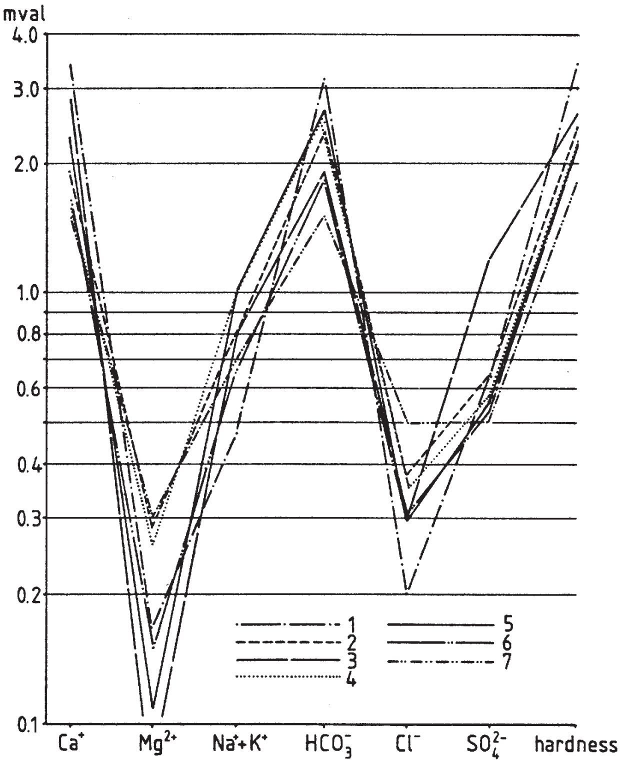

Fig. 3.12. Ionic composition of the surficial water. 1 – Ruda upstream of Lake Wierzchoń, 2 – outlet to Lake Gościąż, 3 – source area of Ruda stream, 4 – Lake Mielec, 5 – Lake Gościąż, 6 – Ruda downstream of Lake Mielec, 7 – Lake Wierzchoń.

impossible. The underwater plants covered with carbonate crust, die out in the beginning of June. Strong reducing conditions, usually with H_2S, occurring within shoals and beaches favour stabilization of numerous chemical elements (in the form of sulphides) brought here with the groundwaters. Some of these elements, e.g. Mn and Fe, after oxidation change into hydroxides. Beyond the littoral zone, in Lake Mielec the deposits are of carbonate facies, while in Lake Gościąż the deposits of sulphide-carbonate facies are accumulated (Wicik 1993). Waters of the lakes and the Ruda stream linking these lakes have strong affinity to groundwaters (Fig. 3.12). They are slightly hard, calcium bicarbonate waters. The stream waters at the inlet to Lake Wierzchoń contain more Ca and HCO_3 ions than waters being in contact with aeration zone in its source area. In lakes Wierzchoń and Brzózka the waters of the Ruda stream lose 20 mg Ca/dm^3 and ca. 70 mg HCO_3/dm^3. At the entrance to the Tobyłka Bay the total content of the main ions in the stream waters decreases by ca. 85 mg/dm^3.

In lakes Gościąż and Mielec, further transformation of chemical properties of the waters of the stream as well as of the springs takes place, and ca. 2 km downstream of the outlet from Lake Mielec the Ruda waters are poorer in Ca and sulphate ions but enriched in HCO_3 ions when compared to the stage at the inflow to the lakes.

3.5. HYDROBIOLOGICAL CHARACTERISTICS AND MODERN SEDIMENTATION OF LAKE GOŚCIĄŻ

Andrzej Giziński, Andrzej Kentzer, Tomasz Mieszczankin, Janusz Żbikowski & Roman Żytkowicz†[*]

The discovery of laminated sediments in Lake Gościąż has initiated interdisciplinary studies of the lake and its surroundings, including palaeoecology and ecology (Ralska-Jasiewiczowa 1993). The varved sediments contain a specific chronological record of environmental changes during ca. 13,000 years. Such a record cannot be read without profound knowledge of the modern structures and functions of the lake ecosystem, in particular the phenomena and processes determining the formation of lacustrine sediments. Sedimentation in lakes responds to external and internal forcing (Sly 1976). Giziński et al. (1992) demonstrated that the functioning of particular lake ecosystems, even in lakes of the same limnological type, appeared to be very different. The “individuality” of lakes shows that the common hydrobiological information is not sufficient for dependable description of the specific ecological situation of lakes at any given time and place.

The investigations, which have been carried out since 1988, aimed at hydrobiological recognition of the structures and functions of the Lake Gościąż ecosystem. The palaeoecological character of the whole program dictated that the main attention be given to modern sedimentation, i. e. to phenomena and processes influencing the character of sediments and lamination. Within these processes both resuspension and redeposition have not been well studied. The importance of sediment transportation and translocation was already emphasized by Żytkowicz (1982, 1989). A rapid development of interest in resuspension and its function both in the ecosystem and in the formation of laminated sediments has been observed in recent years (Wiśniewski 1995).

3.5.1. HYDROBIOLOGY

In studies of abiotic parameters of Lake Gościąż much emphasis was put on studying:

1. The effect of water dynamics on the thermal and oxygen regime.

2. The budget of the most important biogens (nitrogen and phosphorus). Such investigations are the expression of the holistic approach to the lake ecosystem as the dynamic structure. It is likely to be the most reliable source

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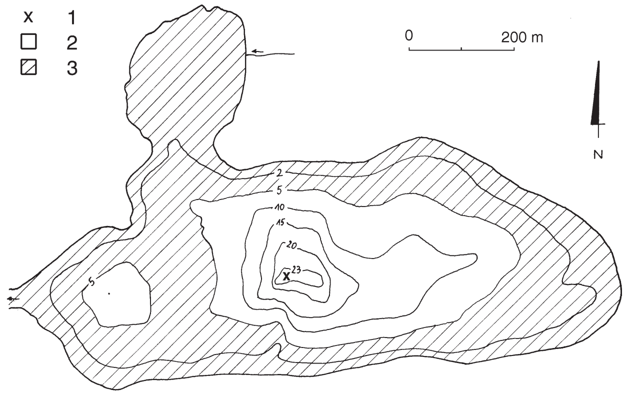

Fig. 3.13. Bathymetry of Lake Gościąż and the division of lake basin into two parts. 1 – sampling station, 2 – the zone of accumulation, 3 – the zone of resuspension (ca. 50% of the whole lake area).

of information regarding the efficiency of the ecosystem (Kentzer et al. 1990, Giziński et al. 1991).

3. The chemistry of different phosphorus fractions in lake sediments. In Golterman's (1988) opinion sediments as a "black box" play a crucial role in the understanding of the phosphorus cycle in lakes. Phosphorus is the factor responsible for the trophy of water bodies (Vollenweider 1968). The trophy, in turn, determines intensity of primary production, especially of phytoplankton, one of the principal components of the matter accumulating on the lake bottom.

The lake is surrounded by fresh conifer forest. There were still field crops until ca. the year 1950. The lake is fed by groundwater (ca. 90% of inflow). The Ruda stream supplies only 10% of inflow (Gierszewski 1993, Chapter 3.3). The groundwater discharges in springs near the shore line on the southern side of the lake. The phytolittoral zone is poorly developed (Kępczyński & Noryśkiewicz, Chapter 3.7). Among emergent plants *Typha angustifolia* and *Phragmites australis* predominate. Submergent plants are mainly represented by *Potamogeton filiformis*, *P. praelongus*, and *P. perfoliatus*. The lake surroundings are used for recreation, mainly by anglers. Due to the situation of the lake within the Landscape Park the touristic pressure has recently diminished.

Table 3.4. Some morphometric parameters of Lake Gościąż.

