Effects of trophic conditions on benthic macrofauna in the vicinity of the River Świna mouth (Pomeranian Bay; southern Baltic Sea)*

OCEANOLOGIA, 45 (1), 2003.
pp. 41–52.

KEYWORDS
Pomeranian Bay
Benthic macrofauna
Biomass
Chlorophyll *a*
Nutrients

Jerzy Masłowski
Department of Oceanography,
Szczecin Agricultural University,
Kazimierza Królewicza 4, PL–71–550 Szczecin, Poland;
e-mail: Jmas@fish.ar.szczecin.pl

Manuscript received 5 December 2002, reviewed 24 January 2003, accepted 11 February 2003.

Abstract

The export of phytal material from the eutrophic Szczecin Lagoon into the Pomeranian Bay creates excellent trophic conditions for the local benthic fauna in the vicinity of the mouth of the river Świna, where the bottom macrofauna is abundant but highly variable. The changes in the bottom macrofauna biomass of selected taxa, chlorophyll *a* and nutrient concentrations were tested for associations. The biomasses of selected taxa varied in significant concordance, which suggests that these changes have common causes. Despite the importance of trophic enrichment to faunal abundance, no relationships between faunal biomass and chlorophyll *a* concentration changes were established. The presence of organic matter enables macrofauna to attain a high biomass, but population fluctuations are controlled by numerous factors. The significant relationship between the changes in the annual average phosphate levels and chlorophyll *a* concentrations in the Szczecin Lagoon indicates the importance of this nutrient to primary production processes in the Lagoon and to the trophic conditions for benthic macrofauna in the vicinity of the Świna mouth.

* This paper was presented at the ECSA Symposium 34 'Estuaries and other brackish areas – pollution barriers or sources to the sea?', Gdańsk–Sopot, 15–20 September 2002.

The complete text of the paper is available in PDF format at http://www.iopan.gda.pl/oceanologia/index.html

1. Introduction

The Szczecin Lagoon, part of the river Odra estuary, receives huge loads of various pollutants, nutrients among them, from the river. This leads to eutrophication of the Lagoon, which is evidenced by frequent blooms of blue-green algae. Surplus phytoplankton and unused nutrients in the Lagoon are discharged into the Pomeranian Bay through three straits; the most important in the water exchange is the River Świna. As a result of nutrient export from the Szczecin Lagoon, primary production in the southern part of the Pomeranian Bay is relatively high (Ochocki et al. 1999).

Outflowing Lagoon water at the surface and compensating bottom currents flowing in towards the mouth of the wina (Majewski 1974) – this is the typical water exchange situation between Lagoon and Bay. The near-bottom flow of the more saline water from the Bay protects marine benthic species from contact with fresh water from the Lagoon and transfers resuspended organic matter towards the mouth.

The bottom macrofauna of the Pomeranian Bay is highly tolerant to variable environmental conditions. Most of these species were listed by Pearson & Rosenberg (1978) as indicators of organic pollution and should respond strongly to changes in additional food sources. Sedimentation of allo- and autochthonous phytoplankton in the vicinity of the point where the River discharges into the Pomeranian Bay creates excellent trophic conditions for benthic filter- and deposit-feeders. The biomass of bottom macrofauna near the Świna mouth has been among the highest in the Bay (Powilleit et al. 1995).

Various annual average quantities of phytoplankton (measured as chlorophyll *a* concentrations) and nutrient concentrations have been recorded near the Świna mouth and in the Szczecin Lagoon (Błaszczak et al. 2001).

The present work attempts to discover relationships between chlorophyll *a* concentrations and benthic macrofauna biomass changes in the vicinity of the Świna mouth and to find out which nutrients are responsible for macrofauna food (chlorophyll *a*) fluctuations.

2. Materials and methods

Benthic macrofauna from the western side of the shipping channel (Fig. 1), the area directly affected by the River Świna discharge into the Pomeranian Bay, was chosen for this study. The sediments in this area are very fine, muddy or gluey in appearance and rich in organic compounds. On the surface of undisturbed samples a grey-green layer of easily resuspended substance was visible. Below the sediment surface there were black patches – evidence of local deoxidisation.

