The hydrochemical and biological impact of the river Vistula on the pelagic system of the Gulf of Gdańsk in 1994. Part 2. Primary production and chlorophyll *a**

OCEANOLOGIA, No. 37 (2)
pp. 207–226, 1995.
PL ISSN 0078–3234

Baltic Sea
Primary production
Seasonal/spatial variability

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Manuscript received April 18, 1995, in final form August 2, 1995.

Abstract

The time and space variability in potential and *in situ* primary production values, and in chlorophyll *a* concentrations in the Gulf of Gdańsk in 1994 are presented and discussed.

The spatial variability in the distribution of these parameters is closely related to both the powerful dynamics of the water masses in this region and the river Vistula discharges. The eutrophicating impact of the Vistula is particularly evident in the narrow inshore zone, to the east and west of the river mouth. Seasonal variability in primary production and chlorophyll *a* concentrations was recorded; their particularly high values in April 1994 were due to the plankton bloom. The assimilation numbers, characterising the intensity of phytoplankton photosynthesis, varied within the 1.6–5.5 mgC mgchl^{-1} h^{-1} range.

* The study was supported financially by: grant No. 6P205043 from the State Committee for Scientific Research, Republic of Poland; funds from the State Committee for Scientific Research, Republic of Poland for the statutory activity of the Institute, and within that for studies of 'The impact of eutrophication on trophic relations in different coastal areas of the south-eastern Baltic'; European Community grant No. CIPA CT–903–0146.

1. Introduction

Recent years have seen a continual increase in the eutrophication of not only the coastal waters but also the bays and even the open waters of the Baltic (Renk, 1991, 1993). This process has been most pronounced in bays affected by river discharges. The water exchange between the inshore and offshore zones, favours, though to different degrees, the spreading of accumulated nutrients, toxic substances or allochthonous organic matter. That is why a great deal of attention has been focused on both the water dynamics and the impact of the above-mentioned discharges on the biocenosis of the near-shore zones (Niemirycz, 1994; Renk *et al.*, 1974, 1992a; Latała, 1993; Pliński, 1993).

The aim of the study, conducted by an interdisciplinary team (see the paper by Pastuszak published under the same general title), was to assess the impact of the discharge of the river Vistula on the distribution of nutrients and chlorophyll *a*, the level of primary production and its utilisation in the ecosystem of the Gulf of Gdańsk. This paper (subtitle: Part 2. 'Primary production and chlorophyll *a*') describes and discusses chlorophyll *a* concentrations and primary production level and their variability in the part of the Gulf of Gdańsk studied in 1994.

2. Material and methods

The measurements of primary production were made during cruises of r/v 'Baltica' in the Gulf of Gdańsk on 8–9 April, 19–25 July and 4–7 November 1994. The isotope technique was applied, and light and dark bottles were used. An aqueous, C^{14} – labelled solution of $NaHCO_3$, with a pH of *ca* 9–10 and an activity of 70–200 kBq, was added to each sample intended for incubation. This was performed either *in situ* in 100 ml glass bottles, the exposure time most often 4 being hours around midday, or in a thermostated incubator. Water was taken from standard BMEPC (1980) depths *i.e.* 0; 2.5; 5; 10; 15 and 20 m. The onboard incubations were done in 50 ml bottles with water from about 0–1 m, and occasionally from 10 and 20 m. The irradiance conditions of the incubator ensured a photosynthetic saturation of 400 $\mu Em^{-2}s^{-1}$, as well as the average temperature of the euphotic layer, required for measurements of potential primary production. Directly after incubation, phytoplankton samples were passed through a set of filters in order to separate them into the following fractions: > 20 μm, 20–2 μm or 20–3 μm; 2–0.7 or 3–07 μm. The following filters were used: net filter – 20 μm, nuclepores or membrane – 2 or 3 μm, and Whatman GF/F – 0.7 μm glass filters. The water for determinations of suspended organic matter production was filtered at the same time.

The activity of all the samples, obtained in the manner described, was measured with a scintillation counter with the application of 6 ml of Beckman's 'Ready Value' scintillation cocktail.

The inorganic carbon, essential for primary production calculations, was measured with the Anderson and Robinson (1946) method (after Głowińska *et al.*, 1975). In the case of the *in situ* incubations, the insolation was measured using a solarimeter connected to an integrator which counted impulses and thus enabled energy units to be calculated.

Chlorophyll *a* concentrations were measured at the same depths as primary production. Water was filtered through the GF/F filter to determine chlorophyll *a* in the whole phytoplankton population and additionally, to determine chlorophyll *a* in each fraction, through the same filters as in the case of the fractioned primary production. The extraction was done with 90% acetone during 24 h in darkness and at a temperature of 4–6°C. The extinction of the centrifuged chlorophyll extract was measured with a spectrophotometer and its fluorescence with a fluorometer, and the chlorophyll concentrations were calculated with the respective application of the Jeffrey and Humphrey (1975) and Evans *et al.* (1987) equations.

3. Results

During the cruise in April 1994, measurements of potential primary production in an incubator only were made at the following stations in the Gulf of Gdańsk: E60, E86, E97, E85, P114 (Fig. 1 and Tab. 1). The potential primary production, measured in the 0–1 m water layer, varied from 40 to 70 mgC m^{-3} h^{-1} at inshore stations, and was equal to 2.5 mgC m^{-3} h^{-1} at offshore station E60 (Fig. 2).

Chlorophyll *a* concentrations at the above stations and in the same layer were 20–33 mg m^{-3} and 1.4 mg m^{-3} respectively (Fig. 2). The vertical distribution of chlorophyll concentrations showed an abrupt decrease in the 0–10 m layer, except at station E60 (Fig. 3).

In July 1994 the stations grid covered a larger area of the Gulf of Gdańsk, including the northern part of the Gulf (Fig. 1 and Tab. 1). The measurements of potential primary production were supplemented by *in situ* measurements (7 *in situ* out of a total of 13 stations).

The potential primary production of the surface phytoplankton varied from *ca* 6 to 38 mgC m^{-3} h^{-1}, and chlorophyll concentrations in this plankton fluctuated from *ca* 2.7 to 11.3 mg m^{-3} (Fig. 4).

The *in situ* primary production in the euphotic layer ranged from 790 to 2070 mgC m^{-2} d^{-1} at an average chlorophyll concentration varying in the 0–10 m layer from 3.2 to 7.2 mg m^{-3} (Fig. 5). The vertical distributions of production and chlorophyll *a* are presented in Figs. 6–8.

