

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 Gościąg was highly probable due to ground-water inflow (Churski et al. 1993) and high slopes (Tab. 3.4). Nevertheless, 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 Gościąg. 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  $\text{CaCO}_3$  was observed in the middle of summer (Wachniew & Rózański, 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  $\text{CaCO}_3$  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 Gościąg. 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 Gościąg:

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 GOŚCIAŻ UNDER PRESENT CLIMATIC CONDITIONS

*Przemysław Wachniew & Kazimierz Rózański\**

#### 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 Gościąg 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  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values (Rózański et al. 1992, Kuc et al. 1993) and changes of other paleoclimatic

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indicators (e. g. pollen record, Ralska-Jasiewiczowa et al. 1992) at the Late-Glacial/Holocene transition prove that the isotopic composition of calcite reflects climatic conditions, at least in part of the record. On the other hand, the isotopic record preserved in the sediments of Lake Gościąg reveals some features that cannot be unequivocally assigned to any documented climatic or environmental changes (Rózański et al., Chapter 8.6). Therefore, a thorough understanding of the processes controlling isotopic composition of calcite formed nowadays in this particular lake system is required. This chapter is aimed at presenting the principal patterns of calcite formation in Lake Gościąg in relation to environmental conditions both from chemical and isotopic points of view.

Laminated sediments of Lake Gościąg consist mainly of calcite which occurs in form of crystals of different shape and size. Of microorganisms developing carbonate tests only green algae *Phacotus* were found in the lake (Kudelko 1994) but their contribution to calcite sedimentation is negligible. Lack of carbonate rocks in the catchment of the lake ensures that the sediments contain no carbonates of detrital origin. This assumption has been proven by the mineralogical studies of the sediments. Among other carbonates only small amounts of rhodochrosite and siderite are present in the sediments (Łacka et al., Chapters 7.3 and 8.2). The mean residence time of water in the lake is 1–2 years (Wachniew 1995). Since the lake is fed mainly by groundwaters,  $\delta^{18}\text{O}$  of its waters should reflect the mean isotopic composition of precipitation over the catchment area slightly modified by evaporation. Finally, Lake Gościąg and its catchment have been for last forty years almost free from direct anthropogenic influences (Goslar, Chapter 9.2.1). The above-mentioned properties make Lake Gościąg a convenient site to investigate in detail the processes controlling isotopic composition of calcite deposited in a natural lake system located in a temperate climatic zone.

In mesotrophic to eutrophic hard-water lakes photosynthesising microorganisms utilize vast quantities of  $\text{CO}_2$  dissolved in water. This leads to supersaturation of the epilimnic waters with respect to calcite and to its subsequent precipitation. The isotopic composition of precipitating calcite is determined by the isotopic composition of dissolved inorganic carbon (DIC), which in the surface lake waters consists mainly (>95%) of bicarbonate ( $\text{HCO}_3^-$ ), and by the isotopic fractionation associated with the precipitation process. Under equilibrium conditions the extent of this fractionation for carbon isotopes only slightly depends on water temperature, changing by few hundreds of permil per  $1^\circ\text{C}$  for temperature range observed in mid-latitude lakes. Thus, one can expect  $\delta^{13}\text{C}$  of precipitating calcite to reflect in the first instance  $\delta^{13}\text{C}$  of DIC pool in the lake. During photosynthesis phytoplankton preferentially removes  $^{12}\text{CO}_2$  from water, while precipitating calcite is enriched in  $^{13}\text{C}$  with

