Primary production of the Southern Baltic in 1979–1983

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Primary production
Southern Baltic
Baltic Monitoring

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Abstract

The paper presents the results of the determination of primary production in 1979–1983, carried out within the frames of the first stage of the Baltic Monitoring Programme. Annual primary production of the open waters of the Southern Baltic was equal to ca 100 $g \cdot C \cdot m^{-2}$. It has been established that primary production in the gulf regions is higher than in the open waters of the Southern Baltic. It follows from the calculations that in the last dozen or so years the annual production of the Baltic increased annually by ca 2.5% on average compared with long-term mean.

1. Introduction

Photosynthesis intensity and the magnitude of primary production can be the measures of productivity of aqueous environment and of water purity. The key role in the processes of organic matter production in seas is played by light and by inorganic compounds dissolved in water, being the main building materials of the formed organic matter. Hence, the trophicity of an environment depends on the chemical compounds dissolved in water, while the inflowing compounds cause eutrophication, and sometimes even intoxication. A particularly fast eutrophication can be due to large amounts of compounds pouring into a sea with river waters contaminated with municipal and industrial wastes, as well as the compounds from chemicalization of agriculture. A significant acceleration of the eutrophication process is observed in recent years in the gulf regions. It can be generally stated that even a small increase in concentration

[1]The investigations were carried out under the research programme R–6.

of nutrients in water can intensify photosynthesis, while a considerable increase in concentration of chemical compounds can even inhibit the primary production. Pollutants entering the sea can sometimes be noxious or even toxic. For example copper causes photosynthesis inhibition even in small concentrations. Phytoplankton can react even to small amounts of pollutants in a relatively short time by a change in the rate of photosynthesis, primary production and mitosis. Due to this, observation of the rate of primary production and phytoplankton biomass should be considered as important elements of the Baltic Monitoring.

Polish investigations on primary production of the Baltic started in 1965, yet they were not carried out systematically, and the frequency of primary production measurements was relatively low (Rochon, 1966, 1968; Renk, 1973, 1974, 1983). The performed investigations do not allow pointing out significant differences in primary production of the particular years. However, on the basis of these results it is possible to determine the long-term mean annual production and the mean course of seasonal changes in primary production (Torbicki, 1975; Renk, 1983). These results can be utilized for monitoring the eutrophication process of the Baltic. Moreover, these investigations allowed characterizing the short–term fluctuations of primary production (Renk *et al.*, 1983).

The presented paper summarizes the results of investigations on primary production carried out within the frames of the first stage of Baltic Monitoring. The investigations were ordered by the Gdańsk Division of the Institute of Environment Protection, the Polish co-ordinator in the International Baltic Monitoring Programme. The investigations on primary production within the frame of the Baltic Monitoring were carried out in the years 1979–1980 by a research team from the Institute of Oceanology of Polish Academy of Sciences in Sopot headed by Prof. Jerzy Dera, and in 1983 by a team from the Sea Fisheries Institute in Gdynia. Two years' break in the investigations carried out within the Baltic Monitoring constitutes a serious difficulty in clear presentation of primary productivity in 1979–1983. Therefore the paper contains also the results of investigations on primary production carried out by the Sea Fisheries Institute in 1979–1983 within the program of complex fishing investigations.

The primary goal of the presented paper is the presentation of the "initial conditions" of primary production at the beginning of the routine Baltic Monitoring.

2. Materials and methods

The following materials were utilized in the paper:

1. Reports from the research carried out by a research team from the Institute of Oceanology of the Polish Academy of Sciences in Sopot in 1979 and 1980, entitled Monitoring of the Baltic Marine Environment (Dera *et al.*, 1980, 1981), containing the results of determination of primary production and hydrooptical measurements. The reports were delivered by the Institute of Environment Protection in Gdańsk.

2. The results of determination of primary production carried out by a research team from the Sea Fisheries Institute in Gdynia, also within the frames of Baltic Monitoring in 1983 (Renk *et al.*, 1986).

3. Own materials gathered during long-term investigations on primary production of the Baltic, used for the determination of the long-term mean production.

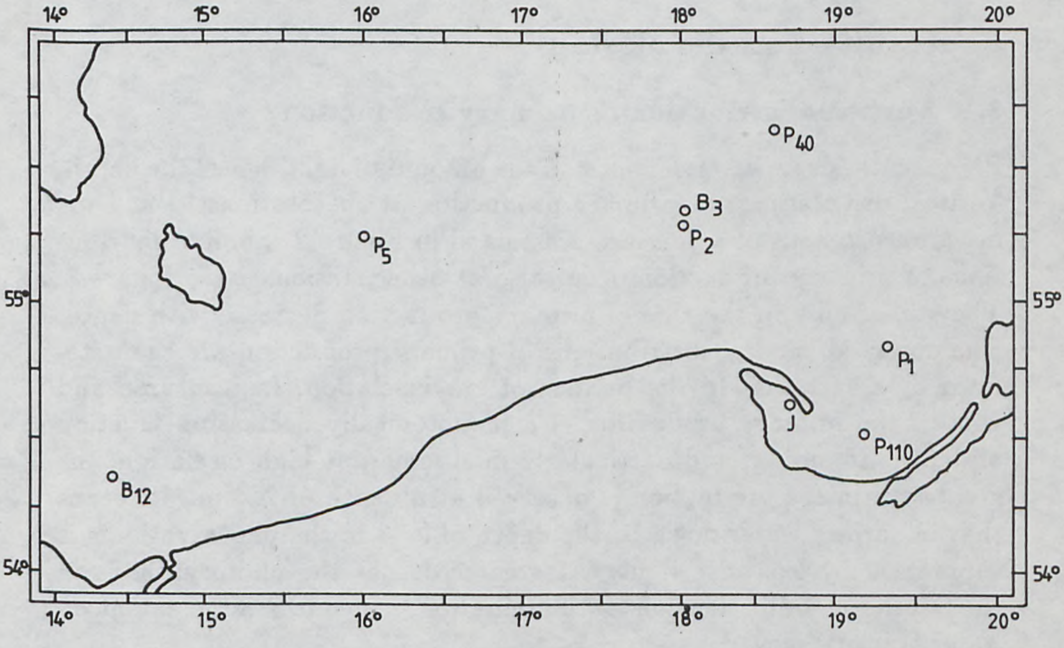

Figure 1: Localization of measuring stations where primary production was determined