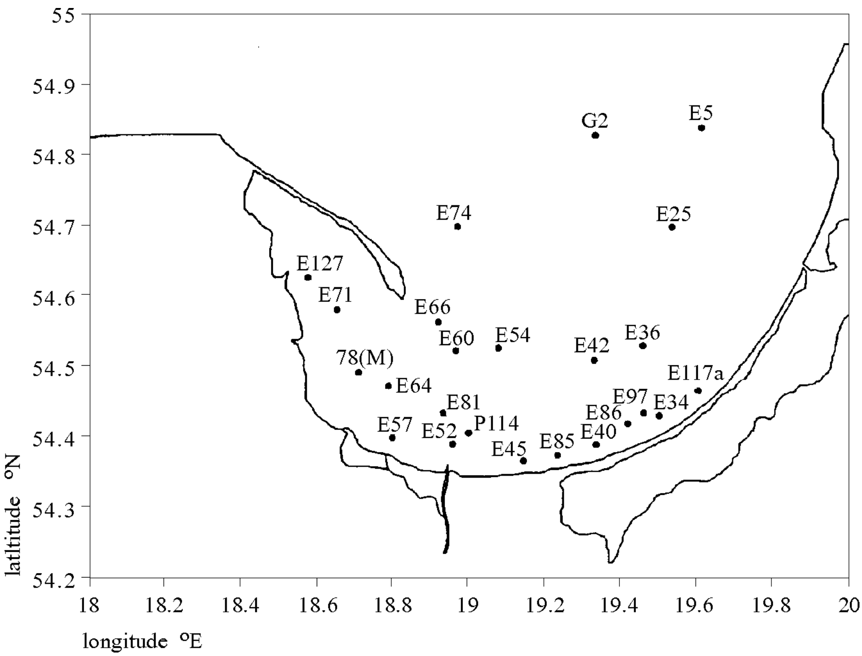


Fig. 1. Location of stations in the Gulf of Gdańsk in April, July and November 1994 at which chlorophyll *a* and primary production were measured

Table 1. List of stations in the Gulf of Gdańsk

Station	Coordinates		Remarks	Station	Coordinates		Remarks
G2	19.33 E	54.83 N	J	E64	18.79 E	54.47 N	J
E5	19.61 E	54.84 N	J	E66	18.92 E	54.56 N	N
E25	19.53 E	54.70 N	J	E71	18.65 E	54.58 N	J, N
E34	19.50 E	54.43 N	N	E74	18.97 E	54.70 N	J
E36	19.46 E	54.53 N	J	78(M)	18.71 E	54.49 N	N
E40	19.34 E	54.39 N	J	E81	18.93 E	54.43 N	N
E42	19.33 E	54.51 N	J, N	E85	19.24 E	54.37 N	A
E45	19.15 E	54.37 N	N	E86	19.42 E	54.42 N	A
E52	18.96 E	54.39 N	J, N	E97	19.46 E	54.44 N	A
E54	19.08 E	54.53 N	J	P114	19.00 E	54.40 N	A
E57	18.80 E	54.40 N	N	E117a	19.61 E	54.47 N	J
E60	18.97 E	54.52 N	A	E127	18.57 E	54.63 N	J

Legend:
A – April study,
J – July study,
N – November study.

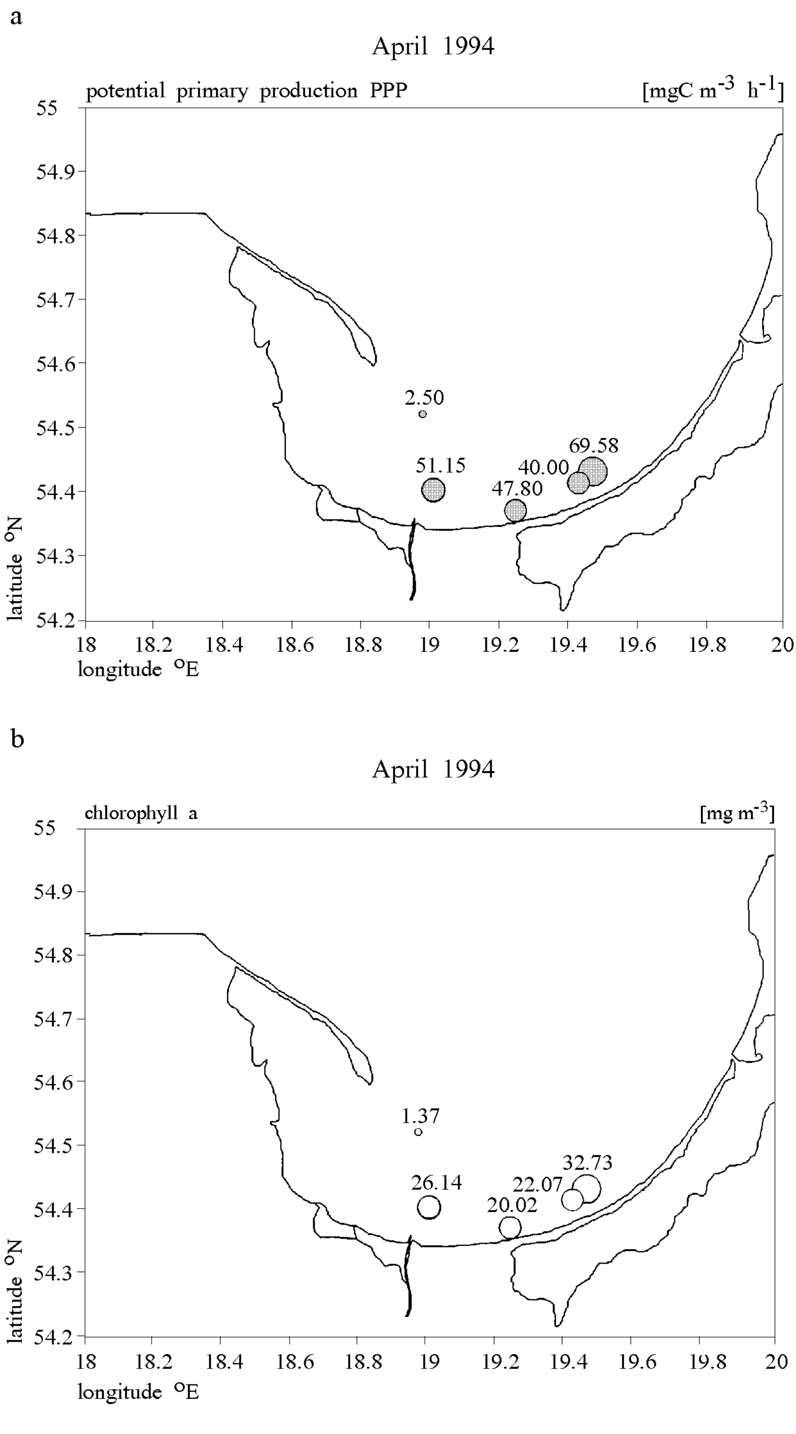


Fig. 2. Distribution of potential primary production (PPP) and chlorophyll *a* concentration at 0 m (April 1994)