respect to DIC. The exchange of  $\text{CO}_2$  between the atmosphere and a lake usually results in the enrichment of  $^{13}\text{C}$  in DIC. Other sources of DIC are surface and groundwater inflows to a lake, and decomposition of organic matter both in the water column and in the sediments, associated with liberation of strongly  $^{13}\text{C}$ -depleted  $\text{CO}_2$  in case of aerobic respiration or strongly  $^{13}\text{C}$ -enriched  $\text{CO}_2$  in case of methanogenesis.  $\delta^{18}\text{O}$  of DIC is controlled by  $\delta^{18}\text{O}$  of water because most of oxygen atoms involved in the  $\text{H}_2\text{O} - \text{CO}_2 - \text{CaCO}_3$  system are contained in water molecules. The temperature dependence of the  $^{18}\text{O}$  equilibrium fractionation factor between water and calcite (change of  $-0.25\text{‰}$  per  $1^\circ\text{C}$ , O'Neil et al. 1969) is large enough to imprint water temperature in  $\delta^{18}\text{O}$  of authigenic calcite. Generally,  $\delta^{18}\text{O}$  of bulk lacustrine calcite can be used as an indicator of paleoenvironmental conditions but accurate reconstruction of past temperatures is impossible due to the number of interfering factors.

#### Sampling and measurement procedures

Regular sampling campaigns on Lake Gościąg were carried out monthly between April and October 1993. The lake waters were sampled at several depths (usually 1, 3, 5, 8, 13, and 18 meters) for chemical and isotope analyses. Sediment samples were collected by use of the sediment traps installed at 10 m above the bottom, in the deepest part of the lake (for details see Giziński et al., Chapter 3.5). The chemical analyses of water samples (pH, alkalinity,  $\text{Ca}^{2+}$  concentration) were performed in the field laboratory within few hours after sampling by use of the ion selective electrodes. Analytical reproducibilities for the chemical analyses ( $1\sigma$ ) were better than 0.03, 4%, 1% respectively. Equilibrium equations were used to calculate the concentrations of the DIC species ( $\text{CO}_2$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ ) (Stumm & Morgan 1981). The pH and SI values were recalculated for the *in situ* temperatures of water. The isotopic compositions of water, DIC, and calcite deposited in the sediment traps were measured. The carbon-isotope ratios of DIC were determined in  $\text{CO}_2$  liberated from the water samples after acidification (Wachniew 1995). The calcite and water samples were prepared for mass-spectrometry analyses by the use of standard methods. The overall precision of  $\delta^{18}\text{O}$  determination was better than 0.1‰ for water and 0.2‰ for calcite. The overall precision of  $\delta^{13}\text{C}$  determination was better than 0.3‰ for DIC and 0.1‰ for calcite. The isotope ratios are expressed versus the VPDB standard for calcite samples and versus the VSMOW standard for water samples.

#### Chemical and isotopic observations of calcite precipitation

The seasonal changes of the monitored chemical and isotopic parameters in the lake waters follow to some ex-

tent the pattern of water temperature changes (see Giziński et al., Chapter 3.5). At the beginning of April, during the spring overturn, pH values in the water column were relatively constant. Later, significant differences were observed, with elevated pH values in the epilimnion persisting until the beginning of September (Fig. 3.20a). The increase of pH in the surface waters was caused by photosynthetic assimilation of  $\text{CO}_2$ . On the other hand, decomposition of organic matter in the bottom waters and in the sediments, accompanied by the release of  $\text{CO}_2$ , led to a decrease of pH in the hypolimnion. A gradual breakdown in the thermal gradient enabled partial mixing of the water column, thus making the differences of pH between the surface and bottom waters in October less pronounced than in the preceding months. The maximum observed pH values were lower than the values reported in the literature for some eutrophic lakes during plankton blooms ( $>9$ , e.g. Emerson 1975, Herczeg & Fairbanks 1987).