The map in Figure 1 presents the localization of stations at which the primary production was measured "in situ" using the radioisotopic method (Steemann Nielsen, 1952; Gargas, 1975), recommended for the determinations of primary production within the Baltic Monitoring by the Baltic Marine Environmental Commission (1980). Bottles with phytoplankton were incubated for four afternoon hours. A solution of radioactive sodium carbonate (^{14}C) of the activity 6 $\mu C/ml$ was used for the determinations. Radioactivity of filters with phytoplankton was measured with a GM counter of the window thickness equal to 1.5 $mg \cdot cm^{-2}$. A correction for the so-called biological standard (Steemann Nielsen, 1965) was applied in the calculations. The total daily insolation was measured with a solarimeter situated on a special mast on the vessel.

The spectrum of the coefficients of diffusive light attenuation by water has been drawn on the basis of the results by hydrooptical measurements performed by scientific team from the Institute of Oceanology of the Polish Academy of Sciences (Dera *et al.*, 1980, 1981). Methods of the performed hydrooptical measurements are described in detail in the papers by Dera (1971, 1983).

3. Results and discussion

3.1. Vertical distribution of primary production

Photosynthesis in water depends on the amount of light, hence the depth. Vertical distributions of primary production at the Stations P_1 and P_{40} in various seasons of a year are prestented in Figure 2. Similar distributions of primary production occur also at other stations – see Figure 3. They differ only in the rate of primary production decrease with depth. The observed vertical distributions of primary production are characterized by a fact that in the periods of low insolation, *i.e.* autumn and winter, the primary production is a monotonically decreasing function of depth. In spring, and particularly in summer, at high insolation, the greatest primary production is observed at a depth of 2–4 m. It means that in surface water down to the depth of ca 3 m the photosynthesis is suppressed by excessive light. At greater depths the photosynthesis in the Southern Baltic depends on illumination, hence to a large extent on water transparency.

A good measure of water transparency is the beam attenuation coefficient. Examples of spectra of this coefficient for the water of the Southern

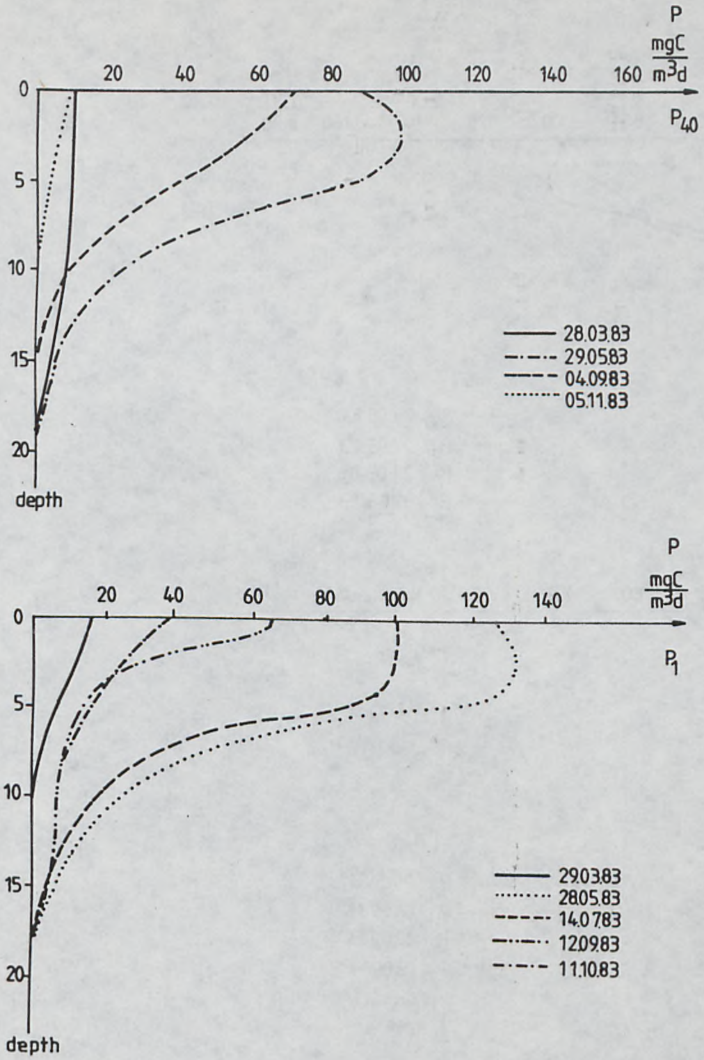

Figure 2: Vertical distribution of primary production in various seasons of 1983 at the P_{40} (Southern part of the Gotland Deep) and P_1 (Gdańsk Deep) Stations

Baltic are presented in Figure 4. It can be generally stated that these coefficients reveal a characteristic minimum in the 525–575 nm wavelength range. The figure illustrates simultaneously that waters of the Pomeranian Bay and the Gulf of Gdańsk absorb light stronger than open waters of the Southern Baltic (Stations P_5, P_{40}). Figure 4 illustrates also the changes in water transparency in the successive years at the Station P_{40}. Numerous measurements and observations indicate that the coefficient of light attenuation by the Baltic water strongly increases during the vegeta-

