

The development of the late-glacial and Holocene diatom flora in Lake Sedmo Rilsko (Rila Mountains, Bulgaria)

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Dedicated to Prof. Elissaveta Bozilova on the occasion of her 70th birthday

ABSTRACT

Diatom analyses were carried out on a 5-meter long sediment core from Sedmo Rilsko, a mountain lake at 2095 m a.s.l. in the Rila Mountains (Bulgaria). They show two distinct late-glacial and four Holocene diatom assemblage zones. The oldest three zones are characterized by periphytic, alkaliphilous to circumneutral diatoms, mainly *Fragilaria* species. These assemblages reflect well-buffered water conditions due to a high amount of clastic inwash. Around 8800 cal. BP a conspicuous change to acidobiontic *Brachysira brebissonii* assemblages took place, which reflects both stabilization of soils in the catchment by a denser vegetation cover and a decrease in alkalinity. At around 6350 cal. BP, after the expansion of coniferous trees in the catchment due to wetter conditions, the *B. brebissonii* abundance decreased substantially and erosional input increased slightly, leading to higher alkalinity in the water column.

KEY WORDS: Diatoms – Mountain lakes – Catchment-lake interaction – Climate change

INTRODUCTION

Mountain lakes have been shown to be sensitive indicators of past, present and future global change. In contrast to lowland lakes mountain lakes often register climate change directly (e.g. Battarbee et al. 2002b). Due to their location at higher elevations they are often not influenced by anthropogenic nutrient enrichment due to human activity in the catchment. Moreover, due to climatic conditions, at higher elevations the length of the open-water season largely determines the productivity in the water column (e.g. Catalan et al. 2002). Climatic conditions also have an influence on catchment processes, such as weathering and the erosion of minerals. These processes influence

water chemistry and thus the aquatic ecosystem (e.g. Psenner and Schmidt 1992; Koinig et al. 1998).

Whereas the development of the vegetation in the Bulgarian mountains is increasingly being unravelled (Bozilova et al. 1996; Bozilova and Tonkov 1994, 2000; Tonkov et al. 2002) there is still little information about the late-glacial and Holocene development of aquatic ecosystems and especially about the diatom flora. The present study was, on the one hand, aimed at understanding diatom assemblage changes in a Bulgarian mountain lake in relation to changes in climate and catchment vegetation. On the other hand, this study represents a first step towards a floristic characterization of the diatom flora of the Rila Mountains.

MATERIAL AND METHODS

Sedmo Rilsko is a cirque lake situated in the north-western region of the Rila Mountains in south-western Bulgaria. The lake lies at 2095 m a.s.l. in the lower subalpine belt. The hydrological catchment includes 3 km² with a vegetation consisting of stands of *Pinus mugo*, *Juniperus sibirica* and open patches of herbaceous vegetation. Sedmo Rilsko is the lowermost of a set of seven connected cirque lakes. It has an open water area of 5.9 ha, a volume of 240000 m³ and a mean and maximum depth of 4.1 m and 11 m, respectively. The catchment geology consists of Palaeozoic metamorphic and intrusive rocks.

In 1994 a 530 cm long sediment core was sampled with a square-rod piston sampler (Bozilova and Tonkov 2000) in the central part of the lake at a water depth of 8.25 m.

Diatom samples of 0.5 cm³ were taken at 10 cm intervals along the sediment core. The topmost unconsolidated 50 cm of sediment were not available for this study. The samples were digested with hot 30% H₂O₂ and 10% HCl before the residue was embedded with Naphrax on permanent slides. A minimum of 400 valves per sample were counted at a magnification of 1000x and the floras of Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b), Lange-Bertalot and Moser (1994), Lange-Bertalot and Metzeltin (1996), and Krammer (2000) were used for identification.

For loss-on-ignition (LOI) analyses about 1 g of dry sediment was combusted at 550 and 950°C following Heiri et al. (2001). LOI at 950°C, however, showed no detectable carbonate content. The biogenic silica concentration of the sediment was determined by the wet chemical dissolution photometric technique after de Master (1981).