The pH values of the lake waters is affected in several processes, e.g. photosynthesis and respiration (Stumm & Morgan 1981). Therefore, the saturation index (SI) should be a better indicator of the intensity of calcite pro-

duction than pH. The saturation index reflects the degree of saturation of the solution with respect to calcite:

$$\text{SI} = \log \frac{(\text{Ca}^{2+})(\text{CO}_3^{2-})}{K_C}$$

where parentheses denote activities of the ions, and  $K_C$  is the equilibrium constant. Calcite precipitates only at positive SI values. During the studied period the surface waters of Lake Gościąg were always supersaturated with respect to calcite while the bottom waters were temporarily undersaturated, what facilitated calcite dissolution (Fig. 3.20b). The highest SI values were recorded on 29 April. Surprisingly, that SI maximum was accompanied by the lowest fluxes of sedimentating organic matter and calcite (Giziński et al., Chapter 3.5). Calcite precipitates only from the supersaturated waters but the degree of supersaturation evidently does not determine the rate of precipitation. The fluxes of organic matter and calcite evaluated with the aid of sediment traps are positively correlated ( $r^2 = 0.92$ ) and their ratio is 1:0.62 (Wachniew 1995). This strong correlation suggests that withdrawal of  $\text{CO}_2$  by phytoplankton, causing saturation of lake waters with calcite, is not the only way the phytoplankton affects formation of calcite crystals. A strong correlation between the occurrence of phytoplankton and calcite production was reported for many lakes (reviewed in Küchler-Krischun & Kleiner 1990). In natural waters growth of calcite crystals is predominantly initiated by heterogeneous nucleation on the surfaces of other solid substrates (Stumm & Morgan 1981). Phytoplankton, its remnants, and other particles may serve as heteronuclei. The SEM photographs of material collected in the sediments traps prove that calcite crystal growth is often initiated on the surface of diatom valves (Starnawska, pers. comm.). Interactions between biological and physicochemical processes leading to precipitation of calcite in lake waters might, through kinetic effects, result in isotopic disequilibrium between precipitate and solution.

The  $\text{Ca}^{2+}$  concentrations in the surface waters were lower than in the bottom waters (Fig. 3.20c), and decreased from April to September. This decreasing trend reflects constant removal of calcium from the water column through precipitation of calcite. The epilimnetic concentrations of DIC did not show such an unequivocal trend, fluctuating in a wide range (Fig. 3.21a). The large negative shifts of  $\text{Ca}^{2+}$  and DIC concentrations observed from 5 July to 5 August both in the surface and bottom waters did not correspond to any significant increase of primary production rates (see Giziński et al., Chapter 3.5). Considering relatively constant rates of calcite and biomass production, the rates of  $\text{Ca}^{2+}$  and DIC supply from other sources of DIC, such as decomposition of organic matter, waters feeding the lake, and dissolution of calcite had to vary considerably over that time.

