ARE THERE ANY TRENDS IN WATER QUALITY, CHLOROPHYLL *A* AND ZOOPLANKTON OF THE VISTULA LAGOON (SOUTHERN BALTIC SEA) AS A RESULT OF CHANGES IN NUTRIENT LOADS?

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ABSTRACT

Only the data from the Polish part of the lagoon have been analysed at this stage. Based on selected criteria, the current trophic status of the Vistula Lagoon was described and its response to decreased commercial fertiliser consumption in Poland and changes in nutrient loads to the lagoon was assessed. Riverine loads of BOD to the Polish part of the lagoon decreased to about 60% of those from 1993, and the total nitrogen loads were 23% lower compared to 1997 levels. However, there were no major changes in total phosphorus loads over the last six years. Trophic Status Indexes, Secchi depth, as well as nitrogen and phosphorus concentrations indicate the high trophic status of the lagoon. Chlorophyll *a* concentrations reflect a moderate/poor status. When the rotifer abundance and the percentage of rotifer species indicating a highly eutrophic status, are taken into account, the lagoon should be regarded as a meso-eutrophic water body type. The lagoon response is not clear: the average BOD values and chlorophyll *a* concentrations have been relatively stable during the last 30 years; nitrate and phosphate concentrations oscillated; the Trophic State Indexes calculated from Secchi depth and total phosphorus presented improvement during the last ten years. Data from the Russian part of the lagoon need to be analysed and other criteria, or parameters, should be taken into account, including phytoplankton taxonomic composition, the abundance and occurrence of blooms, macroinvertebrates and fish.

KEYWORDS: chlorophyll *a*, eutropication, nutrient loads, Vistula Lagoon, water quality, zooplankton.

INTRODUCTION

The Vistula Lagoon (838 km^2) is located in the south-eastern part of the Baltic Sea. It is divided by the Russian – Polish border. About 40% of the total area is located in Poland. The only connection between the lagoon and the Baltic Sea is the strait in the vicinity of Baltiysk (in Russia). The lagoon is shallow; the mean depth in the Polish and Russian parts is 2.4 and 2.8 m, respectively. Its drainage area covers 23,871 km^2 and the average retention time is about 6-7 months. The lagoon is known to suffer from eutrophication problems. Since the beginning of the 1990s, intense land use and industrial changes have taken place in the lagoon drainage basin.
The economic collapse during the transition period at the beginning of 1990s caused dramatic decreases in commercial fertiliser consumption in Poland (Pastuszak, *et al*. 2001), and current consumption levels correspond to those recorded during the early 1970s (nitrate) or even the early 1960s (phosphate) (Figure 1).

The aim of this presentation is to analyse changes in water quality, chlorophyll *a* concentrations and zooplankton abundance, biomass and taxonomic composition as a consequence of changes in nutrient loads to the lagoon.

RIVERINE LOADS

There are 14 rivers in the Polish part of the Vistula Lagoon in which water quality has been monitored over last few years. The three main rivers, the Pas³êka, Elbl¹g and Nogat, which supply over 80% of the total water inflow to the Polish part, have been monitored regularly for more than 20 years. BOD loads decreased (Table 1) to about 60% of those from 1993. This was the result of reduced loads from the three main rivers. No major changes were observed in some small and rather short rivers along the southern coast (Narusa, Suchacz, Kamionka, Stradanka, Grabianka and Olszanka). There were, however, increases in some of these rivers. The total COD loads in 2001 were approximately 15% lower than those of 1996. The total nitrogen loads from the rivers presented a very similar pattern (23% reduction in comparison to 1997 levels). There were no major changes in total phosphorus loads over the last six years (Table 1).

Table 1. Total loads from rivers discharging to the Polish part of the Lagoon (WIOS, 1993-2001).

	1993	1994	1995	1996	1997	1998	1999	2000	2001
BOD (tons/year)	5711	5864		5097	5077	4001	4731	3740	3274
COD (tons/year)	17537	37363		40329	39357	37647	39358	33869	34445
PO4 (tons/year)	536	470			481	478			
NO3 (tons/year)	1417	1446			1284	1599			
Ptot (tons/year)				337	292	269	326	311	324
Ntot (tons/year)				3985	4219	3945	3707	2701	3244

