DEVELOPMENT OF THE LATE SUMMER PHYTOPLANKTON BLOOMS AT THE ENTRANCE TO THE GULF OF FINLAND: RESPONSE TO THE HYDROPHYSICAL AND METEOROLOGICAL CONDITIONS

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Introduction

Two multidisciplinary experiments were carried out by r/v Reet (EMI) and r/v Aranda (FIMR) at the entrance area to the Gulf of Finland in July 14-26, 1996 and July 14-27, 1997. The aim of these studies was to investigate the response of late summer phytoplankton blooms to the meso-scale hydrophysical processes and varying meteorological conditions. The meteorological conditions were quite different from year to year. Due to the cold and rainy summer in 1996 the phytoplankton bloom in our study area was mainly formed by a dinoflagellate *Heterocapsa triquetra* Ehrenberg and a cyanobacterium *Aphanizomenon flos-aquae* (Linné) Ralfs. In 1997, the experiment was carried out during an extraordinary intensive cyanobacterial bloom dominated by species *A. flos-aquae* and potentially toxic *Nodularia spumigena* Mertens.

Measurements

The hydrographic measurements consisted of meso-scale CTD surveys (among those using a towed undulating system) and current measurements using a ship-board ADCP and Aanderaa current meters deployed at the mooring stations. The biological parameters - fractionated chlorophyll *a*, primary production as well as phytoplankton species composition and biomass - were measured daily at the fixed stations (Fig. 1).

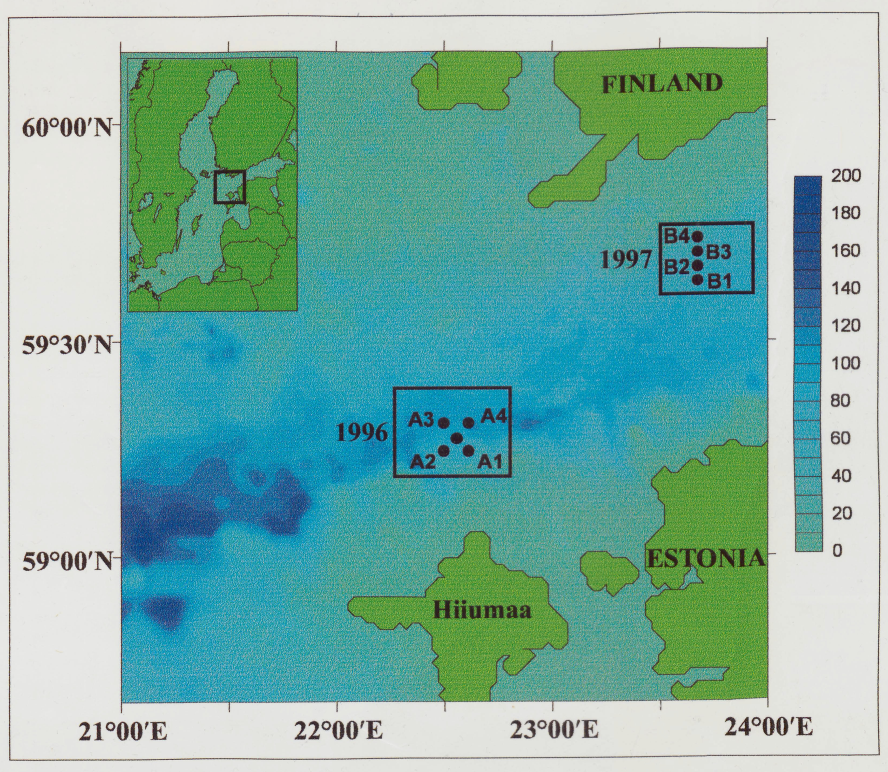

Figure 1. Map of the study area and location of stations during the experiments in July 1996 and 1997.

