

VERTICAL FLUX AND MICROPLANKTON ASSEMBLAGES IN THE GULF OF LIONS DURING SPRING 1990

R.D. PEINERT^{a,b}, S.W. FOWLER^b, J.L.A. ROSA^b,
J.-C. MIQUEL^b & J.-L. TEYSSIE^b

*a Institut für Meereskunde
Düsternbrooker Weg 20, D-2300 KIEL 1, GERMANY*
*b International Atomic Energy Agency
Marine Environment Laboratory
19, Av. des Castellans, MC-98000 MONACO*

ABSTRACT

A vertical flux pulse related to spring phytoplankton development was recorded by moored sediment traps at 42°N 06°E in the Gulf of Lions. May 1990 trap samples from 200m to 2000m depth were comprised of freshly produced organic matter and selected microplankton species from the overlying water column. This vertical flux event was transmitted to the deep sea floor with a high particle sinking velocity of >140 m day⁻¹. Maximal vertical fluxes of 35 mg C m⁻² day⁻¹ and 1.2 mg chl. *a* m⁻² day⁻¹ recorded during this event are low compared to the exports from collapsing spring blooms at higher latitudes but demonstrate that particle production and degradation within the spring pelagic system were not in balance.

INTRODUCTION

Seasonality in vertical particulate fluxes has been reported to occur in various oceanic regimes (Deuser et al. 1981, Honjo 1982) and is generally linked to primary production in the overlying waters. In certain areas, particularly at high latitudes, the seasonal signal reaches the deep-sea floor as a pulse of phytoplankton-derived material emanating from the spring bloom (e.g. Lampitt 1985). Spring vertical flux pulses with an autotrophic origin have not been documented for the Mediterranean Sea. This enclosed ocean is commonly regarded as oligotrophic (Cruzado and Velasquez 1989) implying a low export potential for particles produced in the surface layers. The NW-Mediterranean, however, has particular characteristics as it receives an important river input. Also, vigorous and deep vertical mixing takes place south of the Liguro-Provencal current during winter replenishing nutrient reserves (Cruzado and Velasquez 1989) and at the same time primary production is reduced by light limitation (Williams and Robinson 1990).

Phytoplankton production based on new nutrients *sensu* Dugdale and Goering (1967) normally triggers a spring bloom by April in this offshore region (Minas and Minas 1989). Sedimentation may indeed be the fate for parts of this spring primary produced matter. Such vertical flux events seasonally couple the deep-sea with the pelagic system and stimulate benthic activity (Graf 1989) and aggregates are thought to be important transport vehicles (Alldredge and Silver 1988). By "sweeping" the water column (Smetacek 1985) they may shorten the residence time of clay minerals (Honjo 1982) and other particle associated matter such as trace elements (Fowler et al. this volume), radionuclides and other pollutants. To examine temporal patterns of the vertical particulate flux in the NW-Mediterranean during spring/early summer, a 10 week sediment trap experiment was carried out in the Gulf of Lions as part of the EROS 2000 Programme.

MATERIAL AND METHODS

1. Vertical flux measurements

During the "CYBELE" cruise on board R.V. Marion Dufresne automatic multisample sediment traps (type PPS 3 TECHNICAP: cylindrico-conical collection jar, 0.125 m² aperture) were moored at 42°N 06°E in the Gulf of Lions about 60 nautical miles south of Toulon. From 14 April to 1 July, samples were obtained from 200 m, 500 m, 1000 m and 2000 m depth with a time resolution of 13 days. Trap sampling cups were filled with a 2% buffered formaldehyde solution prior to deployment to prevent *in situ* microbial degradation and grazing by swimmers (US GOFS 1989). Samples were stored at refrigerator temperature upon retrieval. Swimmers were removed prior to splitting by a combination of sieving (1000 µm and 330 µm mesh size) and picking. After taking subsamples of the particulate material for microscopy and chl.*a*, the remainder was desalted and freeze-dried for further analyses.