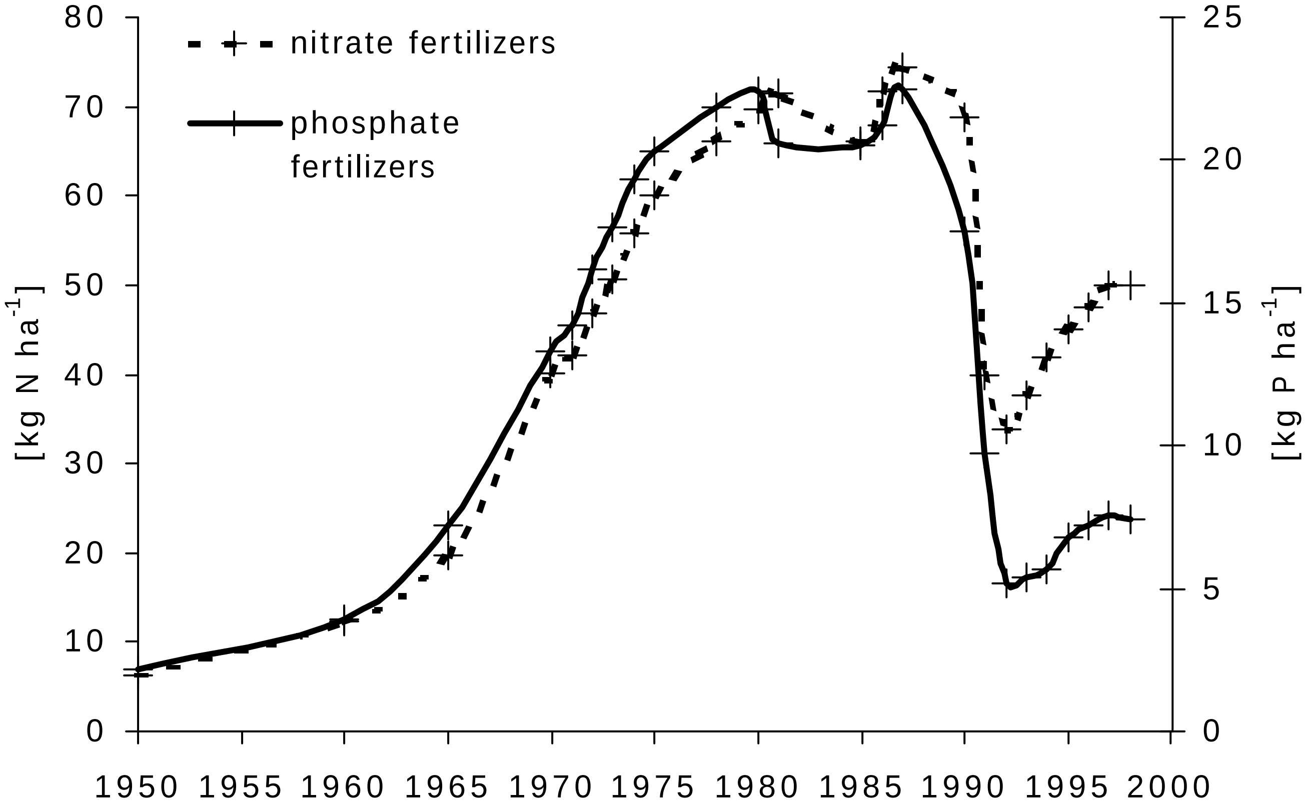

Figure 1. Consumption of commercial fertilizers in Poland (Pastuszak, et al. 2001)

POINT SOURCES DISCHARGING DIRECTLY INTO THE LAGOON

Four new wastewater treatment plants were built in the last ten years in the Polish part of the lagoon in Elbl¹g (1993), Tolkmicko (1994), Braniewo (1996) and Frombork (2001). This was the main reason for the significant reduction of BOD loads into the lagoon. COD loads were also lower in the second half of the 1990s. The highest measured loads of Ptot and Ntot were during the 1996-1999 period (Table 2). This source of nutrients was rather of local importance, because it usually comprised less than 1-2% of the riverine loads. Only the share of total phosphorus loads was higher (3-5% of riverine loads in the 1996-1999 period).

Table 2. Loads from point sources discharging directly to the Polish part of the Lagoon (WIOS 1993-2001).

	1993	1994	1995	1996	1997	1998	1999	2000	2001
flow (m^3/year)	744283	721784	540403	757060	771420	748432	906217	813897	866325
BOD (tons/year)	81	161	65	51	50	28	31	22	14
COD (tons/year)	175	258	124	145	128	96	120	81	117
Ptot (tons/year)	6	5	4	10	13	12	16	5	3
Ntot (tons/year)	43	21	20	36	51	59	45	25	29

WATER QUALITY OF THE LAGOON

Under the specific conditions of the Vistula Lagoon, i.e. low depth and a high, natural level of turbidity driven by winds, Secchi depth (SD) is probably not the best indicator of its trophic status. However, during the last 50 years, considerable changes in SD have been observed in the Polish part (Figure 2). The range of the recorded Secchi depths was much wider during the 1950s than that observed in the 1990s. This indicates the higher trophic status of the lagoon at the present stage. The lack of measurements from the 1970s and 1980s renders further analyses very difficult.