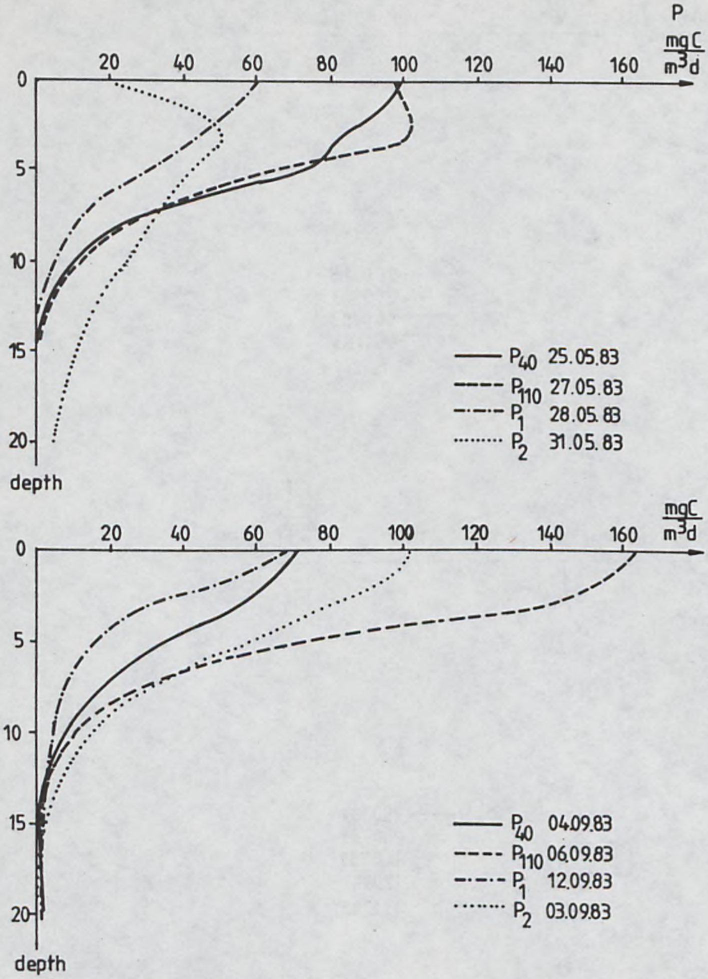

Figure 3: Vertical distributions of primary production at various stations of the Southern Baltic in May and September 1983

tive seasons. Also the course of the spectral function of light attenuation coefficient varies to a certain extent during a year.

Due to varying transparency of the Baltic waters, the thickness of the euphotic depth is also variable. Taking into account the biological criterion, according to which an euphotic layer is a layer above the compensation layer, it can be stated that the thickness of the euphotic layer in the gulf regions is ca 10 m (and sometimes less), while in the open regions of the Southern Baltic it reaches 20 m. The thickness of the eu-

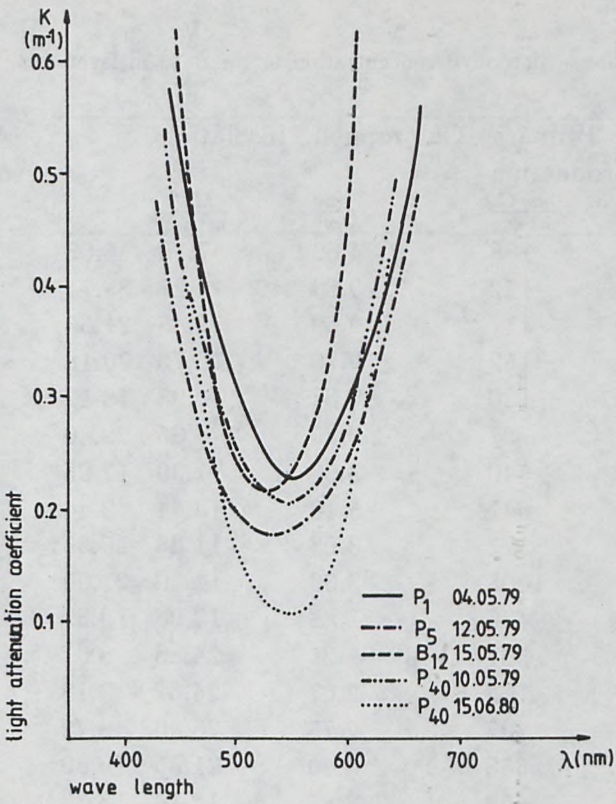

Figure 4: Examples of spectrum of downward irradiance attenuation coefficients in the euphotic layer of the Southern Baltic (determined on the basis of the measurements of Dera *et al.*, 1980, 1981)

photic layer can also be approximately estimated from the diagrams of primary production distribution (Figs. 2 and 3). A comparison of a production from 1 m^3 at various stations allows establishing that gulf regions compared to open sea regions are characterized by higher primary production in surface water, but at the same time the thickness of the productive layers of the gulf waters is lower than that of the open waters.