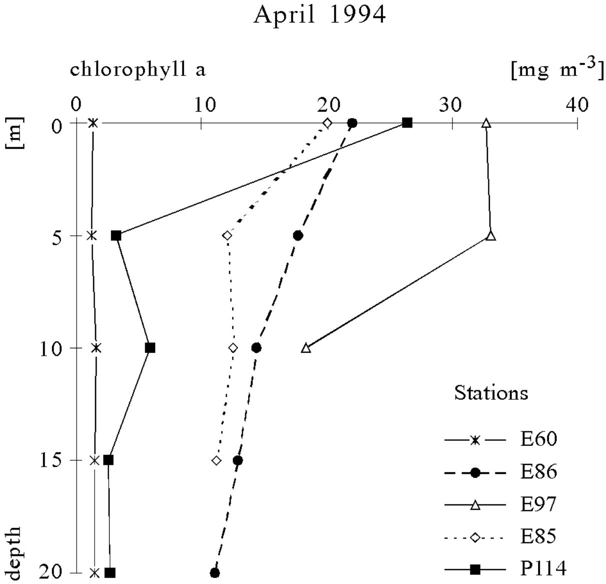


Fig. 3. Vertical profiles of chlorophyll *a* concentrations at selected stations (April 1994)

The distribution of stations investigated in November 1994 is shown in Fig. 1 and Tab. 1. At the surface, the potential phytoplankton primary production varied from 8.5 to 18.3 mgC m^{-3} h^{-1}, chlorophyll concentrations from 4 to 9 mg m^{-3} (Fig. 9). The *in situ* primary production values measured at stations E81 and E45 were 553.6 mgC m^{-2} d^{-1} and 377.6 mgC m^{-2} d^{-1} respectively. A very uneven distribution of chlorophyll was recorded at particular depths in the euphotic layer (Figs. 10–11).

4. Discussion

The values of primary production and chlorophyll *a* concentrations recorded in April 1994 were indicative of a phytoplankton bloom in the near-shore zone. The temperatures reported in that area (in the 3.5–4.5°C range), together with the accumulated nutrients following winter turnover, and the increased water/nutrient discharge due to snowmelt (Pastuszak, 1995), must have induced intensive phytoplankton growth. This was also the case in earlier studies (Renk *et al.*, 1992b). However, the situation was quite different at the northern station E60, where the temperature also exceeded 3°C, but both production and chlorophyll *a* concentrations were lower than in the near shore zone by at least one order of magnitude, indicating that ‘winter’ conditions were still obtaining there. A further indication of this

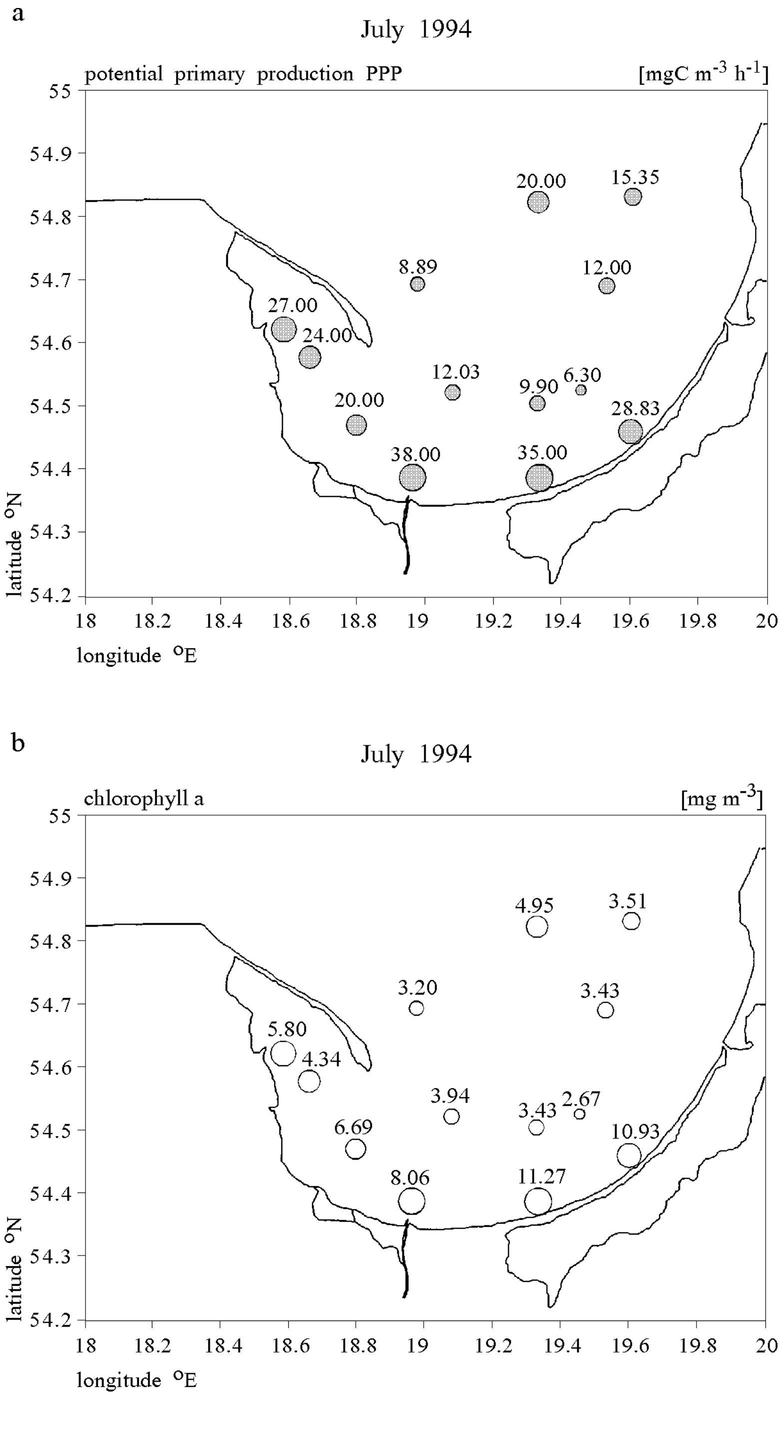


Fig. 4. Distribution of potential primary production (PPP) and chlorophyll *a* concentration at 0 m (July 1994)