Precipitation of calcite in the surface waters may be

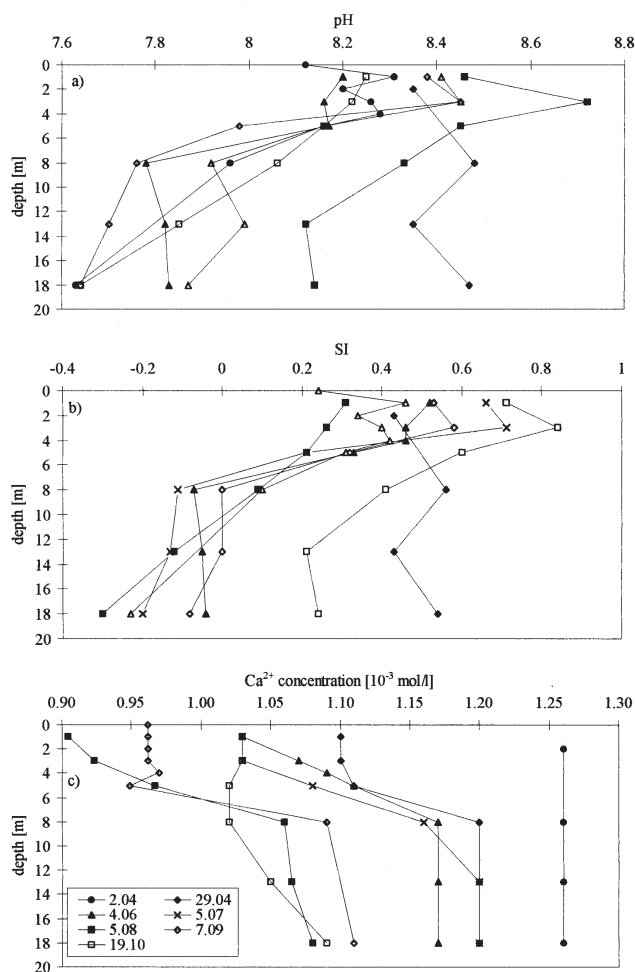


Fig. 3.20. Monthly profiles of: a) pH, b) SI, c)  $\text{Ca}^{2+}$  concentration.



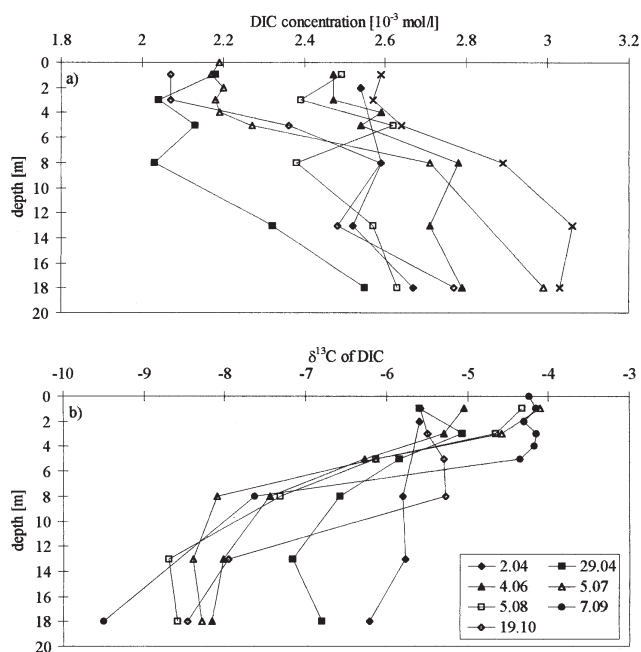


Fig. 3.21. Monthly profiles of a) DIC concentration, b)  $\delta^{13}\text{C}_{\text{DIC}}$ .

caused by the decrease of  $\text{CO}_2$  concentration due to photosynthetic assimilation or by other physicochemical processes, for example changes of water temperature (Kelts & Hsü 1978).  $\text{CO}_2$  utilization by phytoplankton is the most important process affecting saturation of Lake Gościąg surface waters with calcite, water temperature changes have minor influence on the SI values (Wachniew 1995). Calcite was present in the sediment traps during the whole studied period in 1993, always being the main component of the collected material (35–55% by weight, Giziński et al., Chapter 3.5). No distinct maxima of calcite sedimentation were observed except the periods of resuspension during the spring and autumn water column overturns. Results obtained from the sediment traps point to a rather uniform, intense deposition of calcite between mid-April and mid-September 1993. Resuspension and resedimentation of the sediments might account for the significant portion of calcite deposited outside the period of thermal stratification. Calcite transported from shallow parts of the lake contributes to sediments deposited in the deepest parts. Therefore the isotopic signal preserved in annual layer may not entirely correspond to isotopic composition of calcite produced during the corresponding year.