3.2. Daily primary production and its seasonal variations

Daily primary production under the area of 1 m^2 can be determined by graphical integration over the depth of the curves illustrating the vertical distribution of primary production, presented in Figures 2 and 3. The

Table 1: Daily primary production, chlorophyll concentration in the 0–10 m layer and insolation in 1983

Date	Station	Water temp. ^oC	Primary production $\frac{mg \cdot C}{m^2 \cdot day}$	Chlorophyll $\frac{mg}{m^3}$	Insolation $\frac{M \cdot J}{m^2 \cdot day}$	η
23.03	B_{12}	3.7	188	4.66	7.16	5.63
24.03	P_5	3.1	122	0.80	4.27	35.71
25.03	B_3	3.2	117	0.69	7.83	21.66
26.03	B_3	3.2	152	0.70	10.76	20.18
28.03	P_{40}	2.8	136	0.67	10.93	18.57
29.03	P_1	3.2	97	0.70	4.65	29.80
30.03	P_{110}	3.5	540	3.66	11.39	12.95
27.05	P_{110}	12.9	647	5.10	13.44	9.44
28.05	P_1	12.5	577	3.08	11.35	16.50
29.05	P_{40}	9.6	1005	3.30	14.50	21.00
30.05	B_3	9.5	436	1.88	13.98	16.59
31.05	P_5	8.0	561	1.21	24.83	18.67
01.06	B_{12}	12.6	162	2.07	24.62	3.18
14.07	P_1	18.5	707	2.75	26.46	9.72
11.08	B_3	19.9	558	2.40	21.35	10.89
12.08	P_1	18.6	623	3.85	12.14	13.33
01.09	B_{12}		367	2.41	9.63	15.81
02.09	P_5	18.3	473	1.14	8.37	49.57
03.09	B_3	15.5	520	2.36	12.56	17.54
04.09	P_{40}	18.1	313	1.94	7.54	21.40
06.09	P_{110}		730	5.40	16.75	8.07
12.09	P_1		217	2.69	2.39	33.75
11.10	P_1	14.1	195	1.60	7.66	15.91
05.11	P_{40}	8.0	33	1.80	1.30	14.10
07.11	B_3	10.1	32	1.87	0.85	20.30
08.11	P_5	9.4	89	2.68	1.52	21.85
09.11	B_{12}	8.9	219	2.40	3.99	22.87
11.11	P_1	9.9	117	1.63	2.80	25.64
16.11	P_{110}	9.6	40	1.53	1.82	14.36
26.11	J	7.1	21	1.27	0.72	22.97

results of determination of daily primary production under the area of 1 m^2 carried out in 1983 are listed for example in Table 1. Already a superficial evaluation of the results listed in Table 1 demonstrates that primary production of the Southern Baltic is quite differentiated. Since the insolation of this region is less or more uniform, the differences in primary production observed at the particular stations in the successive days can be due to changes in insolation in the particular days, different concentration of phytoplankton biomass, and finally small differences in productivity of these regions. The primary productivity is the best characterized by a conventional parameter allowing for insolation and chlorophyll concentration, *viz.* the relative coefficient of *energetic efficiency of photosynthesis* (Platt, 1969), defined in the following way:

$$\eta = \frac{P}{E \cdot Chl}, \tag{1}$$

where:

P – primary production under an area of 1 m^2;
E – solar radiation energy per unit area of sea;
Chl – mean chlorophyll concentration in the euphotic layer.

It follows from Table 1 that the coefficient of photosynthesis energetic efficiency differed significantly in the particular seasons at various stations. The η coefficient was the lowest directly after the phytoplankton bloom, when a distinct decrease in nutrients concentration in the euphotic layer was usually observed. It has also been observed that this coefficient is lower in gulf waters compared to open waters. This means that the η coefficient determined for the entire euphotic layer decreases in water of lower transparency.

On the other hand, seasonal variability of primary production is primarily due to changes in insolation. It is also influenced by water transparency, temperature and nutrients concentration.

3.3. Regional differences in primary production

Attention has been drawn to spatial variability of primary production already during the illustration of vertical distribution of primary produ-

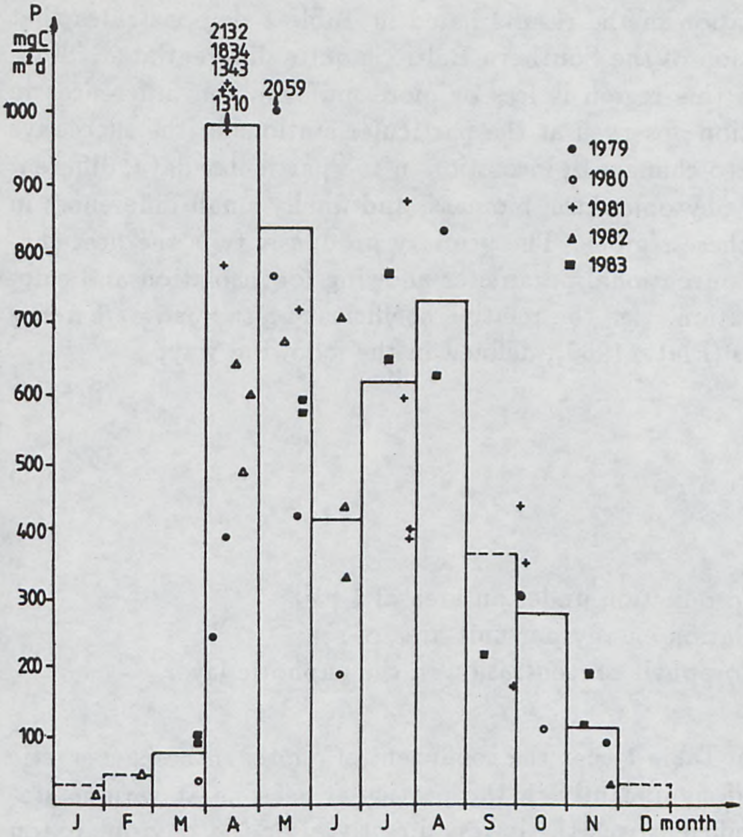

Figure 5: Results of primary production determinations in 1979–1983 at the Gdańsk Deep against the background of mean monthly values for the 1979–1983 period

ction (Fig. 3). Analysis of data in Table 1 allows establishing that primary production of the Gulf of Gdańsk (Stations P_1 and P_{110} is higher than that at the remaining stations. This statement is also testified by Figures 5–8, presenting the results of determination of primary production at the Stations P_2, P_5 and P_{40} against a background of mean monthly values for the 1979–1983 period, calculated as means for the entire area of open waters of the Southern Baltic (means for Bornholm Deep, Słupsk Furrow and southern part of the Gotland Deep).