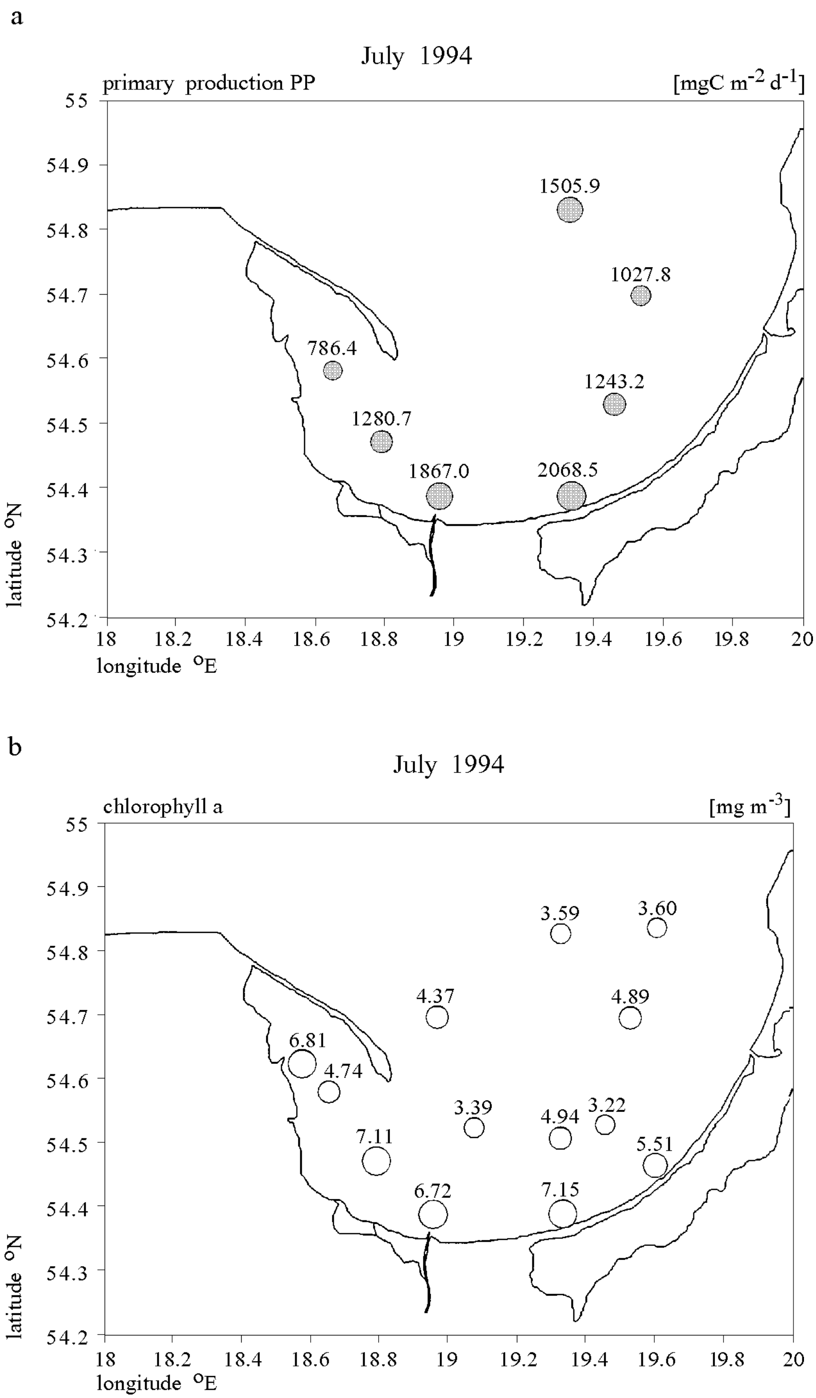


Fig. 5. Distribution of *in situ* primary production (PP) in the euphotic layer and the average chlorophyll *a* concentration in the 0–10 m layer (July 1994)

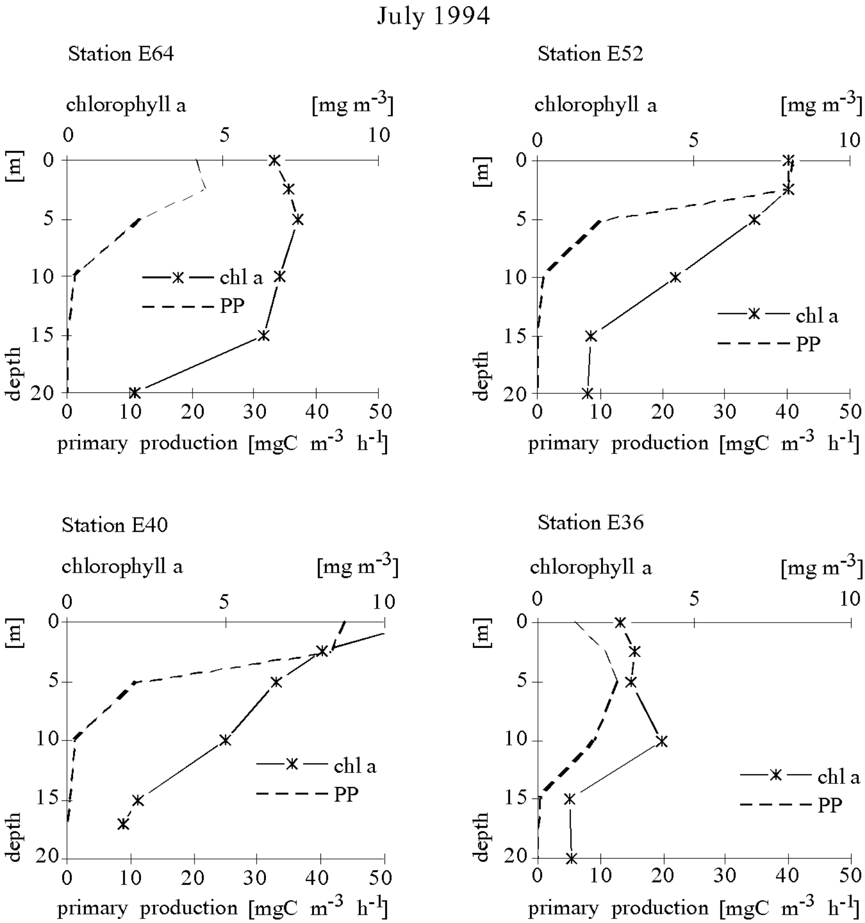


Fig. 6. Vertical profiles of chlorophyll *a* concentrations and primary production at stations E36, E40, E52, E64 (July 1994)

was the vertical distribution of chlorophyll (Fig. 3), which showed nearly identical values in the euphotic layer at station E60, and distinct maxima in the 0–5 m layer, followed by an abrupt drop at stations located near the coast. There are two processes generating such a pattern of distribution, the first being the fact that the surface layer is exposed to solar radiation, which in turn produces a rise in the temperature of this layer and thus more intensive phytoplankton growth. However, the assimilation numbers AN (Fig. 12), which characterise the rate of photosynthesis and are the ratio of the primary production in unit volume at optimum irradiance to the chlorophyll *a* concentration in the same volume, do not indicate that the photosynthetic rate had a deciding influence on such a large biomass of

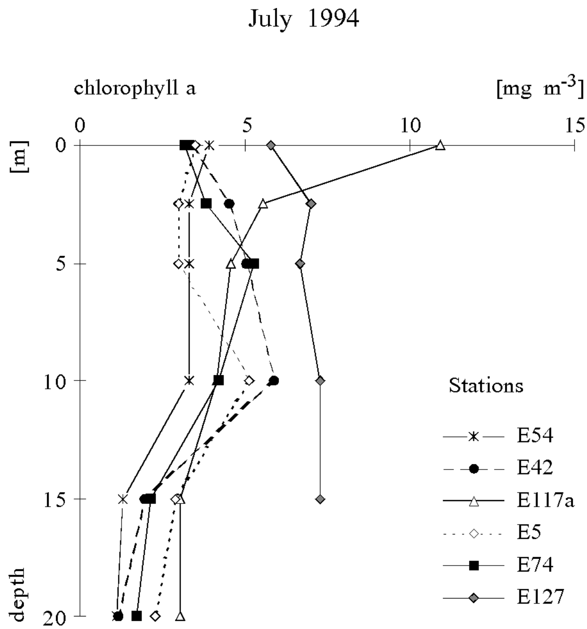


Fig. 7. Vertical profiles of chlorophyll *a* concentrations at stations E5, E42, E54, E74, E117a, E127 (July 1994)

phytoplankton (Figs. 2, 13). This rate differed only slightly from the one observed at E60, where the plankton bloom had not yet begun. It seems, therefore, that the high concentrations of chlorophyll *a* did not result exclusively from the production of the region investigated, but also from a second factor, *i.e.* the discharge of the Vistula carrying organic matter. This statement is confirmed by the vertical distribution of chlorophyll *a* concentration at the station closest to the river mouth (P114), where it is 10 times higher at the surface than at 5 m (Fig. 3). At a more distant station (E97), a separate and transformed riverine pocket of water did not show any difference in chlorophyll *a* concentration at 0 and 5 m.

