Archives of Polish Fisheries	Vol. 1	Fasc. 2	187 - 203	1993

LONG-TERM CHANGES IN THE COMPOSITION AND BIOMASS OF THE PHYTOPLANKTON IN LAKE NIEGOCIN (GREAT MAZURIAN LAKES, POLAND)

Wanda Krzywosz

The Stanisław Sakowicz Inland Fisheries Institute in Olsztyn, Lake Fisheries Station

A b s t r a c t: Long-term and seasonal studies were made on the changes of phytoplankton composition and biomass in a strongly polluted, eutrophic, dimictic Lake Niegocin. Two maxima were distinguished in the seasonal development of the phytoplankton: spring and summer one. During the studies, in 1978 and in 1986 - 1989 diatoms dominated in the phytoplankton during spring circulation. Their biomass ranged from 1.9 to 18.1 mg·dm^{-3}. Summer maximum of phytoplankton development was caused by mass development of blue-green algae, up to 97.8% of the total phytoplankton biomass. Range of average phytoplankton biomass in the peak of development was narrow in particular years, from 5.8 to 8.9 mg·dm^{-3}. The paper presents also an analysis of the relationships between phytoplankton development and selected environmental factors.

Key words: LAKE, PHYTOPLANKTON BIOMASS, DOMINATING SPECIES, SEASONAL VARIABILITY

INTRODUCTION

Rate of lake eutrophication depends on the phosphorus content in water, and in certain cases also on nitrogen content, or on the two elements at the same time (Kajak 1979, Kajak and Zdanowski 1983, Zdanowski 1982). The basic regularity of the eutrophication process consists of an increase of lake trophy, resulting in an increase of phytoplankton biomass and numbers (Kajak 1972, Spodniewska 1974, 1979). Changes in the phytoplankton composition differ in particular lakes. They depend on the degree of eutrophication and on lake morphology and morphometry (Malanowski 1974, Spodniewska 1979, Wojciechowska 1976).

Lake Niegocin is one of the biggest lakes in the complex of Great Mazurian Lakes. Considerable water outflow from this lake results in the fact that it affects a number of lakes located south of the town Giżycko. Lake Niegocin has been polluted with municipal sewage from Giżycko since a number of years and at an increasing rate. This caused an increase of lake trophy and, consequently, in qualitative and quantitative changes in the phytoplankton.

The aim of the studies was to determine variability of the phytoplankton biomass and composition in the last ten years, as well as to define the ecological consequences

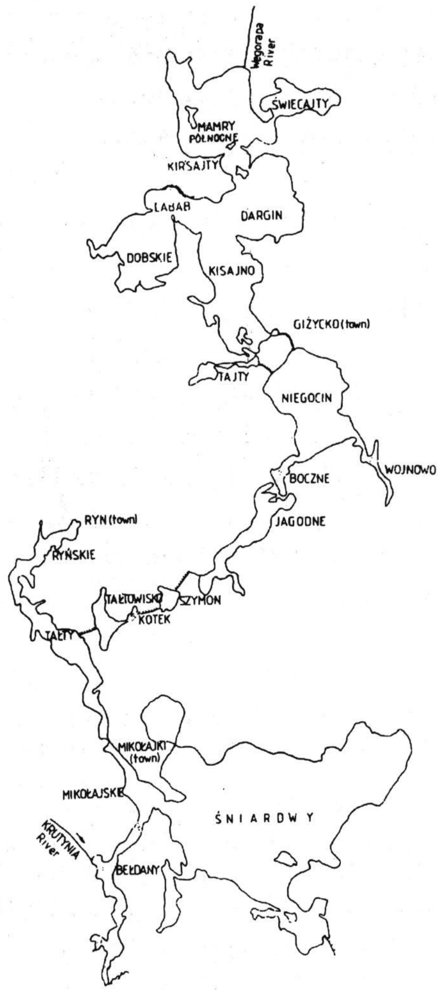

Fig. 1a. Great Mazurian Lakes complex

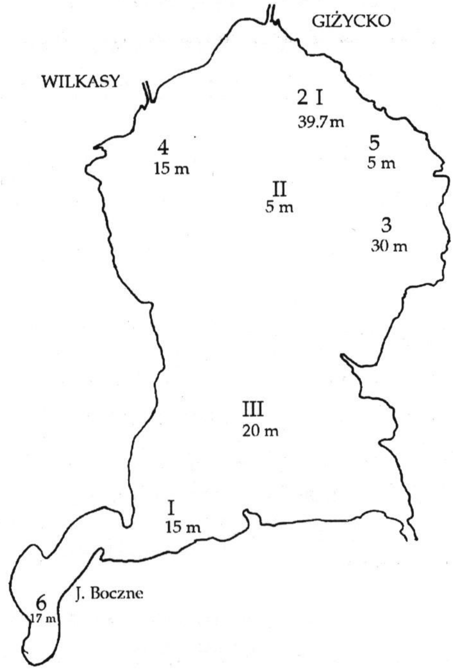

Fig. 1b. Distribution of sampling stations in Lake Niegocin (1-6 stations in 1978, I-III stations in 1986-1989

of these changes at the background of other indices of the eutrophication process in Lake Niegocin.

CHARACTERISTICS OF THE LAKE

Lake Niegocin is located within the range of a changeable water shed. It runs in the vicinity of Giżycko and its location depends on the water flows in lakes Niegocin and Kisajno (Fig. 1a). Lake area is 2600 ha, maximal depth 39.7 m, average depth 9.9 m. Lake volume is 258 million m^3, and average annual outflow has been estimated at

27% of the lake volume. Bottom of Lake Niegocin is very differentiated. There are at least 20 separate kettles and over 30 mid-lak shallows. Large amounts of untreated municipal sewage and industrial wastes reach the lake from two districts of Giżycko i.e. Wilkasy and Borowo, as well as from many recreation sites located at the lake shores.