Figure 3.21b shows the monthly profiles of  $\delta^{13}\text{C}_{\text{DIC}}$  in the lake. At the beginning of April the  $\delta^{13}\text{C}_{\text{DIC}}$  values were almost constant in the water column. This isotopic parameter followed characteristic patterns of other physicochemical parameters in the well-mixed lake (see Figs 3.20 and 3.21). During thermal stratification (May – September) DIC in the epilimnion was enriched in  $^{13}\text{C}$  com-

paring to the bottom waters. The gradual decrease in the  $^{13}\text{C}$  content in the bottom waters was due to the release of  $^{13}\text{C}$ -depleted carbon during the microbial decay of organic matter. The October profile reflects partial mixing of the bottom and surface waters resulting from the gradual vanishing of thermal stratification. The  $\delta^{13}\text{C}_{\text{DIC}}$  values in the epilimnion varied between  $-6\text{‰}$  and  $-4\text{‰}$  and in the hypolimnion between  $-10\text{‰}$  and  $-6\text{‰}$ . The volumetric ratio of the epilimnion to the hypolimnion is approximately 2.5:1. Therefore, the final  $\delta^{13}\text{C}_{\text{DIC}}$  value resulting from the autumn mixing is closer to the epi- than hypolimnetic value. From late autumn to early spring, when photosynthetic activity is low, the isotopic composition of DIC is probably affected mainly by the release of DIC from the sediments, by the exchange of  $\text{CO}_2$  with the atmosphere (when the lake is free of ice cover), and by carbon brought to the lake by inflowing waters. Unfortunately there are no isotope data available for the winter period. However, judging from the April and October profiles (Fig. 3.21b) the  $\delta^{13}\text{C}_{\text{DIC}}$  values should not change significantly during winter. Also for the eutrophic Lake Greifen (Switzerland) no considerable change of the  $\delta^{13}\text{C}_{\text{DIC}}$  values between December and May was reported (McKenzie 1982). Given only minor changes of the carbon isotope ratio of DIC during thermal stratification (less than 2%), its initial value at the onset of thermal stratification determines to a large extent the  $\delta^{13}\text{C}_{\text{DIC}}$  values for the whole period of calcite precipitation.

The carbon- and oxygen-isotope compositions of calcite collected in 1993 in the sediment traps during one to six week periods are presented in Fig. 3.22. The carbon-isotope ratios vary in a much narrower range ( $<1\text{‰}$ ) than those of oxygen ( $<3\text{‰}$ ). The carbon-isotope ratios of calcite samples collected during thermal stratification generally follow the pattern of  $\delta^{13}\text{C}_{\text{DIC}}$  changes (Fig. 3.22a). The weighted mean  $\delta^{13}\text{C}$  of calcite for the whole studied period was  $-1.7\text{‰}$ . The  $^{13}\text{C}$  enrichments between calcite and  $\text{HCO}_3^-$  were determined for the calcite samples collected during 24 hours and for DIC sampled prior to the calcite collection period. The values observed in summer amount to  $2.9\text{‰}$  (5 Jul),  $3.0\text{‰}$  (5 Aug), and  $2.8\text{‰}$  (7 Sept), being in general agreement with the calculated equilibrium enrichments and with the values observed in laboratory experiments (Turner 1982). The apparent enrichment values in spring and autumn were higher:  $3.3\text{‰}$  (29 Apr),  $3.7\text{‰}$  (4 Jun), and  $4.1\text{‰}$  (19 Oct) but close to the values observed during production seasons in Swiss lakes (Hollander & McKenzie 1991) and Canadian lakes (Turner 1982). However, in case of Lake Gościąg these higher values correspond to the periods when the occurrence of intensive resuspension was evident (29 Apr, 19 Oct) or probable (4 Jun) (see Giziński et al., Chapter 3.5).  $\delta^{13}\text{C}$  of resuspended calcite is higher than for calcite produced in the water column (Wachniew 1995). The apparent isotopic enrichments between calcite and  $\text{HCO}_3^-$  may