2. Water column measurements

Water samples were taken on 15 and 28 April at the mooring site. Our bottle casts were part of two time-series of measurements of 3 and 2 days duration each. Aliquots of water taken with Niskin or Go-Flow bottles were filtered on WHATMAN GF/F filters for carbon and chlorophyll *a* analyses. Filters were kept deep-frozen for later land-based analyses. Samples for microscopy were preserved with buffered formaldehyde (2% final concentration) and stored in the dark at room temperature.

3. Laboratory analyses

Microscopy was carried out on trap collections and water samples with an inverted microscope (Utermöhl, 1958). Chlorophyll *a* was measured by the trichromatic method (UNESCO, 1980) using the formula of Jeffrey and Humphrey (1975). A HERAEUS CHN-O-RAPID analyser was used for

carbon analyses. Prior to organic carbon measurements, carbonate was removed by treating samples with 1 M phosphoric acid.

RESULTS AND DISCUSSION

1. WATER COLUMN MEASUREMENTS

Results from water sampling on 15 and 28 April at the mooring site demonstrate subsequent stages of a spring phytoplankton bloom during the early phase of seasonal warming.

On 15 April, chlorophyll *a* as well as carbon were rather evenly distributed in the upper 50 m, ranging between 0.6-0.8 mg chl.*a* m⁻³ and 120-200 mg C m⁻³, respectively (Fig. 1). A weak or a lack of stratification prevailed in the upper 60-80 m at this time, possibly due to mixing by a fierce northerly gale. An integral over 100 m depth yields 50 mg chl.*a* m⁻². Although this value falls into the lower range of results from other measurements taken at that time by Cruzado and Velasquez (pers. communication), it indicates significant autotrophic growth prior to our investigation in this region. Two weeks later on 28 April, a threefold increase in chlorophyll *a* (162 mg m⁻²) was measured in a water column with vertical mixing restricted to a shallow surface layer. Suspended POC had increased as well, albeit only by 20%. Maximum chl.*a* concentrations of >2.5 mg m⁻³ were found within the upper mixed layer but also distinct subsurface peaks were observed beneath it. POC:chl.*a*- ratios changed from about 200 : 1 to 100 : 1 (weight) between 15 and 28 April with minima in the surface- and subsurface phytoplankton peaks (Fig. 1). The data show an increased autotrophic contribution to total suspended carbon on 28 April.

These observations were confirmed with microscope analyses which showed a typical spring phytoplankton community dominated by diatoms. Differences between the two sampling dates for autotrophic microplankton cell numbers and species composition are depicted in Figure 1. Autotrophic biomass in the microplankton size-range was very low on 15 April. It was mainly comprised of two size-classes of the pennate diatom *Thalassiothrix* sp. (60 x 5 µm and 110 x 5 µm) and the 15 µm silicoflagellate *Dictyocha* sp.. Heterotrophic naked ciliates (50 µm diameter), at concentrations of 0.1 - 0.7x10³ cells per liter, were restricted to a discrete layer at 50 - 60 m depth at the base of the mixed layer whereas the autotrophs were rather evenly distributed in the upper 50 m. On 28 April, these naked ciliates were similarly abundant with an identical vertical distribution pattern as noted two weeks earlier. Samples, however, were clearly dominated by diatoms. Both *Thalassiothrix* sp. size-classes had markedly increased in abundance as well as the diatom *Rhizosolenia* sp. which had not been observed earlier. Silicoflagellates, as the only abundant non-diatom autotroph, showed no major differences between the two dates. Figure 1 also depicts substantial differences between the vertical distributions of the respective species.