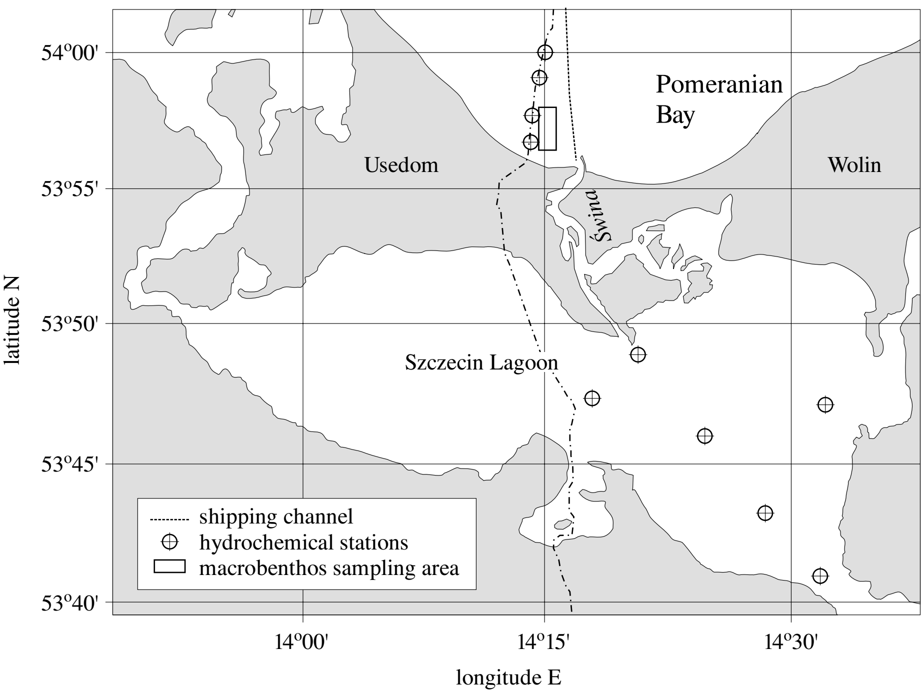

Fig. 1. Map of study area

Macrofaunal samples were collected with a 0.1 m^2 van Veen grab or with a 0.0225 m^2 box corer. The sampling date, number of sampling units taken during each sampling event, the type of gear used and the sampling depth are shown in Table 1.

Table 1. Details of sampling

Month and year	May 1980	Aug 1980	Nov 1980	Aug 1990	Sept 1993	Jun 1994	Jun 1995	Mar 1996	Jul 1996	May 1997	Oct 1997
n	3	3	3	5	3	3	9	3	3	3	3
gear	van Veen	van Veen	van Veen	van Veen	van Veen	van Veen	van Veen	box corer	box corer	box corer	box corer
depth [m]	10	10	10	9	7	9	6–10	8	9.5	10	9–10

n – number of samples

The sediments were passed through a 1 mm mesh sieve, and the residue fixed in 4% buffered formaldehyde. In the laboratory, samples were sorted and the animals identified to the lowest taxon possible. AFDW biomass was determined after three months of storage and incineration for 5 h at a temperature of 495°C.

Data on the water parameters (nutrient and chlorophyll *a* concentrations, oxygen saturation and salinity) from four hydrochemical stations adjacent to the macrofaunal sampling area in the Pomeranian Bay and from six stations in the Polish part of the Szczecin Lagoon (Fig. 1) were taken from Błaszczak et al. (2001). The figures were presented as annual averages based on measurements made 1 m below the surface and 1 m above the bottom at monthly intervals from April to November. For the Pomeranian Bay surface and bottom water parameters were reported separately, whereas for the Szczecin Lagoon these values were averaged.

The concordance of changes in the biomass among the macrofaunal taxa was assessed by calculating W – Kendall's coefficient of concordance, relationships between chlorophyll *a* and biomass of macrobenthic taxa were tested by Spearman's rank correlation, while associations between nutrient concentrations and chlorophyll *a* were tested by product-moment correlation (Sokal & Rohlf 1981). All these tests were performed using the STATISTICA 5.1 computer package.

For the statistical analysis only taxa with a frequency of occurrence $> 75\%$ in samples were selected.

3. Results

One third of the 28 benthic taxa recorded in the vicinity of the Świna mouth during this study was caught frequently and could be used for analysis. All these taxa displayed a highly variable biomass from one sampling event to another (Fig. 2). With a few exceptions, the macrofaunal biomass was dominated by *Mya arenaria*. A second important species in terms of biomass was *Macoma balthica*, which was dominant where *M. arenaria* was absent. These two bivalves together made up $> 80\%$ of the total macrofauna biomass.