According to Giercuszkiewicz-Bajtlik and Głąbski (1982) Lake Niegocin received in 1976 an annual load of total nitrogen 5.91 $g \cdot m^{-2} \cdot year^{-1}$ and of total phosphorus 1.07 $g \cdot m^{-2} \cdot year^{-1}$.

In the period 1986 - 1989 the amount of untreated sewage discharged to Lake Niegocin was (according to the Centre for Environmental Studies and Control) on the average 7440 m^3/day. Nutrient content in the lake epilimnion is presented in Tab. 1. The values are quite high compared to the complex of Great Mazurian Lakes. Considerable increase of nitrogen content in the analysed ten-year period is rather alarming. High lake loading with untreated sewage and considerable effect of the catchment area resulted in noticeable changes in the ecosystem.

TABLE 1

Changes of the mean value and range (in brackets) of temperature, oxygen content, visibility of Secchi's disk, phosphorus and nitrogen content in the epilimnion of Lake Niegocin in 1978[1] and 1986 - 1989[2]

Parameter	Early spring (IV)		Late spring (V–VI)		Summer (VII–VIII)		Autumn (IX–X)	
	1978	1986–1989	1978	1986–1989	1978	1986–1989	1978	1986–1989
Temperature (°C)	4.6	4.6 (3.0–5.4)	14.8	15.7 (13.6–18.2)	18.2	18.5 (17.5–20.4)	9.2	7.7 (7.0–9.4)
O_2 content ($mg \cdot dm^{-3}$)	15.8	14.0 (13.0–14.6)	11.1	10.2 (7.7–11.2)	9.7	8.6 (6.1–10.6)	9.6	9.8 (8.5–10.5)
Visibility of Secchi's disk (m)	1.3	2.3 (1.3–2.9)	1.8	2.2 (1.7–2.5)	1.8	1.4 (1.0–1.7)	3.3	3.1 (2.7–3.5)
PO_4–P ($mg \cdot dm^{-3}$)	0.147	0.183 (0.123–0.256)	0.119	0.134 (0.090–0.192)	0.234	0.183 (0.122–0.231)	0.279	0.266 (0.243–0.293)
Tot–P ($mg \cdot dm^{-3}$)	0.184	0.287 (0.236–0.322)	0.199	0.207 (0.189–0.234)	0.271	0.272 (0.261–0.290)	0.291	0.306 (0.260–0.360)
NO_3–N ($mg \cdot dm^{-3}$)	0.05	0.29 (0.23–0.39)	0.11	0.09 (0.03–0.18)	0.11	0.09 (0.06–0.15)	0.33	0.26 (0.25–0.27)
Tot–N ($mg \cdot dm^{-3}$)	1.02	3.16 (2.05–6.88)	1.50	2.64 (1.45–4.23)	1.69	3.06 (2.11–4.59)	1.76	3.16 (2.55–3.57)
Tot N Tot P	5.5	11.2 (8.7–24.6)	7.5	12.8 (7.2–20.7)	6.2	11.5 (7.8–15.8)	6.0	9.8 (9.0–10.4)

[1] *According to Lossow (unpubl. data)*

[2] *According to Zdanowski (unpubl. data)*

Range of submerged vegetation decreased compared to the period 1957 - 1959 from 5 m depth to 2.5 m depth, so that the area occupied by this vegetation decreased by 44% (Krzywosz et al. 1989).

Visibility of Secchi's disk was on the average 4.5 m in summer 1901 (Olszewski 1948–1951), 2.8 m in 1976 (Zdanowski et al. 1984), 1.8 m in 1978 and only 1.4 m in the period 1986 - 1989.

Depth of the epilimnion decreased considerably, from 12 - 18 m in 1957 - 1964 and 7 - 9 m in 1971 (Bernatowicz et al. 1974) to 8 - 8.5 m in 1976 (Zdanowski et al. 1984) and 4 - 15 m in 1986 - 1989 (data of the Department of Hydrobiology of the Inland Fisheries Institute, Olsztyn).

These changes were accompanied by low oxygen levels during summer stagnation. In 1971 they ranged from 5.6 to 10 $mg \cdot dm^{-1}$ (Bernatowicz et al. 1974), in 1976 from 7.8 to 9.6 $mg \cdot dm^{-1}$ (Zdanowski et al. 1984), and in the study period from 6.1 to 10.6 $mg \cdot dm^{-1}$ (Tab. 1).

Trophic parameters and indices calssify Lake Niegocin to class III of water purity (Kudelska et al. 1983). Also the criteria by Kajak and Zdanowski (1983) reveal that this lake is in class III with respect to trophic conditions.

METHODS

Samples for phytoplankton studies were collected at 6 stations in 1978 and 3 stations in 1986 - 1989. Location of the sampling stations is presented in Fig. 1b. Samples were collected at monthly intervals, since April till October, from different epilimnion levels, every meter, with a Bernatowicz sampler. They were fixed immediately with Lugol's liquid and preserved in formalin. Integrated samples were analysed, characteristic for the whole epilimnion. These were prepared by mixing 100 ml subsamples taken from particular levels, and condensed with the sedimentation method (usually 0.5 - 2.0 ml), so that the sedimented plankton cells could have been counted in a Fuchs-Rosenthal chamber 0.2 mm in height.

Counting of particular species was carried out using a JENAVAL microscope, with 12.5 - 40 x objectives (at least 100 cells, colonies or filaments were counted). To calculate the phytoplankton biomass measurements were made of dominating species (10 - 20 individuals in each sample) and these were used to calculate the volume of colonies of particular species. Volume of other taxons was calculated when their representatives had been found, and also in this case average values for a few months were used. Assuming that the specific weight of algae equals one (1 mm^3 = 1 mg), biomass of particular species was calculated. Cell biomass was determined from the volume of a solid figure most resembling the cell shape, taking into consideration the directives given by Sim (1985) and Wojciechowski (unpubl. data). Organisms smaller than 30 μm were classified as nannoplankton (Pavoni 1963, Spodniewska 1983).