suspended particulate matter at the mooring site

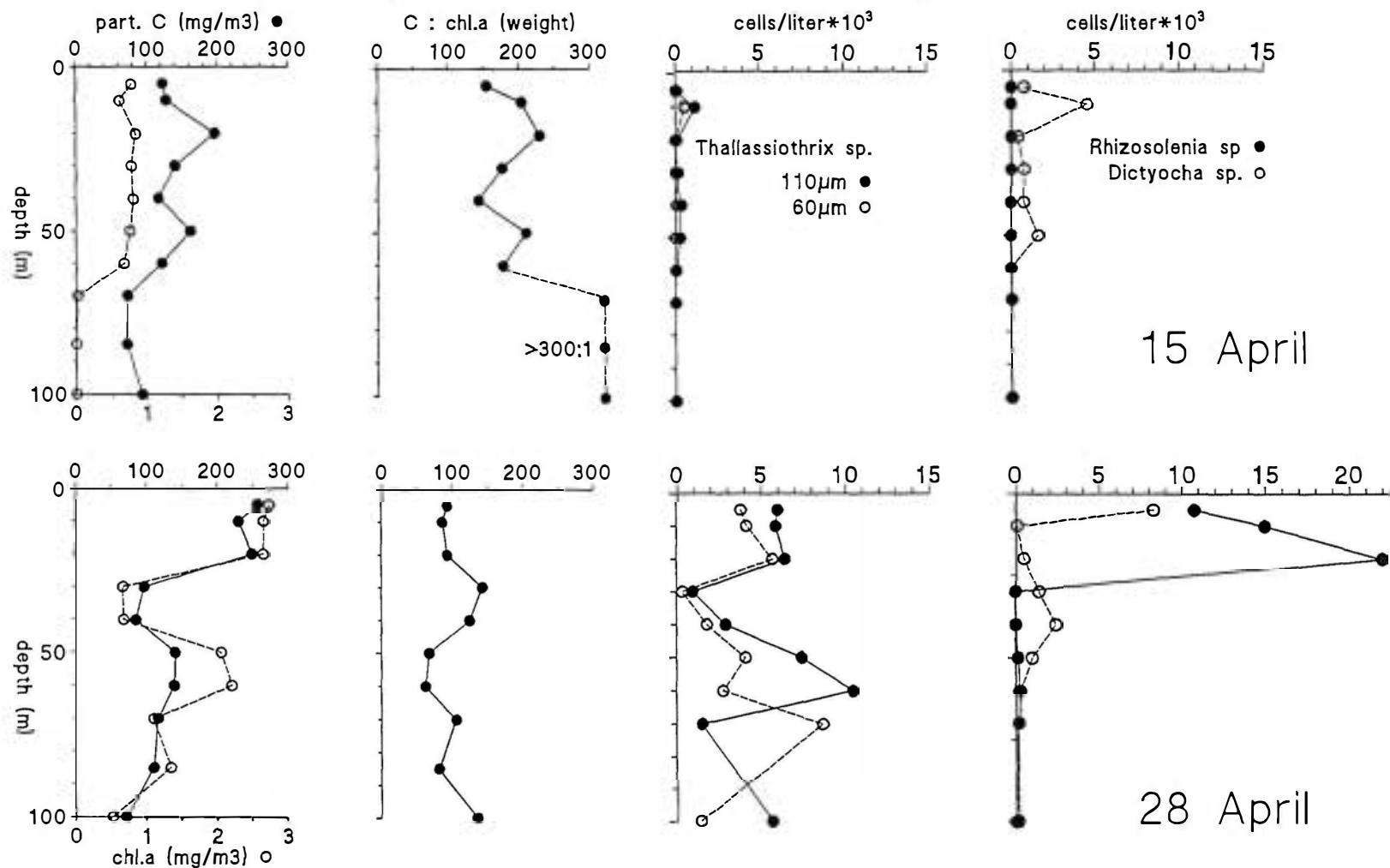


Fig. 1: Vertical distributions of particulate organic carbon, chlorophyll a, C:chl.a-ratios (weight) and cell numbers of three phytoplankters on April 15 & 28 (mooring site).

Rhizosolenia sp. was restricted to the upper 20 m layer whereas *Thalassiothrix* sp. was primarily located below 50 m depth but also contributed substantially to the population near the surface.

Cruzado (pers. communication) found that on 15 April about $1 \mu\text{M NO}_3$ was still available for primary production in near-surface layers and by 28 April concentrations were lowered by approximately a factor of 2 when suspended autotrophic biomass was high. These findings together with our results support the hypothesis that we sampled different stages of a diatom bloom development at the mooring site. However, CTD- and fluorescence profiles taken around 15 and 28 April, respectively, (Brun-Cottan 1991, CYBELE-cruise data report) suggest that our measurements were not made in the very same water mass. Changes in biological parameters between these dates may thus not be totally related to a true temporal development. Observed differences in concentration, composition and vertical distribution of suspended matter at the mooring site two weeks apart nevertheless remain characteristic for a spring bloom development and have a consistent relationship with vertical fluxes.