The average AFDW biomass of macrofauna for one sampling event in this study was 36.4 g m^{-2}. The lowest biomass (0.45 g m^{-2}) was recorded in August 1980. During 1980 the biomass of many benthic taxa, including that of *M. arenaria*, was very low (Fig. 2). It should be noted that *Marenzelleria viridis* was not a component of the Baltic fauna at that time. The highest macrofaunal biomass (82.5 g m^{-2}) was recorded in June 1995; this was principally due to the large contribution of *M. arenaria* (Fig. 2).

During this study, the variations in biomass of selected taxa were synchronous (Kendall's coefficient of concordance, $W = 0.535$; $p < 0001$).

There were no significant correlations between annually averaged macrofaunal taxa biomasses and chlorophyll *a* concentrations, except for correlations between two spionid species, *Pygospio elegans* and *M. viridis*, and the chlorophyll *a* concentration in the Szczecin Lagoon (Table 2).

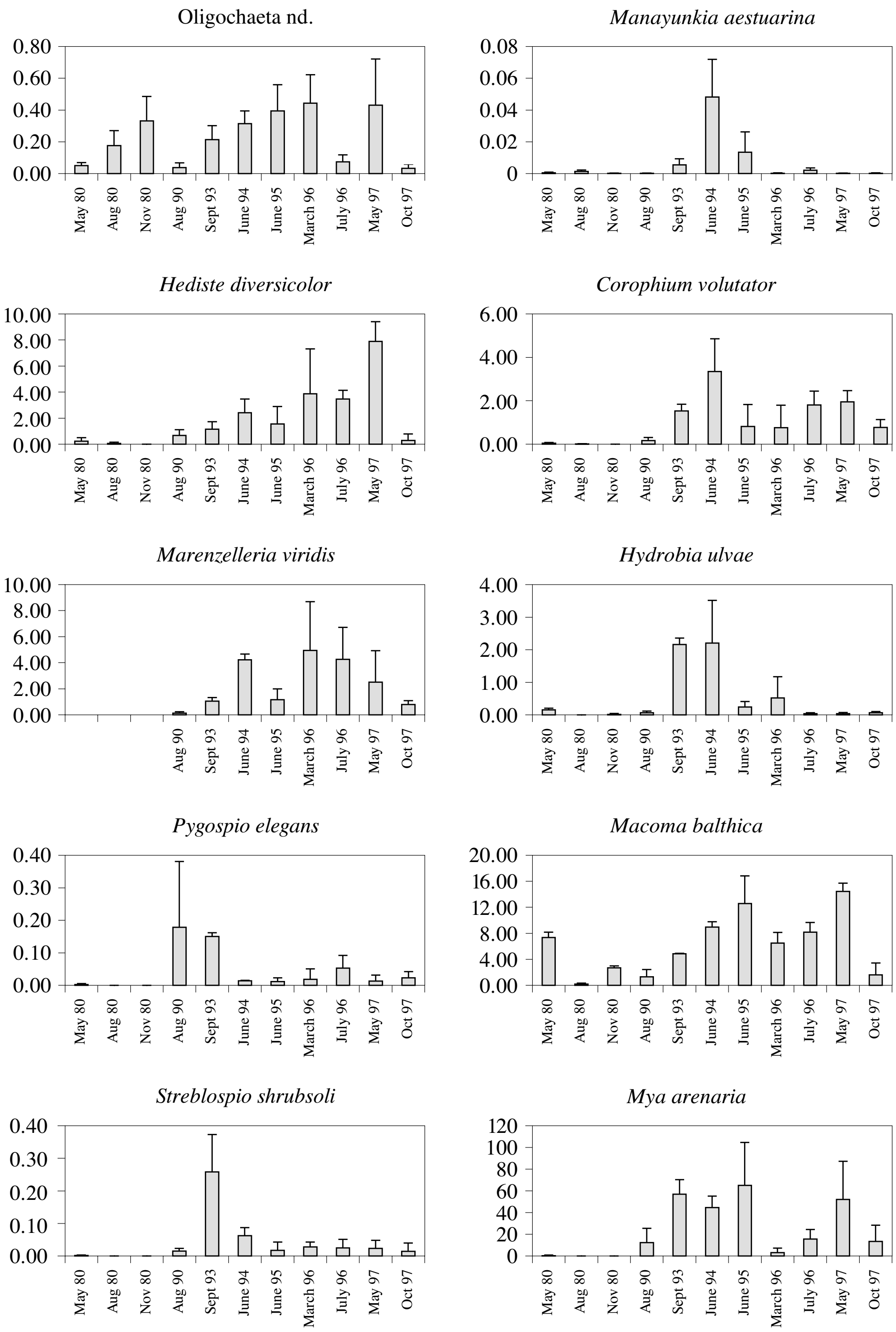

Fig. 2. AFDW biomass ($\bar{x} \pm$ sd; g m^{-2}) of selected macrobenthic taxa in the vicinity of the River Świna mouth

Table 2. Spearman's coefficients of rank correlation (R) between chlorophyll *a* concentration and biomass of macrofaunal taxa

	R	p	n
Chl *a* PBs & Oligochaeta	0.771	ns	6
Chl *a* PBs & *Hediste diversicolor*	0.543	ns	6
Chl *a* PBs & *Marenzelleria viridis*	0.543	ns	6
Chl *a* PBs & *Pygospio elegans*	–0.714	ns	6
Chl *a* PBs & *Streblospio shrubsoli*	–0.371	ns	6
Chl *a* PBs & *Manayunkia aestuarina*	0.086	ns	6
Chl *a* PBs & *Corophium volutator*	–0.315	ns	6
Chl *a* PBs & *Hydrobia ulvae*	–0.257	ns	6
Chl *a* PBs & *Macoma balthica*	0.714	ns	6