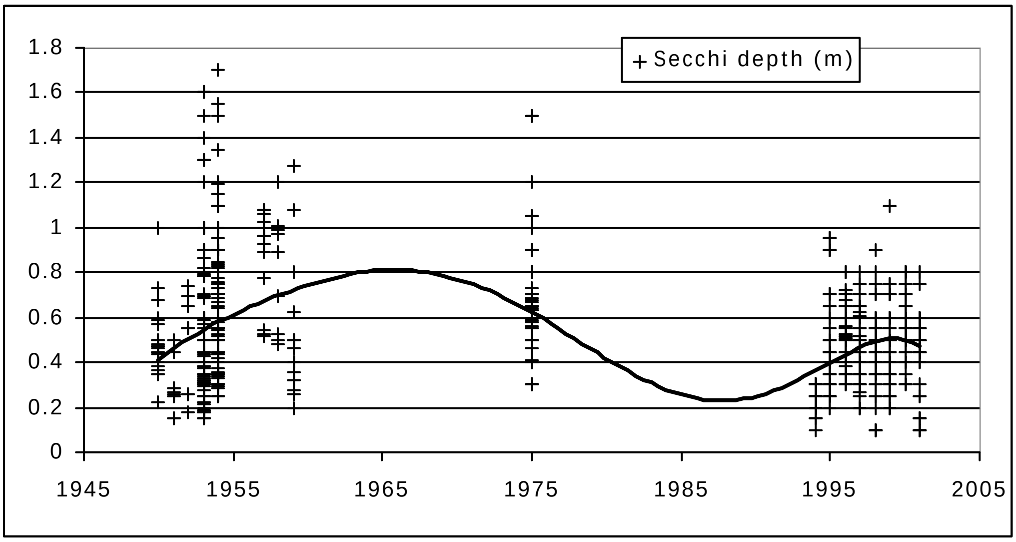

Figure 2. Long-term changes of Secchi depth (m) in the Polish part of the Lagoon (£omniewski, 1958; Piechura, 1962; Ró¿añska and Wiêc³awski, 1978; Szarejko-£ukaszewicz, 1959; WIOS, 1994-2001)

There have been continuous measurements of BOD values in the Polish part since the late 1970s. There have been some year-to-year changes in the range of observations (Figure 3), but average values have been relatively stable over the last 30 years. Apparently, the lagoon did not respond to the decrease of BOD loads from rivers discharging into the Polish part.