2. VERTICAL FLUXES AT THE MOORING SITE

Sediment trap collections from the station cover the spring to early summer period. Spring pelagic system dynamics left a clear fingerprint in trap samples by the amounts of matter exported from surface layers and by its composition.

As the outstanding feature, a very distinct vertical flux maximum of 310, 242 and 241 $\text{mg m}^{-2} \text{ day}^{-1}$ (dry weight) was recorded at 200 m, 1000 m and 2000 m, respectively, during the second trap sampling interval between 27 April and 10 May. Fluxes tailed off during the following two weeks and much lower values were measured towards early summer. Figure 2 depicts the organic carbon and chlorophyll *a* contributions. The two May trap collections from 500 m deviated from this pattern as the peak was much less pronounced. So far we consider this an artefact apparently restricted to the two May sampling intervals which has to be examined in greater detail. Results from the other deployment depths are consistent with respect to the time-pattern and the amounts of collected material and, hence, only these results are discussed here.

The 13 days resolution of our trap collections show that the vertical flux pulse happened on a scale of days after our second water column measurements on 28 April at the mooring site. The fact that the pulse was concomitantly recorded by the 200 m, 1000 m and 2000 m traps demonstrates the rapid transport of material to the deep-sea floor. Since the pulse was recorded during one single sampling interval at all three depths a minimum estimate of the sinking velocity for settling particles of $>140 \text{ m day}^{-1}$ can be computed for this period. This value falls within the range of $50 \text{ m} - 200 \text{ m day}^{-1}$ reported by Alldredge and Gotschalck (1989) for sinking diatom

aggregates.

Maximum org. carbon fluxes amounted to 35, 22 and 18 mg C m⁻² day⁻¹ at 200 m, 1000 m and 2000 m, respectively, increasing by a factor of 3 - 10 compared to the previous sampling interval. The prominent autotrophic source for the vertical flux during this period is shown by the very high chlorophyll *a* content of trap samples with a maximum of 1.2 mg chl.*a* m⁻² day⁻¹ recorded at 200 m (Fig. 2). The time pattern was even more pronounced than for POC since chl.*a* fluxes increased by a factor of 17 to 61 for the respective sampling depths. The spring vertical flux event, accordingly, was characterized by very low POC : chl.*a*- ratios for samples from all depths. Values <100 : 1 (Fig. 2) are even lower than those recorded for suspended matter on 28 April. Together with results from microscopical inspections of trap samples this suggests a preferential sedimentation of autotrophic matter compared to particles from other sources.

The two May sampling intervals represent 33% only of the total deployment time but they accounted for 60%, 87% and 82% of total organic carbon sedimentation at 200 m, 1000 m and 2000 m, respectively. These percentages are even higher for chlorophyll *a* (88%, 97% and 89%). Whereas the time-pattern is identical for all depth horizons, an overall decrease of vertical fluxes with depth is evident which signals degradation even of the particles that are exported with a high sinking velocity during the pulse.

Microscopical analyses showing numerous intact microorganisms as well as broken and empty frustules for the May trap samples are in accordance with these results. The trap samples in fact looked like enriched water samples with a high detrital component. Aggregates were not found in trap samples. High sinking velocities of >140 m day⁻¹ as calculated for particles settling during this period, however, can only be explained by aggregation since individual phytoplankton cells sink at a speed of a few m day⁻¹ or even slower (Smayda 1970, Bienfang 1980, Riebesell 1989). As these aggregates are notoriously fragile (Alldredge and Gotschalck 1989) it is very probable that they were destroyed during the preparation of samples for microscopy.

Settled microplankton was dominated by the pennate diatom *Thalassiothrix* sp. and the silicoflagellate *Dictyocha* sp. (Fig. 3), i.e. by the same species also recorded in the water column in April. However, three tintinnid species (*Eutintinnus* sp., *Dadayella* sp., *Dictyocysta* sp.) that were rarely observed in suspension were found in significant numbers in the May trap samples as well. Naked ciliates of 50 µm size were only collected by the 200 m trap and were restricted to the first sampling period in late April when they were also observed in a discrete layer at the base of the mixed layer.