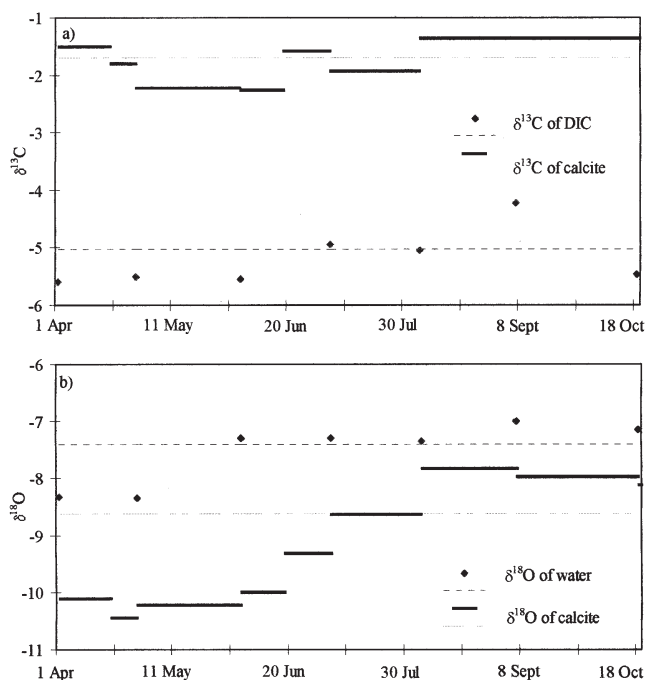


Fig. 3.22. A comparison of the monthly and mean isotopic compositions of calcite from the upper trap and: a)  $\delta^{13}\text{C}$  of DIC b)  $\delta^{18}\text{O}$  of water. Points denote the observed values, lines represent the weighted averages.

differ from the actual values, because  $\delta^{13}\text{C}_{\text{DIC}}$  and water temperature vary considerably within the epilimnion. Collected bulk calcite samples consist of portions with different isotopic composition, whereas DIC was sampled only immediately before exposition of the traps.

The oxygen-isotope ratios of the collected calcite samples vary in a wide range. This may be partly due to the worse overall precision of  $\delta^{18}\text{O}$  determinations (0.2‰). Calcite precipitated during April to June was considerably more depleted in  $^{18}\text{O}$  than calcite precipitated in summer and winter. This change exceeds increase in  $\delta^{18}\text{O}$  of lake waters caused by evaporation. The weighted mean  $\delta^{18}\text{O}$  of calcite for the studied period is -8.6‰ while  $\delta^{18}\text{O}$  of lake waters for the same period is -7.4‰. For the period from 29 April to 19 October when contribution of resuspended material was probably small the corresponding values are -8.8‰ and -7.3‰, respectively. Assuming equilibrium fractionation of oxygen isotopes between water and calcite (O'Neil et al. 1969) these values give average water temperature 22°C while the actual value was 17°C. The expected  $\delta^{18}\text{O}$  values of calcite calculated for this period is -7.5‰. Calcite precipitated in the lake seems to be depleted in  $^{18}\text{O}$  comparing to isotopic equilibrium with lake water at least on a scale of one year. As in the case of  $\delta^{13}\text{C}$  the calculated  $\delta^{18}\text{O}$  values of calcite should be weighted by the intensities of calcite precipitation at the corresponding depths. However, spatial and temporal variations of water temperature and its isotopic composition within the euphotic zone cannot account for the discrepancies between the calcu-

lated and observed  $\delta^{18}\text{O}$  values of calcite because the estimated temperature of water (22°C) is higher than observed at the lake surface for most of the studied period.

#### Implications for paleoenvironmental reconstructions

Precipitation of calcite in Lake Gościąg was observed during the whole studied period of 1993. Supersaturation of surface waters with respect to calcite was caused by the intensive assimilation of  $\text{CO}_2$  by phytoplankton organisms during photosynthesis. The fluxes of calcite and organic matter evaluated with the aid of sediment traps were strongly correlated. The high degree of supersaturation alone does not suffice to induce precipitation of calcite. Apparently, the growth of calcite crystals took place in the presence of phytoplankton or its remnants, which served as nucleation centers.