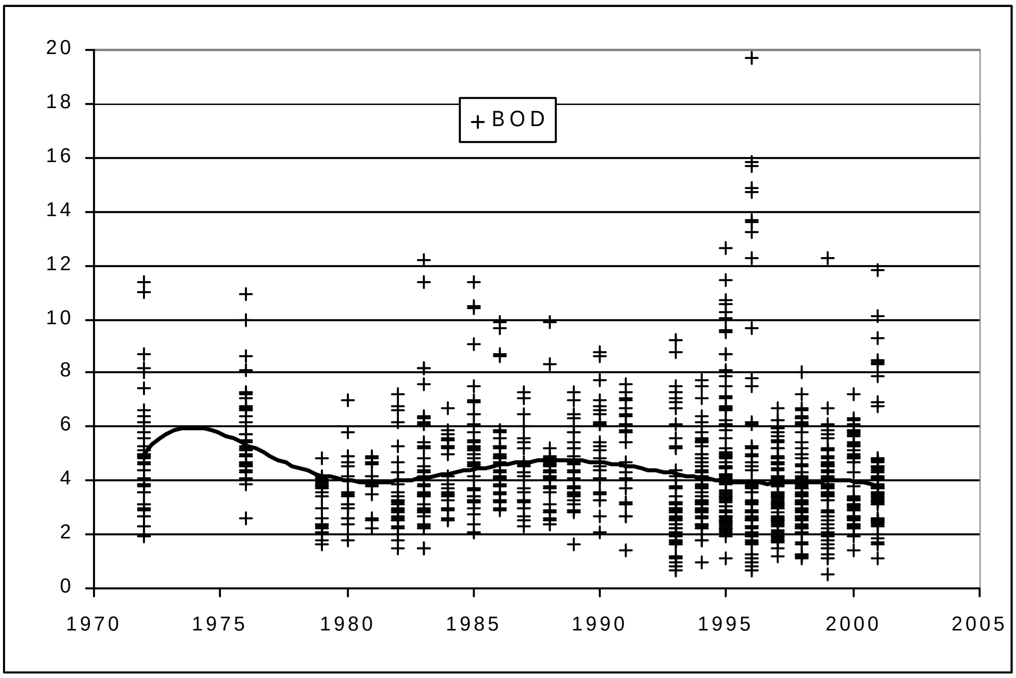

Figure 3. Long-term changes of BOD (mgO_2/l) in the Polish part of the Lagoon (WIOS, 1972, 1976, 1979-2001)

There are rather small differences in the yearly averages of nitrate concentrations in the Polish part (Figure 4). The lowest observed values were recorded in the late 1980s, following which concentrations increased. Samples were basically collected monthly. In 1991, 1993 and 1995 they were taken during the autumn months only, and therefore the average values calculated for these years were higher when compared with those of preceding or subsequent years. During 1998-1999 and 2001, the range of observed concentrations was much wider. The average Ntot values oscillated between 1350 and 2410 µm/l over the last six years. This reflects a poor status according to the Estonian classification of water quality in lakes (Noges *et al*. 2003).

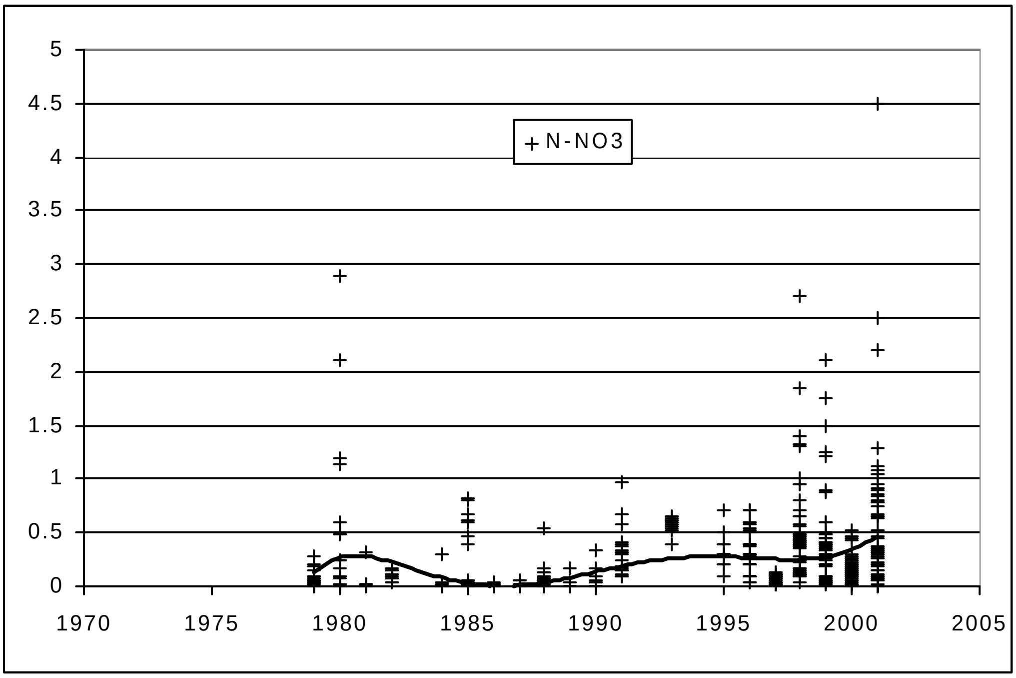

Figure 4. Long-term changes of N-NO_3 (mgN/l) in the Polish part of the Lagoon (WIOS, 1979-2001)

The measured concentrations of phosphates in the Polish part of the lagoon fluctuated strongly over the last 30 years (Figure 5). The lowest values were observed in the 1980s. The widest range and the highest average was recorded in 1993, after which phosphate concentrations dropped again. Similarly to the pattern of nitrate concentrations, phosphates started to increase in 2001. The yearly averages of Ptot during the 1994-2001 period ranged between 167 and 290 µm/l (1460 µg/l in 1993). This again indicates a poor status according to the Estonian classification of water quality in lakes (Noges *et al*. 2003).