A comparison of trap sample microplankton composition from the vertical flux peak with water column composition from 28 April indicates a species specific sedimentation of organisms as has also been found by Passow (1991) in the context of a sedimenting bloom. The diatom *Rhizosolenia* sp. which was a prominent form in the suspended diatoms was not collected by the traps in any significant numbers. The opposite was the case for the three

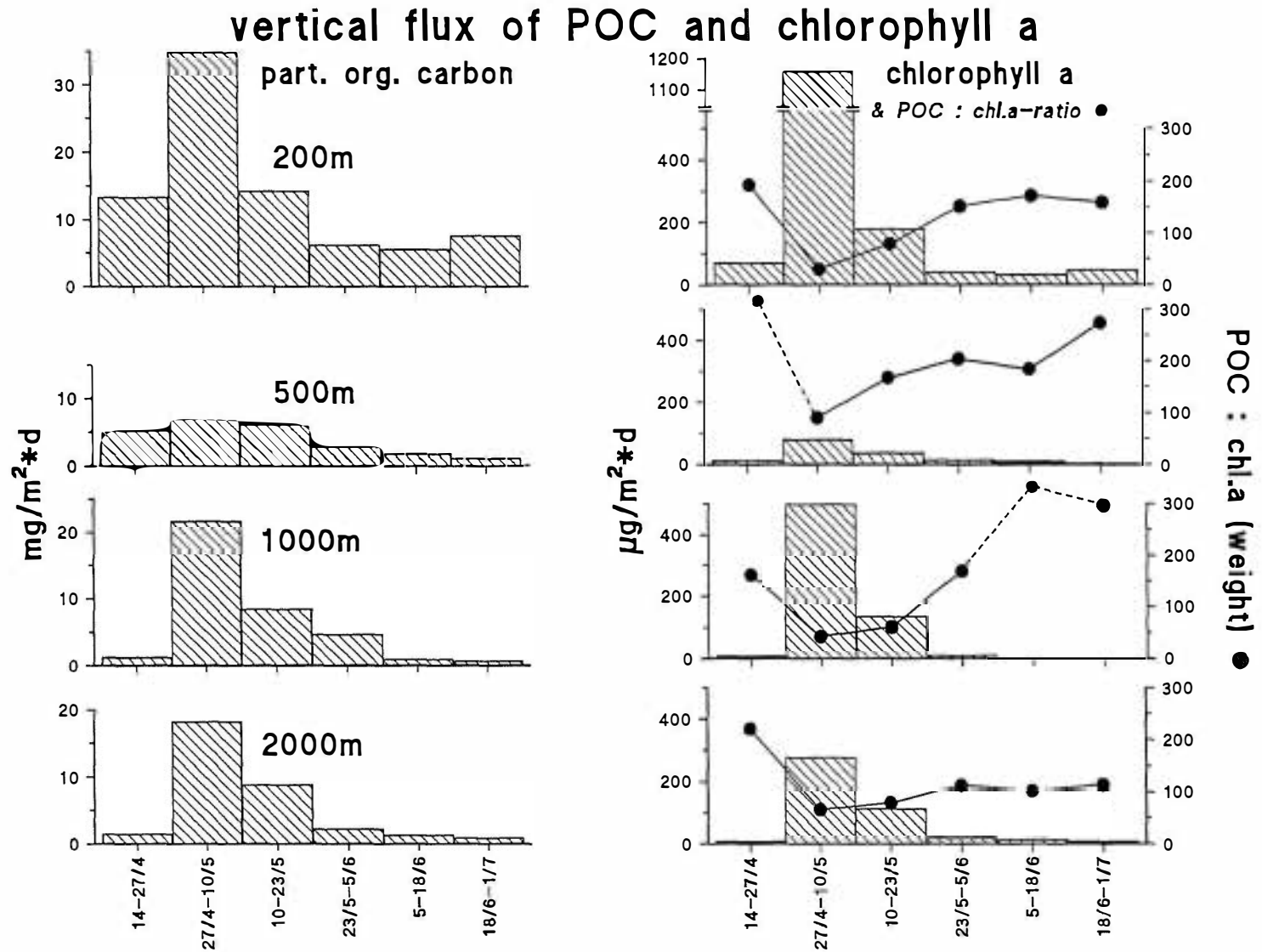


Fig. 2: Vertical flux of particulate organic carbon (POC) and chlorophyll a (histograms) recorded by moored automatic sediment traps. POC : chl.a- ratios (weight) given as dots.

