all canyon axis sites by a proportion of 1.6 to 3.2 (Fig. 14). This further confirms previous results obtained in various parts of the world ocean, where at any given location on the slope flux increases with increasing depth (Biscaye et al., 1988; Monaco et al., 1990b; Biscaye and Anderson, 1994; Heussner et al., 1996b).

At the mesoscale (x * 10 -100 Km), mean mass fluxes normalized to the mean flux of the 500 m.a.b canyon axis trap off Marseilles globally increase from the Marseilles site down to the Barcelona site to 34 times. They subsequently strongly decrease at the Baleares site. Downstream flux increase is approximately proportional for the various canyon traps at a given site, as shown by mean fluxes of traps in identical position, normalized to the mean fluxes of their counterpart traps in the Marseilles site: 3 to 4-fold increase at the Sète and Perpignan sites, 4 to 5 off Barcelona. This situation is not observed for the open slope traps, for which the flux increase is less important (1.9-fold increase for the Perpignan open slope trap) or even no flux increase as for the Barcelona open slope. For equivalent traps, the Baleares exhibit mean annual values which represent only 20-30 % those off Marseilles.

**Annual fluxes of the major constituents of settling particles**

Fig. 16 summarizes the overall compositional variability of settling particles from the various traps. Variability is expressed by the coefficient of variation (CV = standard deviation as % of the mean) of total mass flux and major constituents for each trap. On a general scale, variability is highest for the total mass fluxes and lowest for lithogenic contents. For all trap positions except canyon heads, contents in major biogenic constituents (organic and inorganic carbon, opal) become less variable in the direction of the general circulation, that is from Marseilles down to Barcelona and then strongly increase for the Baleares samples. For the variability in lithogenic content, on the contrary, a steady increase between Marseilles and the Baleares is found. The explanation of these general trends can be found in the covariation of composition with total mass flux (Heussner et al., 1996a).
The overall distribution of the weightened annual mean contents for each constituent and for all traps directly reflects that of total mass fluxes: the higher the mass fluxes, the lower the biogenic contents. Organic carbon means vary between 1.25 % (Sète) and 7.91 % (Balears). The general trend is a decrease southward from Marseilles to Barcelona. Balears samples present the highest mean at each trap position. Organic carbon content decreases in the following way: mid-water canyon axis trap, open slope, near-bottom canyon axis, canyon head. This reflects the progressive dilution of the marine biogenic signal by lithogenic particles (either resuspended or freshly introduced to the region by rivers).

The trends for mean inorganic carbon contents are less obvious since the range of values is very narrow. For equivalent trap positions, the Balears present the highest means for the near-bottom canyon and open slope traps. Inorganic carbon has two origins, detrital (through resuspension) and authigenic (primary flux signal from surficial waters), and the latter becomes more important, relatively, when the mass fluxes are low.

The highest opal means are generally observed for the mid-water and open slope traps, reinforcing the idea that this constituent originates from marine production.

The lithogenic fraction is calculated by subtracting organic matter (C org. x 2), carbonate (taken as calcium carbonate; C inorg. x 8.33) and opal from total mass flux. Mean values are quite similar from Marseilles to Perpignan (around 60 %), increasing slightly at the Barcelona site. The Balears present the lowest lithogenic mean contents, around 50 %. The terrigenous contribution is therefore dominant at all sites, even at the Balears, a result which is typical of continental margins.

From the combination of weighted mean mass fluxes and annual mean contents, mean annual fluxes of the major constituents are calculated for the different sites (Fig. 17). These values integrate the various sources of variations described above and represent therefore a basis of comparison with other parts of the Mediterranean. They are important to define the amount of particulate material exported to depth in sites of different trophic regimes.

The most striking feature of Fig. 17 is the strong contrast of fluxes along the continental margin from Marseilles down to Barcelona and those registered at the Balears site, which appear almost negligible. Fluxes in the southwestern part of the Gulf of Lions and off Barcelona largely dominate the system. The main characteristics of particle transfer are therefore a strong alongslope increase in the amount of material exported, an increase with depth at any site of the margin and an across-slope decrease. Particulate transfer on any of these constituents is essentially driven by the factors controlling the overall mass transfer.