Conclusions

- Due to the different meteorological conditions, the late summer phytoplankton bloom at the entrance area to the Gulf of Finland was formed by *Heterocapsa-Aphanizomenon* community in 1996 and by filamentous cyanobacteria (including potentially toxic *Nodularia spumigena*) in 1997.
- The spatio-temporal variations of chlorophyll *a* concentration, phytoplankton primary production and species composition were clearly affected by the meso-scale hydrophysical processes (downwelling, jet current, eddy, front) during both study periods.
- The formation of an anticyclonic eddy was reflected in the horizontal pattern of patchiness of phytoplankton species composition and primary productivity. In contrast to the surrounding waters, the phytoplankton community structure in the almost isolated water mass inside the eddy remained unchanged. The highest production values in the central part of the eddy suggest that favourable conditions for phytoplankton growth should exist there.
- The higher chlorophyll *a* concentration and primary production are observed in the vicinity of the salinity front. Thus, the dynamics of the meso-scale front could cause the accumulation of phytoplankton biomass and enhanced productivity in the frontal area.

Acknowledgements

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Clearly defined physical phenomena – wind forced downwelling and near-slope jets as well as a meso-scale anticyclonic eddy with diameter of ~20 km – were observed in the study area in 1996 (Fig. 2). The eddy was formed by 20 July after the weakening of the wind and relaxation of the downwelling, being almost steady until the end of the experiment. The dominant phytoplankton groups during the experiment were cyanobacteria and dinoflagellates. For the first period (18-20 July) a dinoflagellate *Heterocapsa triquetra* was predominating and for the second period of the experiment (21-26 July) a cyanobacterium *Aphanizomenon flos-aquae* prevailed (Fig. 2). Only at Station A4 *Heterocapsa* continued to dominate during the whole experiment time. The mean surface water temperature rose from 13.5°C to 15.5°C during the study period, and the mean surface water salinity varied between 6.4 and 6.7 psu (Fig. 3a). The Chl *a* concentration decreased during the first three days (Fig. 3b). After 20 July, a continuous increase of chlorophyll *a* concentration was observed. Chl *a* was found mainly in the <20-μm size fraction (1.4-4.5 mg m^{-3}). The mean concentration of Chl *a* in the >20-μm size fraction was about 0.5 mg m^{-3} during the first days and about 1.0 mg m^{-3} during the last days. The mean primary production value over all stations showed a decreasing trend during the downwelling period. Later, when the surface water temperature started to grow, the mean primary production increased and stayed at a higher level (6-7 mg C m^{-3} h^{-1}) until the end of the experiment (Fig. 3c). Quite good correlation between the preceding day wind speed and the phytoplankton mean primary production was found (the correlation coefficient r = 0.41 at p<0.05).

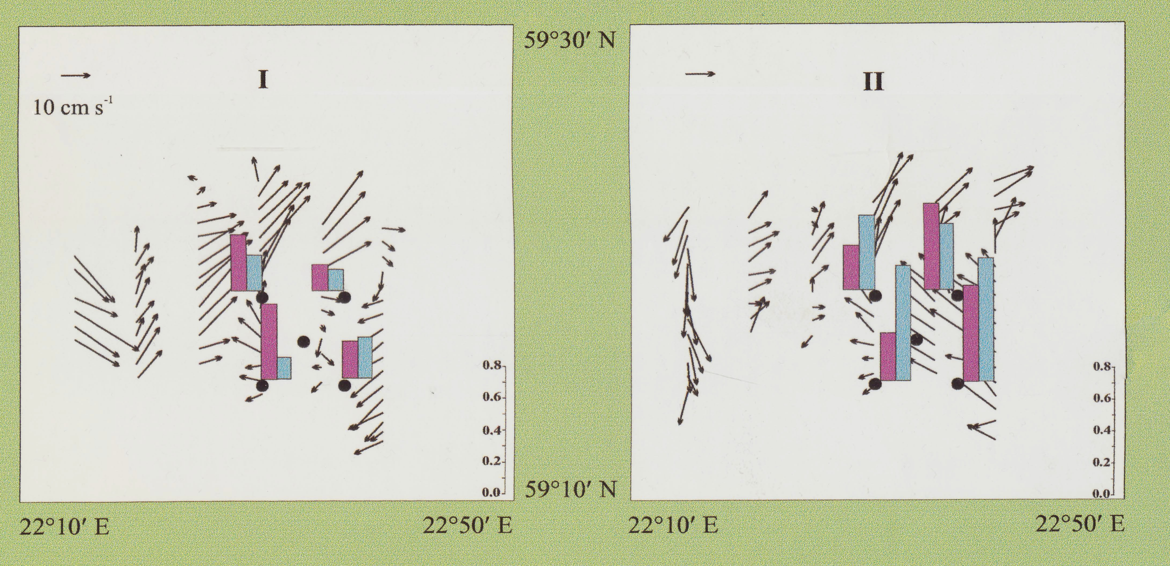

Figure 2. Mean biomass of *Heterocapsa triquetra* (violet bars) and *Aphanizomenon flos-aquae* (blue bars) during downwelling event (18-20 July 1996; I) and after eddy formation (21-26 July 1996; II). Scale is given in mg l^{-1}. ADCP velocity stick-plots on 12 m depth on 19 July and on 21 July are shown.