vertical flux of microplankters

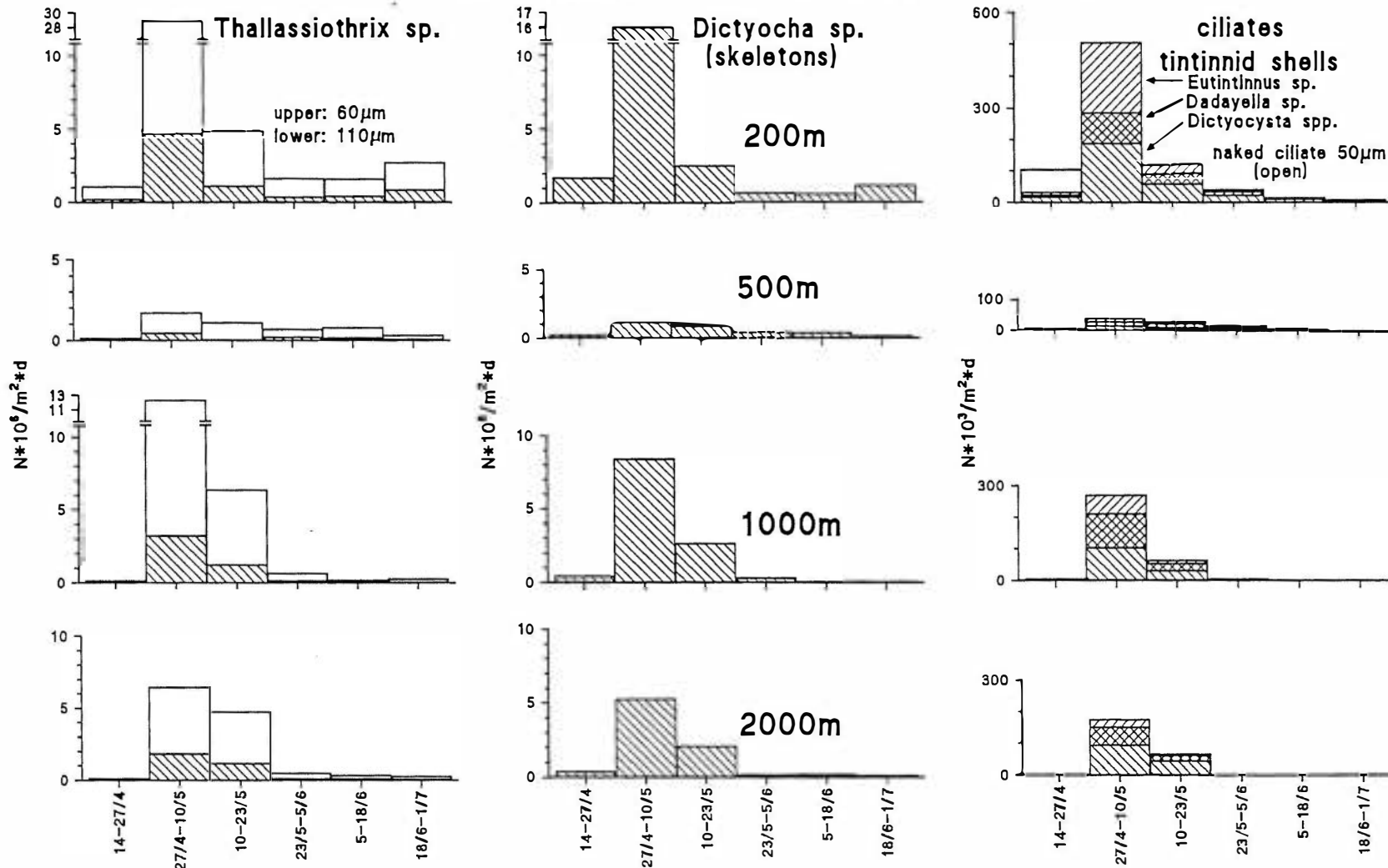


Fig. 3: Vertical flux of microplankton species (cell numbers) recorded by moored automatic sediment traps