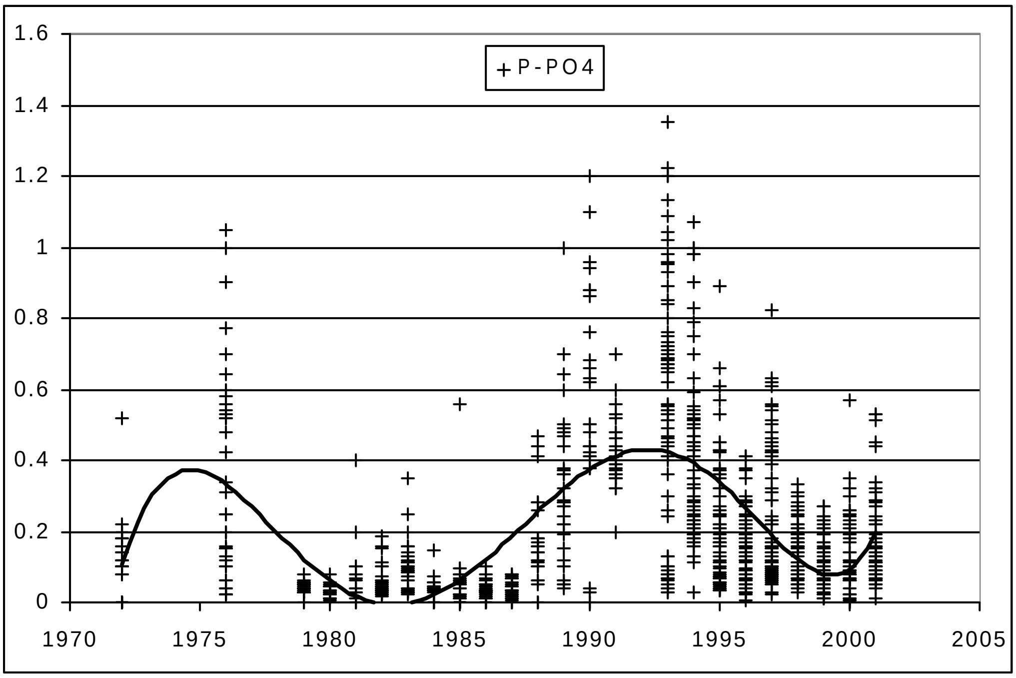

Figure 5. Long-term changes of P-PO_4 (mgPO_4/l) in the Polish part of the Lagoon (WIOS, 1972, 1976, 1979-2001)

TROPHIC STATE INDEX (TSI)

The Trophic State Index was calculated from Secchi depth, chlorophyll *a* and total phosphorus using formulas proposed by Carlson (1977). There are differences among the indexes, but all of them are high which indicates the high trophic status of the lagoon (Table 3). The idea of this classification was to avoid using discrete classes like oligotrophic, mesotrophic and eutrophic, and instead to provide a continuous measure of trophic status. These indexes were proposed for fresh waters (lakes, streams and rivers), and perhaps values calculated for the Vistula Lagoon should not be compared directly with those of lakes. However, the description of trophic types of more than 60 Polish lakes proposed by Karabin (1985) indicates that the Vistula Lagoon is a polytrophic water body.

Table 3. Trophic State Index (Secchi depth, chlorophyll *a*, and total phosphorus) calculated on the basis of yearly average values measured in the Polish part of the Vistula Lagoon. (£omniewski, 1958; Piechura, 1962; Ró¿añska and Wiêc³awski 1978; Szarejko-£ukaszewicz, 1959; WIOS, 1993-2001)

	TSI (sd)	TSI (chl)	TSI (TP)
average	70.0	65.6	83.1
min	61.8	58.9	51.7
max	79.1	70.2	109.2

Temporal changes in TSI values were observed (Figure 6) with a decrease during the 1950s and again during the 1990s. The highest values were calculated at the beginning of 1990s. The chlorophyll index had the shortest time-series and the most unclear pattern.

