Chlorophyll *a* concentration and distribution in the Southern Baltic in the years 1979–1983*

OCEANOLOGIA, No. 30
pp. 77–91, 1991.
PL ISSN 0078-3234

Baltic Sea
Chlorophyll *a*
Eutrophication

JAN NAKONIECZNY, HENRYK RENK
Marine Biology Centre,
Polish Academy of Sciences,
Gdynia

JÓZEF WIKTOR
Institute of Oceanology,
Polish Academy of Sciences,
Sopot

Manuscript received January 03, 1989, in final form April 10, 1991.

Abstract

The article presents the results of chlorophyll *a* distribution measurements carried out in the Southern Baltic in the years 1979–1983. Open sea water of the Southern Baltic contained on average 1–3 $mg \cdot m^{-3}$ of chlorophyll *a*, after the spring phytoplankton bloom which usually takes place in April or May. In the Gulf of Gdańsk and in the Pomeranian Bay the chlorophyll *a* concentrations were considerably higher and increased towards the estuaries of Vistula and Odra Rivers. As regards the long term analysis of the chlorophyll *a* concentration in the Gdańsk Deep, a noticeable increasing trend was been observed.

1. Introduction

The measurement of chlorophyll *a* concentration in sea water constitutes one of the elements, besides the rate and magnitude of the primary production, the quantitative and quality composition of phytoplankton and the phytoplankton biomass, of phytoplankton analysis. Chlorophyll *a* can be used as a simplified indicator of the phytoplankton biomass distribution in the examined basins. Despite significant temporal fluctuations in chlorophyll concentration (Renk *et al.*, 1983; Sournia, 1974) and despite the fact

* The investigations were carried out under the research programme CPBP 03.10, coordinated by the Institute of Oceanology of the Polish Academy of Sciences.

that the ratio of chlorophyll *a* to the cell carbon is not constant and depends on environmental conditions, the simplicity of chlorophyll *a* determination makes it a very useful indicator of phytoplankton biomass distribution (Steemann Nielsen, 1963; Steemann Nielsen and Jørgensen, 1962).

The results presented here are considered from this point of view. In general, the presented analysis of chlorophyll *a* distribution gives initial material for further development of the Baltic Monitoring Programme, especially as regards the analyses of chlorophyll *a* fluctuations and in view of a trend towards increasing chlorophyll *a* concentration observed in the preliminary stage of the Programme in the Gdańsk Deep which may be caused by the Baltic eutrophication (Renk *et al.*, 1985b).

2. Materials and methods

The location of the measurement stations is presented in Figure 1. The experimental material was collected during research cruises in the Polish zone of the Baltic classified into two categories:

- Baltic Monitoring Programme cruises, organised by the Institute of Meteorology and Water Management, Maritime Branch, Gdynia. In the years 1979–1980 these cruises contributed 142 samples from the Pomeranian Bay and open sea Stations (P1, P40, P5) and 230 samples in the years 1980–1983 from the Pomeranian Bay, open sea zone (P1,

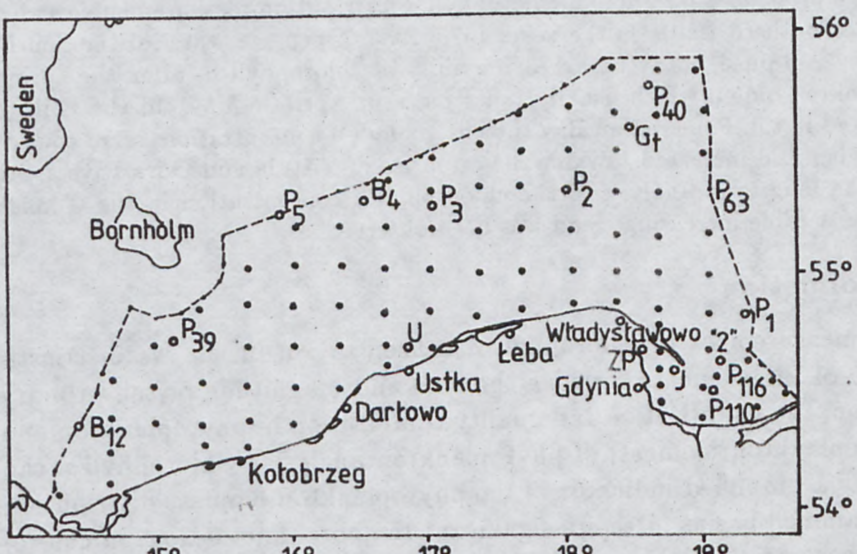

Fig. 1. Location of chlorophyll *a* sampling stations.
○ – established stations of chlorophyll and primary production measurements,
∘ – stations of r/v 'Profesor Siedlecki' expeditions

P40, P39, P3, P2, P63) and the Gulf of Gdańsk. The measurements of chlorophyll *a* concentration in the years 1979–1980 were performed by a team from the Institute of Oceanology of the Polish Academy of Sciences, Sopot (Dera *et al.*, 1980, 1981) and later by the Institute of Environment Protection, Gdańsk Branch.

- Oceanographic cruises of the Sea Fisheris Institute including routine oceanographic measurements at the following Stations: P1, P5, P40, P3, P2, B4, 'U', ZP, J, '2'. These cruises contributed 800 determinations of chlorophyll *a*.
- Three expeditions aboard the r/v 'Profesor Siedlecki' in the spring–summer seasons of 1981, 1983 and 1985 with complex oceanographic analyses at over 100 stations. Chlorophyll *a* concentration was measured at the standard depths of 0, 5 m and 10 m during these expeditions, while during the remaining cruises it was additionally analysed at depths of 3, 15 and 20 m .