The diatom diagram was zoned numerically using optimal sum-of-squares partitioning (Birks and Gordon 1985) as implemented in the program ZONE (Lotter and Juggins 1991). The significant number of diatom assemblage zones was assessed by using the broken stick model (Bennett 1996).

To assess taxonomic richness in the diatom assemblages, rarefaction analysis was carried out. Rarefaction analysis estimates the number of taxa in a standardized sampling unit (Birks and Line 1992).

RESULTS AND DISCUSSION

According to Bozilova and Tonkov (2000) the lowest part of the core consists of late-glacial sediments of pre-Allerød age, whereas they attribute the sediment between 437 and 413 cm to the Younger Dryas cold phase. The chronology of the sediment core is based on three calibrated AMS-radiocarbon dates, the pollen-inferred onset of the Younger Dryas and the core top (Bozilova and Tonkov 2000) that were used in a depth-age model (Fig. 1). According to this depth-age model the sediment accumulation rates were low during the late-glacial and early Holocene (Fig. 1) and increased rapidly ca. 8000 cal. years ago.

Organic matter contents of between 10 and 25% characterize the sediment below ca. 400 cm. In the early Holocene, however, the amount of organic matter steadily increases from ca. 25 to over 50%. The LOI results (Fig. 1), as well as the palaeobotanical evidence (Bozilova and Tonkov 2000), suggest a change from predominantly allochthonous clastic sediment to autochthonous organic sediment in connection with increasing vegetation cover in the catchment of Sedmo Rilsko. The highly organic Holocene deposits mainly represent the result of the productivity in the water column (see e.g. Battarbee et al. 2002a).

Optimal sum of squares zonation revealed six significant diatom assemblage zones. These zones are mainly characterized by changes in the relative abundance of small *Fragilaria* species (Fig. 2). During zone D-1 (pre-Allerød, according to Bozilova and Tonkov, 2000) the diatom assemblages are dominated by *Fragilaria pinnata*, which is typical for late-glacial (e.g. Round 1964; Haworth 1969) or arctic and alpine environments (e.g. Lotter et al. 1997, 1999).

Zone D-2 (Allerød to beginning of Younger Dryas) is characterized by periphytic diatoms such as *Fragilaria neoproducta* and *Gomphonema parvulum*. But the centric planktonic *Cyclotella radiosa* also occurs with relative abundances of more than 30%, showing a marked decrease during the Younger Dryas cold phase. This high abundance of a planktonic diatom is in contrast to the results of many other late-glacial diatom studies but suggests that favourable climatic conditions for the development of a planktonic flora already existed.

In zone D-3 (Younger Dryas to ca. 8800 cal. BP) other periphytic taxa such as *Achnanthes minutissima*, *Nitzschia* sp. and *Brachysira neoexilis* dominate the assemblages (Fig. 2). On the basis of the high abundance of alkaliphilous to circumneutral diatoms in assemblage zones D-1 to D-3 it can be concluded that the lake must have had a higher alkalinity than today and was thus well buffered. The sparse late-glacial and early Holocene vegetation cover in its hydrological catchment (Bozilova and Tonkov 2000) favoured soil erosion as evidenced by the low LOI content (Fig.1). This erosional input also brought cations into the lake, which increased its alkalinity.