These annual mean fluxes represent also the best available estimates of carbon inputs to the benthic system as well as the importance of carbon (e.g., energy) export from the surficial waters. Organic carbon is delivered either by primary production in overlying waters or by resuspension of deposited organic matter. Based on the present, but also on former results (Heussner et al., 1993), we therefore consider that 15-20 mg m$^{-2}$ d$^{-1}$ could be a good estimate of the amount of primary flux reaching the mid-slope depth of about 1000 m in this part of the Mediterranean. As a corollary, fluxes above this value should
represent advective transport of organic carbon from other parts of the margin, most probably the shelf and upper slope regions. This mechanism would therefore deliver from 40 (Perpignan open slope) to 70% (Barcelona canyon axis) of the organic carbon to mid-slope sediments, and almost the totality at canyon heads. These first order calculations are approximately correct only if one assumes that primary production and/or the amount of exported production (e.g., new production) is more or less constant over the entire system. Conan et al. (1996) estimate new production off Marseilles at 140-160 mg C m⁻² d⁻¹. Despite all the approximations made in this kind of calculation, this estimate would indicate that almost 90% of the exported production would be remineralized (or exported laterally) during particle settling through the first hundreds meters of the water column. Further integration of this kind of results will be necessary in the future to better assess carbon export from surficial waters.

Factors controlling particle transfer vs. flux variations

Daily river discharges (Rhône and Llobregat) and meteorological conditions (wind speed and direction) at 2 sites (near Marseilles and near Perpignan) are so far available, and allow to investigate the connections between flux variations and variations of some internal (dynamical and hydrological) and external (climatological) factors (cf. Chap. 3 and 4.1, and Fig. 18).

As we have seen from the previous chapters, strong seasonal variations in total mass fluxes are recorded for the Marseilles and Baleares sites, with mean mass fluxes 5 to 10 times higher in winter than in summer (Fig. 14). On the Perpignan and Barcelona sites, winter fluxes differ from the summer fluxes by a factor of two at the most. Also, large fluctuations of mass fluxes appear at the same periods on the northern sites. Those observed in winter are generally concomitant with more intense winds and river discharges (Fig. 18). The rivers supply the shelf with particulate matter, while the wind enhances its resuspension and dispersion. The winter period is also characterized by an homogenization of the water column, dense shelf water cascading (Durrieu de Madron and Panouse, 1996) and an intensification of the mean flow and current variability at depth. Thunus (1996) shows from numerical simulations that the seasonal changes of the shelf circulation in the Gulf of Lions yield significant different dispersion patterns of particulate matter with an enhanced winter exportation of the suspended material at the southwestern limit of the Gulf of Lions (Durrieu de Madron et al., 1996). The role of these latter exchange processes is confirmed, but with strong spatial variations due mainly to the bathymorphologic constraints.

The mesoscale variability of the deep slope current has been characterized by monthly kinetic energy (mean and eddy kinetic energies) by Heussner et al. (1996a). A winter increase of monthly KE values is observed at the Marseilles, Barcelona and Baleares sites, where the Northern Current skirts the slope. These periods of intensified flow and shelf-slope exchanges are coherent with some major winter peaks of mass fluxes. The Perpignan site, which is located outside the main path of the Northern Current, is little affected by its winter mesoscale variability. However, even under different dynamical conditions, large mass flux peaks also occur during winter. The latter probably results from other exportation processes, as for example the intensification of shelf circulation and cascading of dense water formed on the shelf, which is particularly strong on the southwestern part of the Gulf of Lions. These results emphasize the simultaneous
influence of various climatological and dynamical processes, which converge to produce conditions extremely favourable to off-shelf export of particulate matter.