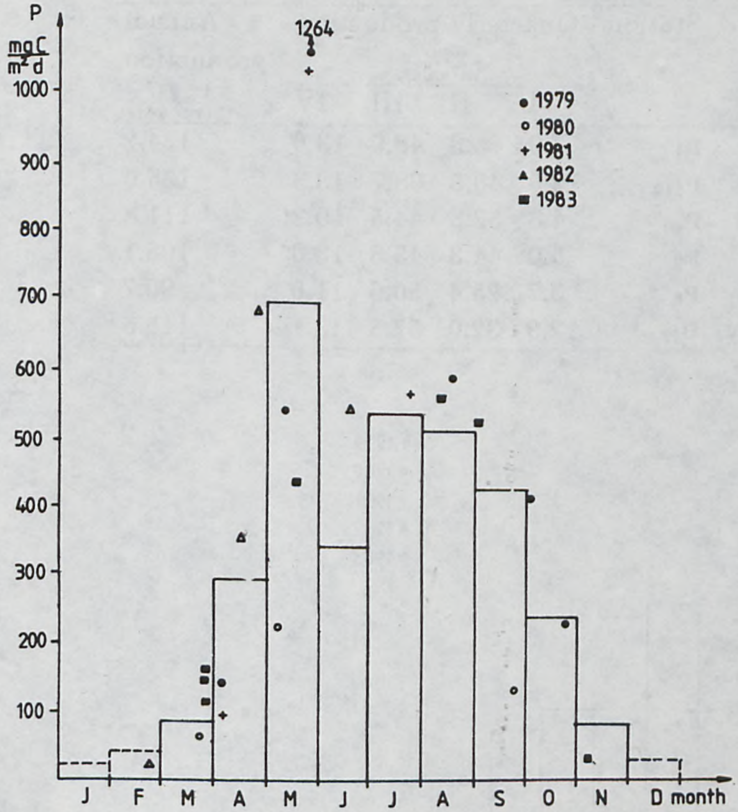

Figure 6: Results of primary production determinations in 1979–1983 at the Słupsk Furrow against the background of mean monthly values for the 1979–1983 period

The differences in quarterly and annual primary production at the particular stations of the Southern Baltic can be illustrated by Table 2, listing the values averaged for the five years' period (1979–1983). It follows from Table 2 that the regions of the Gulf of Gdańsk (Stations P_1 and P_{110}) and the Pomeranian Bay (Station B_{12}) are cheracterized by the highest annual primary production. The fact that the production at the Station B_{12} is lower than at the P_1 and P_{110} Stations can be due to a lower depth of Station B_{12} (less than 10 m).

Table 2: Annual and quarterly primary production at various stations of the Southern Baltic (means for 1979–1983)

Region	Station	Quarterly production $\frac{g \cdot C}{m^2 \cdot quar.}$				Annual production $\frac{g \cdot C}{m^2 \cdot year}$
		I	II	III	IV	
Gdańsk Deep	P_1	7.9	65.3	48.0	13.0	134.2
Gulf of Gdańsk	P_{110}	12.5	40.5	68.7	13.3	135.0
Gotland Deep	P_{40}	4.3	52.8	44.5	10.2	111.8
Słupsk Furrow	P_2	5.0	44.3	45.8	13.0	108.1
Bornholm Deep	P_5	3.7	25.4	50.6	11.0	90.7
Pomeranian Bay	B_{12}	12.9	32.0	57.5	13.1	115.5

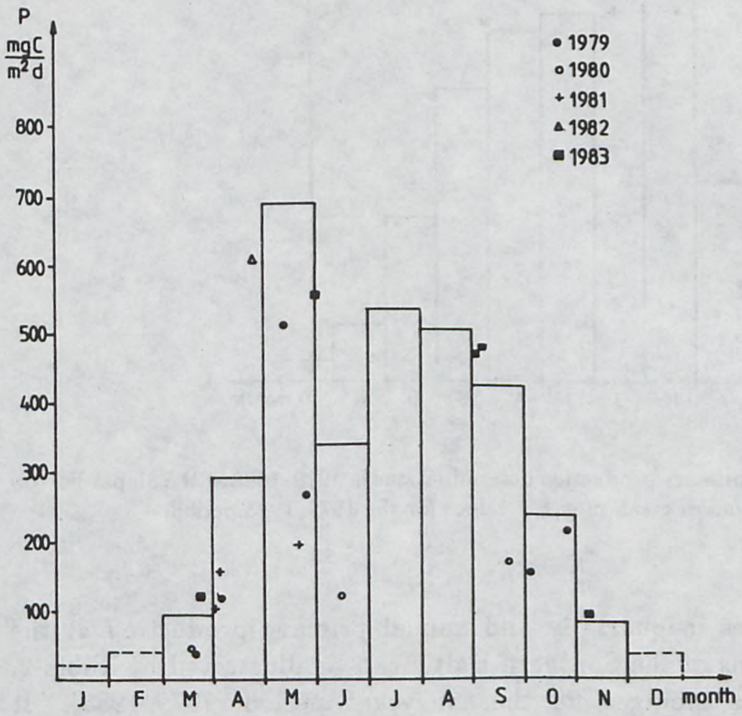

Figure 7: Results of primary production determinations in 1979–1983 at the Bornholm Deep against the background of mean monthly values for the 1979–1983 period