Water samples collected with Nansen bottles were immediately filtered through Whatman GF/C filters. Frozen (−10°C) filters were stored for further analysis on land. Chlorophyll *a* was extracted with 90% acetone and its concentration was measured spectrophotometrically (BMEPC, 1980; Edler, 1979). The calculations were carried out using the Jeffrey and Humphrey (1975) equations. In general, chlorophyll *a* concentrations are given as mean values for the 0–10 m water layer in $mg \cdot m^{-3}$.

3. Results

3.1. Spatial distribution of chlorophyll *a*

Spatial distribution of chlorophyll *a* in the 0–10 m water layer from 9–29 July 1981 is shown in Figure 2. The results of the measurements conducted at over 100 stations during the cruise of the r/v 'Profesor Siedlecki' served to prepare this chart. Chlorophyll *a* measurements were carried out simultaneously in the coastal zone aboard the fishing boat 'Dr Lubecki'. Similar expeditions aboard the r/v 'Profesor Siedlecki' were undertaken in the summers of 1983 and 1985 and the results of the chlorophyll *a* measurements were used to calculate the mean values for the summer season. Distribution of the mean chlorophyll *a* concentration in the summer seasons 1981, 1983 and 1985 are shown in Figure 3.

It is clear that the open water of the Southern Baltic contained less chlorophyll *a* than the water of the bays. Particularly high amounts of chlorophyll *a* were recorded in the estuaries of the Vistula and Odra Rivers.

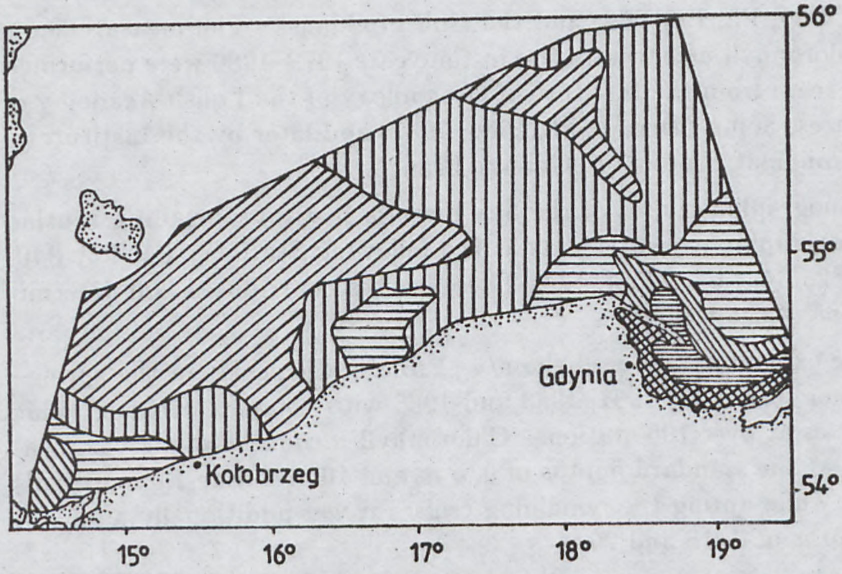

Fig. 2. Distribution of mean chlorophyll *a* concentrations in the 0–10 m water layer, 9–29 July 1981:

> 10 mg · m^{-3} | 4–5 mg · m^{-3} | 2–3 mg · m^{-3}
5–10 mg · m^{-3} | 3–4 mg · m^{-3} | 1–2 mg · m^{-3}

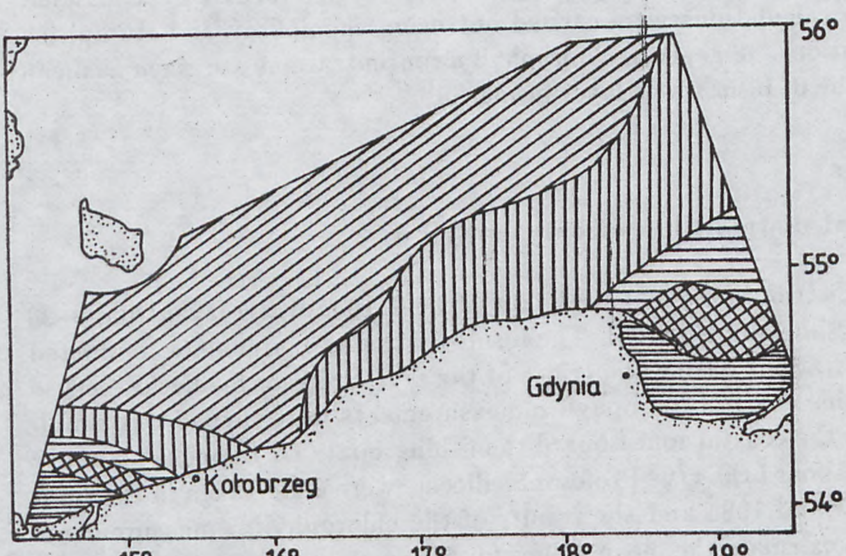

Fig. 3. Distribution of mean chlorophyll *a* concentrations in the 0–10 m water layer in summer season (mean values for the three summer seasons 1981, 1983 and 1985):

> 5 mg · m^{-3} | 3–4 mg · m^{-3} | 4–5 mg · m^{-3}
2–3 mg · m^{-3} | 1–2 mg · m^{-3}