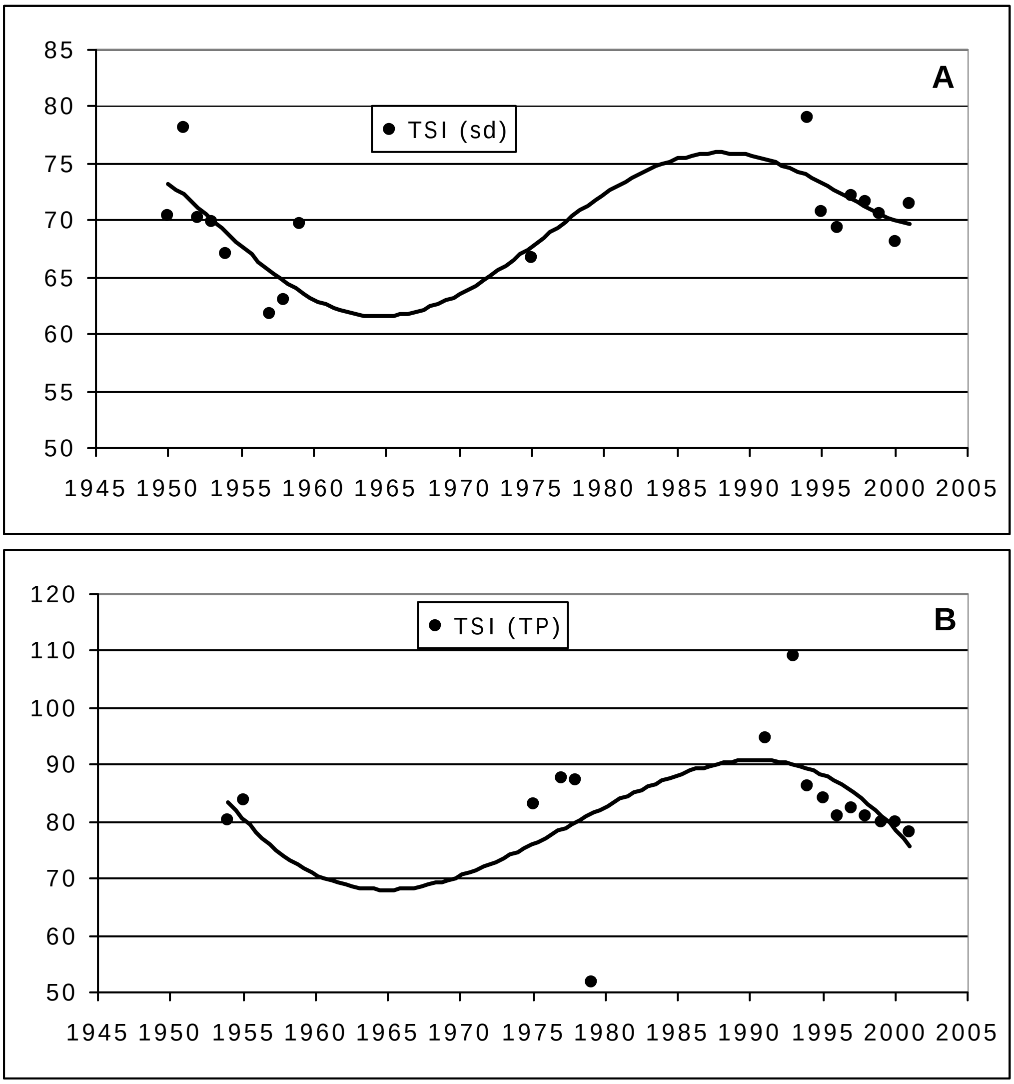

Figure 6. Long-term changes of Trophic State Index (Secchi depth, and total phosphorus) calculated on the basis of yearly average values measured in the Polish part of the Vistula Lagoon. (£omniewski, 1958; Piechura, 1962; Ró¿añska and Wiêc³awski, 1978; Szarejko-£ukaszewicz, 1959; WIOS, 1986, 1987, 1989-1991, 1993-2001)

CHLOROPHYLL A

Chlorophyll *a* concentrations in the Polish part of the Vistula Lagoon have been stable over the last 30 years, with average values ranging between 35 and 43 mg m^{-3} (Figure 7).