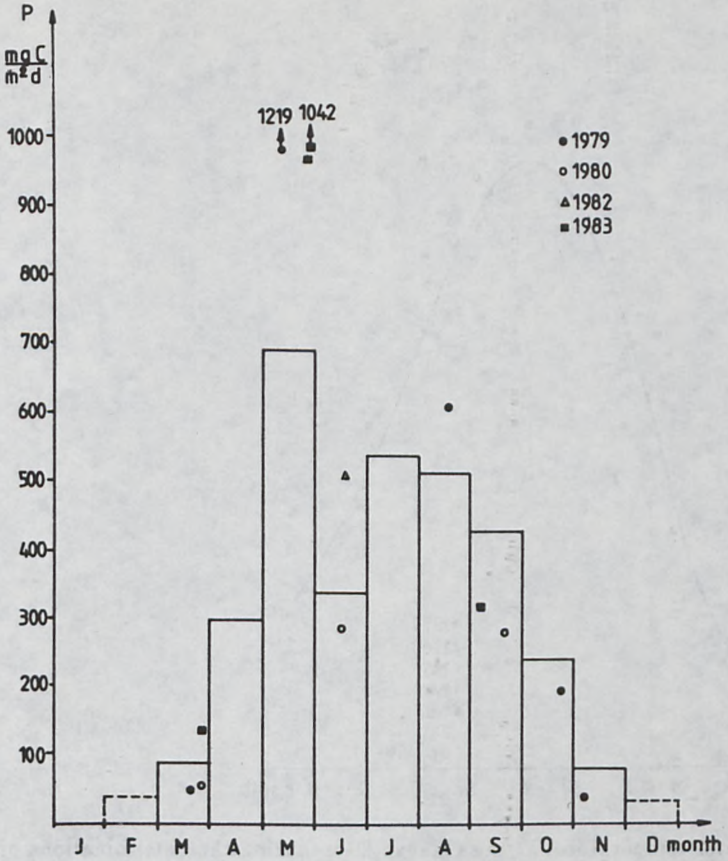

Figure 8: Results of primary production determinations in 1979–1983 at the Gotland Deep against the background of mean monthly values for the 1979–1983 period

3.4. Changes in primary production in the particular years

Changes in primary production in the successive years manifested themselves most distinctly in spring seasons, especially through the date of spring bloom of phytoplankton, duration of the bloom and effects related to gradual exhaustion of nutrients during phytoplankton bloom. The date of the spring phytoplankton bloom depends to a large extent on the begining of thermocline formation in the euphotic layer, hence the temperature of the surface water. Figure 9 presents the results of determination of surface water temperature at the Gdańsk Deep. The curve in the Figure illustrates the course of mean seasonal variations in surface

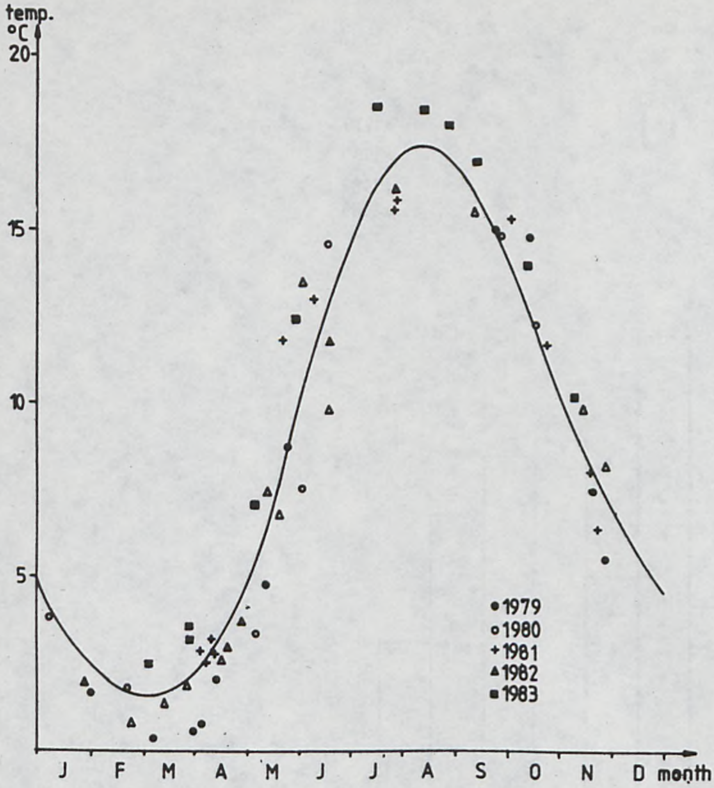

Figure 9: Surface water temperatures at the Gdańsk Deep during the determinations of primary production. Solid line depicts mean values for the 1960–1983 period

water temperature at the Gdańsk Deep, averaged for a twenty years' period (1960–1983). In 1979 the maximum production indicating the climax of the spring bloom at the Gdańsk Deep was observed on the 9th May. It can be stated therefore that the spring phytoplankton bloom at the Gdańsk Deep was delayed by ca four weeks. At the remaining stations the spring bloom occurred also in May. This was probably due to relatively low temperature of surface waters in this time. As a result of the delayed and timediffused phytoplankton bloom, the concentration of nutrients could have remained relatively high till late spring. In spring and autumn 1979 the primary production at the Southern Baltic was relatively high, higher than average.

Measurements of primary production carried out in 1980 revealed a low rate of phytosynthesis, and demonstrated additionally that also in this year the spring phytoplankton bloom occurred only in May. These measurements indicate low primary production in this year.

No measurements of primary production for a purposes of the Baltic Monitoring were carried out in 1981 and 1982. The measurements performed by the Sea Fisheries Institute (within another research project) indicate that in spring seasons of both the years the primary production was higher than the long-term mean, while in summer and autumn 1981 the rate of primary production was much lower than the long-term mean. No measurements were carried out in the second half of 1982.