Chl *a* PBs & *Mya arenaria*	0.029	ns	6
Chl *a* PBb & Oligochaeta	0.116	ns	6
Chl *a* PBb & *Hediste diversicolor*	0.580	ns	6
Chl *a* PBb & *Marenzelleria viridis*	0.406	ns	6
Chl *a* PBb & *Pygospio elegans*	–0.058	ns	6
Chl *a* PBb & *Streblospio shrubsoli*	–0.232	ns	6
Chl *a* PBb & *Manayunkia aestuarina*	–0.551	ns	6
Chl *a* PBb & *Corophium volutator*	–0.377	ns	6
Chl *a* PBb & *Hydrobia ulvae*	–0.522	ns	6
Chl *a* PBb & *Macoma balthica*	0.058	ns	6
Chl *a* PBb & *Mya arenaria*	–0.406	ns	6
Chl *a* SL & Oligochaeta	–0.214	ns	7
Chl *a* SL & *Hediste diversicolor*	–0.143	ns	7
Chl *a* SL & *Marenzelleria viridis*	**–0.829**	**< 0.05**	**6**
Chl *a* SL & *Pygospio elegans*	**0.786**	**< 0.05**	**7**
Chl *a* SL & *Streblospio shrubsoli*	0.143	ns	7
Chl *a* SL & *Manayunkia aestuarina*	–0.071	ns	7
Chl *a* SL & *Corophium volutator*	–0.036	ns	7
Chl *a* SL & *Hydrobia ulvae*	0.143	ns	7
Chl *a* SL & *Macoma balthica*	–0.250	ns	7
Chl *a* SL & *Mya arenaria*	0.393	ns	7

Chl *a* PBs – concentration of chlorophyll *a* in the Pomeranian Bay surface water.
Chl *a* PBb – concentration of chlorophyll *a* in the Pomeranian Bay near-bottom water.
Chl *a* SL – concentration of chlorophyll *a* in the Szczecin Lagoon water.

p – probability of significance; n – number of samples; ns – non significant.

The results of testing for association between annually averaged concentrations of nutrients and chlorophyll *a* (Table 3) revealed significant correlations between phosphates and chlorophyll *a* concentrations in the Szczecin Lagoon as well as between nitrates in the Szczecin Lagoon and chlorophyll *a* in the surface water of the Pomeranian Bay in the vicinity of the Świna mouth.