The waters at the above-mentioned stations, particularly in the surface layer, are characterised by a higher temperature, well over 4°C, lower salinity, and very high nutrient concentrations. These facts confirm the allochthonous origin of these water masses, which form separate mini-ecosystems (Grelowski and Wojewódzki, in press; Pastuszak, 1995).

In spring the net and picophytoplankton proved to be the most effective in the production of organic matter.

In July 1994 the highest potential primary production at the surface was also recorded in the entire near-shore zone and the northernmost part

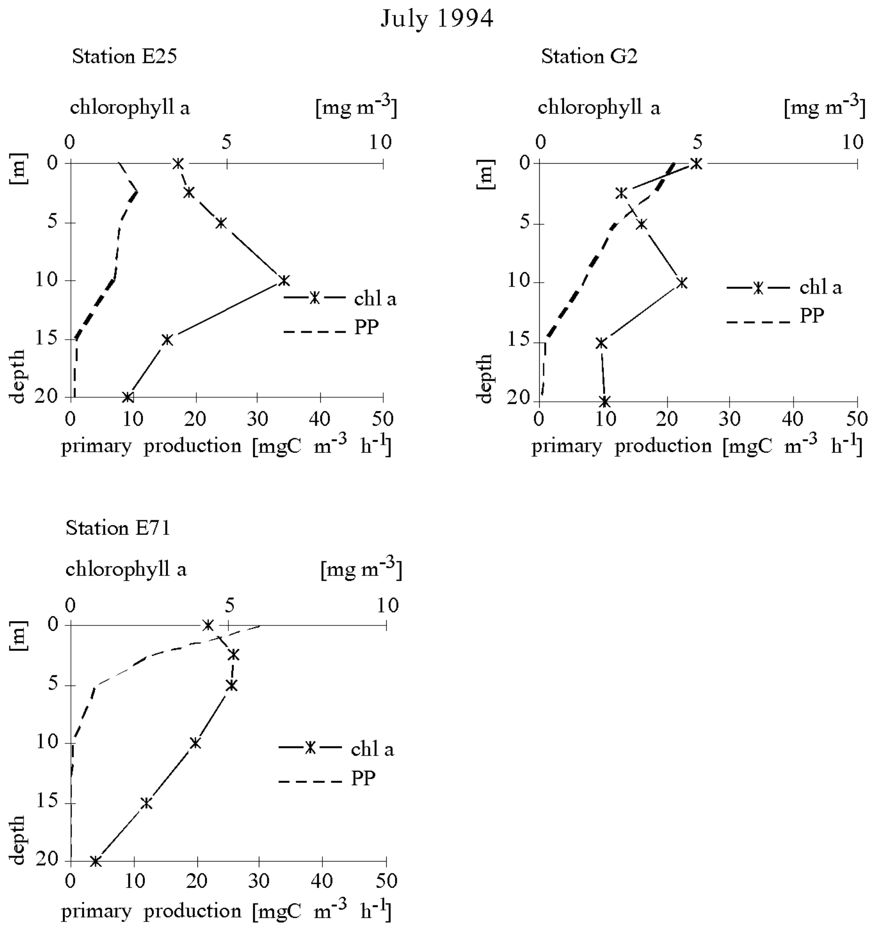
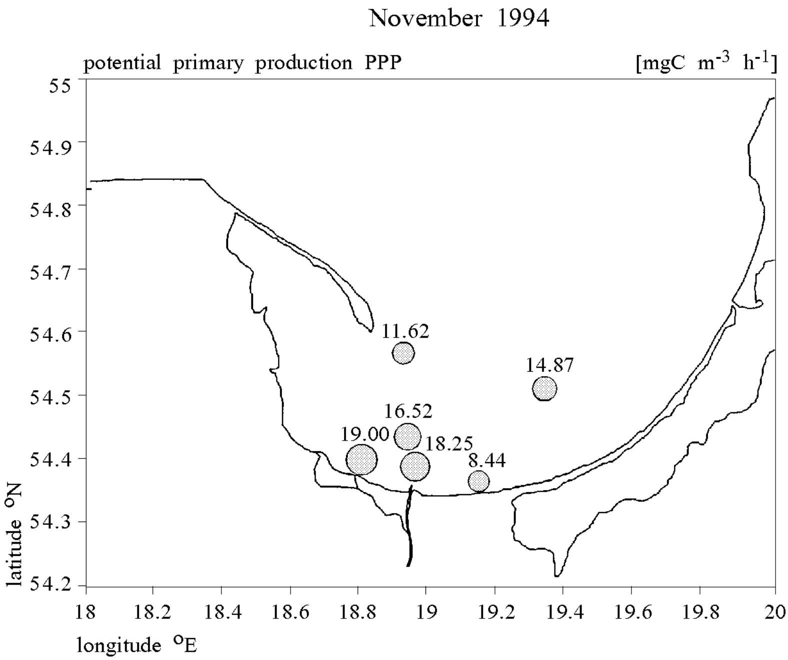


Fig. 8. Vertical profiles of chlorophyll *a* concentrations and *in situ* primary production at stations E25, E71, G2 (July 1994)

of the Gulf of Gdańsk. The lowest values were observed in the central part of the Gulf (Fig. 4). The pattern of chlorophyll *a* concentration was similar to that of primary production (Fig. 4).