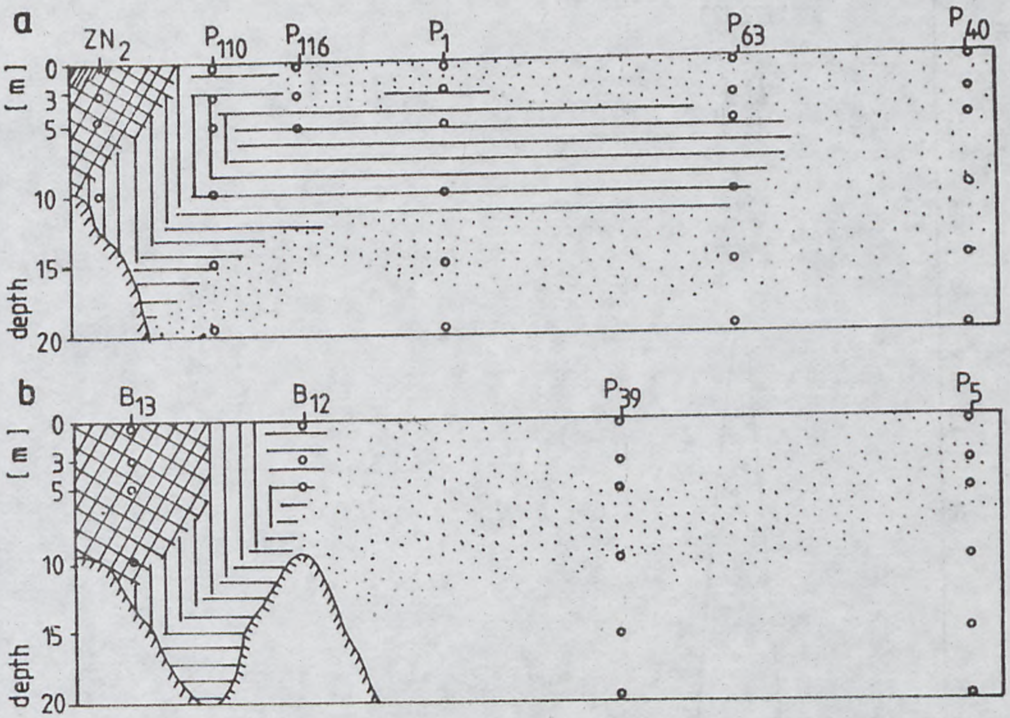

Fig. 4. Distribution of mean chlorophyll *a* concentrations in the cross-sections of the Gulf of Gdańsk – a and the Pomeranian Bay – b (mean values for the summer season 1982 and 1983):
> 20 mg · m^{-3} 5–3 mg · m^{-3} 20–10 mg · m^{-3}
3–2 mg · m^{-3} 10–5 mg · m^{-3} < 2 mg · m^{-3}

Figure 4 presents the distribution of chlorophyll *a* in the summer seasons of 1982 and 1983. The impact of both rivers on the chlorophyll *a* concentration can be clearly seen. The extent of this influence was greater in the Vistula than in the Odra estuary. Generally, in the Gulf of Gdańsk higher chlorophyll *a* concentrations were noticed than in the Pomeranian Bay, running up to the open sea zone. Therefore the concentrations determined in the Gdańsk Deep region were higher than those for the Słupsk Furrow or in the Bornholm Deep.

3.2. Seasonal fluctuations of the chlorophyll *a* concentration in the Gdańsk Deep

The measurements of chlorophyll *a* concentrations during a single year and even in the period 1979–1983 (*i.e.* following the Baltic Monitoring

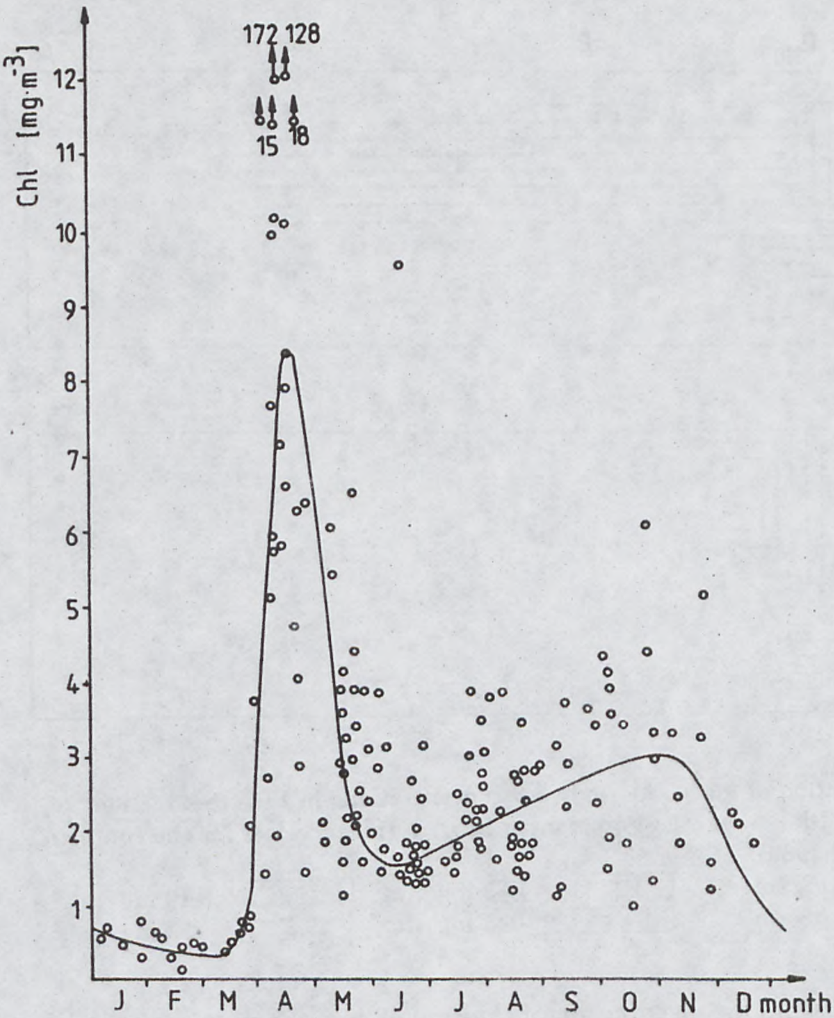

Fig. 5. Mean chlorophyll *a* concentrations in the 0–10 m water layer of the Gdańsk Deep in 1970–1983 (according to the Institute data). The curve corresponds to the averaged seasonal changes of the chlorophyll concentration