Area	41.7 ha
Volume	2073 tys. m^3
Maximum depth	24 m
Mean depth	4.97 m
Maximum length	1.168 km
Maximum width	0.735 km
Depth of the epilimnion[1)]	4.3 m
Index of mixing (I_m)[2)]	0.87
Slope factor ($\overline{\alpha}_p$)[3)]	12.5%

[1)] Depth of the epilimnion (in metres) = $4.4\sqrt{D}$,
where D = effective fetch (in kilometres) (after Patalas 1960)

[2)] I_m (Index of mixing) = $\frac{4.4\sqrt{D}}{\text{mean depth}}$ (after Giziński 1974)

[3)] For definition of $\overline{\alpha}_p$ see Håkansson & Jansson (1983: 195)

An accurate description of Lake Gościąż and its drainage basin have been presented in previous chapters.

Following Wetzel & Likens (1990) the morphological parameters are essential for assessing the thermal stability, biological productivity, and many other structural and functional constituents of the lake ecosystem. Giziński (1978) stressed the morphological features of the lake basins that determined water dynamics. They affect the oxygen regime and particularly the disturbance of the near-bottom oxymicrostratification. In Lake Gościąż (Fig. 3.13, Tab. 3.4) the real thickness of epilimnion (5.4 m) is bigger than that calculated according to Patalas (1960) formula (4.3 m). Thus the water dynamics is higher than expected, probably due to western winds frequently blowing along the axis of the lake. Also, a very large difference between the maximum and mean depth suggests a distinct division of the lake basin into two parts:

– the shallow part (5–6 m), featured by the flat bottom and high water mass dynamics;

– the deep one, with high steep slopes and "stagnant" water.

In the shallow part one would expect good oxygen conditions, and in the deep part poor conditions. The shallow part is the zone of resuspension, and the deep part is the zone of accumulation.

The particularly steep slope occurring in the deep part of the lake basin is an uncommon feature in Polish lakes, which usually reveal a steeper slope in the sublittoral and a rather flat profundal zone.

Physical and chemical parameters of water

During the summer a distinct thermal stratification was observed. The temperature gradient was high, reaching 4°C per 1 m. So the thermocline effectively separated surficial, warm, frequently mixed water layer from the deeper, less moving, and much colder one. Strong winds can generate an intensive mixing and lowering of the thermocline. On the other hand, lack of winds and warm weather can initiate the formation of a new shallow thermocline. Such a situation could have been observed in Lake Gościąż on August 4, 1994. The basic thermocline existed at the depth of 6 to 9 m, and the new additional one at a depth of 2 to 5 m (Fig. 3.14). Another anomaly was the displacement of the thermal stratification produced by appreciable sudden inflows of groundwater in the eastern part of the lake (Churski et al. 1993, and Chapter 3.3).

Parallel to the thermocline, the oxycline was also

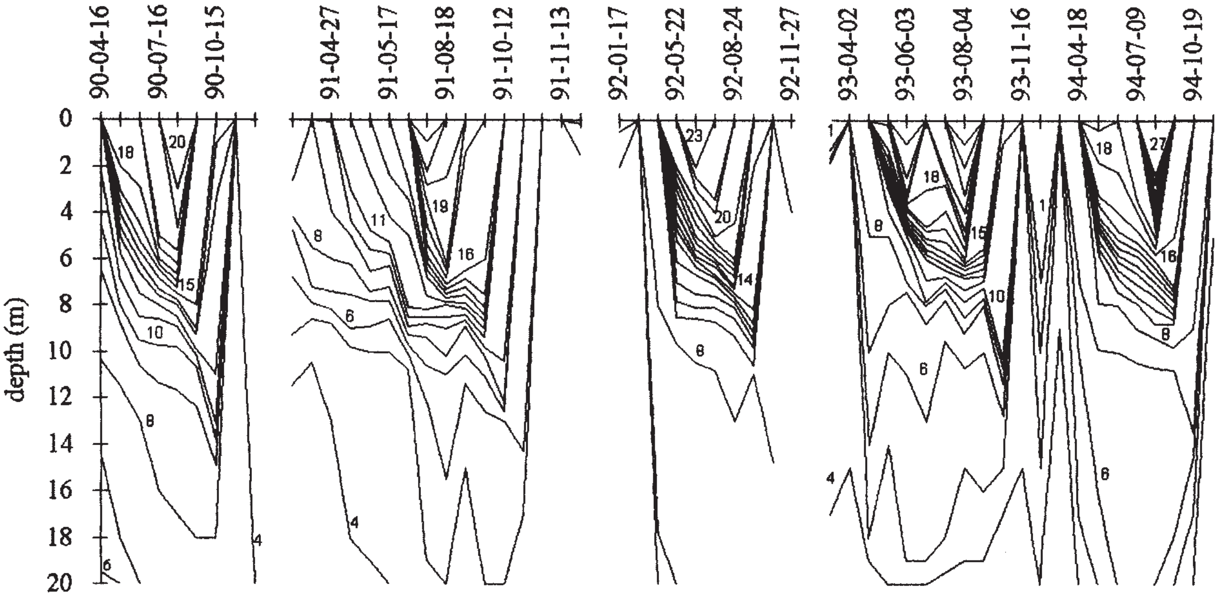

Fig. 3.14. Distribution of tempetrature (in °C) with depth and time in Lake Gościąż (measurements performed by Churski, Marszelewski & Mieszczankin).

formed. This resulted from condensation and decomposition of settling seston particles in the metalimnion. The oxygen concentrations in the hypolimnion decreased to zero at the end of the summer. That is a typical feature of eutrophic lakes. The oxygen conditions strongly influenced the zooplankton and the distribution of bottom fauna in Lake Gościąż.

An average Secchi disc visibility (SD) reached ca. 2 m (range – 1.2 to 4.2 m). Kudełko (unpubl.), using this parameter, obtained a trophic state index ($TSI_{(SD)}$), according to the Carlson (1977) formula:

$$TSI_{SD} = 10(6 - \frac{\ln SD}{\ln 2})$$

where SD is in meters. TSI_{SD} assumes values from 0 to 100; 0–42 means oligotrophy, 43–55 mesotrophy and 56–100 eutrophy. TSI_{SD} for Lake Gościąż was 53, i. e. it appeared rather mesotrophic. Other trophic parameters (see below) clearly demonstrated an eutrophic character of the lake. Thus in this case the Carlson index was not very helpful.

Hydrochemical studies have shown that Lake Gościąż is highly eutrophic. The mean total phosphorus (P_{tot}) was 0.524 mg/dm^3, and organic nitrogen (N_{org}) was 7.241 mg/dm^3. The N:P ratio (14:1) was typical for eutrophic lakes. The dominant form of mineral nitrogen was ammonium ($N\text{-}NH_4$), with a mean concentration of 0.432 mg/dm^3, whereas mean concentrations of nitrate ($N\text{-}NO_3$) and nitrite nitrogen ($N\text{-}NO_2$) were respectively 0.038 and 0.012 mg/dm^3 (Tab. 3.5). The concentration of compounds in the lake water did not differ from that recorded in other highly eutrophic lakes (Golachowska 1971, Giziński et al. 1991). Likewise, high concentration of the compounds in the groundwater was similar to that in the lake itself (Tab. 3.5).

The nutrient loading originating from the drainage basin was very high (3.5 g P/m^{2}year, 40 g N/m^{2}year in 1991–92, and 2.9 g P/m^{2}year, 42.5 g N/m^{2}year in 1992–93). Such a load exceeded the level regarded as dangerous (Vollenweider 1968). It should be stated that in the years 1991–1994 the nutrient concentration in the lakes, especially of phosphorus, systematically diminished. Mean annual P_{tot} concentrations (mg/dm^3) in the following years were: 1991/92 – 0.600; 1992/93 – 0.499; 1993/94 – 0.205.