The benthic response

Meiofauna, which represents the more reactive component of the benthic faunal compartment, has been investigated during three cruises: Flubal 93, Euroswap 94 and Euromarge 95 (cf. Chap. 3). Benthic macrofauna has been analysed during the last two cruises.

As a result, two faunal patterns can be pointed out:

a) The first is related to the continental margin and shows unexpectedly, at comparable depths, a relative enhancement of meiofaunal densities in the canyon axes as compared to the adjacent interfluves (Fig. 19); this is particularly well illustrated by the Flubal '93 and Euroswap '94 Figs.

b) The second, more classical pattern, is observed at the Balearic margin where meiobenthos abundances regularly decrease with increasing depths.

The average level of meiofaunal abundance recorded during each cruise is roughly comprised in the 250-750 ind.5 cm⁻² range and does not reflect a significant year-to-year variation among the entire ecosystem. While referring to the same period (e.g., June to August), Table 4 data set however support the hypothesis of the enhancement of communities in 1995. Patchiness of populations strongly affects mean values of densities which should therefore be considered under circumspection. By comparison with previous records (see, for example, the review by Soyer, 1985), the relative high level of standing stocks recorded during the Euromarge-NB experiment is explained by the better efficiency of the multi-corer as compared to other samplers such as the Reineck and/or the USNEL box-corers (Bett et al., 1994).

Macrofauna is particularly scarce in the whole investigated area and should therefore be considered as undersampled. No significant feature is therefore detectable with regard to an interfluve vs. axis comparison. The species composition however shows a dominance of Bivalves at the northern sites (e.g. Marseilles and Perpignan) and the replacement of these by Polychaetes at the Balearic margin. Faunal abundance and composition which are presumably linked to energy supply to the seabed thus reveal differences in the functioning of the four selected sites of the benthic survey.

Analysis of SPI and surface photographs have revealed evidence of a zone of intense crustacean bioturbation on the mid continental slope between 400 and 1000 m, which follows closely that of the zone of upper slope sediment accumulation described by Courp and Monaco (1990). The presence of large burrow fields whether active or relict are the integrated response of the benthos to sediment accumulation and organic carbon flux over time.

The presence of a zone of intense burrowing activity has important implications for sediment geochemistry. Burrows may increase the area of the sediment/water interface by a factor of > 2 which affects solute chemistry and microbial activity due to increased sub-surface sediment oxygenation. Excavated mounds change surface Benthic Boundary
Layer (BBL) flow characteristics and alter sediment shear characteristics. The mounds may act as baffles promoting retention of fine material in the troughs. Relict burrows identifiable in profile images due to infill by pellet fluff must promote rapid sub-surface transfer of 'fresh' organic material.

Given the lack of autochtonous primary production, the benthic biota is entirely supported by organic matter supply at the sediment-water interface. Faunal abundance is therefore expected to be linked to biochemical parameters which classically refers to the bulk of POM (TOC, POC, TON) or to its utilizable fractions (hydrolyzable organic carbon «HOC», total amino acids «Aa», total sugars). All these descriptors were taken into account in the three synoptic surveys while a special attention was paid to chlorophyllous pigments as indicators of phytodetritus deposition.

From the rather large data set (17<n<66) collected over the 1993-1995 period, several statistically significant positive correlations have been found (Buscail et al., 1996). It is confirmed that the widely used POC descriptor has poor meaning with respect to the trophic conditions on the bottom. The observed covariation of meiofauna and nitrogen underlines the general relationship with the pool of organic matter while, surprisingly, negative trends are found with descriptors of the POM labile fractions (HOC, aminoacids, sugars). It should be mentioned that meiobenthos density is also independent from the geochemical nature of the substrate (characterized by the carbonate content) of the Northwestern Mediterranean system (Buscail et al., 1996). Apart from nitrogen, the best explanation of the community standing stock is finally found in the abundance of phytodetritic matter at the sediment-water interface, particularly through Chl.a content which is related to freshly sedimented material. This suggest the prominent role of phytoplanktonic blooms in sustaining the benthic biomass.