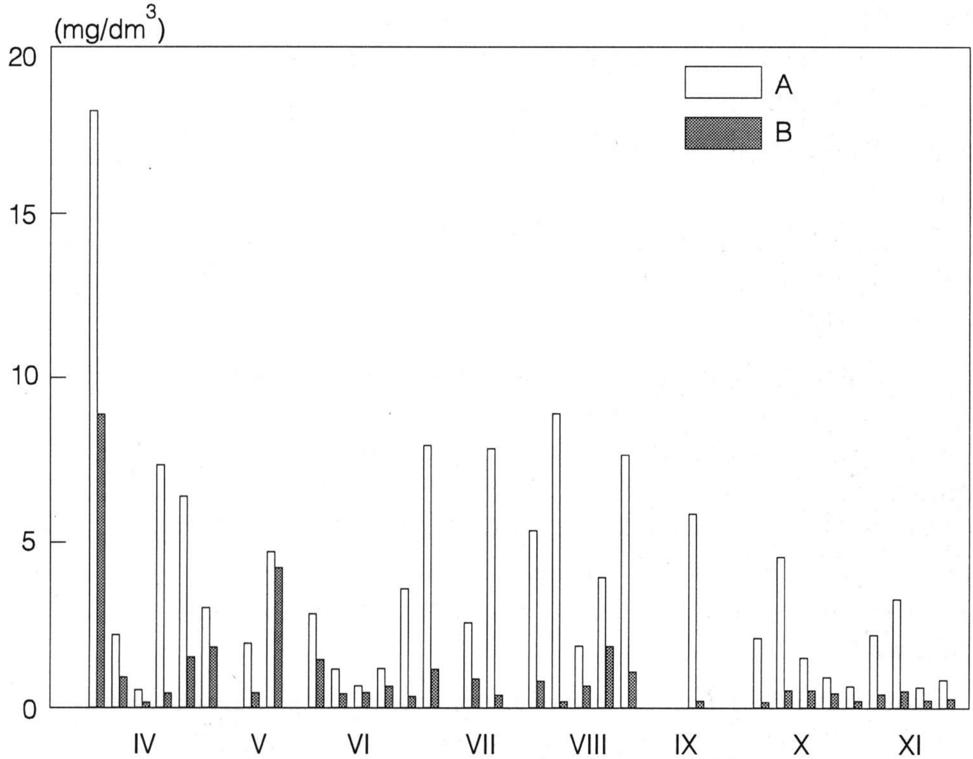

Fig. 2. Seasonal changes of total phytoplankton and nannoplankton biomass in the epilimnion of Lake Niegocin in 1978 (1), 1986 (2), 2987 (3), 1988 (4), and 1989 (5). Symbols: A - total phytoplankton biomass, B - nannoplankton biomass

Water samples for qualitative analyses of the phytoplankton were collected in summer 1978 and 1986. 20 - 35 l of lake water were filtered (equal water volumes from each meter in the epilimnion layer) through a plankton net no. 25 and preserved with formalin. Species analysis of the diatoms was performed basing on diatom slides.

Measurements of the visibility of Secchi's disk, temperature, and water temperature were made simultaneously with the phytoplankton sampling. Water samples for chemical analyses were also collected (oxygen content with Winkler's method, water chemistry and in 1987 and 1988 also chlorophyll a and pheophytin levels). Analyses of the chemical composition of water and of chlorophyll a and pheophytin contents were made by the Department of Hydrobiology of the Inland Fisheries Institute in Olsztyn, with the Standard Methods (1975) and the methods by Hermanowicz et al. (1976) for water chemistry, and after Lorenz (1967) for chlorophyll and pheophytin content.

RESULTS

Totally 68 phytoplankton species were found in Lake Niegocin in course of the studies. Forms which cannot be preserved in formalin (i.e. flagellates) were not taken into account.

As regards the species numbers, diatoms (*Bacillariophyceae*) occupied the first position - 29, followed by green algae (*Chlorophyta*) - 16, blue-green algae (*Cyanophyta*) - 15, *Chrysophyceae* - 4, *Dinophyceae* - 3, and *Cryptophyceae* - 1.

The following forms were the dominants and subdominants: *Melosira granulata* (Ehr.) Ralfs, *M. islandica* O.Müll., *M. islandica subsp. helvetica* O.Müll., *Asterionella formosa* Hass, *Cyclotella comta* (Ehr.) Kutz, *Stephanodiscus hantzchii* Grun, *Synedra ulna* (Nitzch.) Ehr., *S. acus* Kutz, *Tabelaria fenestrata var. asterionelloides* Grün, *Microcystis aeruginosa* Kutz., *M. incerta* (Lemm.) Starmach, *M. wessenbergii* Komarek, *Aphanisomenon flos-aquae* (L.) Ralfs, *Anabaena flos-aquae* Breb., *A. spiroides* Kleb., *Oscillatoria sp.*, *O. radeckei* Van Goor., *Ceratium hirundinella* (F.B. Müller) Bergh, *Peridinium sp.*, *Cryptomonas sp.*

Some regularities in the changes of phytoplankton composition and biomass were observed in 1978 and 1986 - 1989. Phytoplankton developed more abundantly in two periods, when its biomass was higher. The first period was just after ice melting, in early spring, the other during summer stratification. Much lower biomass of the phytoplankton was noted in autumn (Fig. 2).

SEASONAL CHANGES OF THE PHYTOPLANKTON COMPOSITION AND BIOMASS IN 1978

Average biomass of the phytoplankton in 1978 differed in particular months (Fig. 2). The highest level of 18.1 $mg \cdot dm^{-3}$, with about 50% represented by the nannoplankton, was observed in April (Fig. 2). As regards the sampling stations, higher biomass was observed at the station above the deepest lake part (about 25 $mg \cdot dm^{-3}$) and in Lake Boczne. Diatoms dominated at all stations (Tab. 3). They were represented mostly by the genera: *Melosira*, *Cyclotella*, *Synedra*, *Navicula* and *Stephanodiscus* (Tab. 2)

In late spring the phytoplankton biomass was much lower, about 3 $mg \cdot dm^{-3}$ on the average, the share of the nannoplankton being still quite high (about 55%). Biomass of the phytoplankton differed at particular stations from 1.2 to 5.1 $mg \cdot dm^{-3}$ in May, and from 0.7 to 5.1 $mg \cdot dm^{-3}$ in June. Diatoms were fairly abundant, and so were *Dinophyceae* and *Cryptophyceae* in May, while in June diatoms and blue-green algae were most abundant (Fig. 3, Tab. 3).