On the basis of results of hydrochemical investigations in the two following years (1991/92 and 1992/93), the budget was made for the two major nutrients (phosphorus and nitrogen, Tab. 3.6). The accumulation of these elements in the lake was estimated with respect to differences between their "import" and "export". In the first year of examinations, the accumulation of P was 575 kg (35% of an annual import), and of N 1484 kg (11%). Nutrient accumulations were similar to those noted in the efficiently functioning ecosystem of the eutrophic Lake Partęczyny Wielkie (Kentzer et al. 1990). It can be concluded that the nutrient-balance calculations revealed hydrochemical stability for Lake Gościąż and the high efficiency of its self-regulatory mechanisms.

The stability of phosphorus deposition in the bottom sediments depends on the chemical character of phosphorus binding (fractions). A mobile fraction NaOH-P (P bound to aluminium and organic matter) constituted ca. 80% of P_{tot}. An appreciable contribution of this fraction corresponds to potential intensity of P exchange at the water-mud interface. More detailed hydrochemical ana-

Table 3.5. The chemical composition of water in Lake Gościąż in its surficial inflow and in the groundwaters (mg/dm^3) – 1991/1993. x – mean values, r – range.

		Lake*) water	Ground water	Surficial inflow	Surficial outflow
P_{tot}	x	0.524	0.474	0.355	0.430
	r	0.070–1.380	0.115–1.430	0.050–1.032	0.060–1.040
$P–PO_4$	x	0.133	0.179	0.156	0.068
	r	0.015–0.310	0.060–0.438	0.015–0.590	0.013–0.235
N_{org}	x	7.241	6.786	5.650	7.092
	r	1.800–13.050	1.900–16.000	1.900–11.690	1.800–13.050
$N–NH_4$	x	0.432	0.148	0.222	0.225
	r	0.000–1.300	0.000–0.466	0.000–0.413	0.000–0.536
$N–NO_3$	x	0.038	0.065	0.050	0.042
	r	0.000–0.111	0.011–0.155	0.011–0.190	0.000–0.152
$N–NO_2$	x	0.012	0.021	0.014	0.009
	r	0.000–0.045	0.001–0.049	0.001–0.080	0.000–0.019
Ca^{2+}	x	44.1	49.3	41.9	43.6
	r	32.2–58.1	38.1–60.0	20.1–68.0	39.7–54.5
Mg^{2+}	x	11.7	9.8	10.7	11.2
	r	3.2–21.6	4.0–18.4	4.8–19.2	3.2–17.6
Cl^-	x	15.1	20.0	16.1	14.5
	r	7.2–24.9	10.1–29.5	7.2–24.5	7.2–22.3

*) the mean values for the whole column of water; usually concentrations were higher near the bottom

Table 3.6. The phosphorus (P_{tot}) and nitrogen (N_{tot}) budget in Lake Gościąż for 2 years (1991/92 and 1992/93).

	Years	Input, kg	Output, kg	Accumulation in the lake	
				Kg	% of input
P_{tot}	1991/92	1573	998	575	36%
	1992/93	1340	998	342	25%
N_{tot}	1991/92	18017	16533	1484	8%
	1992/93	19162	17078	2048	11%

lyses (Kentzer 1995) have proved that the real exchange intensity between water and sediment was not so high. It was estimated that the phosphorus particles are recycled at the water-mud interface 3–4 times before the definitive burial in the sediment or leaving the lake with outflowing water.

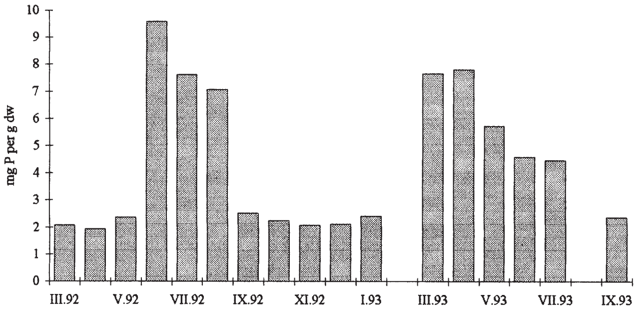

Fig. 3.15. Changes of P_{tot} concentrations (mg/g dry weight) in sediments of Lake Gościąż, from March 1992 to September 1993 (after Kentzer 1995).

Changes of P concentration in the surface layer of sediments had a cyclic character (Fig. 3.15). Kentzer (1995) presented the alternating occurrence of two periods. The first is spring-summer season with the high P_{tot} concentration, when the P deposition prevented its release. In autumn-winter, P release predominated over deposition (low P concentration in sediments).

The phosphorus accumulation in the lake was the result of the character and the quantity of sedimenting material as well as the processes occurring in the sediments.

Phytoplankton

Phytoplankton of Lake Gościąż has only been identified during the vegetation season of the year 1993 (Kudełko 1994). In the phytoplankton under study 268 taxa were identified in the Cyanophyta, Dinophyta, Chrysophyceae, Bacillariophyceae, Chlorophyta, Cryptophyceae, Xantophyceae, and Euglenophyta. The largest assemblage of species was reported in April (142 taxa) and

Table 3.7. The list of the most important (over 80% of stability) and some rare phytoplankton species in Lake Gościąż (from Kudełko 1994).

Important phytoplankton taxa

CYANOPHYTA
Microcystis aeruginosa Kütz.
Microcystis wesenbergii Kom.
Gleocapsa limnetica (Lemm.) Holl.
Gleocapsa minima (Keiss.) Holl.
Woronichinia naegeliana (Unger) Elenk.
Phormidium mucicola Hub.-Pest. et Neum.
Phormidium tenue (Ag. et Gom.) comb. Agan et Kom.
Anabaena flos-aquae Breb. ex Born. et Flah.

DINOPHYTA
Ceratium hirundinella (O.F.Müll.) Bergh.
Peridinium cinctum (O.F.Müll.) Ehr.

CHRYSOPHYCEAE
Dinobryon divergenes Imhof

BACILLARIOPHYCEAE
Aulacoseira granulata (Ehr.) Simonsen
Cyclotella meneghiniana Kütz.
Cyclotella atomus Hust.
Cyclotella bodanica Grun. in Shneid.
Stephanodiscus alpinus Hust. in Huber-Pestall.
Stephanodiscus hantzschii Grun. (in Cleve et Grun.)
Diatoma tenuis Agardh
Asterionella formosa Hass.
Fragillaria crotonensis Kitton
Fragillaria reicheltii (Voigt) Lange-Bert.
Fragillaria ulna (Nitzsch) Lange-Bert.
Fragillaria pinnata Ehr. var. *pinnata*
Fragillaria brevistriata Grun in Van Heurck
Navicula cari Ehr.
Navicula schoenfeldii Hust.
Gyrosigma attenuatum (Kütz.) Rabenh.
Cymbella silesiaca Bleish. in Rabenh.
Amphora inariensis Kramm.

CHLOROPHYTA
Phacotus lenticularis (Ehr.) Stein
Eudorina elegans Ehr.
Pediastrum boryanum (Turp.) Menegh
Pediastrum duplex Meyen
Oocystis lacustris Chod.
Monoraphidium subclavatum Nyg.
Coelastrum microporum Nag. in A.Br.
Staurastrum pseudopelagicum W. et G.S. West

Rare phytoplankton taxa

CRYPTOPHYCEAE
Cryptomonas marssonii Skuja

XANTOPHYCEAE
Characiopsis sp.