Programme) did not yield a clear picture of its seasonal fluctuations, and for this reason the analysis was carried out using data from long-term observations in the Gdańsk Deep, especially measurements at Station P1 where they were the most numerous. Figure 5 presents the mean chlorophyll *a* concentration in the 0–10 m water layer recorded at P1 in 1970–1983. It is worth noticing that quite a number of the experimental points in Figure 5 represent values of several measurements taken in a day. The curve represents the average seasonal fluctuations of chlorophyll *a* concentration in the Gdańsk Deep.

The spring phytoplankton bloom usually occured in April, when the temperature of the surface water layer exceeded 3°C. During the bloom the chlorophyll *a* concentrations in the euphotic zone reached high levels – even over 20 mg per 1 m^3. After the spring bloom, from May to October, chlorophyll concentration in the Gdańsk Deep oscillated between 2 to 3 $mg \cdot m^{-3}$, with a generally increasing trend during the summer. From November a decrease in chlorophyll *a* concentrations was observed, lasting till February of the following year.

The presented here general view of chlorophyll *a* seasonal fluctuations leads to a conclusion that a comparative analysis of the chlorophyll concentration in the particular years can be carried out only for the post-bloom period, *i.e.* from June to October. If not the high concentrations encountered during the bloom would muddle the analysis by inclusion of the mean values for the spring season that carried considerabe errors resulting from accidental measurements of various stages of the bloom.

Seasonal fluctuations of chlorophyll *a* concentration at other stations of the Southern Baltic were similar. The main differences were in the date of the spring phytoplankton bloom – appearing earlier in shallow regions and later in the Gotland Deep. In addition, the level of the mean chlorophyll *a* concentration varied depending on the station, as shown in Figure 3.

3.3. Chlorophyll *a* concentration fluctuations in subsequent years

The comparison of the chlorophyll *a* content in subsequent years turned out to be difficult taking into account the 'monitoring measurements' because the data were scarce and also the frequency of sampling was insufficient as regards the time variability of the parameter. Because the span of the phytoplankton bloom was usually shorter than the interval between the cruises, the bloom was not always observed at its peak. The elevated chlorophyll *a* concentrations recorded (the most probable evidence of the bloom at the particular stations) are listed in Table 1.

It was found that maximal concentrations of chlorophyll *a* appeared in the open Baltic water when the surface water temperature reached about 3°C, *i.e.* when the thermocline started to form in the euphotic zone. The most distinct picture of the phytoplankton bloom was observed in April 1981 at P1 when a considerable increase in chlorophyll *a* concentration was recorded, accompanied by considerable primary production, a gradual de-

Table 1. Maximal concentrations of chlorophyll *a* recorded in spring

Data	Station	Chlorophyll *a* [$mg \cdot m^{-3}$]	Primary production [$mg C \cdot m^{-2} \cdot d^{-1}$]	η	Water temperature [°C]
1979.03.22	B12	4.89	720	9.14	
1979.04.10	ZP	6.82	359	3.59	3.4
1979.05.09	P1	5.45	1059	14.24	
1979.05.23	B3	4.02	1264	17.89	6.3
1980.05.09	P1	6.04	771	12.69	3.4
1981.04.06	P1	6.36	1050	11.55	3.1
1981.04.10	P1	6.45	1185	13.45	2.7
1981.04.11	P1	17.50	1983	7.58	3.3
1981.04.16	J	16.03	1343	10.27	3.9
1982.04.16	P1	4.68	646	15.77	2.6
1982.04.25	B2	5.15	688	7.17	3.7
1982.04.26	P1	6.28	595	10.52	3.6

crease in the relative photosynthesis energy efficiency η[1] and a gradual decrease in nutrient concentration.

For these reasons the probable periods of phytoplankton blooms were excluded from the comparative analysis. The analysis was carried out for the mean values of measurement from June to October in the particular

Table 2. Mean chlorophyll *a* concentration in the euphotic zone from June to October (summer seasons) of the successive years [$mg \cdot m^{-3}$]

Region	Year				
	1979	1980	1981	1982	1983
Gdańsk Deep	2.8	2.7	3.0	2.4	2.8
Open sea zone of the Southern Baltic	2.1	2.1	2.4	2.3	2.2
Gulf of Gdańsk			6.8	5.9	9.0
Pomeranian Bay			4.7	4.1	12.7

year. The mean concentrations of chlorophyll *a* calculated accordingly are presented in Table 2. The highest concentrations in the open sea zone were recorded in 1982. In the summer of 1983 the water of the open Baltic contained less chlorophyll *a* than in 1981. On the other hand, in the period

[1]The relative coefficient of the photosynthesis energy efficiency η describes the ratio between the primary production per 1 m^2 and the mean chlorophyll *a* concentration in the euphotic zone and the radiation energy per 1 m^2 of the sea surface (Platt, 1969).

of analysis the chlorophyll *a* distribution in the coastal region, particularly in the bays, was reversed. The Gulf of Gdańsk and the Pomeranian Bay contained more chlorophyll *a* in 1983 than in 1981. In the remaining years of the studied period the number of observations was consierably limited, therefore the respective mean values are less reliable.