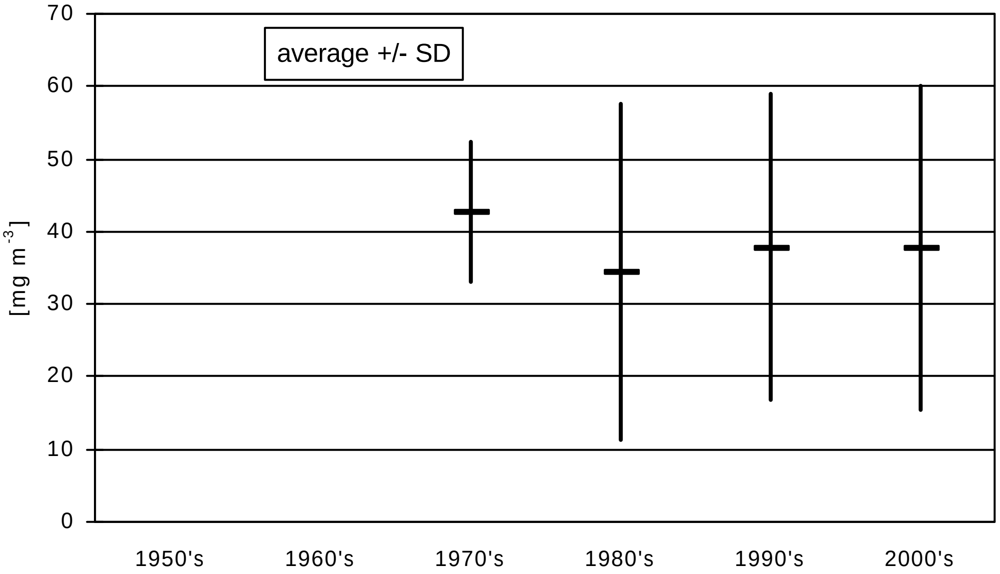

Figure 7. Chlorophyll a concentrations (Lata³a, 1978; WIOS, 1986, 1987, 1989-1991, 1993-2001)

This means that the level of primary productions during this period did not change either. The maximum observed values did not usually exceed 100 mg m^{-3} (there were a few exceptions when chlorophyll ranged between 107 and 161 mg m^{-3} at a few stations during 1999 and 2001). Concentrations in the Vistula Lagoon did not reach the estimates of the Curonian Lagoon (BERNET, 2000), with averages of 40-50 mg m^{-3} and concentrations 350-400 mg m^{-3} registered in some years (1995). According to the criteria system to assess the ecological status of lakes, developed in Estonia (Noges *et al*. 2003), the calculated averages reflect the moderate/poor status of the Vistula Lagoon.

ZOOPLANKTON

The comparison of the data from the late 1970s to that of the late 1990s indicates that there was a decrease of about 30-35% in the total zooplankton abundance observed during the April-May period, and in June it reached almost 50%. The reduction of total zooplankton biomass was even more pronounced at 8%, 39% and 85% when April, May and June, respectively, were compared. The abundance and biomass of copepods decreased. Therefore, the share of the two other groups (rotifers and cladocerans) increased. The larger proportion of rotifers resulted in the lower mean individual weight of zooplankton organisms during the 1990s (Figure 8).

The number of zooplankton species is low in the Polish part of the lagoon. There are freshwater, brackish water and marine taxa (Ró¿añska, 1963). The number of species decreases with an increase of salinity. During the 1950s and 1970s, 34 species of rotifers, ten species of cladocerans and ten species of copepods were identified (Ró¿añska, 1963; Adamkiewicz-Chojnacka, 1983). The number of rotifer and copepod species decreased to 13 and 7, respectively, in the 1990s (Krajewska – personal communication).

There were seasonal changes in taxonomic composition. In early-spring in the 1970s, *Hexarthra fennica* (Levander) dominated the zooplankton abundance. In May, the abundance of *Eurytemora affinis* (Poppe) increased. During summer, rotifer species *Filinia longiseta* (Ehrenberg) and *Keratella cochlearis* (Gosse) dominated. Subsequently, the abundance of *Eurytemora affinis* (Poppe) increased again in autumn. Among rotifers *Keratella cochlearis* , *Filinia longiseta,* , *Synchaeta* sp. *Hexarthra fennica* and *Keratella quadrata* (Müller) dominated (Adamkiewicz-Chojnacka, 1978).

The presence of the species *F.longiseta*, *Brachionus angularis*, *Brachionus calyciflorus* and *Keratella cochlearis v. tecta* (Gosse) is an indicator of the eutrophic status of a lake (Turoboyski, 1979). During the 1950s *Brachionus* were not as abundant in the Polish part of the lagoon as they would become in subsequent years. This was an indicator of increasing eutrophication (Ró¿añska, 1963; Adamkiewicz-Chojnacka, 1978; Adamkiewicz-Chojnacka, 1983) during the 1960s and 1970s. At the end of the 1990s, *Brachionus calyciflorus* comprised the bulk of the rotifer biomass (Krajewska – personal communication).

Taking into account the rotifer abundance during the 1998-1999 period (705 000 and 467 000 ind. m^{-3}, respectively) and the percentage of rotifer species indicating the highly eutrophic status of lakes (Krajewska – personal communication), the Vistula Lagoon should be regarded as a meso-eutrophic water body type (Karabin, 1985).