EUGLENOPHYTA
Trachelomonas sp.
Colacium vesiculosum f. *arbuscula* (Stein) Huber-Pest.

in June (144 taxa), the smallest in July (64) and in August (62). The dominant group were diatoms (158 taxa), green algae (66 taxa) and blue-green algae (23 taxa). The list of species reaching over 80% stability is given in Table 3.7. Besides these widespread species two species rarely reported in Poland were found: *Surirella suecica* Grun. in Van Heurck and *Oestrupia zachariassi* (Reich.) Hust.

The mean phytoplankton biomass was 1.35 mg/dm^3 (range 0.18–3.11 mg/dm^3). Diatoms predominated and constituted about 41% of total biomass. The highest phytoplankton biomass was observed in the summer (up to 3.11 mg fresh weight per dm^3 in July, Tab. 3.8). The lowest biomass was recorded in November (0.182 mg/dm^3), but species diversity at that time was very high (127).

Based on species composition, Lake Gościąż can be classified as a eutrophic lake, whereas based on the mean biomass it is mesotrophic.

Phytoplankton examinations have demonstrated a cyclic occurrence of species in the lake. Seasonal type of fluctuations was also observed in the youngest part of sediments (Goslar 1993). Obviously, phytoplankton living or dead settles down. In Table 3.9 diatom taxa noted in the water and in the sediments were set together. Occurrence at the same time of some species in the water and in the sediment does not have to be a rule. Such a situation resulted from either the annual changes of phytoplankton development or resedimentation of previously resuspended sediments.

Zooplankton

The preliminary results of studies on the zooplankton of Lake Gościąż were published by Błędzki (1993) and they are summarized below.

In the pelagic and the littoral zones 14 taxa of Rotatoria, 21 taxa of Cladocera, and 7 taxa of Copepoda (Tab. 3.10) have been found. The number of Rotatoria ranged from 66 to 269 ind/dm^3 (mean – 170 ind/dm^3) and the number of Crustaceae ranged from 19 to 177 ind/dm^3 (mean – 118 ind/dm^3). The number of reported taxa in Lake Gościąż (42) was high compared to that in other lakes of northern Poland (the average 32, Giziński et. al. 1992). The vertical distribution of zooplankton in the

Table 3.8. Biomass of the dominant phytoplankton taxa (mg/dm^3) in Lake Gościąż in 1993 (from Kudełko 1994). (+) taxa with the minimum biomass.

Taxon	20.04	23.05	19.06	16.07	10.08	03.09	24.09	10.11
CYANOPHYTA								
Microcystis aeruginosa Kütz.	+	0.008	+	0.006	0.008	0.024	+	+
M.wesenbergii Kom.	+	0.015	+	0.078	0.004	+	+	+
Gleocapsa limnetica (Lemm.) Holl.	+	+	+	0.005	0.052	0.022	+	+
Woronichinia naegelina (Unger) Elenk.	+	0.221	+	+	+	+	+	0.005
Phormidium tenue (Ag.et Gom.) comb. Agan et. Kom.	+	0.063	+	0.103	0.225	0.667	0.321	+
Aphanizomenon flos-aquae (L.) Ralfs			+	0.002	0.02	0.044	+	
Anabaena flos-aquae Breb. ex Born. et Flah.		0.038	+	0.134	0.53	0.347	0.016	0.001
DINOPHYCEAE								
Ceratium hirundinella (O.F.Müll.) Bergh.	0.029	0.073	+	1.969	0.006	0.017	0.176	+
BACILLARIOPHYCEAE								
Cyclotella bodanica Grun. in Shneid.	0.097	0.128	+	0.008	0.147	0.016	0.1	0.017
Stephanodiscus hantzschii Grun. (in Cleve et Grun.)	0.316	0.005	+	0.002	0.013	0.006	0.03	0.014
Asterionella formosa Hass.	0.003	0.002	+	0.215	0.418	0.035	0.045	0.008
Fragilaria crotonensis Kitton	0.103	0.009	+	0.17	0.341	0.254	0.17	0.007
Fragilaria reicheltii (Voigt) Lange-Bert.	0.003	+	+	0.365	0.385	0.107	0.075	0.003
Fragilaria ulna (Nitzsch) Lange-Bert.	0.038	0.002	+	0.006	0.241	0.096	0.137	0.006
CHLOROPHYTA								
Pediastrum boryanum (Turp.) Menegh.	0.087	0.021	+	+	0.167	+	+	0.02
Biomass of specificated taxa	0.676	0.585		3.063	2.557	1.635	1.07	0.075
Total biomass of phytoplankton	0.795	0.868		3.114	2.792	1.773	1.285	0.182

summer (Tab. 3.11) differed significantly for different strata due to oxygen depletion. Considering the small area and the low diversity of littoral zone, zooplankton of that area did not play an important role in the functioning of the lake ecosystem.

A substantial element of zooplankton in Lake Gościąż were the “effective filtrators” (Gliwicz 1977). In periods of maximal productivity their contribution to the total lake zooplankton biomass was ca. 80% (Tab. 3.12). The rich assemblages of “effective filtrators” limiting the phytoplankton development were related to the high efficiency of the functioning of the ecosystem. The pelagic mechanisms of the lake functioning were also very efficient.

Zoobenthos

The benthic fauna of Lake Gościąż was studied by Żbikowski (1993, 1995). In this chapter the summary of his investigations is presented.

The taxonomic composition and distribution of zoobenthos in Lake Gościąż were typical for highly eutrophic lakes (Tables 3.13 and 3.14). The taxonomic diversity and abundance of the majority of bottom fauna groups (except Chaoboridae and Ceratopogonidae larvae) were the highest in the littoral zone and clearly decreased with depth.

Larvae of 23 Chironomidae taxa were noted in the littoral part of the lake, with the dominance of *Pseudochironomus* e.g. *prasinatus* and *Cladotanytarsus* e.g. *man-*

Table 3.9. Seasonal changes of selected species of phytoplankton found in water (from Kudełko 1994) and in the youngest part of the Lake Gościąż laminated sediments (from Goslar 1993).

	Spring	Summer	Autumn
Water (1993)	*Stephanodiscus hantzschii*	*Aulacoseira* spp. (= *Melosira* spp.) *Asterionella formosa* *Fragilaria crotonensis* *Fragilaria ulna* (= *Synedra ulna*)	*Fragilaria crotonensis* *Fragilaria ulna* (= *Synedra ulna*)
Sediments (ca. 1870–1960)	*Stephanodiscus hantzschii* *Asterionella formosa* *Asterionella* f. var. *gracillima*	*Fragilaria crotonensis* *Synedra acus* (= *Fragilaria ulna* var. *acus*)	*Melosira* ssp. (= *Aulacoseira* spp.)

Table 3.10. The list of species of zooplankton in Lake Gościąż (from Błędzki 1993).

ROTATORIA

Asplanchna priodonta Gosse
Brachionus angularis Gosse
Conochilus hippocrepis Ehrenberg
Filinia longiseta (Ehrb.)
Kellicottia longispina Kell
Karatella cochlearis cochlearis Gosse
Karatella cochlearis tecta Gosse
Karatella quadrata (O.F.Müller)
Polyarthra dolichoptera (Jol.)
Polyarthra euryptera (Wierz.)
Polyarthra vulgaris (Carl.)
Synchaeta pectinata (Ehrb.)
Trichocerca birostris (Minkiewicza)
Trichocerca similis (Wierz.)