The photosynthetic efficiency did not always coincide with high production and chlorophyll *a* concentrations in July 1994 (Figs. 4, 13). The region to the east of the Vistula mouth, was characterised by the highest values of both potential production and chlorophyll concentration, but only by average AN values, similar to those recorded in the central part of the Gulf, where production was several times lower. The highest intensity of organic matter production was found among the phytoplankton in the area closest to the Vistula mouth, in Puck Bay, and in the Gdańsk Deep. A slightly a



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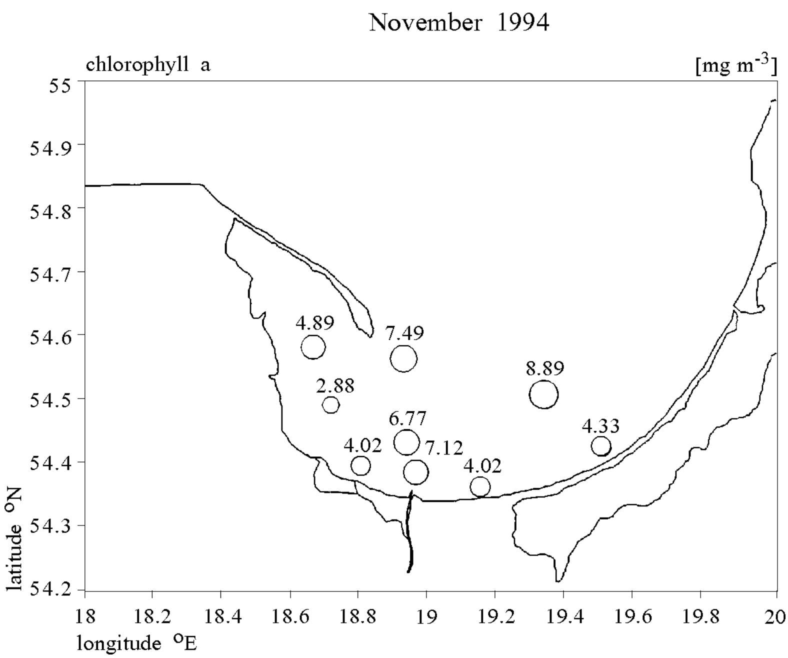


Fig. 9. Distribution of potential primary production and chlorophyll *a* concentrations at 0 m (November 1994)

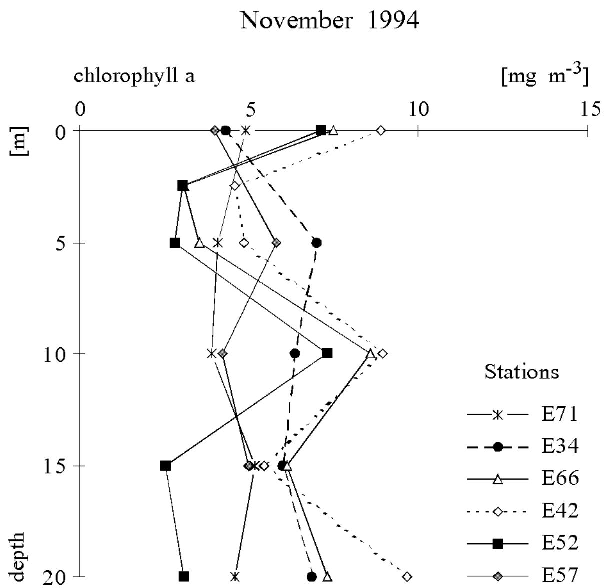


Fig. 10. Vertical profiles of chlorophyll *a* concentrations at selected stations (November 1994)

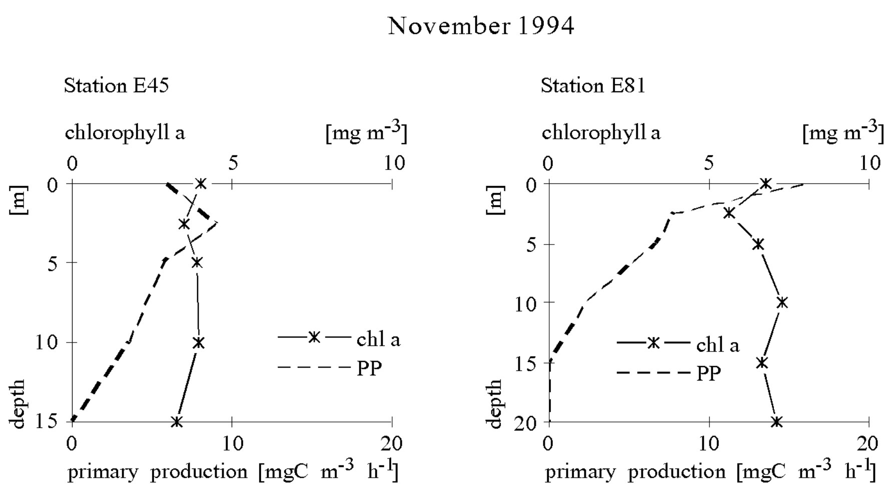


Fig. 11. Primary production and chlorophyll *a* concentrations (November 1994)

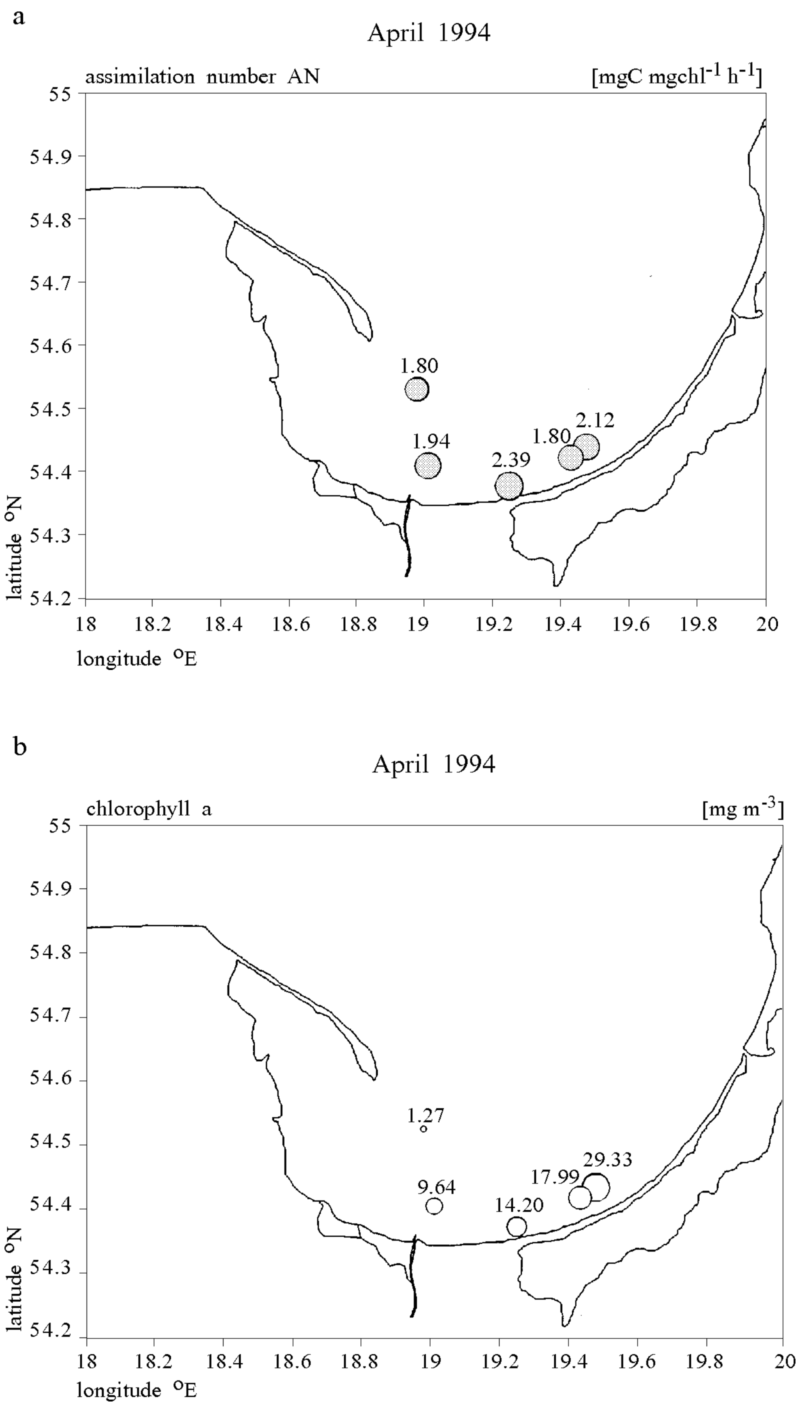
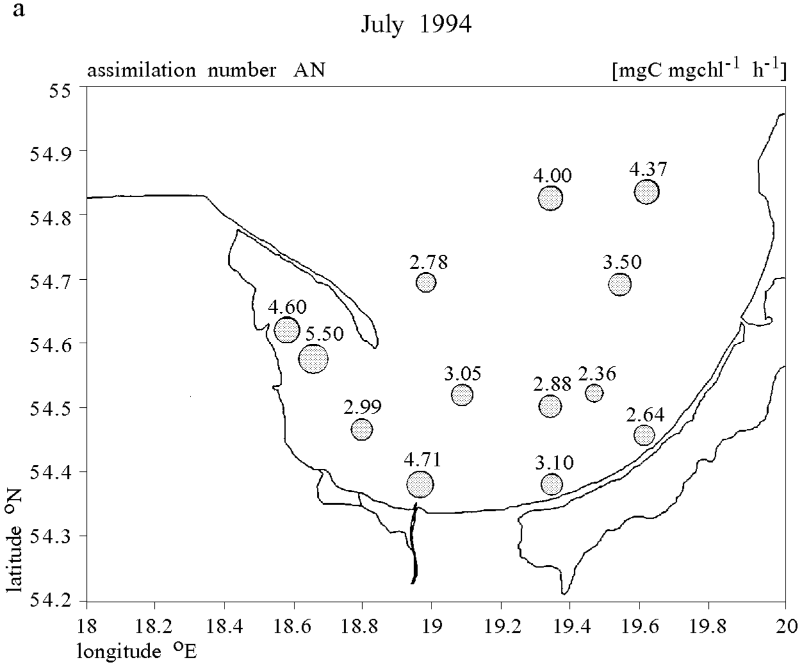