Table 3. Product-moment correlation coefficients (r) between nutrients and chlorophyll *a*

	r	p	n
N PB & Chl *a* PB	0.424	ns	16
N SL & Chl *a* PB	**0.813**	$<$ **0.001**	**16**
N SL & Chl *a* SL	–0.182	ns	16
P PB & Chl *a* PB	–0.139	ns	16
P SL & Chl *a* PB	–0.139	ns	16
P SL & Chl *a* SL	**0.660**	$<$ **0.01**	**21**

N PB – nitrate concentration in the Pomeranian Bay surface water.
N SL – nitrate concentration in the Szczecin Lagoon water.
P PB – phosphate concentration in the Pomeranian Bay surface water.
P SL – phosphate concentration in the Szczecin Lagoon water.
Chl *a* PB – chlorophyll *a* concentration in the Pomeranian Bay surface water.
Chl *a* SL – chlorophyll *a* concentration in the Szczecin Lagoon water.
p – probability of significance; n – number of samples; ns – non significant.

4. Discussion

Despite the high variability in macrofaunal biomass (Fig. 2), the significance of Kendall's coefficient of concordance suggests the presence of a common cause for such synchrony. The results of Spearman's test (Table 2) exclude variations in chlorophyll *a* concentration as a major factor giving rise to changes in the benthic biomass. Even the significant correlation between the chlorophyll *a* concentration in the Szczecin Lagoon and the biomass variations in two polychaetes (a positive correlation for *P. elegans* and a negative one for *M. viridis*) (Table 2) cannot be considered the result of trophic associations. Since both polychaete species are deposit feeders (Fauchald & Jumars 1979), they should respond in similar ways to differences in the amount of available food. Closer inspection of the data yielded another explanation of the test results. The chlorophyll *a* concentrations in the Szczecin Lagoon were much higher in 1990–1993 than in other years (Błaszczak et al. 2001), and the highest biomasses of

P. elegans were detected in that period (August 1990 and September 1993 (Fig. 2)). *P. elegans*, a small polychaete with an average life span of less than one year, shows great variation in connection with reproduction mortality and attains high densities in the late summer and autumn (Persson 1983, Brey 1991). The differences observed during the present study could be due to the different seasons of collection and the life cycle of this polychaete. *M. viridis*, a polychaete species relatively new to the Baltic, spread rapidly in the Pomeranian Bay in the late eighties and early nineties of the last century (Kube et al. 1996). In the study area this expanding species attained higher biomasses after 1993. In both cases the observed variations in biomass were not associated with changes in trophic conditions.

The very high biomass of macrofauna recorded in the vicinity of the Świna mouth (Powilleit et al. 1995) is undoubtedly due to organic enrichment resulting from the high primary productivity of the Szczecin Lagoon and the export of phytal material into the Pomeranian Bay. Chlorophyll *a* concentrations in the Lagoon are several times higher than those near the Świna mouth (Błaszczak et al. 2001), which are the highest in the entire Pomeranian Bay (Ochocki et al. 1999).

There are numerous reasons why a fauna consisting of organic pollution indicators (Pearson & Rosenberg 1978), and which ought to respond to changes in organic matter content, does not fluctuate in accordance with chlorophyll *a* fluxes. Many sources of variability contribute simultaneously to the differences observed in the macrofauna samples collected from time to time, which is why the proportion of temporal changes in the total variability of macrobenthic communities cannot be adequately assessed. Numerous sources of variability, including the high spatial variability of macrofauna, have confounded temporal comparisons of the macrofaunal biomass in the Pomeranian Bay (Masłowski 2001). As this study was limited to a small area where the sediments are fairly uniform, there should be less variability resulting from habitat heterogeneity. But even in relatively uniform habitats, the distribution of macrofauna is patchy (Thrush 1991) and the influence of spatial variation on the results of temporal comparisons cannot be excluded. Additional variability could arise if in successive years the macrofauna were collected in different seasons or with different gear. The box corer penetrates into sediments 2–3 times deeper than the van Veen grab and the sampling surface of the former does not change with depth of penetration. Comparisons between the results of sampling with the box corer and the van Veen grab performed by Powilleit et al. (1995) must take the effects of the equipment's performance and the mesh size of the sieve into consideration. In the case of species capable of deep penetration into the sediments, i.e. *Hediste diversicolor*, *M. viridis* and *M. arenaria*, the type of gear used could impair biomass assessments. According to Powilleit et al. (1995), the van Veen grab underestimates the biomass of *H. diversicolor* by 23%, *M. viridis* by 57% and *M. arenaria* by 32% in comparison with the box corer. The effect of the mesh size of the sieve on the biomass of those species could be neglected on account of the animals' size.