CLADOCERA

Acroperus harpae (Baird)
Alona affinis[*] (Leydig)
Alona quadrangula[*] (O.F.M.)
Alonella nana[*] (Baird)
Bosmina coregoni (Baird)
Bosmina longirostris (O.F.M.)
Bosmina longispina (Leydig)
Camptocercus sp.[*] (O.F.M.)
Ceriodaphnia pulchella (G.O. Sars)
Ceriodaphnia quadrangula (O.F.M.)
Chydorus sphaericus (O.F.M.)
Diaphanosoma brachyurum (Liév.)
Daphnia cucullata Sars
Daphnia longispina (O.F.M.)
Disparalona rostrata (Koch.)
Eurycercus lamellatus[*] (O.F.M.)
Graptoleberis testudinaria[*] (Fisher)
Leptodora kindti (Foche)
Pleuroxus aduncus[*](Jurine)
Pleuroxus uncinatus[*] (Baird)
Peracantha truncata[*] (O.F.M.)

COPEPODA

Cyclops kolensis Lillj.
Cyclops vicinus Uljamn
Eucyclops serulatus (Fisher)
Mesocyclops leuckarti (Claus)
Thermocyclops oithonoides (Sars)
Eudiaptomus gracilis (Sars)
Eudiaptomus graciloides (Lillj.)

[*] recorded only in surficial layer of lake sediments

Table 3.11. The vertical distribution of zooplankton in Lake Gościąż (Błędzki 1993). N – ind/dm^3; B – µg/dm^3 dry weight.

	Epilimnion		Metalimnion		Hypolimnion		0.5m above the bottom	
	N	B	N	B	N	B	N	B
Rotatoria	175	61	70	4	65	5	6	1
Crustacea	325	1168	200	397	85	192	25	41
Total zooplankton	500	1229	270	401	150	197	31	42

cus. Mollusca were noted only in the littoral zone. This group was represented by *Pisidium* sp. (the most numerous genus), *Dreissena polymorpha, Valvata naticina,* and *Lymnaea peregra*. The Chironomidae larvae were the most numerous (44% of all zoobenthos and nearly 2 times more than Oligochaeta – 27%). Larvae of midges predominated also in biomass of all zoobenthos (excl. Mollusca) (32%).

In the sublittoral zone, in comparison with the littoral zone, a significantly lower taxonomic diversity was

Table 3.12. The contribution (% of biomass) of the effective filtrators in the total of zooplankton of Lake Gościąż (Błędzki 1993).

Month	IV		VIII		XI	
	Crustacea	total zoopl.	Crustacea	total zoopl.	Crustacea	total zoopl.
Epilimnion	18	14	80	78	80	73
Meta- and hypolimnion	29	12	79	69	74	74

Table 3.13. The taxonomic composition and the number of chironomids larvae (ind/m^2) in the particular zones of Lake Gościąż. Mean values of five study years (1988–92). L – littoral, S – sublittoral, UP – upper profundal, LP – lower profundal.

Chironomidae	L	S	UP	LP
Procladius spp.	38	79	13	9
Chironomus f.l. *plumosus* L.	–	51	35	–
Cryptochironomus sp.	116	2	–	–
Cladotanytarsus sp.	480	1	–	–
Pseudochironomus prasinatus Staeg.	763	–	–	–
Tanytarsus sp.	453	–	–	–
Microtendipes e.g. *chloris* Mg.	212	–	–	–
Polypedilum e.g. *nubeculosum* Meig.	198	–	–	–
Tanypus kraatzi Kieff.	40	6	–	–
Tanypus vilipennis Kieff.	10	7	–	–
Endochironomus e.g. *dispar* Mg.	77	–	–	–
Endochironomus e.g. *tendens.* F.	46	–	–	–
Glyptopendipes e.g. *gripecoveni* Kieff.	50	–	–	–
Chironomus f.l. *semireductus* Lenz	–	10	1	–
Polypedilum e.g. *convictum* Walk.	13	–	1	–
Polypedilum e.g. *bicrenatum* Schr.	15	–	–	–
Strictichironomus psammophilus Tshern.	15	–	–	–
Cladopelma sp.	–	9	1	–
Ablabesmyia sp.	13	–	–	—
Dicrotendipes tritomus Kieff.	10	–	–	–
Dicrotendipes e.g. *nervosus* Staeg.	10	–	–	–
Cladopelma viridula	10	–	–	–
Cricotopus latidentatus Tshern.	10	–	–	–
Chironomus f.l. anthracinus Zett.	10	–	–	–
Demicryptochironomus sp.	7	–	–	–
Einfeldia e.g. *carbonaria* Mg.	–	8	–	–
Cryptochironomus e.g. *pararostratus* Lenz.	–	–	–	2
Microchironomus sp.	–	1	–	–
Chironomidae – X[*]	7	–	–	–
Chironomidae n.d.	47	–	–	–
Chironomidae “pupae”	38	1	1	–

[*] unidentified forms of chironomids, different from the mentioned above

found (Tab. 3.14). The number of Chironomidae is 15 times lower, and Oligochaeta nearly 7 times lower. In the extralittoral zone of the lake Oligochaeta were represented only by *Potamothrix hammoniensis*. No Ephemeroptera or Mollusca were found. The taxonomic composition of Chironomidae larvae was typical for eutrophic lakes. Ceratopogonidae larvae were the most frequent in the sublittoral zone, and the Chaoboridae larvae were found there. They would have been more characteristic of the deep profundal zone. Oligochaeta were more numerous than Chironomidae, but Chironomidae had higher biomass than Oligochaeta.

In the upper profundal zone, the bottom fauna was still poorer (in quality and in number) except Chaoboridae larvae, which were dominant in this zone – 1175 ind/m^2. They constituted 87% of individuals and 73% of biomass of all the bottom fauna. Large *Chironomus plumosus* was frequently found among Chironomidae. Ceratopogonidae larvae were rare.

In the lower profundal zone Chaoboridae still dominated. The rest of the bottom fauna was represented only by a few Oligochaeta and Chironomidae. The most important forms among Chironomidae larvae were predators, but not any specific forms were recorded for that zone.

In the whole extralittoral zone (i.e. sublittoral, upper and lower profundal) of the lake, the highest abundance of macrozoobenthos was observed during spring and autumn circulation, and the lowest one during the summer stratification. It is argued that the abundance of zoobenthos in the lake was limited mainly by oxygen deficiency. The eubenthos (fauna living in the surface of the bottom sediment) was not abundant enough (below 0,5 g/m^2) to have any influence on the formation and the

Table 3.14. Number of individuals (N, ind/m^2), number of taxa (NT) and biomass (B, g/m^2) of the bottom fauna in Lake Gościąż, in particular zones; values from 1988–1992 years. $\bar{x}$ – mean, min. – minimum, max. – maximum, BwM – biomass without Mollusca (g/m^2).