Fig. 12. Distribution of the assimilation number AN at 0 m and average chlorophyll *a* concentrations in the 0–10 m layer (April 1994)

a



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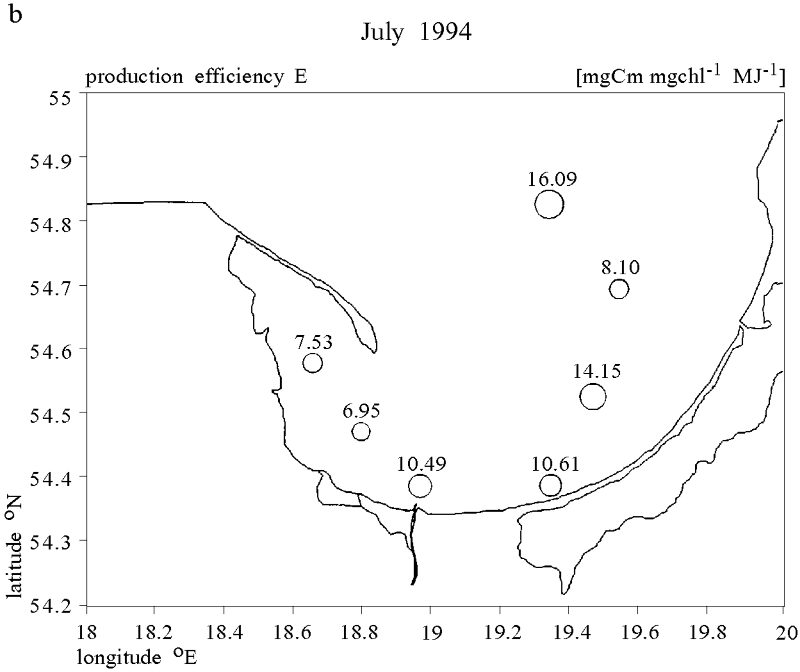

Fig. 13. Distribution of the assimilation number AN at 0 m and the coefficient of production efficiency E (July 1994)

different picture appears when one looks at the distribution of *in situ* production values in the entire euphotic layer (Fig. 5). The highest global production of suspended matter in the whole euphotic layer was sometimes accompanied by maximum values of surface potential production (E40, E52), but this was not always the case, as can be seen at stations E36, E71.

Analyses of the vertical distribution of primary production and chlorophyll *a* values at stations E40 and E52 in July 1994 showed that the majority of the organic matter was produced in the 0–5 m layer, making up over 80% of the global production of the entire euphotic layer. The chlorophyll concentrations at stations E40 and E52 exceeded 8 mg m^{-3} at the surface and at 2.5 m, and dropped to 6.7 mg m^{-3} at of 5 m. This thin layer played a key role in the total production in the time and region investigated, showing that high production values resulted from high concentrations of plankton. The situation at station E71 was similar, where over 80% of the total production was attributed to a five-meter-deep layer, but the chlorophyll concentrations at surface were 1.5 or 2 times lower than at stations E40 and E52. That is why the global production in the euphotic layer is much lower at E71 than at E40 and E52. The water transparency, measured with the Secchi disc, was low and was equal to 2.5 m at the three last-mentioned stations.

The production curve at station E36 for the same period was entirely different. The photosynthetic maximum was found at 5 m, which indicated an inhibition of production in the layer above this depth. Production in this layer was $> 40\%$ of the total production. However, the thickness of the euphotic layer was considerably greater, the transparency was 4.5 m, which in turn resulted in a higher production than could be estimated from the potential production and the assimilation number.

For the real environmental and light conditions occurring during observations, it is advisable to apply a conventional coefficient of efficiency E[1] (the ratio of daily production under $1m^2$ to the average chlorophyll concentration in the 0–10 m layer and the daily insolation), enabling comparisons of photosynthetic efficiency (E) in the entire euphotic layer to be made (Platt, 1969). A comparison of calculated E coefficients shows that in July 1994 the most effective production was observed in the region of Gdańsk Deep.

The vertical distribution of chlorophyll *a* reaches a maximum at 10 m, starting from E42 and proceeding towards the north-east, and a maximum at 5 m, starting from the Vistula mouth and proceeding westwards. These

[1] the term 'chlorophyll *a* cross-section for photosynthesis – Ψ_{tot}', commonly used in the bibliography, is approximately equivalent to the term 'photosynthetic efficiency' used in this paper.