The characteristic pattern of spatio-temporal variations is as follows. The surface water salinity was at Station A4 on average 0.17 psu higher than the mean salinity at the other stations on 21-26 July (Fig.4a), indicating that this station was located inside the eddy. At the stations, where a little higher values of chlorophyll *a* were measured during the downwelling event (Stations A2 and A3), lower values of Chl *a* were obtained in presence of the meso-scale eddy (Fig. 4b). In contrast, at Station A4, the concentration was lower than at other stations during the first days and higher than at other stations (except Station C), when the eddy has been formed. Spatial variation of primary production was quite low during the first three days, but deviations from the mean value varied in large range (from -2.5 to 2.5) since the eddy formation (Fig.4c). The highest production values at Station A4 suggest that favourable conditions for phytoplankton growth should have been existed in almost isolated water mass within the eddy.

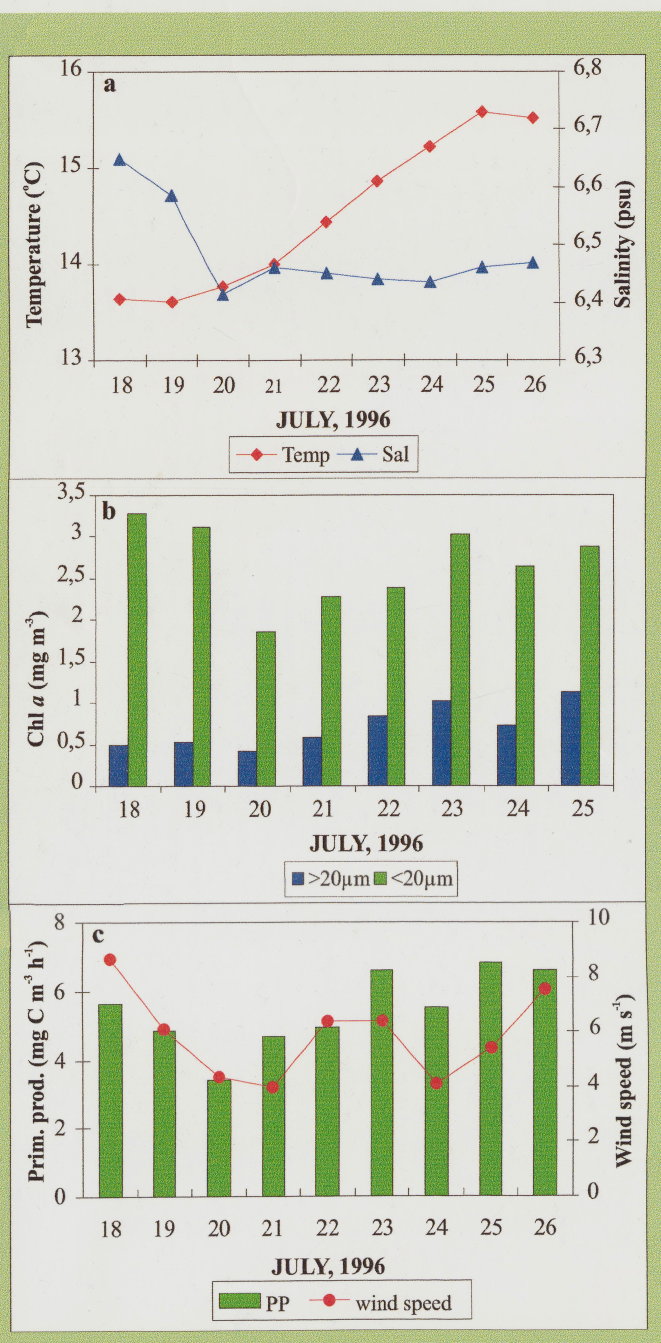

Figure 3. Daily mean surface water temperature and salinity (a), daily mean chlorophyll *a* in different size fractions (b), and daily mean potential phytoplankton primary production and preceding day wind speed (c) at the sampling stations on 18-26 July 1996.