Taxa		Littoral			Sublittoral			Upper profundal			Lower profundal		
		$\bar{x}$	min.	max.	$\bar{x}$	min.	max.	$\bar{x}$	min.	max.	$\bar{x}$	min.	max.
Chironomidae	NT	23*	3	9	10*	1	7	5*	–	3	2*	–	2
	N	2688	739	6401	175	26	487	52	–	154	11	–	52
	B	488	2.1	18.7	2.15	0.11	10.5	1.32	–	4.52	0.02	–	0.15
Oligochaeta	N	1554	337	2736	239	46	1077	119	–	303	36	–	103
	B	136	0.54	3.33	0.85	0.02	4.5	0.26	–	0.7	0.1	–	0.53
Chaoboridae	N	–	–	–	385	–	3402	1175	51	7169	4213	51	16897
	B	–	–	–	1.51	–	11.33	4.36	0.2	28.01	14.19	033	65.94
Ceratopogonidae	N	165	–	755	340	26	1026	5	–	26	–	–	–
	B	–	–	–	0.67	0.05	1.15	0.01	–	0.05	–	–	–
Ephemeroptera	N	957	–	2075	–	–	–	–	–	–	–	–	–
	B	–	–	–	–	–	–	–	–	–	–	–	–
Mollusca	N	448	–	2075	–	–	–	–	–	–	–	–	–
	B	22.76	–	43.36	–	–	–	–	–	–	–	–	–
Total zoobentos	N	5812	1479	9434	1139	359	3813	1351	205	7238	4260	154	16975
	B	37.9	4.09	6266	518	1.24	15.89	5.95	0.88	28.07	14.31	0.6	65.98
	BwM	15.14	3.04	36.56	518	1.24	15.89	5.95	0.88	28.07	14.31	0.6	65.98
Dominant taxa among Chironomidae (%)		*Pseudochironomus prasinatus*		29	*Procladius* spp.		45	*Ch. plumosus*		69	*Procladius* spp.		82
		Cladotanytarsus e.g. *mancus*		18	*Chironomus plumosus*		29	*Procladius* spp.		25	*Cryptochironomus* e.g. *pararostratus*		18

* – sum of taxa

transformation processes of the bottom sediments, i. e. on disturbance of laminations. The eubenthos should be 200-times more frequent to disturb the lamination effectively.

To recapitulate, the bottom fauna of Lake Gościąż had a rather "predator" character (domination of Chaoboridae, numerous Ceratopogonidae larvae, and the main role of *Procladius* spp. larvae among Chironomidae), which could disturb the biocoenosis balance. Unexpectedly small quantity of eubenthos below the 11 m depth could be a symptom of that disturbance in the deepest part of the lake.

Concluded lake characteristics

Hydrobiologic studies of Lake Gościąż have proved that it is a dimictic, strongly thermally stratified eutrophic lake. The occurrence of the thermocline and oxycline, dictated the distribution of zooplankton and zoobenthos. The lake ecosystem is stable and efficient with relation to: 1) the high diversity of phytoplankton and zooplankton, 2) the high contribution of "effective filtrators" in zooplankton, which could effectively control algal development, 3) the high phosphorus accumulation in the lake sediments (to 35% of the total annual input). The low abundance of benthic fauna found at maximum depth indicated the lack of sediment mixing (bioturbation) and diminished exchange in the water-mud interface.

3.5.2. MODERN SEDIMENTATION

Tomasz Mieszczankin

Modern sedimentation studies qualify the functioning efficiency of water ecosystems and the manner in which sediments are formed. The ecosystem is stable when external inflows do not bring about changes in its biological structures, and the primary sedimentation (net sedimentation) reflects its productivity. Sedimentation is closely related to the parameters controlling the water dynamics, which influences wind/wave action, and it is also related to the morphology of the lake basin (morphological features were discussed previously). In many lakes the sedimentation rate is determined by processes of resuspension, which can play a fundamental role in the palaeoecological aspects of sedimentation in lakes (Davis et al. 1984).

The measurements of sedimentation rate in Lake Gościąż were done in 1991 (Kentzer & Żytkowicz 1993) and 1993–1994. Sedimentation rate was measured by cylinders (10 cm in diameter and 30 cm height) with an aspect ratio (height/diameter) of 3:1 (Blomqvist & Håkansson 1981). Modern sedimentation studies in Lake Gościąż were started by Żytkowicz (1982), who described some details of methodology of investigations elsewhere. Funnel traps with a diameter of 70 cm and a height of 120 cm were used so that material for chemical analyses

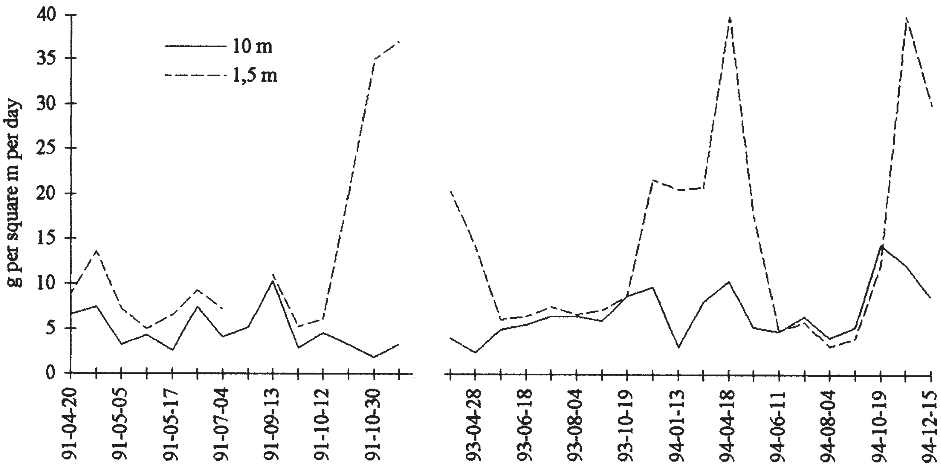

Fig. 3.16. Tripton sedimentation (g/m^{2}d) 1.5 m and 10 m above the bottom in Lake Gościąż in years 1991 and 1993–1994, as measured in traps. Mean values for upper and bottom traps were 5.9 g/m^{2}d and 13.1 g/m^{2}d, respectively.

(also stable-isotope analyses, see Wachniew & Różański, Chapter 3.6) could be obtained quickly and effectively. Sediment traps were deployed at the maximum-depth station (1.5 m), and 10 m above the bottom for 1 to 10 weeks. The collected material was dried under diminished pressure at 20°C. Organic matter was determined as a loss on ignition at 520°C for 3 hours. $CaCO_3$ was estimated through the treatment of ash remaining after combustion with 1 N HCl and titration of Ca^{2+} by 0.01 N EDTA with murexide. The results of calcite estimation were verified by re-combustion at 900°C (Geyh et al. 1971).

In the period of investigation, minimum sedimentation rate was 1.84 g/m^{2}d, and maximum – 40.0 g/m^{2}d (Fig. 3.16). Mean sedimentation rate was 5.9 g/m^{2}d in upper traps and 13.1 g/m^{2}d in bottom traps (Tab. 3.15). Mean annual net sedimentation in upper traps was ca. 2150 g/m^2 and 4780 g/m^2 1.5 m above the bottom. Sedimentation was higher during spring and autumn circulations than during summer stagnations. During periods without ice-cover sedimentation remained high. However, even the short duration of ice-cover in March 1993 and February 1994 caused considerable decrease of accumulation rate respectively to 4.52 and 3.8 g/m^{2}d. In traps exposed for a longer time (Jan. 13 to March 29, 1994) sedimentation was much higher (see Fig. 3.16 and Tab. 3.16). It could be assumed that before freezing over and directly after ice melting the sedimentation rate was very high.

During overturns the sedimentation recorded in upper and bottom traps differs considerably (see high value of b-a in Tab. 3.15).This was probably result of resedimentation. In periods of summer stratification these differences were much smaller, and in 1996 even negative. It seems to be the result of mineralization during settling. The average differences between upper and bottom traps were 13.72 g/m^{2}d during circulation and 0.68 g/m^{2}d in summer.

Sedimentation of $CaCO_3$ was closely correlated with tripton sedimentation. The maximum values occurred during circulation and the minimum in the summer stagnation periods (Fig. 3.17). The lowest concentration of calcite (37%), reported as the weight percent in tripton (not considering ice-cover occurrence), was observed at the moment of the strong thermocline formation (Fig. 3.18). Thereafter there was a slow increase of calcite concentration until it reached its maximum (ca. 56%) at the end of the vegetation season. The contribution of $CaCO_3$ in tripton had declined through the winter to reach its minimum at the end of spring, when the new thermocline was formed.