tintinnid species which sedimented in large numbers but were rarely found in the water column. Other organisms did not sink in proportion to their abundance in the water column. The smaller size-class of *Thalassiothrix* sp., for example, was clearly overrepresented in trap samples. During the sedimentation peak the ratio small : large cells was 5.1 : 1 for the 200 m trap and 1.4 : 1 for those in suspension (100 m water column). Also, the silicoflagellate *Dictyocha* sp. sedimented in relatively larger numbers than *Thalassiothrix* sp.. The ratio of *Thalassiothrix* : *Dictyocha* cell numbers was 1.8 : 1 for the 200 m trap sample, compared to 6.3 : 1 for the water column.

The vertical flux of intact autotrophic cells did not abruptly cease towards early summer. However, vertical fluxes greatly decreased and trap sample composition changed concomitantly, indicating the seasonal transition to summer enhanced heterotrophic activity in the pelagic food web. Numbers of sedimented zooplankton fecal pellets increased markedly by a factor of >3 after the vertical flux pulse compared to the $2 - 4 \times 10^3 \text{ m}^{-2} \text{ day}^{-1}$ collected before and during the peak. The pellet contribution to trap samples was roughly estimated from measured volumes and assuming a density of 1.24 g cm^{-3} . Whereas pellets of different shape, size and origin lumped together formed a major portion of the (small) summer mass flux, their contribution was minor during the spring sedimentation peak (1 - 8%). The spring pellet sedimentation, although relatively low, nevertheless provides circumstantial evidence that spring phytoplankton growth did not take place without the influence of zooplankton grazing. Peinert et al. (1986, 1989) showed that grazing by certain zooplankton feeding types (e.g. filter feeding copepods) serves to retain bio-essential elements within the pelagic food web and, hence, counteracts losses via sedimentation. However, because of the nature of our sampling and the time-scale of the experiment, we can only speculate on the quantitative impact of zooplankton grazing on spring sedimentation in this region of the NW-Mediterranean.

CONCLUSION

If the results from this study are typical, spring phytoplankton development in the NW-Mediterranean Sea may be followed by a significant sedimentation event including intact cells of selected species. A considerable impact may be assumed with respect to a co-precipitation of suspended non-biogenic matter and other particle associated elements and compounds in the course of such events.

ACKNOWLEDGEMENTS

We thank captain C. Loudes and the crew of R.V. "Marion Dufresne" for their efficient service at sea. J.-C. Brun-Cottan is thanked for his efforts as the "CYBELE" cruise leader and for supplying hydrographical data. This work was funded by the Commission of the European Communities' programme under the contract number MAST-0016-C (EBD). The IAEA - Marine Environment Laboratory operates under an agreement between the International Atomic Energy Agency and the Government of Monaco.

REFERENCES

- ALLDREDGE, A.A. and C.C. GOTSCHALCK (1989). Direct observation of the mass flocculation of diatom blooms: characteristics, settling velocity and formation of diatom aggregates. *Deep-Sea Res.* **26**, 159-171.
- ALLDREDGE, A.A. and M. SILVER (1988). Characteristics, dynamics and significance of marine snow. *Prog. Oceanog.* **20**, 41-82.
- BIENFANG, P.K. (1980). Phytoplankton sinking rates in oligotrophic waters off Hawaii, USA. *Mar. Biol.* **61**, 69-77.
- BRUN-COTTAN, J.-C. (1991). Cruise and scientific report N.W. Mediterranean: R/V Marion Dufresne 12 April -10 May 1990, EROS 2000 programme. 83pp.
- CRUZADO A. and Z.R. VELASQUEZ (1989). Nutrient distribution in the Gulf of Lions. In: Proceedings from the EROS 2000 First Workshop on the Northwest Mediterranean Sea. eds. J.-M. Martin and H.Barth. *Water Pollution Research Reports of the Commission of the European Community* **13**, pp 67-78.
- DEUSER, W.G., E.H.ROSS and R.F. ANDERSON (1981). Seasonality in the supply of sediment to the deep Sargasso Sea and implications for the rapid transfer of matter to the deep ocean. *Deep-Sea Res.* **28**, 495-505.
- DUGDALE, R.C. and J.J. GOERING (1967). Uptake of new and regenerated forms of nitrogen in primary production. *Limnol. Oceanogr.* **12**, 196-206.
- FOWLER, S.W., T.F. HAMILTON, R.D. PEINERT, J. LAROSA and J.-L. TEYSSIE (*this volume*). The vertical flux of rare earth elements in the northwestern Mediterranean.