4. Discussion

The presented distributions of chlorophyll *a* concentration and its seasonal fluctuations do not include the daily and short-term oscillations of the chlorophyll concentration. Short-term fluctuations in particular have recently gained a lot of research attention (Renk *et al.*, 1983, 1984, 1985a; Sournia, 1974). It has been established that chlorophyll *a* concentration oscillates daily according to the daily rhythm of phytoplankton production and zooplankton grazing on phytoplankton, and random oscillations of chlorophyll *a* also take place. At certain moments a considerable amount of chlorophyll *a* is derived from algae of very small cells with generation periods of a few hours: chlorophyll *a* concentration can increase by as much as two-fold in several hours. Long-term observations (Renk *et al.*, 1985) point out that average amplitudes of the daily chlorophyll oscillations were of 20% magnitude. Taking into account all these facts it is evident that spatial distributions of chlorophyll *a* concentration determined on a basis of discrete measurements might include considerable errors resulting from random short-time fluctuations of chlorophyll.

The analysis presented in this article is based on the data on mean chlorophyll *a* concentrations calculated from several measurements during a day, though there were a number of single measurements data as well. For this reason the chlorophyll distribution picture should not be treated as definite, constant in time, but rather as a picture with isolinies dimmed due to short-time fluctuations.

In spite of these shortcomings, the presented analysis still enables the determination of the most eutrophied regions with the application of chlorophyll *a* as the eutrophication indicator. This conclusion seems to be fairly justified because of the proportionality between the inorganic nitrogen content and the chlorophyll *a* concentration observed in the river estuaries and in the bays. The highest amounts of chlorophyll *a* were recorded in the areas around the estuaries of the Vistula and Odra Rivers (Fig. 4). These regions also revealed elevated concentrations of nutrients. The distribution of chlorophyll *a* and nutrient concentration along the distance from the river estuaries in the Pomeranian Bay and in the Gulf of Gdańsk is illustrated in Figure 6. Such a situation has become typical in these regions, as the phenomenon is observed since 1971 (Renk *et al.*, 1976). Figure 7 shows

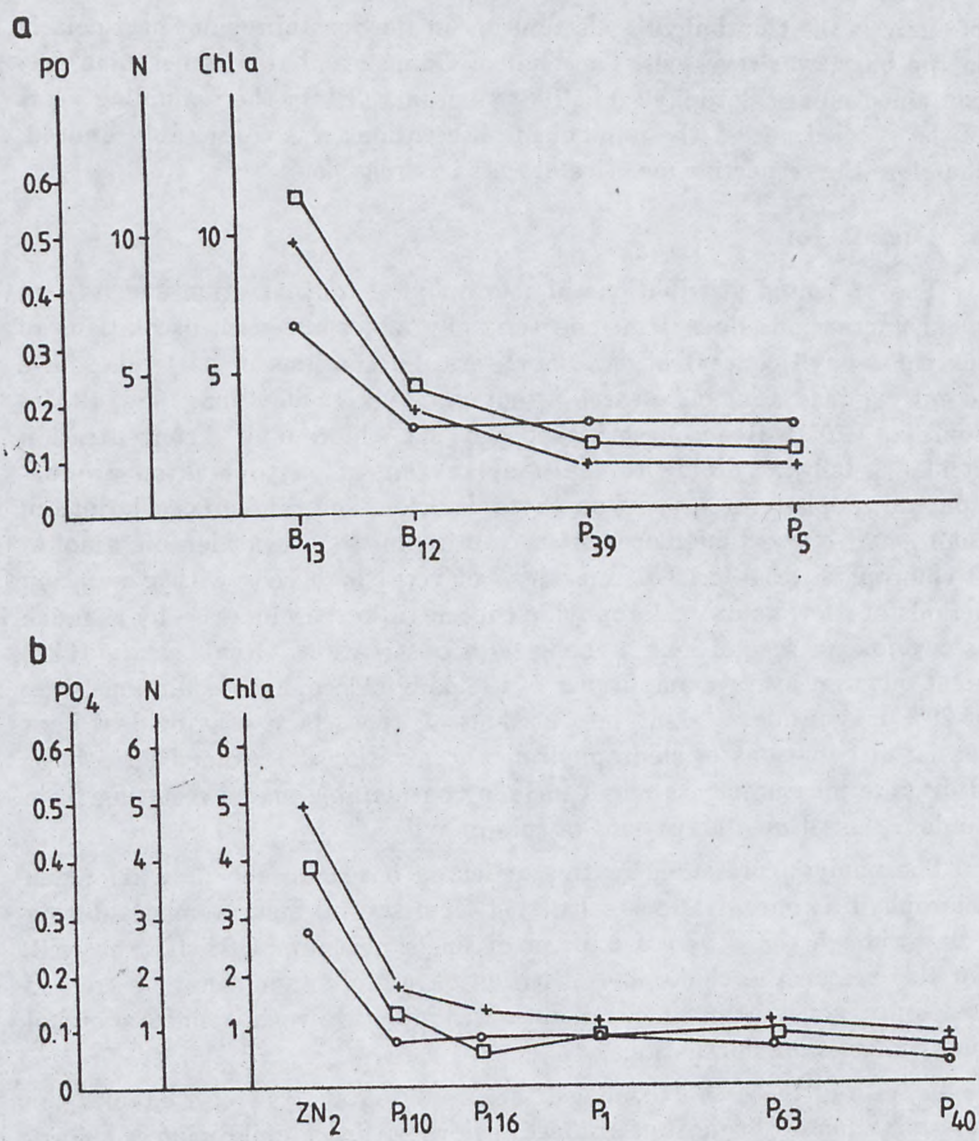

Fig. 6. Chlorophyll *a* and biogenic salts concentration changes versus the distance from the river mouth, a – Pomeranian Bay, Odra River, b – Gulf of Gdańsk, Vistula River (mean values for the years 1982–1983).
+ Chl *a* ($mg \cdot m^{-3}$), ○ N (μg at $\cdot l^{-1}$), □ PO_4 (μg at $\cdot l^{-1}$)