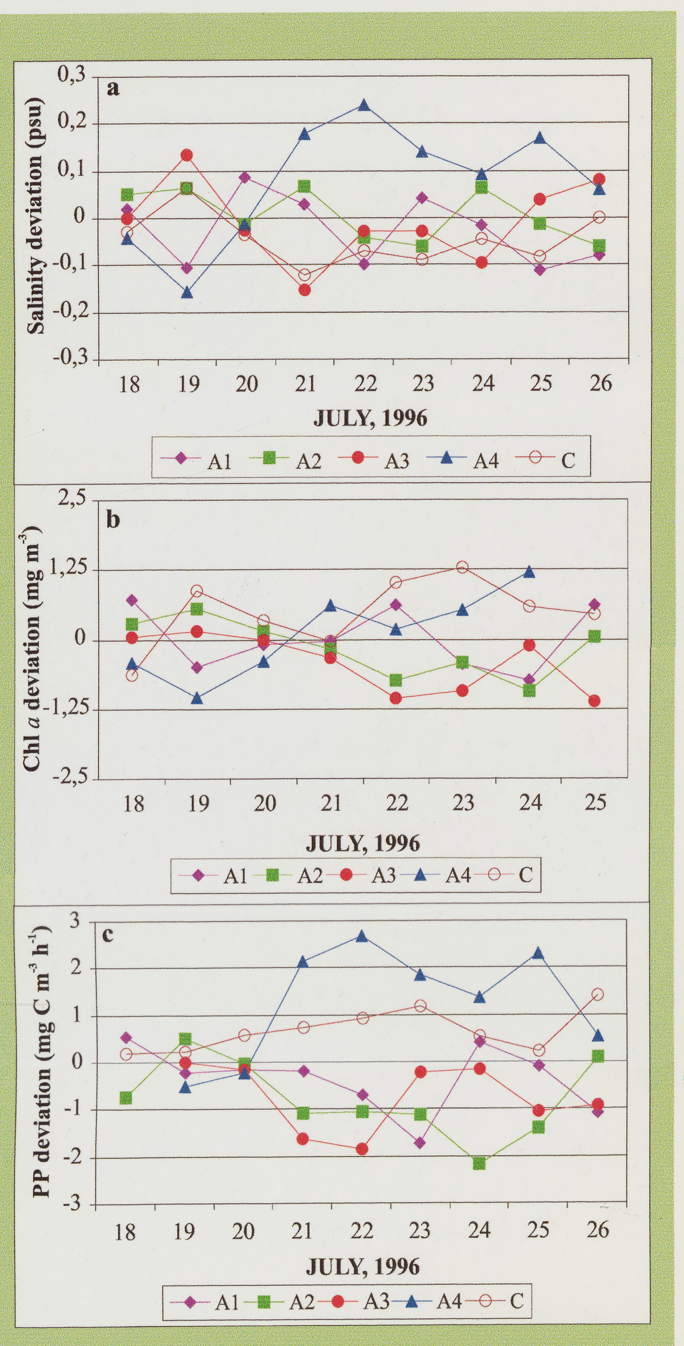

Figure 4. Salinity (a), chlorophyll *a* (b) and primary production (c) deviations from the daily mean values at sampling stations on 18-26 July 1996.