To rule out any possible distortion of the Spearman's test results resulting from differences in the equipment used, the biomasses of *H. diversicolor*, *M. viridis* and *M. arenaria* recorded in 1996 and 1997 were reduced in accordance with the percentages cited above. Repetition of Spearman's test on such manipulated data revealed no significant associations between chlorophyll *a* and biomass in any of the tested taxa. This indicates that the significant correlation between chlorophyll a from the Szczecin Lagoon and *M. viridis* (Table 2) were due to differences in performance of the samplers used.

Leaving aside the variability arising out of the representation of a macrobenthic community by samples, there are several other reasons which could explain the lack of associations between average annual chlorophyll *a* concentrations and variations in the biomass of macrofaunal taxa.

- The differences in average year-to-year chlorophyll *a* concentrations were not high enough to provoke a response from the macrofauna.
- Little is known how and in what proportion each of the tested water masses – the Szczecin Lagoon water, the Pomeranian Bay surface water and the Pomeranian Bay bottom water – contribute to the food pool available to benthic fauna in the study area. The end effect could be independent of the chlorophyll *a* concentrations in each water mass.

Abrupt changes in the macrobenthic community due to various natural or anthropogenic events could obliterate the effect of changes in food supply as well. Some episodes, for instance, migrations or mass mortality due to reproduction or disease, concern individual taxa. Other phenomena, like drastic environmental changes, affect the whole community. As the macrofauna sampling area was located near the shipping channel (Fig. 1), sediment disturbance due to dredging, dumping etc. could have seriously affected the benthic communities and been responsible for the situation observed in 1980, when many taxa were absent or present only in low biomasses (Fig. 2). However, according to information from the Maritime Office in Szczecin, no hydro-engineering activities were being carried out in the area at that time, so it must have been some unexplained natural event that caused this situation. In the study area extreme changes in the environmental conditions, such as physical forcing, salinity and oxygen saturation, are rather unexpected. Sediments in the Baltic Sea below a depth of 6 m are rarely disturbed by waves (Persson 1983). Moreover, because of the Bay's configuration, the study area is sheltered, and the frequency of sea states above 5 on the Beaufort Scale is 0.4% (Majewski 1974). The salinity in this area varies greatly at the surface as a result of pulsating outflows from the Lagoon, but near the bottom it is stable. Annual average bottom water salinities in 1980–2000 were in the 6.25–9.12 PSU range (Błaszczak et al. 2001). Wind-induced water circulation in the Pomeranian Bay, and good wind mixing resulting from the shallowness of the Bay (< 20 m), ensure good oxygen conditions for bottom fauna. In the vicinity of the macrofaunal sampling area annual average values of the bottom water oxygen saturation in 1980–2000 ranged from 85.8 to 98.3% (Błaszczak et al. 2001). Nevertheless, such generally favourable environmental conditions can change suddenly. In summer 1994 a prolonged period of calm, hot weather led to stagnation and local anoxia in the SW Pomeranian Bay. The bottom fauna suffered some mortality (Kube & Powilleit 1997), after which gradual recuperation took place. Another natural phenomenon affecting the bottom fauna, the extreme flood event in summer 1997, could have been responsible for the low macrofaunal biomass in October 1997 (Fig. 2). Many extreme events are short-lived and often pass undetected in routine monitoring procedures; nevertheless, they can strongly affect biota and be the unknown cause of observed changes.

The significant relationship between phosphates and chlorophyll *a* in the Szczecin Lagoon (Table 3) indicates the importance of variations in that nutrient to primary production processes in the Lagoon. Ochocki et al. (1999) found phosphates to be the factor limiting primary production processes in the inshore waters of the Pomeranian Bay. Phosphate is thus crucial as regards primary production in the Szczecin Lagoon and the inshore waters of the Pomeranian Bay, shaping as it does the food supply for macrofauna in the vicinity of the Świna mouth.