the distribution of chlorophyll *a* in the Gulf of Gdańsk cross-section in July 1971. Similar levels of chlorophyll *a* concentration were observed by Latała (1985) in this region in 1981.

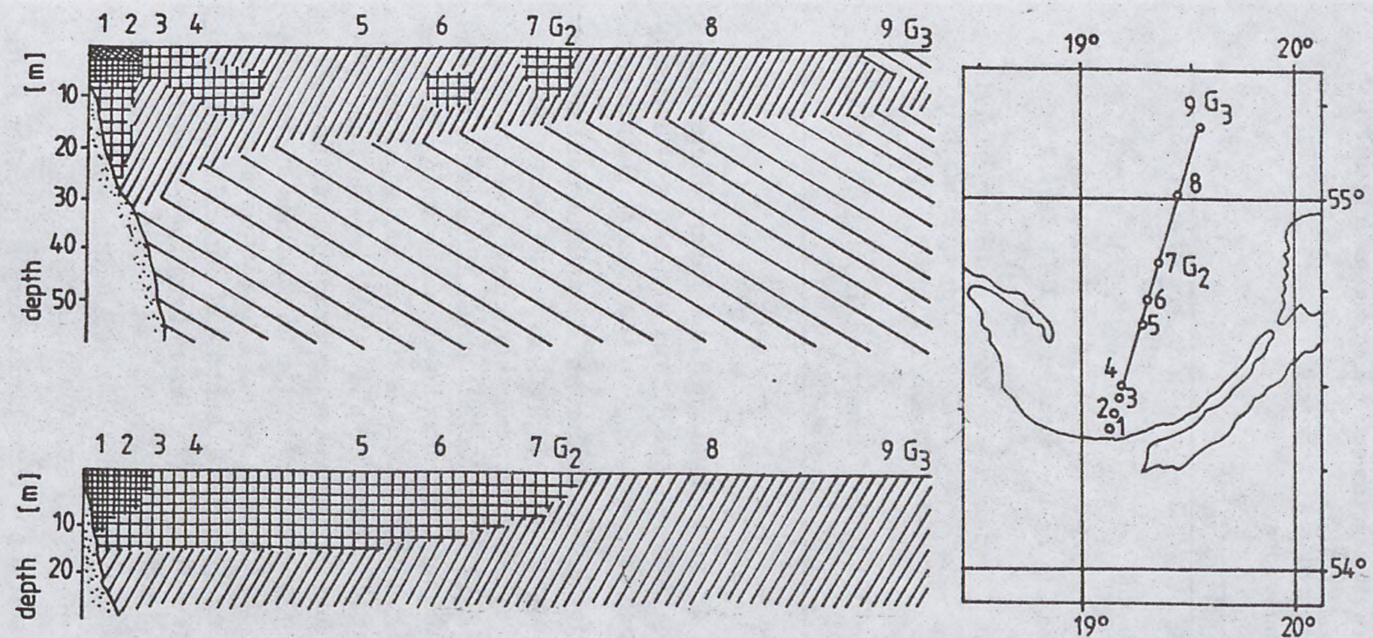

Fig. 7. Chlorophyll *a* distribution in the Gulf of Gdańsk in June and September 1971:

0–1.00 mg · m^{-3}

1.01–2.00 mg · m^{-3}

2.01–5.00 mg · m^{-3}

5.01–30.0 mg · m^{-3}

30.1–45.00 mg · m^{-3}

Table 3. Chlorophyll *a* concentration in the eutrophied regions [$mg \cdot m^{-3}$]

Region	Chlorophyll *a* concentrations in summer		Source
	maximal	mean	
Kiel Bight	60	2.1–3.5	von Bodungen *et al.*, 1975; Krey, 1974
Gulf of Lűbeck	9	2–4	Rohde and Schulz, 1973
Pomeranian Bay	14	2–6	Renk, 1973; Renk *et al.*, 1974
Gulf of Gdańsk	30	2–12	Renk *et al.*, 1974, 1976; Latała, 1982, 1985
Gulf of Riga	49	1–5	Yourkovsky and Bramane, 1974, 1975; Yourkovsky *et al.*, 1976
Region of Tvărminne	22	1–7	Niemi, 1972, 1973
Pojoviken (Gulf of Finland)	20	10–18	Lassig and Niemi, 1973, 1975
Region of Stockholm	50	10–30	Engstrőm, 1973

The eutrophying impact of the Vistula and Odra Rivers diminishes in the direction of the open sea zone, though it was sometimes still clearly noticeable in the adjacent open sea areas, *e.g.* in the Gdańsk Deep region.