The carbon-isotope ratios of calcite collected in sediment traps were relatively constant, reflecting changes of  $\delta^{13}\text{C}_{\text{DIC}}$ . Variations of  $\delta^{13}\text{C}$  of calcite in the sedimentary record might be thus interpreted as a result of changes in the lake system affecting its carbon budget. Results of numerical modelling of DIC evolution (Wachniew & Rózański 1997) show that DIC originating from decomposition of organic matter is a crucial element of the carbon budget of the lake. Large amounts of organic carbon must be transported into Lake Gościąg because decomposition of organic matter within the lake appeared to be at least by one third higher than its production. Generally, sources of isotopically light carbon (DIC contained in groundwaters feeding the lake and organic carbon from the catchment) are associated with water input. Increased water input (e.g. due to higher precipitation rate over the catchment) should result in lowering of  $\delta^{13}\text{C}_{\text{DIC}}$ . The same might be effect of deforestation leading to increased surface runoff and larger amounts of particulate organic carbon transported into the lake. On the other hand, escape of  $^{13}\text{C}$  depleted  $\text{CO}_2$  and  $\text{CH}_4$  into the atmosphere increases  $\delta^{13}\text{C}_{\text{DIC}}$ . Intensity of transport of gases through the water-air interface is wind-controlled. Variations of  $\delta^{13}\text{C}$  of calcite observed in the sedimentary record can also result from gradual filling of the lake basin with sediments which leads to lowering of the mean residence time of water in the lake.

The oxygen-isotope ratios of calcite collected in the sediment traps during the studied period show that precipitated calcite was depleted in  $^{18}\text{O}$  with respect to the expected equilibrium values especially for samples collected in spring. The reasons for this apparent disequilibrium remain unknown. On the other hand, data available from the Late-Glacial, and early Holocene (Kuc et al., Chapter 7.6) and youngest parts (Goslar & Wachniew 1995) of the sediment cores extracted from Lake Gościąg clearly show that the recorded changes of the  $\delta^{18}\text{O}$  values of authigenic calcite remain a useful proxy indicator of

the climatic changes, with the temporal resolution of the isotope signal in the order of several years.

### 3.7. MACROPHYTE VEGETATION OF NA JAZACH LAKES AND THE DISTRIBUTION OF THE SURROUNDING PLANT COMMUNITIES

*Klemens Kepczyński† & Andrzej Noryskiewicz*

The complex of four lakes (Wierzchoń, Brzózka, Gościąg, and Mielec) called Na Jazach, and the stream Ruda connecting the lakes were the object of the floristic and phytosociological field research, together with the surrounding forest areas and the nearest peatbogs. The field studies were started in 1987 and continued until 1994.

#### The flora of the Na Jazach lake complex

The flora of the Na Jazach lake complex includes 560 species of vascular plants belonging to 81 families. Its richness is the consequence of the considerable diversity of habitats. An essential part of the flora is composed of species adapted to aquatic, submerged, and moist habitats. Another significant group is formed by species occurring in various forest and brushwood habitats. On the other hand, there are comparatively few representatives of xerothermic grasslands.

The most numerous components of the flora represent the following families: Compositae (60 species), Gramineae (49), Cyperaceae (39), Caryophyllaceae (32), Rosaceae (29), Papilionaceae (24), Scrophulariaceae (22), and Labiatae (20). 26 families of the plant list are represented by only one species, and 24 families by 2 or 3 species. Among the taxa found in the study area native species predominate, while alien species, including 42 archeophytes and 13 kenophytes, constitute only a low percentage of the flora.

The majority of the kenophytes come from North America, less frequently from Asia, and taxa coming from the Mediterranean area in a wide sense predominate among archeophytes. The fairly common kenophytes are *Acorus calamus*, *Solidago serotina*, *Senecio vernalis*, *Padus serotina*, *Erigeron canadensis*, and *Acer negundo*. To the most frequently occurring archeophytes belong *Capsella bursa-pastoris*, *Geranium pusillum*, *Erodium cicutarium*, *Herniaria glabra*, *Bilderdykia convolvulus*, *Spergula arvensis*, *Anchusa officinalis*, and *Scleranthus annuus*.