In 1997, the salinity front between the fresher coastal waters and saltier open gulf waters crossed the sampling transect. The front observed in the northern part of the transect during the first days, migrated southward on 18-19 July (Fig. 5). Later, the front moved to its initial position and an exceptionally cold and saline water mass appeared in the southern part of the sampling transect on 23-24 July. The observed intense phytoplankton bloom was dominated by filamentous cyanobacteria (Fig. 5) – *Aphanizomenon flos-aquae* (mainly in the beginning) and *Nodularia spumigena* (during the second half of the study). Evenly high cyanobacterial biomass in the beginning of the study (on 16-19 July) decreased considerably and transformed to a patchy distribution after 21 July. Calm and sunny weather caused a surface accumulation and decay of the cyanobacteria (see Photo 1). The concentration of nodularin in the samples collected from the phytoplankton patches was found in the range of 0.55 – 0.99 μg mg^{-1} dry weight (analyses made by Dr. Linda A. Lawton, Aberdeen, Scotland). The second dominant group were dinoflagellates (Fig. 5). The mean surface water temperature rose from 17-18°C in the first half of the experiment to 19-20°C in the second (Fig. 6a). Temporal course of the mean surface water salinity followed the described movements of the salinity front – the lower salinity values coincided with the southern position of the front and *vice versa*. The mean chlorophyll *a* concentration in the <20-μm size fraction decreased until 23 July and revealed some increase during the last two days of the study (Fig. 6b). Chl *a* concentration in the >20-μm size fraction was 1.0 mg m^{-3} during the first half and 0.5 mg m^{-3} during the decay phase (except cases when sampling was made in the patches; e.g. 21 and 24 July). The observed, in general decreasing, trend of the mean primary productivity was well correlated with the variation of preceding day wind speed (the correlation coefficient r = 0.79 at p<0.05; Fig. 6c).