At the moment, the relation between chlorophyll *a* and nutrient concentrations in the eutrophied areas is not well marked; in the period between 1971–1974 there was a clear relation between chlorophyll *a* and inorganic nitrogen contents (Renk, 1972, 1973; Renk *et al.*, 1974). Simultaneously the ratio of inorgranic nitrogen to inorganic phosphorus, in the spring–summer term, exceeded 15 : 1, and diminished from the river estuaries' vicinity to the open sea zone to the value of 4 : 1 and even lower (Majewski *et al.*, 1974, 1976; Renk *et al.*, 1976). In the following years significant fluctuations of the N : P ratio were observed, probably caused by the fluctuations of the phosphorus and nitrogen inflow with the river water. These inflow fluctuations, in turn, were probably resulted from the technology of mineral fertilization applied in agriculture and the drainage of fertilizers from the soil with rain. According to Trzosińska (in press) the N : P ratio manifested a considerable increase in the water of the Southern Baltic due to the inflow of nutrients with river water (Larsson *et al.*, 1985; Żmudziński, 1986).

High chlorophyll *a* concentrations were also observed in other Baltic bays similar to the Gulf of Gdańsk and the Pomeranian Bay (Bagge and Lehmusluoto, 1971; von Bodungen *et al.*, 1975; Krey, 1974; Rohde and Schulz, 1973; Waern and Hűbinette, 1973) as shown in Table 3.

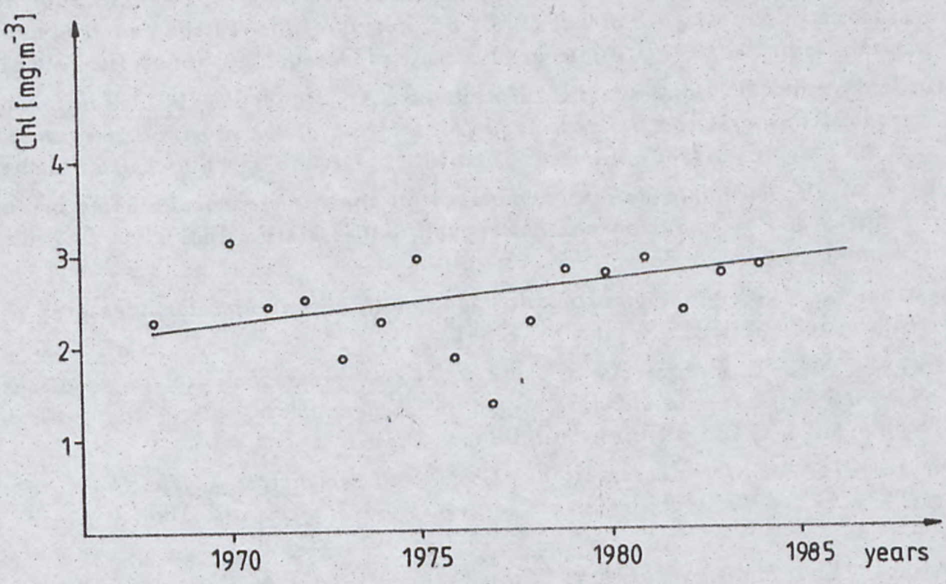

Fig. 8. Mean chlorophyll *a* concentrations in the 0–10 m water layer in summer seasons of 1968–1984 in the Gdańsk Deep

The prolonged inflow of biogenic salts to the Baltic Sea resulted in eutrophication of this basin and in consequently in an increase in the mean chlorophyll *a* concentration. Although chlorophyll *a* concentrations oscillate in a relatively wide range and the mean values for the particular years were erroncous to a certain extent, the general and noticeable trend is the increase in chlorophyll *a* concentration in the Gdańsk Deep (Renk *et al.*, 1985b, 1988). This increase reached a level of about 2% per year over several years relative to the mean value (see Fig. 8). A 2% increase in the annual primary production was also observed in the Gdańsk Deep (Renk *et al.*, 1988).

References

Bagge P., Lehmusluoto P., 1971, *Phytoplankton primary production in some Finnish coastal areas in relation to pollution*, Merentutkimuslait. Julk., 235, 3–18.

Baltic Marine Environment Protection Commission, 1980, *Guidelines for the Baltic Monitoring Programme for the First Stage.*

von Bodungen B., von Bröckel K., Smetacek V., Zietzschel B., 1975, *Ecological studies on the plankton in the Kiel Bight. I. Phytoplankton*, Merentutkimuslait. Julk., 239, 179–186.

Dera J., Hapter R., Kosakowska A., Pempkowiak J., Woźniak B., 1980, *Monitoring środowiska morskiego Bałtyku, 1979 (Monitoring of the marine ennvironment of the Baltic Sea, 1979)*, mimeogr., Institute of Oceanology, Sopot, (in Polish).

Dera J., Woźniak B., Bojanowski R., Kosakowska A., Hapter R., 1981, *Monitoring środowiska morskiego Bałtyku, 1980 (Monitoring of the marine environment of the Baltic Sea, 1980)*, mimeogr., Institute of Oceanology, Sopot, (in Polish).

Edler L., 1979, *Recommendation on methods for marine biological studies in the Baltic Sea. Phytoplankton and chlorophyll*, Baltic Marine Biologists, 5, Univ. of Lund, Sweden, 1–38.

Engström G., 1973, *Phytoplankton distribution in the archipelago measured as chlorophyll a*, OIKOS Suppl., 15, 176–178.

Jeffrey S. W., Humphrey G. F., 1975, *New spectrophotometric equations for determining chlorophyll a, b, c in higher plants, algae and natural phytoplankton*, Biochem. Physiol. Pflanzen., 167.

Krey J., 1974, *Long-term observations of ecological parameters in Kiel Bight from 1957–1972, with special reference to monthly averages*, Ann. Biol. ICES, 29, 63–64.