TABLE 2

Phytoplankton composition in Lake Niegocin in 1978 and 1986

Species	1978																																										1978														
	Month																																																								
	IV						V						VI						VII						VIII						X						XI						IV			VI			VIII			X			XI		
	Stattion																																																								
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CYANOPHYTA																																																									
Anabena flos-aquae Breb.													+		+	+	+		+		+	+				+				+																+	+	+	+	+	+						
Anabena spiroides Kleb.																										+																															
Anabena sp.													+	+	+				+					+		+				+																											
Aphanizomenon flos-aquae L. Ralfs														+						+		+		+		+		+			+		+			+							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Gomphosphaeria lacustris Chod.																										+																								+							
Merismopedia tenuissima Lemm.																																														+	+	+	+	+	+						
Microcystis aeruginosa Kütz.																			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+							+		+	+	+	+	+	+	+	+	+	+		+	+
Microcystis incerta (Lemm.) Starmach																																																			+	+	+	+	+	+	+
Microcystis viridis (A.Br.) Lemm.																																												+					+	+	+		+	+			
Microcystis wesenbergii Komarek																																																	+	+	+						
Microcystis sp.																			+	+	+	+	+	+	+	+	+	+	+	+																						+					
Lyngbya sp.																																																		+				+			
Oscillatoria agardhii Gomont	+					+	+			+					+	+		+						+											+																						
Oscillatoria redeckei Van Gor																				+						+		+	+															+	+	+	+	+	+	+	+	+					
Oscillatoria sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+		+	+	+	+	+					+			+		+				+	+	+	+	+	+	+	+	+	+	+			+	+
BACILLARIOPHYCEAE																																																									
Asterionella formosa Hass.	+	+	+	+	+	+		+			+		+		+																							+					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Asterionella zasuminenssis (Cabejsz.)																																											+	+	+												
Cyclotella comta (Ehr.) Kütz.		+	+	+																																							+	+	+							+	+			+	+
Cyclotella sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+					+						+	+	+	+		+	+	+	+	+	+	+															
Diatoma elongatum (Lyngb.) Ag.	+	+	+	+	+	+	+			+	+	+	+		+	+		+	+		+	+	+	+										+												+											
Diatoma hiemale (Lyngb.) Heib.								+		+				+																																											
Fragilaria brevistriata Grun.																																												+	+									+			

Species	1978																																										1978														
	Month																																																							
	IV						V						VI						VII						VIII						X						XI						IV			VI			VIII			X			XI		
	Stattion																																																						
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Fragilaria construens (Ehr.) Grun.																																														+	+	+									
Fragilaria crotonensis Kitt.	+	+	+	+		+		+				+																				+				+		+		+			+	+	+	+		+	+	+	+	+			+	+	+
Fragilaria lapponica Grun.																																																	+	+							
Gyrosigma acuminatum (Kütz.) Rabh.		+		+																																							+	+													
Melosira arenaria Moore																																						+																			
Melosira Binderana Kütz.										+								+			+			+												+	+		+	+	+	+	+	+	+	+	+	+				+	+	+	+	+	+
Melosira granulata (Ehr.) Ralfs.	+	+	+	+	+	+	+		+	+												+	+															+				+	+			+	+	+								+	
Melosira islandica O.Müll.		+																																				+					+	+	+							+	+		+	+	+
Melosira islandica subsp.helvetica O.Müll.																																														+	+	+									
Melosira varians Ag.														+																		+						+					+	+	+							+		+	+	+	+
Melosira sp.	+	+	+	+	+	+					+			+			+		+	+			+												+		+		+		+																
Navicula cryptocephala Kütz.	+	+	+	+	+	+					+																								+		+	+			+		+	+	+											+	
Navicula sp.	+	+	+	+	+	+																															+	+	+	+	+	+													+	+	+
Nitzschia sp.	+	+	+	+	+	+					+																	+							+		+		+		+	+													+	+	+
Stephanodiscus astraea (Ehr.) Grun.		+		+																																		+						+	+	+	+	+							+	+	+
Stephanodiscus dubius (Fricke) Hust.																																													+											+	
Stephanodiscus Hantzschii Grun.	+		+	+	+	+	+		+	+	+	+	+		+	+	+	+	+						+						+		+	+	+	+	+		+	+	+	+		+	+	+	+	+				+			+	+	+
Stephanodiscus sp.	+	+	+	+	+	+																															+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Synedra acus Kütz	+	+				+																																+		+		+	+	+	+											+	+
Synedra ulna (Nitzsch) Ehr.	+	+	+	+	+	+				+	+	+	+	+	+	+	+	+					+					+						+									+	+		+	+	+				+					
Tabellaria fenestrata var.asterionelloides Gr.		+	+	+																																																					
Tabellaria flocculosa (Roth) Kütz.	+	+	+	+	+	+																																																			
DINOPHYCEAE																																																									
Ceratium hirundinella (F.B.Müller) Bergh																										+																								+								
Gymnodinium sp.							+	+	+		+					+									+											+							+	+	+											+	+
Peridinium sp.								+											+		+			+	+	+	+	+		+						+				+											+					+	+