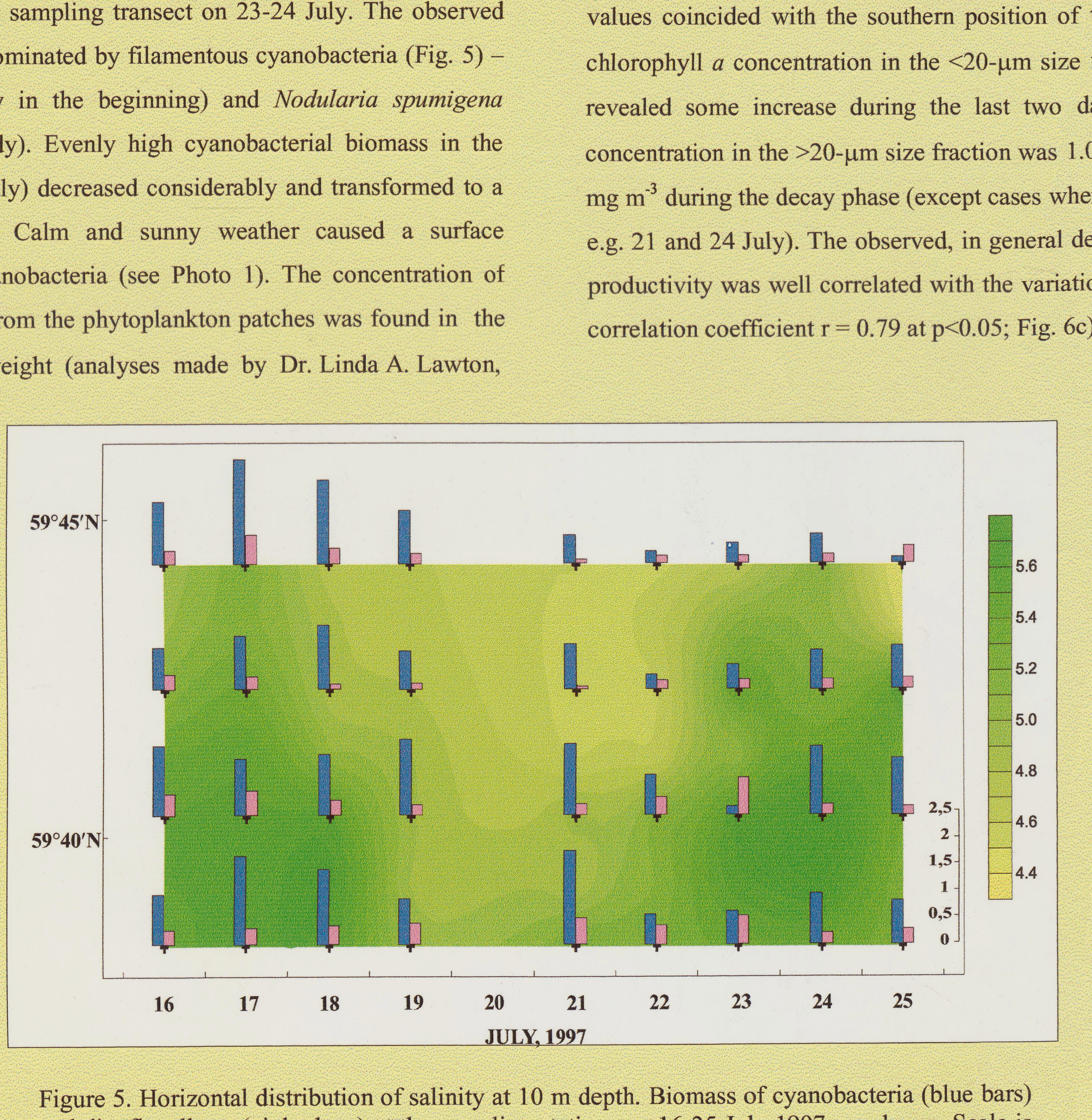

Figure 5. Horizontal distribution of salinity at 10 m depth. Biomass of cyanobacteria (blue bars) and dinoflagellates (violet bars) at the sampling stations on 16-25 July 1997 are shown. Scale is given in mg l^{-1}.

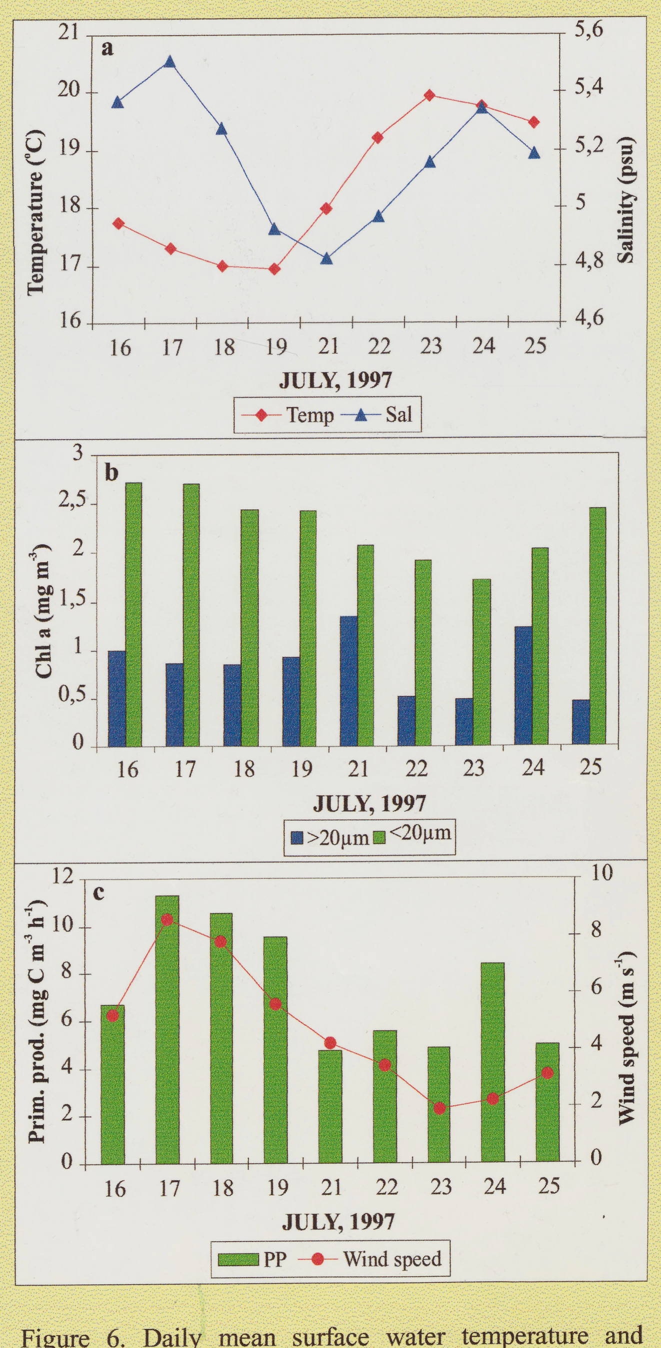

Figure 6. Daily mean surface water temperature and salinity (a), daily mean chlorophyll *a* in different size fractions (b), and daily mean potential phytoplankton primary production and preceding day wind speed (c) at the sampling stations on 16-25 July 1997.