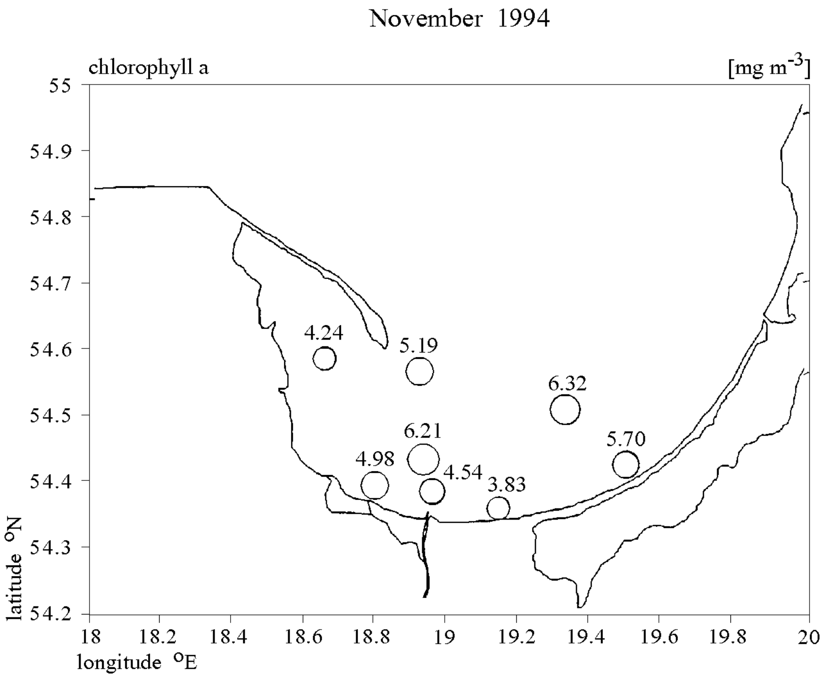

Fig. 14. Distribution of chlorophyll *a* concentrations in the 0–10 m layer (November 1994)

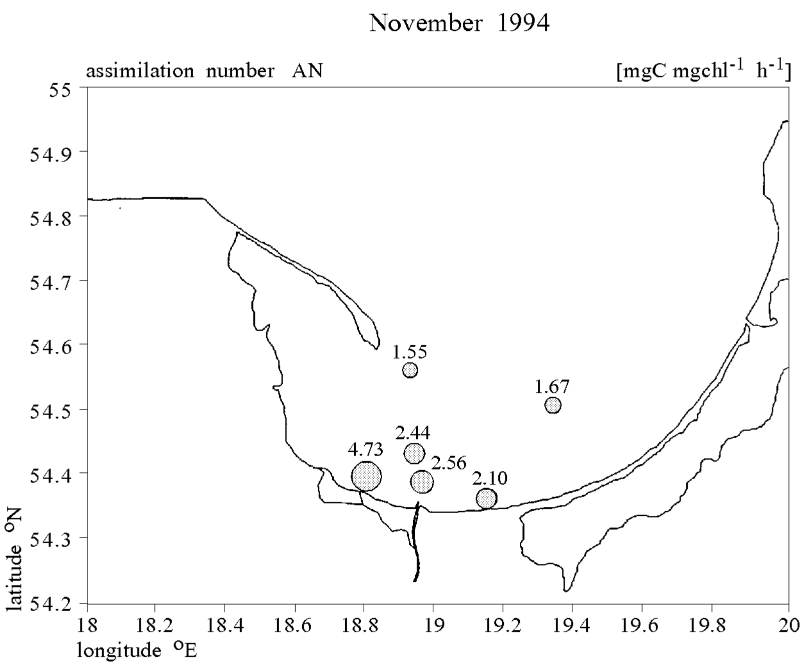

Fig. 15. Distribution of the assimilation number AN at 0 m (November 1994)

variations are probably related to the depth of the thermocline (Grelowski and Wojewódzki, in press).

In July 1994 the contribution of nanoplankton to the production of organic matter biomass was the highest.

In November 1994 the potential primary production did not differ much from that measured in the central part of the Gulf in July 1994; however, this resulted from the much greater concentrations of chlorophyll *a* present in November. The spatial distribution of chlorophyll *a* was entirely different from that found in the summer. Higher concentrations of pigments both at the surface and in the 0–10 m layer were found not off the river mouth but at some distance from it (Figs. 9 and 14). This consequently affected the assimilation number, which was low (below 2 mgC mgchl^{-1} h^{-1}) at stations located far from the Vistula mouth. In the remaining cases the AN was not high either, with the exception of station E57 where it reached 4.7 mgC mgchl^{-1} h^{-1}, a value comparable with those observed in summer 1994 (Fig. 15) and where high nutrient values were observed (Pastuszak, 1995).

A northward transport of surface water, generated by strong southerly winds, was observed in November 1994, and this resulted in a compensatory upwelling of cold subsurface waters in the narrow coastal zone (Grelowski and Wojewódzki, in press). These intensified water dynamics were also responsible for the formation of separate pockets of water and were probably responsible for the spatial distribution of the chlorophyll *a* concentrations recorded.

The *in situ* production, measured at two near-shore stations *i.e.* (E81 and E45) was low and was 553.6 and 377.6 mgC m^{-2} d^{-1} respectively. This must have been due to the lower chlorophyll *a* concentrations and the much lower insolation at that time, because the efficiency coefficient E attained values comparable with the highest ones measured in summer, *i.e.* 16.88 and 14.58 mgCm mgchl^{-1} MJ^{-1}.

The production process in November was sustained mainly by net plankton ($> 20\mu$m).

5. Conclusions

- In the inshore region of the Gulf of Gdańsk the highest values of both potential primary production and surface chlorophyll *a* were measured in April 1994, during the spring bloom, the lowest in November 1994.
- The intensity of phytoplankton production in the surface layer of the inshore zone, expressed by the assimilation number AN, was highest in summer, but much lower in spring and autumn. AN values below 2 mgC mgchl^{-1} h^{-1} were measured only in April and November 1994; values above 4.5 mgC mgchl^{-1} h^{-1} were recorded in Puck Bay, and

north of the Vistula mouth in June 1994, and west of the river mouth in November 1994.

- The *in situ* primary production measured in summer 1994 showed significant regional differences, despite the nearly identical insolation. Its highest values were measured to the north and west of the Vistula mouth and in the Gdańsk Deep, the lowest values in Puck Bay. In autumn it was several times lower.
- Great spatial variability in surface chlorophyll *a* concentrations was observed in April 1994 when the inshore zone was distinguishable by the initiation of the plankton bloom. Great regional variability was also seen in July 1994 as a result of nutrient discharge, which stimulated photosynthesis, and from increased discharges of planktonic organic matter produced earlier in the river. A quite opposite situation was noted in November 1994 when lower chlorophyll *a* concentrations were recorded in the inshore zone, than in the northern part of the Gulf.
- In summer thermal stratification plays a key role in the vertical distribution of chlorophyll *a* in the euphotic layer.

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