Species	1978																																										1978														
	Month																																																								
	IV						V						VI						VII						VIII						X						XI						IV			VI			VIII			X			XI		
	Stattion																																																								
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CRYPTOPHYCEAE																																																									
Cryptomonas sp.				+			+	+	+	+		+				+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+			+			+		+												
CHLOROPHYTA																																																									
Actinastrum Hantzschii Lag.																				+		+			+	+		+	+	+	+	+	+	+	+	+																					
Ankistrodesmus falcatus (Corda) Ralfs																														+																											
Chlamydomonas sp.																																																	+	+	+		+	+			
Closterium sp.																				+				+			+			+																			+	+	+						
Coelastrum microporum Nag.														+			+	+																											+									+			
Cosmarium sp.																				+		+		+								+		+		+		+				+										+				+	+
Kirchneriella obesa (West.) Schmidle																										+	+	+	+	+																			+	+	+						
Pandorina morum (O.F.Müller) Boy														+			+	+																												+	+	+									
Pediastrum boryanum (Turp.) Me-negh.								+				+	+	+	+	+	+	+																									+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Pediastrum duplex Meyen								+				+	+	+	+	+	+	+	+	+	+	+	+	+	+																						+	+			+			+			
Pediastrum tetras (Ehrenb.) Ralfs														+				+							+																									+							
Scenedesmus quadricauda (Turpin) Breb.							+			+	+				+	+						+	+	+			+	+	+					+										+			+	+					+			+	+
Spirogyra sp.																																														+	+	+					+	+			
Staurastrum paradoxum Meyen																																																							+	+	+
Staurastrum sp.																									+	+	+	+	+	+																			+	+	+						
Tetraedron minimum (A.Br.) Hansg.																			+	+	+	+	+	+	+			+		+																							+				
CHRYSOPHYCEAE																																																									
Dinobryon divergens Imh.													+	+	+	+	+	+								+																				+	+	+									
Dinobryon sertularia Ehr.														+		+				+		+			+	+																				+											
Dinobryon sociale Ehr.													+		+		+		+	+					+	+																				+	+	+				+					
Mallomonas sp.																																				+	+				+															+	+

TABLE 3

Changes of the total phytoplankton biomass, diatom, blue-green algae and nannoplankton abundance in the epilimnion of Lake Niegocin at six sampling stations in 1978

Month	Station	Total phytoplankton biomass (mg·dm^{-3})	Diatoms (%)	Blue-green algae (%)	Nannoplankton (%)
IV	1	15.5	98	2	48
	2	24.4	99	1	34
	3	8.7	99	1	91
	4	14.8	96	3	51
	5	19.8	99	1	39
	6	25.4	99	1	58
V	1	2.8	33	5	66
	2	3.6	34	2	74
	3	3.3	39	4	62
	4	5.1	74	3	48
	5	1.2	92	1	51
	6	2.1	59	25	66
VI	1	5.1	60	40	57
	2	2.6	70	30	56
	3	1.4	57	36	53
	4	4.6	57	31	59
	5	0.7	53	47	53
	6	2.5	52	48	17
VII	1	8.6	35	43	22
	2	5.9	62	31	9
	3	8.3	27	50	14
	4	7.7	64	25	12
	5	5.8	51	33	16
	6	11.1	42	47	10
VIII	1	2.1	1	70	8
	2	7.8	0	90	3
	3	4.9	0	48	30
	4	8.2	1	85	17
	5	2.9	0	75	25
	6	6.0	0	84	7
X	1	1.8	10	88	12
	2	1,8	40	59	7
	3	3.2	1	97	4
	4	1.3	20	78	16
	5	2.7	1	98	1
	6	1.2	38	32	12
XI	1	1.6	85	13	15
	2	4.9	100	0	3
	3	2.8	100	0	12
	4	0.8	42	0	15
	5	1.5	97	0	22
	6	1.0	71	29	45

Average biomass of the phytoplankton during summer stagnation was about 7 $mg \cdot dm^{-3}$, with considerable share of nannoplanktonic forms (Fig. 2). Variations of the biomass in July were from 5.8 to 11.1 $mg \cdot dm^{-3}$, and in August from 2.9 to 8.2 $mg \cdot dm^{-3}$. Lower range of variations in the phytoplankton biomass in summer was observed at station 5 (near the discharge of sewage). Blue-green algae and diatoms dominated at all stations (Tab. 3).

Autumn circulation was characterized by much lower biomass of the phytoplankton, about 2 $mg \cdot dm^{-3}$, with the predomination of nannoplanktonic forms (Fig. 2). Variations between the stations at the begining of autumn circulation were within the range 1.2 to 3.2 $mg \cdot dm^{-3}$, with blue-green algae still dominating, where as later (November) the diatoms were most abundant (Tab. 3).

SEASONAL CHANGES OF THE PHYTOPLANKTON COMPOSITION AND BIOMASS IN 1986 - 1989

In the period 1986 - 1989 average phytoplankton biomass in April was 4.1 $mg \cdot dm^{-3}$. The lowest value 0.5 $mg \cdot dm^{-3}$ was observed in 1987, the highest (7.3 $mg \cdot dm^{-3}$ in 1988. In 1986 and 1987 phytoplankton studies carried out at 3 stations in Lake Niegocin revealed small variations of the biomass (Tab. 4). In April 1986 - 1989 composition of the phytoplankton was predominated by diatoms, with the exception of two stations in 1987, at which blue-green algae and *Dinophyceae* were fairly abundant (Tab. 4, Fig. 3).

Early spring development of diatoms was followed by a decrease of their biomass in May - June 1986 - 1989 to 2.2 $mg \cdot dm^{-3}$. Attention should be given to 1987 and 1988, when the phytoplankton biomass was much higher due to the development of *Dinophyceae* and *Cryptophyceae*, not with standing diatom domination (Fig. 3).

Average phytoplankton biomass during summer stagnation was more or less the same in consecutive years, about 7 $mg \cdot dm^{-3}$, with the exception of 1987 (2.1 $mg \cdot dm^{-3}$). At most stations the values were similar in July and August, the only exception being station three in August 1987, when lower values were noted (Tab. 4). In July 1986 - 1989, and in August 1986, 1987 and 1989 blue-green algae dominated at all stations, while in August 1988 - diatoms together with blue-greens (Tab. 4). Water blooms in Lake Niegocin may occur earlier (end of June) or later (begining of September), depending on the insolation and winds. This is confirmed by high biomass values noted on 25 June in 1991 (unpubl. data) and in September 1987 (Fig. 2). In the whole period of the studies summer blooms were caused by colonial and filamentous blue-green algae. Share of nannoplankton in the phytoplankton biomass increased as diatom biomass increased.