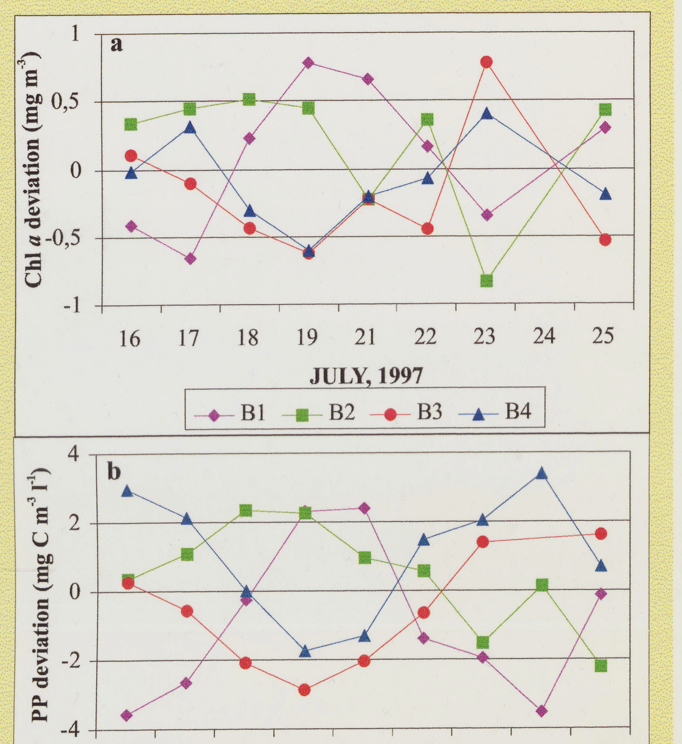

Figure 7. Chlorophyll *a* (a) and primary production (b) deviations from daily mean values at the sampling stations on 16-25 July 1997.

Meso-scale deviations of chlorophyll *a* concentration and potential primary production were rather similar to each other at all stations (Fig 7). More or less regular changes in the first half of the study have been replaced by more irregular variations in the second half (reflecting the appeared enhanced patchiness in the horizontal distribution of phytoplankton). In general (with some exceptions), the behaviour of variables at the near shore stations (B3 and B4) is identical, but opposite to that at the open sea stations (B1 and B2). The higher Chl *a* content and primary productivity are observed in the vicinity of the salinity front – at Stations B3 and B4 in the beginning and at the end of the study, when the front had its northern position, and at Stations B1 and B2 in the middle, when the front was moved to the south. Thus, the dynamics of the observed front could provide conditions for the accumulation of phytoplankton biomass and enhanced productivity.

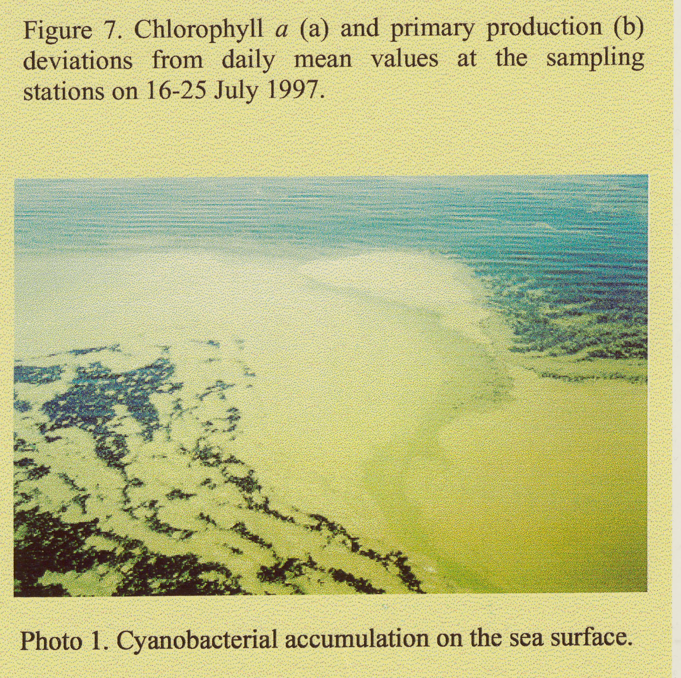

Photo 1. Cyanobacterial accumulation on the sea surface.