The significant correlation between nitrates in the Szczecin Lagoon and chlorophyll *a* in the vicinity of the Świna mouth (Table 3) seems to be the effect of a common cause. Differences in the annual outflows of the river Odra could be the reason for the results obtained. Nitrogen discharges correlate well with the river Odra outflow (Pastuszak 1996). An increase in the water volume carried by the river Odra into the Szczecin Lagoon intensifies the outflow of Lagoon water into the Pomeranian Bay. High chlorophyll *a* concentrations near the Świna mouth are mainly due to the export of Lagoon phytoplankton; the local primary production there is rather low, despite the high nutrient concentrations (Ochocki et al. 1999). Hence in years when larger volumes of water flow out with the Odra, the discharge of nitrates into the Szczecin Lagoon and the export of chlorophyll a into the Pomeranian Bay also increase.

5. Conclusions

The benthic macrofaunal biomass in the vicinity of the Świna mouth was found to fluctuate in synchrony, which is indicative of a common cause of the observed changes.

Changes in trophic conditions were not proved to be a major cause of fluctuations in benthic fauna. The benthic macrofaunal community is presumably shaped by a variety of causes, which frequently go undetected.

Phosphates were found to be the factor controlling the processes of primary production and the trophic conditions of benthic macrofauna in the study area.

References

Błaszczak T., Złoczowska I., Wierzchowska E., Jurkowska K., Kazimierski B., Wiśniowski Z., Cichocka A., Gajdecki A., Janecki B., 2001, *Water*, [in:] *Report on the state of the environment in the province of Western Pomerania*, M. Landsberg-Uczciwek (ed.), (in Polish), Published in: www.wios.szczecin.pl/wios_html/rozdzia/l5_4htm

Brey T., 1991, *Interactions in soft bottom benthic communities: quantitative aspects of behaviour in the surface deposit feeders Pygospio elegans (Polychaeta) and Macoma balthica (Bivalvia)*, Helgoländer Meeresunters., 45, 301–316.

Fauchald K., Jumars P. A., 1979, *The diet of worms: a study of polychaete feeding guilds*, Oceanogr. Mar. Biol. Ann. Rev., 17, 193–284.

Kube J., Powilleit M., 1997, *Factors controlling the distribution of Marenzelleria cf. viridis. Pygospio elegans and Streblospio shrubsoli (Polychaeta: Spionidae) in the southern Baltic Sea area, with special attention for the response to an event of hypoxia*, Aquat. Ecol., 31, 187–198.

Kube J., Zettler M. L., Gosselck F., Ossig S., Powilleit M., 1996, *Distribution of Marenzelleria viridis (Polychaeta: Spionidae) in the southwestern Baltic Sea in 1993/94 – ten years after introduction*, Sarsia, 81, 131–142.

Majewski A., 1974, *The hydrological characteristics of the Pomeranian Bay*, Wyd. Kom. i Łącz., Warszawa, 115 pp., (in Polish).

Masłowski J., 2001, *Temporal changes in the Pomeranian Bay macrozoobenthos biomass: chance events and regular trends*, Piscaria (Folia Univ. Agric. Stetin.), 218 (28), 97–104.

Ochocki S., Chmielowski H., Nakonieczny J., Zalewski M., 1999, *The impact of Odra river waters on the seasonal and spatial distribution of primary production and chlorophyll a concentrations in the Pomeranian Bay in 1996–1997*, Oceanologia, 41 (3), 373–388.

Pastuszak M., Nagel K., Nausch G., 1996, *Variability in nutrient distribution in the Pomeranian Bay in September 1993*, Oceanologia, 38 (2), 195–225.

Pearson T. H., Rosenberg R., 1978, *Macrobenthic succession in relation to organic enrichment and pollution of the marine environment*, Oceanogr. Mar. Biol. Ann. Rev., 16, 229–311.

Persson L.-E., 1983, *Temporal and spatial variation in coastal macrobenthic community structure, Hanö Bay (southern Baltic)*, J. Exp. Mar. Biol. Ecol., 68, 277–293.

Powilleit M., Kube J., Masłowski J., Warzocha J., 1995, *Distribution of macrobenthic invertebrates in the Pomeranian Bay (southern Baltic) in 1993/94*, Bull. Sea Fish. Inst., Gdynia, 3, 75–87.

Sokal R. R., Rohlf F. J., 1981, *Biometry*, 2nd edn., W. H. Freeman and Comp., San Francisco, 859 pp.

Thrush S. F., 1991, *Spatial patterns in soft-bottom communities*, TREE, 6 (3), 75–79.