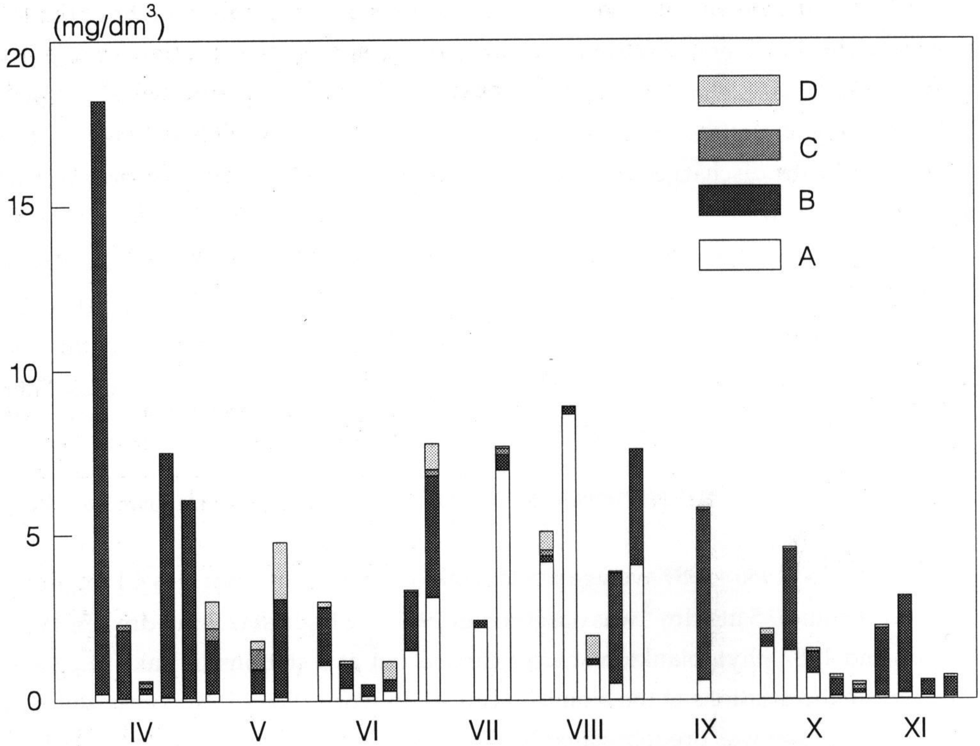

Fig. 3. Seasonal changes of average biomass of the dominating taxonomic in the phytoplankton in the epilimnion of Lake Niegocin in 1978 (1), 1986 (2), 2987 (3), 1988 (4), and 1989 (5). Symbols: A - *Cyanophyta*, B - *Bacillariophycae*, C - *Dinophycae*, D - *Cryptocyphae*

During autumn circulation in 1986 - 1989 average biomass of the phytoplankton decreased 1.6 mg·dm^{-3}. Variations at particular stations were from 3.1 to 4.7 mg·dm^{-3} in October, and from 2.3 to 4.1 mg·dm^{-3} in November. In early autumn blue-green algae and diatoms dominated on the phytoplankton, and in late autumn only diatoms (Fig. 3).

DISCUSSION

Changes of the visibility of Secchi's disk and high levels of chlorophyll a, pheophytins, nitrogen and phosphorus, accompanied by phytoplankton development are important parameters which reflect degradation of Lake Niegocin.

Long-term measurements of the visibility of Secchi's disk during most intensive development of the phytoplankton revealed a decreasing trend, from 1.8 m in 1978 to 1.2 m in 1989. Similar visibility was observed in other degrading eutrophic lakes: Jagodne, Tałty Ryńskie, Mikołajskie and Bełdany (Krzywosz et al. 1989).

Chlorophyll content in Lake Niegocin showed considerable variations in the annual cycle (Hutorowicz, unpubl. data). During spring and autumn circulation lower chlorophyll concentrations were observed than during summer stagnation (Tab. 5). Higher chlorophyll levels were accompanied by phytoplankton blooms and were characteristic of highly eutrophic lakes (Krzywosz et al. 1989). Mass development of the algae was followed by an increase of pheophytin and chlorophyll levels. This is a usual phenomenon which has been observed also by other authors (Mucha and Rybak 1979).

TABLE 5

Changes of the average values and range of variations of chlorophyll a and pheophytin (in brackets) content in the epilimnion of Lake Niegocin in 1978 and 1988 (after Hutorowicz, unpubl. data)

Month	Chlorophyll a ($mg \cdot dm^{-3}$)		Pheophytins ($mg \cdot dm^{-3}$)	
	1987	1988	1987	1988
V	3.75	2.80	3.27	11.89
	(3.45–3.93)	(0.48–4.17)	(2.92–3.53)	(7.62–14.52)
VI	1.00	2.53	4.75	6.25
	(-0.20–2.20)	(2.00–3.21)	(3.15–6.35)	(5.17–7.82)
VII	11.46	26.7	7.67	13.78
	(8.98–13.95)	(22.66–29.12)	(5.50–9.84)	(10.71–15.39)
VIII	3.63	31.92	6.57	14.95
	(1.28–8.82)	(16.03–44.15)	(1.72–9.94)	(9.67–21.17)
X	1.60	1.60	5.97	1.20

Nutrient content (nitrogen and phosphorus) in the epilimnion of Lake Niegocin was high compared to other eutrophic lakes of Mazurian Lakeland (Zdanowski et al. 1984). In 1986 - 1989 phosphorus content in spring increased compared to 1978, and in all other periods an increase of nitrogen levels was observed (Tab. 1).