The composition of tripton under ice in the years 1993 and 1994 was different (Tab. 3.16). In April 1993 after the ice melted, the composition of sedimenting seston

Table 3.15. Mean sedimentation (g/m$^{2}\cdot$d) 10 and 1.5 m above the bottom during circulation (C) and stratification (S) periods in Lake Gościąż.

Depth	1991		1993		1994		Mean		Mean for period 1991–1994
	C	S	C	S	C	S	C	S	
a – 10 m	4.44	5.36	5.35	6.37	8.85	5.15	6.21	5.63	5.90
b – 1.5 m	15.86	7.36	18.72	7.10	25.20	4.47	19.93	6.31	13.12
b–a	11.42	2.00	13.37	0.73	16.35	–0.68	13.72	0.68	7.22

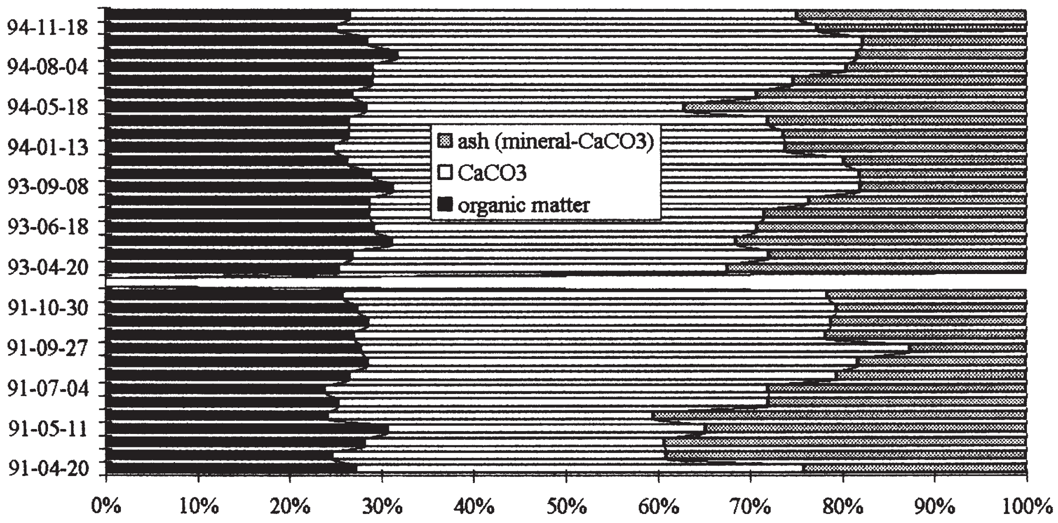

Fig. 3.17. Concentrations of calcite and organic matter (in %) in tripton from Lake Gościąż.

was very similar to that observed a month before, under ice. However, in the year 1994 directly after ice melting, i.e. in March, the tripton composition appeared distinctly different from that in February under ice.

Mean annual sedimentation in Lake Gościąż in the years 1991 and 1993–1994 (3500 g/m^{2}year) was much higher than in other lakes with laminated sediments: 300 g/m^{2}year in meromictic Lake Fayetteville (Brunksill 1969) and 410–550 g/m^{2}year in dimictic Elk Lake (Nuhfer et al. 1993). Such differences could have resulted from the lower trophy of the compared lakes and/or from the high contribution of re-sedimenting matter. Lake Gościąż is a dimictic lake also. The cyclic character of sedimentation in Lake Gościąż in the period of investigation depends on the alternate occurrence of circulation and stagnation periods. During winter without ice-cover tripton sedimentation is also high.

The low sedimentation rate in the summer (Fig. 3.16) depends on the thermocline (Fig. 3.14), which is a natural barrier for the sedimenting matter (Lastein 1976). The increase of tripton flux started from the beginning of the water mixing and extension of the resuspension zone. The considerable difference between upper and bottom traps during mixing periods (Tab. 3.15) demonstrated that resuspension and resedimentation initiated increasing flux of particulate matter. Bottom traps measured net sedimentation plus resedimentation, while traps under the thermocline measured only net sedimentation (Bloesh 1994, Håkansson 1994). During the summer stagnation, when in the lower profundal resuspension was not registered, somewhat higher sedimentation (12%) in bottom traps (Tab. 3.15) should have been connected with the "funnel effect" (Ohle 1962).

The morphology of the lake basin, described earlier, let us distinguish two zones: the shallow one of resuspension and the deep one of accumulation, with a high slope

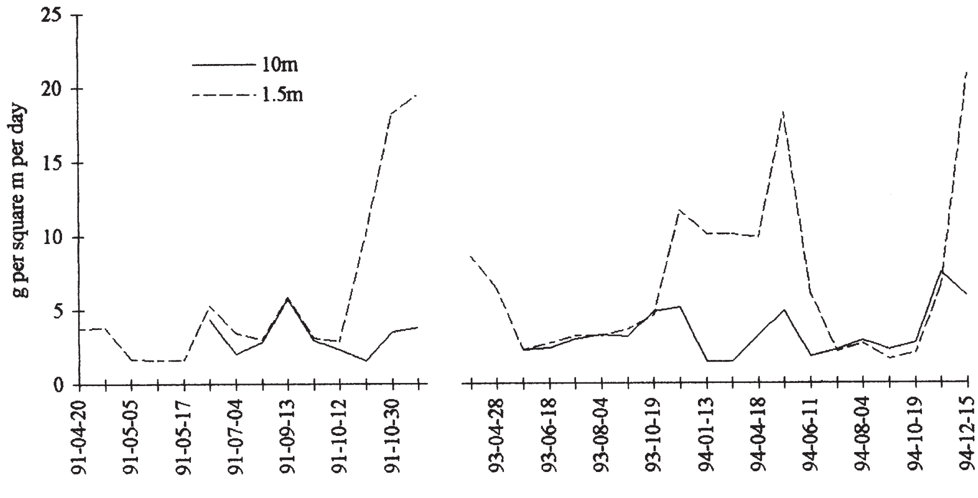

Fig. 3.18. Calcite sedimentation (in g/m^{2}d) 1.5 m and 10 m above the bottom in Lake Gościąż.

Table 3.16. Sedimentation rate (g/m^{2}d) and composition (%) of tripton in Lake Gościąż under ice cover (in March 1993 and February 1994). Funnel-shaped traps were set up 10 and 1.5 m above the bottom; exposure time – 24 h.; (–) lack of data.

Sedimentation of	Depth	11.03.1993	28.02.1994
Tripton	10 m	–	1.09 (100%)
	1.5 m	4.52 (100%)	3.80 (100%)
Organic matter	10 m	–	0.38 (34.6%)
	1.5 m	1.20 (26.5%)	1.39 (36.5%)
Calcite	10 m	–	0.05 (4.9%)
	1.5m	1.82 (40.2%)	0.11 (10.4%)

factor (17.5%), which was a very substantial feature for the processes of sediment transportation and deposition (Håkansson 1977).

A high dynamics of sedimentation during circulation periods clearly showed that the sediment formation in Lake Gościąż depended first on the processes of sediment distribution and focusing. The separation of two parts (Fig. 3.13) facilitated understanding of sedimentation mechanisms in the lake. The shallow part was affected by resuspension practically over the whole year, except for ice-cover periods. Most of the particles recycled back to the water column were mainly deposited in the deep part, in the zone of accumulation. The high depth and the occurrence of the lamination excluded bottom resuspension in the deepest central part of the lake till recent times.

The influence of the shallows on sedimentation is greater where the area of this zone is larger (Håkansson & Jansson 1983). Because in Lake Gościąż the area of the shallows was 50%, occurrence of resuspension seems to be certain. If sedimentation near the bottom (13.1 g/m^{2}d) was twice higher than the amount recorded in upper traps (5.9 g/m^{2}d), in the deep part sediments could have been accumulated from the area twice as large. Also in Elk Lake (Nuhfer et al. 1993) sediment resuspension induced over twice the sedimentation rate, from ca. 500 to 1154 g/m^{2}year.