Many floristic rarities have been noted in the flora of the Na Jazach lake complex and the adjacent areas. They include plants under full protection (16 species) or partial protection (10 species), and 49 species are rare in the whole Płock Basin. The following species are fully protected: *Lycopodium annotinum*, *L. clavatum*, *Diphysium complanatum*, *Dianthus superbus*, *Pulsatilla pratensis*, *P. patens*, *Nuphar luteum*, *Drosera rotundifolia*, *Hedera*

*helix*, *Chimaphila umbellata*, *Lilium martagon*, *Orchis fuchsii*, *Epipactis helleborine*, *E. palustris*, *Listera ovata*, and *Liparis loeselii*. Under partial protection are *Polypodium vulgare*, *Nymphaea alba*, *Ribes nigrum*, *Frangula alnus*, *Primula officinalis*, *Ledum palustre*, *Arctostaphylos uva-ursi*, *Viburnum opulus*, *Helichrysum arenarium*, and *Convallaria majalis*.

The following rare species are particularly interesting: *Ophioglossum vulgatum*, *Cystopteris fragilis*, *Dryopteris cristata*, *D. dilatata*, *Alnus incana*, *Salix nigricans*, *Viola epipsila*, *Agrimonia procera*, *Trifolium lupinaster*, *Angelica archangelica* subsp. *litoralis*, *Andromeda polifolia*, *Myosotis laxa* ssp. *caespitosa*, *Utricularia minor*, *U. intermedia*, *Teucrium scordium*, *Scheuchzeria palustris*, *Potamogeton praelongus*, *Rhynchospora alba*, *Cladium mariscus*, *Carex diandra*, *C. remota*, *C. limosa*, and *Sparganium minimum*. Other floristic peculiarities are some relict moss species: *Camptothecium nitens*, *Thuidium lanatum*, *Meesia triquetra*, *Paludella squarrosa*, and *Scorpidium scorpioides*.

Due to the absence of fields under crop in the area considered, the synanthropic species are very poorly represented in the present-day flora. The economically utilized plants are generally only forest trees. The most common tree species is pine (*Pinus sylvestris*), occurring in all kinds of forests. In extremely poor habitats this species develops dwarf forms.

#### Plant communities

Basing on the analysis of 600 phytosociological relevés carried out in the area under study, 64 syntaxonomic units of 14 classes have been characterized (Tab. 3.17). The nomenclature and classification have been adopted mainly after Matuszkiewicz (1967, 1981), some other authors being also referred to (Pałczyński 1975, Jasnowski & Jasnowski 1983, Neuhäuslova & Neuhäusl 1985).

The full classification of plant associations distinguished is contained in Tab. 3.17. The simplified map of plant communities is presented in Fig. 3.23.

The vegetation is differentiated according to the prevailing habitat conditions (hydrologic conditions, types of soils and their nutrient resources, topographic features). Five basic groups of plant communities can be distinguished here, i. e. aquatic, reedswamp, mire, brushwood, and forest vegetation groups. In addition, "saum" and synanthropic, mainly ruderal, communities occur over small areas, developing in the vicinity of seasonally used human settlements and along roads and roadsides. One of the principal factors affecting the vegetation diversity of the area in question is water, deriving from the small (66 km<sup>2</sup>) catchment area of the stream Ruda and stored in four lakes (Gościąg, Wierzchoń, Brzózka and Mielec) and in the stream flowing through them and discharging into the Vistula River near Dobiegniewo.



Mapped by: K. Kępczyński, A. Noryskiewicz



Fig. 3.23. Map of plant communities of the lake complex Na Jazach and its surroundings (mapped by K. Kępczyński & A. Noryskiewicz).