Other symptom of the degradation of Lake Niegocin is the development of algae. Analyses of the phytoplankton development and its biomass in the epilimnion of Lake Niegocin revealed that in 1978 and 1986 - 1989 variations of the two parameters occurred in one year only. They referred to the average phytoplankton biomass which was lower in spring and summer 1987 (Fig. 2). This was most probably caused by less sunlight and lower water and air temperatures (Tab. 7) than in other years. Observations by Malanowski (1974) confirm this statement.

Since a number of years there have been no changes as regards phytoplankton composition in spring. Diatoms were always the dominating group, similarly as in other eutrophic lakes (Spodniewska 1955, 1974, 1978, 1979). They were represented mostly by species from the genera: *Melosira*, *Cyclotella* and *Stephanodiscus*. The highest diatom biomass was observed in April, when the concentrations of mineral phosphorus and nitrogen were also the highest (Fig. 3, Tab. 1). Decreasing concentrations of phosphorus and nitrogen were accompanied by a decrease in phytoplankton abundance. Spring mixing of water caused scattering of the phytoplankton over the whole water column, so that its biomass per unit of water volume became the same as in summer.

TABLE 6

Changes of the total biomass and phytoplankton composition in the epilimnion of Lake Niegocin during summer stagnation in 1971, 1973, 1976–1978 and 1986–1989

Year	Total phytoplankton biomass ($mg \cdot dm^{-3}$)	Nannoplankton ($mg \cdot dm^{-3}$)	Diatoms ($mg \cdot dm^{-3}$)	Blue-green algae ($mg \cdot dm^{-3}$)
1971[1]	4 - 13	-	-	-
1973[1a]	7.1	2.3	4.0	0.6
1976[1b]	7.1	0.5	6.8	0.3
1977[1c]	3.1	2.8	0.2	0.1
1978[2]	6.6	0.9	1.8	3.6
1986[2a]	8.9	1.1	0.2	8.7
1987[2b]	3.4	0.5	1.8	1.3
1988[2]	5.8	1.0	1.8	3.7
1989[2a]	7.6	1.0	3.4	4.1

Notes: 1 - VII (after Bernatowicz et al. 1974), 1a - VIII (after Spodniewska 1978), 1b - VIII, IX (after Spodniewska 1979), 1c - IX (after Spodniewska, unpubl. data), 2 - VII and VIII, 2a - VIII, 2b - VII and IX

Average phytoplankton biomass in Lake Niegocin during summer stagnation did not vary much in the past 20 years (Tab. 6). This was due to strong water mixing and water flow in the lake. Domination of diatoms and blue-green algae also did not change pointing to high lake trophy. July and August were usually characterized by phytoplankton blooms. A cool year 1987 was the only exception, when the highest phytoplankton biomass was observed in September (Fig. 2). An increase of chlorophyll a levels accompanied an increase of average phytoplankton biomass in summer (Tab. 7). *Microcystic aeruginosa*, *Aphanisomenon flos-aquae* and *Anabaena* were most abundant during summer stagnation. They were accompanied by the species belonging to *Melosira*, *Cyclotella* and *Stephanodiscus*. Average phytoplankton biomass (about 6 $mg \cdot dm^{-3}$) during summer stagnation was relatively low compared to other lakes of similar trophy (Spodniewska 1967, 1974, 1979). This resulted from specific morphoedaphic conditions in the lake, as well as from the sampling procedure (monthly intervals). It would be advisable to collect the samples more frequently in summer and then to select these which reflected the periods favouring algal blooms (windless weather, high air and water temperatures, high insolation).

TABLE 7
Changes of air temperature and insolation in Giżycko region in spring, summer and autumn 1978 and in 1986 - 1989 (data of the Institute of Meteorology and Water Management, Białystok Branch)

Parameter	Early spring (IV)		Late spring (V–VI)		Summer (VII–VIII)		Autumn (IX–X)	
	1978	1986 - 1989	1978	1986 - 1989	1978	1986 - 1989	1978	1986 - 1989
Average air temp.(°C)	5.1	6.2 (5.0*–7.8**)	12.8	13.9 (12.7*–15.2)	15.5	17.0 (15.7*–17.9)	9.1	10.3 (7.2–13.7)
Insolation (h)***	154	154 (129*–196)	507	467 (327*–550)	363	455 (414*–486)	169	268 (246–280)

*Notes: * - data for 1987, ** - range of variations, *** - insolation in hours*

Phytoplankton studies carried out at the end of June 1991 (unpubl. data), when the conditions were especially favourable for water blooms, revealed that the phytoplankton biomass in the littoral zone could reach up to 860.0 mg·dm^{-3} wet weight, at relatively low (14.0 mg·dm^{-3} wet weight) biomass in the lake epilimnion. This means that water flow and water mixing induced by winds limited the bloom in the areas of open water, not with standing high lake trophy. Low biomass of algae might have also been due to toxic substances discharged to the lake with untreated sewage (Spodniewska 1979).

Autumn phytoplankton, composed mostly of diatoms and blue-green algae, closed typical seasonality of algae development in Lake Niegocin. Average biomass in this period was low (1.5 mg·dm^{-3}) compared to the values observed by Spodniewska (1974) in Lake Mikołajskie.

Nannoplankton in Lake Niegocin was quite an important component of the phytoplankton. Its highest share was observed during spring circulation, slightly lower in summer and autumn (Fig. 2, Tab. 3, 4). Nannoplankton abundance in the annual cycle was very similar to that observed in Lake Mikołajskie (Spodniewska 1974), and during summer stagnation to the levels recorded in lakes Nidzkie, Bełdany, Ryńskie, Jagodne and Guzianka (Spodniewska 1979). Share of nannoplanktonic forms decreased in summer, when the biomass of blue-green algae increased. This suggests that Lake Niegocin is fairly susceptible to water blooms.