Among copepods, *Eurytemora affinis* (Poppe) dominated. The most abundant species of cladocerans were *Bosmina longirostris* (Müller), *Diaphanosoma brachyurum* (Levin) and *Leptodora kindtii* (Focke) (Ró¿añska, 1972; Adamkiewicz-Chojnacka, 1978; Krajewska – personal communication).

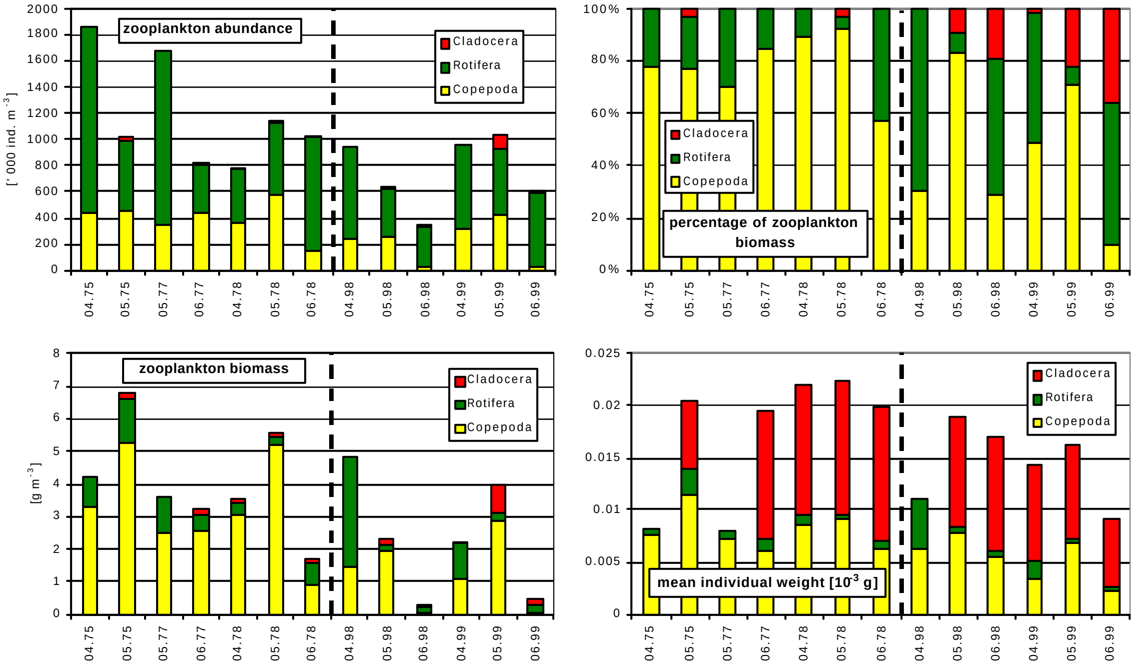

Figure 8. Changes in zooplankton abundance, biomass, mean individual weight and percentage of major taxonomic groups in the Polish part of the Lagoon (Adamkiewicz-Chojnacka and Leœniak, 1985; Adamkiewicz-Chojnacka and Fait, 1987; Krajewska - personal communication)

CONCLUSIONS

1. Data from the Russian part need to be analysed and other criteria, or parameters, should be taken into account, including phytoplankton taxonomic composition, the abundance and occurrence of blooms, macroinvertebrates and fish.
2. Riverine loads of BOD (to the Polish part) decreased to about 60% of those from 1993; the total nitrogen loads were 23% lower in comparison to 1997 values; there were no major changes in total phosphorus loads over the last six years.
3. Point sources discharging directly into the lagoon (in the Polish part) were rather of local importance, because they usually comprised less than 1-2% of the riverine loads.
4. The range of the Secchi depths recorded during the 1950s was much wider than that observed in the 1990s. This may indicate the higher trophic status of the lagoon at the present stage. However, due to the specific conditions of the Vistula Lagoon, it is probably not the best indicator of its trophic status.
5. Nitrogen and phosphorus concentrations in the Polish part reflect a high trophic status (bad water quality).
6. The Trophic State Indexes calculated from Secchi depth, chlorophyll *a* and total phosphorus were high which indicated the high trophic status of the lagoon. However, TSI (SD) and TSI (TP) have improved over the last ten years.
7. Chlorophyll *a* concentrations in the Polish part have been stable over the last 30 years; the calculated averages reflect the moderate/poor status of the Vistula Lagoon.
8. Taking into account the rotifer abundance during the 1998-1999 period and the percentage of rotifer species indicating the highly eutrophic status, the Vistula Lagoon should be regarded as a meso-eutrophic water body type.

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