The following measurements of primary production within the frames of the Baltic Monitoring were carried out only in 1983. It follows from these measurements that in spring and summer the primary production was higher than the long-term mean. In spring and summer seasons of this year the observed water temperatures in the euphotic layer were higher than the long-term mean. In November 1983, apart from the Gdańsk Deep and the B_{12} Station (Pomeranian Bay), the primary production was lower than the long-term mean.

4. Discussion

4.1. Regional changes in primary production

Regional changes in productivity manifest themselves in differences in the thickness of the euphotic layer, differences in the magnitude of primary production in the euphotic layer, *i.e.* production under the area of 1 m^2, and in different dynamics of seasonal changes in primary production. The mentioned differences are noticeable during measurements of primary production carried out with sufficiently high frequency (Niemi, 1972, 1975; Renk *et al.*, 1983). Unfortunately the measurement frequency applied in the Baltic Monitoring requires longer time interval. In this case the differences in primary production at various stations of the Southern Baltic have been illustrated on the basis of mean values calculated for a five years' period from 1979 to 1983 (Table 2).

The thickness of the euphotic layer and vertical distribution of primary production depend on optical properties of sea water. It follows from Figure 4 that the spectra of light attenuation coefficients in Baltic waters differ at the particular stations. Coefficient of attenuation of light of a certain wavelength by sea water is a sum of coefficients of light absorption by pure sea water and the dissolved chemical compunds (particularly organic substances) and the coefficients of light scattering by water, the dissolved chemical substances and the suspensions, plankton included (Dera, 1971, 1983). During the May–August period the coefficients of light attenuation by sea water strongly increase due to biological activity of phytoplankton. In gulf and estuarial regions water contains more suspensions and other components absorbing light, hence in these regions the thickness of the euphotic layer is smaller (Bagge and Lehmusluoto, 1971; Bodungen *et al.*, 1975; Engström, 1973; Krey, 1974; Niemi, 1972; Yuorkovsky and Bramane, 1974). This is distinctly illustrated by primary production distributions in Figures 2 and 3.

It follows from our measurements that the thickness of the euphotic layer of Southern Baltic open waters is equal on average to 15–20 m. Investigations of other authors confirm such a thickness of the euphotic layer (Nehring and Francke, 1971; Suschenya and Mikhalkovitch, 1961; Ackefors and Lindahl, 1975). In the regions of the Gulf of Gdańsk and the Pomeranian Bay the thickness of the euphotic, layer is smaller and decreases when approaching the river estuaries. In the estuarial regions the thickness of the euphotic layer does not exceed 10 m. A similarly small thickness of the euphotic layer is observed also in other coastal regions of the Baltic, particularly in eutrophicated regions adjacent to large urban agglomerations: Rugen region (Hübel, 1968), Riga Bay (Koblentz-Mishke and Konovalov, 1981), Stockholm region (Waern and Hübinette, 1973) and Finnish Bay (Bagge and Lehmusluoto, 1971; Bagge and Niemi, 1971; Niemi, 1975).

Regional differences in primary production manifest themselves also through different magnitude of annual primary production. Annual primary production depends to a large extent on annual insolation. Insolation of the Southern Baltic is approximately uniform. Table 3 presents examples of total annual insolation measured at coastal actinometric stations in Kołobrzeg and Gdynia (Institute of Meteorology and Water Management). Taking into account the similar insolation, the differences in primary production listed in Table 2 can be due to differences in productivity of these regions, and particularly to the impact of pollutants, originating mainly from rivers. Annual production of the open waters of the Southern Baltic is equal to ca 100 $g \cdot C \cdot m^{-2}$ (Lindahl, 1977; Kaiser *et al.*, 1981; Renk, 1983). In the regions of the Odra River and Vistula River estuaries it is sometimes higher by 50%.

Table 3: Total annual insolation at the actinometric stations in Gdynia and Kołobrzeg in 1961–1970 [$M \quad J/m^2$] (according to the data from IMGW – PIHM)

Year	Gdynia	Kołobrzeg
1961	3458	3709
1962	3442	3726
1963	4053	3810
1964	3835	3961
1965	3437	3672
1966	3634	3425
1967	3764	3714
1968	4011	4120
1969	4044	4065
1970	3613	3722
Mean	3730	3793

Primary production of the central and northern part of the Baltic is lower compared to the Southern Baltic. Nevertheless, also in these regions it differs largely depending on the inflow of river waters and liquid wastes from large urban agglomerations. The magnitude of primary production at various regions of the Baltic is presented in Tables 2 and 4.

4.2. Time variations of primary production of the Southern Baltic

Different factors determine the seasonal variations of primary production in different month. In the January–March period an increase in insolation is accompanied by an increase in photosynthesis intensity. Water temperature is the lowest in this period (Fig. 9). In the Southern Baltic water is well mixed in the entire isohaline layer, which assures nutrient concentrations favourable for photosynthesis. It can be stated therefore that during the January–March period it is the insolation that determines the production of phytoplankton. In April the beginnings of spring thermal stratification favouring the spring phytoplankton bloom are observed. An increase in insolation and water temperature is accompanied by an increase in primary production, which leads to a significant increase in phytoplankton biomass, *i.e.* to phytoplankton bloom. As a consequence, due to intensive vegetation during the spring bloom the concentration of nutrients in the euphotic layer significantly decreases (Schulz *et al.*, 1978),