Spatial distribution of the phytoplankton in Lake Niegocin is illustrated by the studies carried out in 1978, when there were more sampling stations than in 1986 - 1989. In early spring the phytoplankton biomass was lower than at other stations only at one station (shallow, located most to the east). In the other months there were no noticeable differences between the stations. This may be connected with tachymictic character of the lake. In 1986 - 1989 variations of total phytoplankton biomass at the three sampling stations were also small in particular months. Station two (most shallow, located southward in May 1988 was the only exception. Phytoplankton biomass was much higher there, with considerable share of *Cryptophyceae*.

REFERENCES

Bernatowicz S. i in. 1974 - Charakterystyka limnologiczna jeziora Niegocin na tle postępującej eutrofizacji - Zesz. Nauk. ART Olsztyn 3: 142–172

Hermanowicz W. i in. 1976 - Fizyczno-chemiczne badania wody i ścieków - Arkady, Warszawa

Giercuszkiewicz-Bajtlik M., Głąbski E. 1981 - Predicting the pollution of Great Masurian Lakes from point and nonpoint sources - Ekol. pol. 29: 361–374

Kajak Z. 1972 - Potrzeby i możliwości badań w zakresie przeciwdziałania niekorzystnym skutkom eutrofizacji - Wiad. ekol. 18: 148–168

Kajak Z. 1979 - Eutrofizacja jezior - PWN, Warszawa

Kajak Z., Zdanowski B. 1983 - Ecological characteristics of lakes in north-eastern Poland versus their trophic gradient. I. General characteristics of 42 lakes and their phosphorus load. Study objectives and scope - Ekol. pol. 31: 239–256

Krzywosz T. i in. 1989 - Charakterystyka gospodarki rybackiej w systemie Wielkich Jezior Mazurskich w warunkach sterowania jego zasobami - IRS Olsztyn, maszynopis

Kudelska D., Cydzik D., Soszka H. 1983 - System oceny jakości jezior - Inst.Kszt.Środ. Warszawa, maszynopis

Lorenzen G.J. 1967 - Determination of chlorophyll and pheo-pigments: Spectrophotometric equations - Limnol. Oceanogr. 12: 246–343

Malanowski Z. 1974 - Biomasa i zasobność troficzna planktonu roślinnego trzech eutroficznych jezior mazurskich - Inst. Ekol. PAN Dziekanów Leśny, maszynopis

Mucha A., Rybak J.I. 1979 - Plankton roślinny Jeziora Długiego - Zesz. Nauk. ART Olsztyn 9: 55–61

Olszewski P. 1948–1951 - Dotychczasowe wiadomości z zakresu chemizmu jezior na Mazurach - Kosmos A 66: 411–459

Sim A.T. 1985 - The phytoseston of the Vistula River between Góra Kalwaria and Nowy Dwór Mazowiecki in 1982 - Ekol. pol. 33: 439–453

Spodniewska J. 1955 - Plankton jeziora Tajty - Ekol. pol. A 3: 181–228

Spodniewska J. 1967 - Dynamics of the abundance and biomass of phytoplankton in lakes Mikołajskie and Tałtowisko - Ekol. pol. 15: 139–153

Spodniewska J. 1974 - The structure and production of phytoplankton in Mikołajskie Lake - Ekol. pol. 22: 65–106

Spodniewska J. 1978 - Phytoplankton as the indicator of lakes eutrophication. I. Summer situation in 34 masurian lakes in 1973 - Ekol. pol. 26: 53–70

Spodniewska J. 1979 - Phytoplankton as the indicator of lakes eutrophication. II. Summer situation in 25 masurian lakes in 1976 - Ekol. pol. 27: 481–496

Standard methods for the examination of water and wastewater 1975 - American Public Health Association, Washington

Wojciechowska W. 1976 - Dynamics of phytoplankton biomass in two lakes of a different limnological character - Ekol. pol. 24: 237–252

Zdanowski B. 1982 - Variability of nitrogen and phosphorus contens and lake eutrophication - Pol. Arch. Hydrob. 29: 541–597

Zdanowski B., Korycka A., Zachwieja J. 1984 - Thermal and oxygen conditions, and the chemical composition of the water in the Great Masurian Lakes - Ekol. pol. 32: 651–677

STRESZCZENIE

WIELOLETNIE ZMIANY STRUKTURY I BIOMASY FITOPLANKTONU JEZIORA NIEGOCIN (WIELKIE JEZIORA MAZURSKIE, POLSKA)

Zbadano sezonową zmienność biomasy i struktury fitoplanktonu w jeziorze Niegocin (eutroficzne, dymiktyczne, głębokość średnia 9,9 m) w ostatnim dziesięcioleciu. W rozwoju fitoplanktonu jeziora Niegocin obserwowano dwa maksima: wiosenne i letnie. W okresie wiosennym od lat struktura fitoplanktonu nie ulegała zmianom. Dominującą grupą glonów w strukturze fitoplanktonu były okrzemki (rys. 3, tab. 3, 4). Najwyższą średnią biomasę okrzemki tworzyły w kwietniu (około 7,0 mg·dm^{-3}), gdy koncentracje fosforu i azotu mineralnego były najwyższe (rys. 3, tab. 1). Zmniejszającym się koncentracjom fosforu i azotu towarzyszył spadek biomasy ogólnej fitoplanktonu (tab. 1, rys. 2).

W porównaniu z wcześniejszymi badaniami przeprowadzonymi w jeziorze Niegocin w latach siedemdziesiątych (Bernatowicz i in. 1974, Spodniewska 1978, 1979, materiały własne nie publikowane), w okresie stagnacji letniej nie stwierdzono zwiększania się biomasy ogólnej fitoplanktonu. Utrzymywanie się średniej biomasy ogólnej fitoplanktonu od szeregu lat na podobnym poziomie (średnio około 6,0 mg·dm^{-3}) świadczy o stabilnej strukturze fitoplanktonowej, charakterystycznej dla zbiorników silnie zeutrofizowanych i zanieczyszczonych.

Adres Autora:

Mgr inż. Wanda Krzywosz
Instytut Rybactwa Śródlądowego
Pracownia Rybactwa Jeziorowego
11-500 Giżycko
ul. Rajska 2