To disclose the profound effect of the pollen assemblages finally incorporated in sediments, tripton was examined palynologically (Mieszczankin & Noryśkiewicz unpubl.). It was demonstrated that in the central part of Lake Gościąż pollen sedimentation in bottom traps was much higher than in the upper ones. That "excess" had to be a result of redeposition. The more obvious proof was that bottom traps were influenced by the greater portion of resuspended material, like the registrating of maximum pollen assemblages after freeze-up, when suspended particles could have been "calmly" settled (Fig. 3.19). Pollen grains of plant taxa out of their flowering season were also found in tripton. The number of species was much higher in the bottom traps too. Davis (1973) showed that the intensification of pollen se-

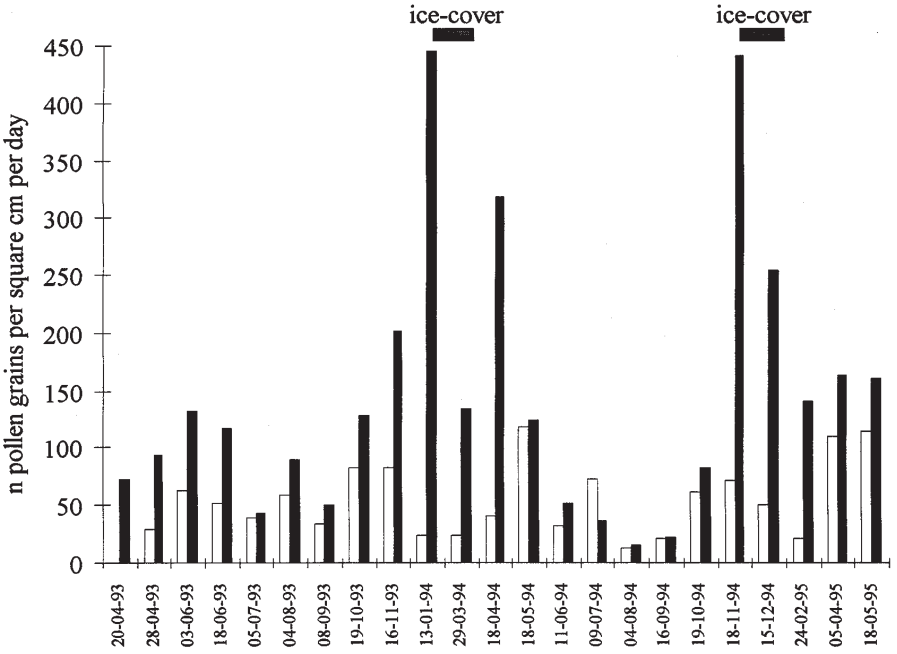

Fig. 3.19. Sedimentation of pollen grains per square centimetre per day 1.5 m (black) and 10 m (white) above the bottom in Lake Gościąż.

dimentation was a result of bottom-sediment resuspension and downward transport, with deposition in the profundal zone.

Apart from wind/wave-induced resuspension Hilton et al. (1986) distinguished other mechanisms related to sediment redistribution (translocation), such as current erosion (turbidity currents) and slumping or sliding on slopes. The occurrence of such events in Lake Gościąż was highly probable due to ground-water inflow (Churski et al. 1993) and high slopes (Tab. 3.4). Neverthless, in the whole 18 m profile of laminated sediment, the occurrence of turbidites was not observed (Goslar, Chapter 6.1, Więckowski et al., Chapter 5.1).

Calcite was the main constituent of tripton in Lake Gościąż. Its maximum sedimentation (Fig. 3.17) and high percentage contribution in seston settling during circulation (Fig. 3.18) was the evidence that sediments deposited in the shallows tend to be carried into deeper areas.

The maximum precipitation of $CaCO_3$ was observed in the middle of summer (Wachniew & Różański, Chapter 3.6). Thus on the whole area of the lake bottom, the layer enriched in calcite should have been created in the summer and the dark one during the cooler periods, when calcite formation was limited. During circulation, sediment deposited in the shallows was resuspended and resedimented downward in the lake basin. The examination confirmed that in the deep parts of the lake the formation of a layer with higher concentration of $CaCO_3$ took place by the end of the thermal stratification and immediately afterwards (compare Fig. 3.14 and 3.17). Seasonal changes of sedimentation would have indicated the formation of laminations. It was also established that ice cover contributed to calm sedimentation, thus conducive to the formation of the specific layer (Tab. 3.16). The lack of ice cover, the extension of time of water mixing, and the high sedimentation rate probably precluded the accumulation of the specific sediment layer in winter, and as a consequence the absence of lamination in such a year. In the last few years persistent ice cover was not observed, but that did not apply in the last 30 years, when Goslar (1993) did not detect laminations. Accordingly, winter with or without ice cover probably was not critical for the disappearance of the varves in Lake Gościąż. It is likely that reasons can be found in the increase of the sedimentation dynamics during circulation periods.

If sediment lamination was not a secondary phenomenon resulting from diagenesis, probably the following reasons apply for the absence of sediment stratification in Lake Gościąż:

1) Disturbances of periodicity in those processes favourable for sediment lamination.

2) Intensification of resuspension and redeposition. The resuspension and the homogenization of sediment layers diminished the differentiation of the resedimenting material.

Water dynamics and sediment resuspension

Morphological and hydrobiological parameters show that the lake could be divided into two parts (Fig. 3.13), with different water dynamics: the shallow (depth 5–6 m) dynamic part, with resuspension and the deep static part with oxygen deficits (the zone of accumulation). Their individual character determined the structure and the function of the lake ecosystem. The distinct thermocline separated these two parts during the summer stagnation, and it was a barrier for sedimenting tripton. The lake to the depth of 5–6 m is shallow and polymictic. The modern sedimentation studies proved that resuspension in the shallows induced approximately double sedimentation rate in the deep part. Mechanisms of sediment translocation (turbidity currents, slumping and sliding) and its focusing are also expected. These assumptions were confirmed by the morphological parameters of the lake basin and the measures of pollen sedimentation. The most intensive pollen sedimentation was recorded after freeze-up as a result of previous sediment resuspension. It was probable that seasonal variations in the character of tripton were too small to observe the formation of clear varves. The lack of ice-cover prolonged the water circulation and supported the high sedimentation rate. It was likely that increase in the water dynamics and sedimentation was the cause for the lamination decay in recent years.

The sedimentation studies are continued. A lot of material has not been worked out yet. Further investigations will emphasize the tripton palynology, crystallography, and microscopic analyses (particularly phytoplankton). All those topics will be presented in the separate publications.

3.6. ISOTOPIC COMPOSITION OF CALCITE DEPOSITED IN LAKE GOŚCIĄŻ UNDER PRESENT CLIMATIC CONDITIONS

Przemysław Wachniew & Kazimierz Różański[*]

Isotopic record of lacustrine calcite in the sediments

Information preserved in isotopic composition of lacustrine calcite plays a very important role in studies aimed at reconstruction of past climates on continental areas. Since their very beginning the interdisciplinary studies of Lake Gościąż have included attempts to reconstruct past climatic conditions with the carbon- and oxygen-isotope ratios of calcite obtained from the sediment cores. A very good correlation between abrupt changes of the $\delta^{13}C$ and $\delta^{18}O$ values (Różański et al. 1992, Kuc et al. 1993) and changes of other paleoclimatic

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[*] We thank T. Mieszczankin for delivering the sediment trap samples.