- GRAF, G. (1989). Benthic-pelagic coupling in a deep-sea benthic community. *Nature* **341**, 437-439.
- HONJO, S. (1982). Seasonality and interaction of biogenic and lithogenic particle flux at the Panama Basin. *Science* **218**, 883-884.
- JEFFREY, S.W. and G.F. HUMPHREY (1975). New spectrophotometric equations for determining chlorophylls a, b, c₁ and c₂ in higher plants, algae and natural phytoplankton. *Biochem. Physiol. Pflanzen* **167**, 191-194.
- LAMPITT, R.S. (1985). Evidence for the seasonal deposition of detritus to the deep-sea floor and its subsequent resuspension. *Deep-Sea Res.* **32**, 465-471.
- MINAS, M. and MINAS, H.J. (1989). Primary production in the Gulf of Lions, with considerations to the Rhone river inputs. In: Proceedings from the EROS 2000 First Workshop on the Northwest Mediterranean Sea. eds. J.-M. Martin and H.Barth. *Water Pollution Research Reports of the Commission of the European Community* **13**, pp 112-125.
- PASSOW, U. (1991). Species-specific sedimentation and sinking velocities of diatoms. *Mar. Biol.* **108**, 449-455.
- PEINERT, R., U. BATHMANN, B.V.BODUNGEN and T.NOJI (1987). The impact of grazing on spring phytoplankton growth and sedimentation in the Norwegian Current. In: Particle flux in the Ocean. eds. E.T.Degens, E.I.Izdar and S.Honjo. *Mitt. Geol.-Paläont. Inst., Univ. Hamburg. SCOPE/UNEP Sonderband* **62**, 149-164.
- PEINERT, R., B.V.BODUNGEN and V.S. SMETACEK (1989). Food web structure and loss rate. In: *Productivity of the ocean: present and past*. eds. W.H. Berger, V.S.Smetacek and G.Wefer. John Wiley & Sons Ltd., Chichester, pp 35-48.
- RIEBESELL, U. (1989). Comparison of sinking and sedimentation rate measurements in a diatom winter/spring bloom. *Mar. Ecol. Prog. Ser.* **54**, 109-119.
- SMAYDA, T.J. (1970). The suspension and sinking of phytoplankton in the sea. *Oceanogr. Mar. Biol. Ann. Rev.* **8**, 353-414.
- SMETACEK, V.S. (1985). Role of sinking in diatom life-history cycles: ecological, evolutionary and geological significance. *Mar. Biol.* **84**, 239-251.

- UNESCO (1980). Determination of chl.a in sea water. Report of intercalibration tests sponsored by SCOR. UNESCO Technical Papers in Marine Science.
- US GOFS (GLOBAL OCEAN FLUX STUDY) (1989). Sediment trap technology and sampling. *U.S.GOFS Planning Report 10*, 94pp.
- UTERMÖHL, H. (1958). Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. *Mitt. int. Verein. Limnol.* **9**, 1-38.
- WILLIAMS; P.J.le and C. ROBINSON (1990). Seasonal differences in the control of productivity in the Rhone Outfall Region of the Gulf of Lions. In: Proceedings from the EROS 2000 Second Workshop on the North-West Mediterranean Sea. eds. J.-M. Martin and H.Barth. *Water Pollution Research Reports of the Commission of the European Community* **20**, pp 145-154.