Larsson U., Elmgren R., Wulff F., 1985, *Eugrophication and the Baltic Sea. Changes and consequences*, Ambio, 14(1), 9–14.

Lassig J., Niemi A., 1973, *Amounts of chlorophyll a in the Baltic during June and July 1969 and 1970*, OIKOS Suppl., 15, 34–42.

Lassig J., Niemi A., 1975, *Parameters of production in the Baltic measured during cruises with r/v 'Aranda' in June and July 1971*, Merentutkimuslait. Julk., 239, 34–40.

Latała A., 1982, *The chlorophyll content in the surface waters of the western part of the Gdańsk Bay*, Stud. i Mater. Oceanol., 39, 15–33, (in Polish).

Latała A., 1985, *Chlorophyll content in the surface waters of the Gulf of Gdańsk Proper in 1981*, Stud. i Mater Oceanol., 46, 11–22, (in Polish).

Majewski A., Trzosińska A., Żmudziński L., 1974, *Environmental conditions in the Baltic in 1971–1975*, Wiad. Meteorol. i Gospod. Wodnej, I(XXII), 4–12, (in Polish).

Majewski A., Trzosińska A., Żmudziński L., 1976, *Warunki środowiskowe Bałtyku w okresie 1971–1975, (Environmental conditions in the Baltic in 1971–1975)*, Prz. Geof., XXI, (in Polish).

Niemi A., 1972, *Observations on phytoplankton in eutrophied and non-eutrophied archipelago waters of the southern coast of Finland*, Memoranda Soc., Fauna, Flora Fennica, 48, 63–74.

Niemi A., 1973, *Ecology of phytoplankton in the Tvarminne Area. SW coast of Finland*, Acta Botanica Fennica, 100, 2–68.

Platt T., 1969, *The concept of energy efficiency in primary production*, Limnol. Oceanogr., 14, 653–661.

Renk H., 1972, *Chlorophyll a in the Southern Baltic in 1972*, Ann. Biol. ICES, 28, 74–76.

Renk H., 1973, *Primary production of the Southern Baltic water*, Stud. i Mater. MIR, Gdynia, A/12, 5–126, (in Polish).

Renk H., Torbicki H., Ochocki S., 1974, *Influence of river water on the distribution of phytoplankton biomass*, Proc. 16th Conf. of the Baltic Oceanogr., Kiel, 15, 198–210.

Renk H., Torbicki H., Ochocki S., 1976, *Rozmieszczenie chlorofilu w morzu w rejonach ujściowych rzek*, Stud. i Mater. Oceanol., 15, 187–202.

Renk H., Ochocki S., Pytel H., 1983, *Short-term variations of primary production and chlorophyll in the Gdańsk Deep*, Pol. Ecol. Stud., 9, 341–359.

Renk H., Ochocki S., Nakonieczny J., 1984, *Diel fluctuations of the Baltic Sea*, ICES Biol. Oceanogr. Com. C.M., 1984/L, 23.

Renk H., Borysiak M., Nakonieczny J., Ochocki S., 1985a, *Diurnal fluctuations of the phytoplankton biomass*, Stud. i Mater. Oceanol., 46, 150–180, (in Polish).

Renk H., Nakonieczny J., Ochocki S., Gromisz S., 1985b, *Long-term changes of phytoplankton and zooplankton biomass in the Southern Baltic*, ICES Biol. Oceanogr. Com. C.M., 1985/L, 28.

Renk H., Nakonieczny J., Ochocki S., 1988, *Primary production in the Southern Baltic in 1985 and 1986 compared with long-term mean seasonal variation*, Kieler Meereforsch. Soderh., 6, 203–209.

Rohde K. H., Schulz S., 1973, *Biological production in polluted coastal waters*, OIKOS Suppl., 15, 209–213.

Sournia A., 1974, *Circadian periodicities in natural population of marine phytoplankton*, Adv. Mar. Biol., 12, 325–389.

Steemann Nielsen E., 1963, *Productivity, definition and measurement*, [In:] *The Sea, 2*, Hill M. N. (Ed.), Interscience Publ., John Wiley and Sons, New York – London, 129–164.

Steemann Nielsen E., Jørgensen E. G., 1962, *The physiological background for using chlorophyll measurements in hydrobiology and a theory explaining daily variations in chlorophyll concentration*, Arch. Hydrobiol., 58, 349–357.

Trzosińska A., in press, *Substancje biogeniczne w południowym Bałtyku (Biogenic substances in the Southern Baltic)*, (in Polish).

Waern M., Hübinette L., 1973, *Phosphate, nitrate and ammonium in the archipelago during 1970. 2. Nutrients and their influence on the algae in the Stockholm Archipelago during 1970*, OIKOS Suppl., 15, 164–170.

Yourkovsky A., Bramane A., 1974, *Chlorophyll and seston in the upper layers of the Baltic Sea in 1972*, Ann. Biol. ICES, 29, 67–68.

Yourkovsky A., Bramane A., 1975, *Chlorophyll a in the Baltic Sea and the Gulf of Riga in 1973*, Ann. Biol. ICES, 30, 74–76.

Yourkovsky A., Linea R., Bramane A., Sidrevits L., Yourkovska A., Vitinya M., 1976, *Phosphorus and seasonal dynamics of phyto-bacteria and zooplankton in the Baltic Sea in 1974*, Ann. Biol. ICES, 31, 75–79.

Żmudziński L., 1986, *Zanieczyszczenie Morza Bałtyckiego (Pollution of the Baltic Sea)*, Kosmos, 35(1), 79–93, (in Polish).