Table 4: Annual primary production of the Southern Baltic

Region	Period	Production $\frac{g \cdot C}{(m^2 \cdot year)}$	Source
Gdańsk Deep	1966–1984	124.5	Polish investigations
Gulf of Gdańsk	1966–1984	135.0	Polish investigations
Słupsk Furrow	1966–1984	108.4	Polish investigations
Bornholm Deep	1966–1984	95.8	Polish investigations
Gotland Deep	1966–1984	113.4	Polish investigations
Bornholm Deep		90	Kaiser and Schulz, 1973, 1975
Mecklemburg Bay		130	Schulz and Kaiser, 1974, 1975
Gotland Deep		95	Schulz and Kaiser, 1974, 1975
Rűgen region		90–900	Hűbel, 1968
Kattegatt	1954–1960	97.5	Steemann Nielsen, 1965
Kattegatt	1977	90.4	Gargas *et al.*, 1978
Oeresund	1972–1973	70–183	Edler, 1978
Bothnia Bay	1973–1974	70	Lindahl, 1977
Finnish Bay			
Tvắrmine	1967–1971	48–65	Niemi, 1975
Loviisa	1969	40	Bagge and Niemi, 1971
Helsinki region	1968	150–200	Bagge and Lehmusluoto, 1971

which results in a large decrease of photosynthesis intensity in the weeks following the bloom, despite the further increase in insolation. Low values of *relative energetic efficiency of photosynthesis* – η, are usually observed after the phytoplankton bloom. Large primary production in July is due apart from high insolation probably also to higher water temperature, at which the biochemical reactions, and particularly the regeneration of nutrients, are faster than in the other seasons of a year (Jawed, 1973; Mullin *et al.*, 1975; Harrison, 1980). At the end of August the primary production decreases due to a decrease in insolation lasting till the end of a year. However, the primary production in the autumn season is higher than in spring at comparable insolation. This is undoubtedly due to higher water temperature and higher nutrients concentration.

The course of seasonal variations in primary production depicted above can be changed or disturbed depending on meteorological, environmental, trophic and other factors. These factors can also influence the annual primary production.

Table 5: Annual primary production of the Southern Baltic

Region	Region area thous. km^2	Years 1979	1980	1981	1982	1983
Gdańsk Deep	3.2	134.4	123.0	137.6	121.8	122.3
Gulf of Gdańsk	3.0		130.2	~154		142.2
Gotland Deep	3.2	113.7	~103			113.7
Słupsk Furrow with central coastal zone	16.4	~120		~106	~106	98.6
Bornholm Deep	6.4	97.5	~85	~89		100.6

Annual primary production depends to a large extent on insolation. It follows from Table 3 that the total annual solar radiation per unit sea area can vary in the particular years by 10% compared to the mean. Changes in insolation in the successive years can result in changes in annual primary production. Approximate values of annual primary production at the particular stations of the Southern Baltic calculated on the basis of the results of measurements are listed in Table 5. On the basis of the results of annual primary production listed in Table 5 the total annual primary production of the Polish fishing zone has been calculated. Values missing in the Table has been replaced by respective long-term mean values (Renk, 1983). Approximate total annual primary production of the Polish fishing zone in the particular years is presented in Table 6. It follows from this Table that during the investigation period the highest primary production was observed in 1979, while the lowest – in 1980. Long-term (1965–1984) mean annual primary production of the Polish fishing zone is equal to 3.33 million tons of carbon, whereas the total primary production of the entire Baltic Sea calculated on the basis of the results listed in Table 4 is equal to 35.4 million tons C.

It should be emphasized that the value of annual primary production considered irrelevant of other parameters (physical and chemical) cannot be a measure of the environmental situation, the more that the evaluation of annual primary production carried out on the basis of a few results obtained in a certain year is biased with a relatively large error due to random fluctuations of photosynthesis. These fluctuations depend on many physical, chemical and biological factors, like for example phytoplankton grazing by zooplankton. Hence, the degree of eutrophication of a certain region can be determined on the basis of primary production

Table 6: Total annual primary production of the Polish fishing zone

Year	Primary production [million t carbon/year]
1979	3.76
1980	3.40
1981	3.55
1982	3.52
1983	3.44
Mean 1979–1983	3.55
Mean 1965–1984	3.33

measurements carried out with sufficiently high frequency during a long time. Systematic measurements of primary production are carried out with sufficiently high frequency only in the coastal regions of the Baltic (Bagge and Lehmusluoto, 1971; Bagge and Niemi, 1971; Niemi, 1975) and at light ships (Steemann Nielsen, 1965; Gargas *et al.*, 1978; Aertebjerg Nielsen *et al.*, 1981; Lindahl, 1977; Ackefors and Lindahl, 1975).

In order to determine the long-term trends in primary production one can use the values of mean annual primary production calculated as means for certain time intervals (few years). Mean annual primary production of the Gdańsk Deep for the 1971–1974 period was equal to 108.8 $g \cdot C \cdot m^{-2}$; while for the 1979–1983 period 134.2 $g \cdot C \cdot m^{-2}$. On the basis of this difference in annual primary production it can be calculated that mean annual increase in phytoplankton production within this period was equal to ca 2.5% per year.

An increase in primary production was accompanied by an increase in phytoplankton biomass, manifesting itself through an increase in mean chlorophyll concentration in the euphotic layer. According to the measurements of the Sea Fisheries Institute in Gdynia, during the last dozen or so years the mean chlorophyll concentrations in the 0–10 m water layer in the Southern Baltic has been increasing by ca 2% annually. Long-term observations of annual primary production carried out in the Słupsk Furrow and at the Bornholm Deep also reveal an increase in primary production. Observations carried out at the Arkona Deep by Schulz *et al.* (1982) indicate an annual increase in chlorophyll concentration by ca 1.3%. On the other hand, according to these authors the magnitude of primary production and zooplankton biomass in the 0–25 m layer slightly decreased at the Arkona Deep.

An incease in annual primary production has also been observed in the Belt region (Steemann Nielsen, 1965; Gargas *et al.*, 1978), while long-term Danish measurements performed in the Kattegatt within the period 1954–1977 did not reveal any increase in annual primary production (Gargas *et al.*, 1978; Steemann Nielsen *et al.*, 1976). An increase in primary production due to eutrophication has also been observed in the Sound (Edler, 1978).

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