By targeting all core samples near the sites of sediment trap moorings, the sampling strategy of Euromarge-NB intended to find new evidence of the benthic-pelagic coupling. A few pairwise comparisons between fluxes and faunal biomasses are so far available, all of them drawn from the Lacaze-Duthiers (Perpignan site) experiment of June 1994. An acute concordance is found between meiofauna densities and mass fluxes measured at 35-40 m.a.b. during the 15-days period preceding the benthic sampling. More detailed analysis of the sediment trap organic matter reveals that POC, nitrogen, aminoacids and sugar fluxes are equally linked with the meiobenthos standing stocks. Reversely, no covariation between chlorophyllous pigments and meiofauna is observed. Additional data from similar experiments previously conducted in the tropical Atlantic and Bay of Biscay finally lead to a linear model for the meiofauna-POC flux relationship (Fig. 20).
Carbon budgets

The integration of primary productivity data, measured carbon fluxes through the water column, carbon fluxes reaching the sediment/water interface (derived from sedimentation rates measured by $^{210}$Pb, organic carbon content in the sediment, and sediment bulk density) and the organic carbon content in the subsurface sediment allows to establish the carbon budget for a given site. The calculation procedure follows the guidelines by Buscail et al. (1990), who calculated the carbon budget in the Perpignan mesotrophic site. During EUROMARGE-NB this budget has been established for the first time in the Marseilles, Barcelona and Baleares sites, and recalculated for the Perpignan site.

The Baleares carbon budget represents the first obtained in Western Mediterranean oligotrophic conditions (Fig. 21). The primary productivity amounts 110.5 $\text{gr C m}^{-2} \text{ y}^{-1}$ (Estrada and Margalef, 1988). Only 2.22% of the primary productivity reaches the 700 m depth sediment trap, while 4.5% of the primary productivity is measured at the near-bottom, 1200 m depth, sediment trap. This situation indicates an advective input which represents about the 50% of the carbon near-bottom flux. Again, in surface sediment, a decrease is observed, down to 3.9% of the primary productivity. This decrease represents a loss of 12.2% with respect to the near-bottom sediment trap flux. The reasons for that decrease are not known strictly. Finally, the subsurface sediment contains a mean of organic carbon of only 0.3%, it is 1.8% of the measured primary productivity, or about half the carbon content of the surface sediment. So, only about 2% of the surficial waters primary productivity becomes stocked into the sediment.

ACKNOWLEDGEMENTS

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Due to its nature, a synthetic article cannot include all the relevant and detailed information produced during the project's life, and the decision about what has to be included, being subjective by nature, is the responsibility only of the Project Coordinator. For those colleagues whose contributions are not included in this synthesis, it is necessary to state that their inputs are equally appreciated and have at least the same scientific merit than the ones finally chosen and as such they have been incorporated in the Extended Contribution volumes which complement and complete this synthesis, and which were released to the EC in due time.
REFERENCES


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<td>IV 11</td>
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<td>40.13°N-03.29°E</td>
<td>1350-Ca</td>
<td>30-500</td>
<td>05.94-06.95</td>
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<td>IV 12</td>
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<td>850-In</td>
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Table 2.- Research cruises carried out into the EUROMARGE-NB project.

<table>
<thead>
<tr>
<th>Dates</th>
<th>Cruise name</th>
<th>Research ship</th>
<th>Study sites</th>
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<tr>
<td>Mesoscale cruises</td>
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<tr>
<td>30.07-18.08.93</td>
<td>Fluvial '93</td>
<td>Minerva</td>
<td>I to IV</td>
</tr>
<tr>
<td>17.06-02.07.94</td>
<td>Eurosweep '94</td>
<td>Tethys II</td>
<td>II, III and IV</td>
</tr>
<tr>
<td>15.05-01.06.95</td>
<td>Big '95</td>
<td>Hesperides</td>
<td>IV and S of III</td>
</tr>
<tr>
<td>04.06-08.07.95</td>
<td>Euromarge '95</td>
<td>Le Suroît</td>
<td>I to IV</td>
</tr>
<tr>
<td></td>
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<tr>
<td>Local cruises</td>
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<tr>
<td>20.04-29.04.93</td>
<td>Concentra I</td>
<td>Garcia del Cid</td>
<td>III</td>
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<tr>
<td>01.06-22.06.93</td>
<td>Varimed</td>
<td>Hesperides</td>
<td>III and IV</td>
</tr>
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<td>03.09-05.09.93</td>
<td>Suivillon 4</td>
<td>P. Georges Petit</td>
<td>I and II</td>
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<td>Suivillon 5</td>
<td>Tethys II</td>
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<td>22.10-25.10.93</td>
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<td>Garcia del Cid</td>
<td>III</td>
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<td>22.11-01.12.93</td>
<td>Technillon 2</td>
<td>P. Georges Petit</td>
<td>II</td>
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<td>04.12.93</td>
<td>Suivillon 6</td>
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<td>II</td>
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<td>12.02-13.02.94</td>
<td>Suivillon 7</td>
<td>L'Europe</td>
<td>I and II</td>
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<td>24.04-02.05.94</td>
<td>Suivillon 8</td>
<td>L'Europe</td>
<td>I and II</td>
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<td>Garcia del Cid</td>
<td>III and IV</td>
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<td>Suivillon 9</td>
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<td>I and II</td>
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<td>L'Europe</td>
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<td>P. Georges Petit</td>
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<td>I and II</td>
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<td>Garcia del Cid</td>
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<td>28.11-05.12.94</td>
<td>Balear Traps II</td>
<td>Salvamar C.B.</td>
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<td>Tethys II</td>
<td>II</td>
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<td>17.05-27.05.95</td>
<td>Suivillon 12</td>
<td>P. Georges Petit</td>
<td>I and II</td>
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Table 3.- Total phytoplanktonic biomass in the Baleares, Perpignan and Marseilles sites. Figures in mg m$^{-3}$

<table>
<thead>
<tr>
<th>Depth</th>
<th>Baleares</th>
<th>Perpignan</th>
<th>Marseilles</th>
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<td>100m</td>
<td>9</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>65m</td>
<td>49</td>
<td>71</td>
<td>29</td>
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<tr>
<td>40m</td>
<td>79</td>
<td>228</td>
<td>32</td>
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<td>20m</td>
<td>23</td>
<td>66</td>
<td>45</td>
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<tr>
<td>5m</td>
<td>59</td>
<td>58</td>
<td>15</td>
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Table 4.- Mean densities of meiobenthos at the four main depth levels (A= 250-300m, B = 500-800m, C = 1000-1400 m, D = 2000-2200 m) of the Euromarge-NB experiment (1993-1995).

<table>
<thead>
<tr>
<th></th>
<th>1993</th>
<th>1994</th>
<th>1995</th>
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<td>Interfluve</td>
<td>Axis</td>
<td>Interfluve</td>
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<tr>
<td>Mean</td>
<td>409.03</td>
<td>560.83</td>
<td>629.67</td>
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<td>S.E.</td>
<td>125.01</td>
<td>232.08</td>
<td>62.06</td>
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<td>n</td>
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<td>11</td>
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<table>
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<tr>
<th></th>
<th>1993</th>
<th>1994</th>
<th>1995</th>
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<tbody>
<tr>
<td></td>
<td>Interfluve</td>
<td>Axis</td>
<td>Interfluve</td>
</tr>
<tr>
<td>Mean</td>
<td>376.99</td>
<td>347.10</td>
<td>304.94</td>
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<tr>
<td>S.E.</td>
<td>107.63</td>
<td>155.19</td>
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<td>n</td>
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<td>18</td>
<td>9</td>
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</table>

D.S.E. | 174.60 |

n     | 6     |