Diatom assemblage zone D-4 (ca. 8800 to ca. 6350 cal. BP) is characterized by the mass-occurrence of *B. brebissonii* and the decline of other periphytic diatoms (Fig. 2). Based on its occurrence many authors characterize this species as a diatom indicative of oligotrophic and acid lakes (e.g. van Dam et al. 1994; Bigler and Hall 2002). Other genera with affinities to acid waters such as *Eunotia* and *Pinnularia* also increase markedly during this zone, indicating that alkalinity of the water decreased markedly during zone D-4. This was most likely due

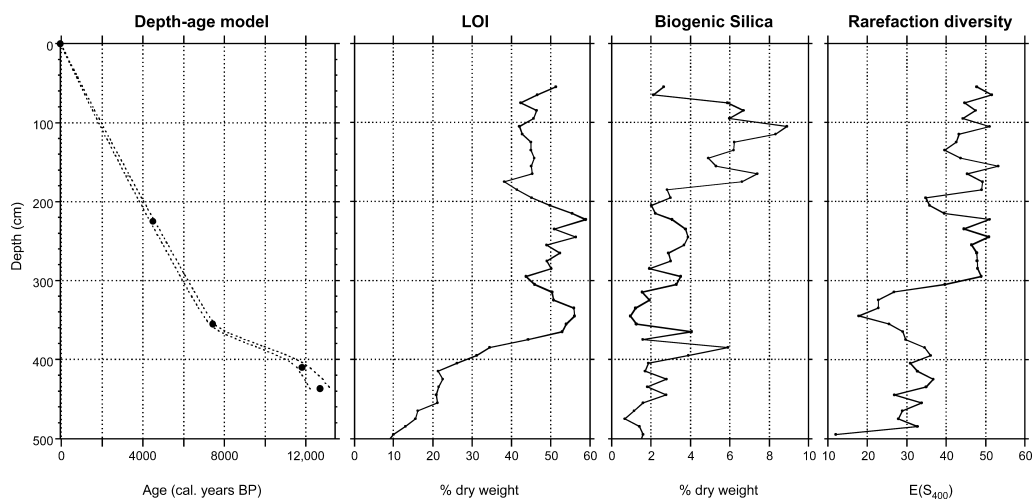


Fig. 1. Depth-age model (note that the lowermost date is inferred from palynological data), loss-on-ignition (LOI) data representing the amount of organic sediment, biogenic silica (representing diatom productivity) and rarefaction analysis (representing diatom diversity) for a sediment core from Sedmo Rilsko (Rila Mountains).

to soil stabilisation (and thus less erosion) by increased vegetation cover in the catchment of Sedmo Rilsko, which is also evidenced by the high LOI content at values above 50% (Fig. 1). For this period Bozilova and Tonkov (2000) inferred a vegetation characterized by *Betula pendula* stands and groups of pine, green alder and willow. Taking the pollen curve of *Tilia* (Fig. 3, but also *Ulmus*, *Acer*, *Quercus cerris*, see Bozilova and Tonkov, 2000) as a proxy for the thermic climate, the Holocene climatic optimum would coincide with diatom assemblage zone D-4.

Diatom assemblage zone D-5 (ca. 6350 to ca. 3300 cal. BP) is characterized by a substantial decline in *B. brebissonii*. Circumneutral and alkaliphilous *Fragilaria* species (*F. construens*, *F. pseudoconstruens*, *F. exigua*) as well as *A. minutissima* increase again during this zone (Fig. 2), whereas the acidophilous taxa remain present at lower percentages. At the onset of D-5 there is evidence in the pollen diagram for the expansion of several coniferous trees such as *Pinus* and *Abies* (Fig. 3). Bozilova and Tonkov (2000) interpret this as an uphill expansion of the coniferous forest belt due to an increase in precipitation and consequently also of humidity. This change in the precipitation regime may have resulted in an increased erosional input into the lake. The decrease in LOI content (Fig. 1) contemporaneous with the pollen signal confirms that this was the case. The enhanced allochthonous clastic input is likely to have led to higher alkalinity and buffering capacity in the lake, thus favouring circumneutral and alkaliphilous diatoms again.

A second decrease in LOI is observed starting at ca. 220 cm sediment depth (ca. 4500 cal. BP), which coincides with an increase in the acidobiontic *B. brebissonii*, followed by peaks of the acidophilous *Anuloseira alpigena* and *A. cf. distans*, and eventually by an increase

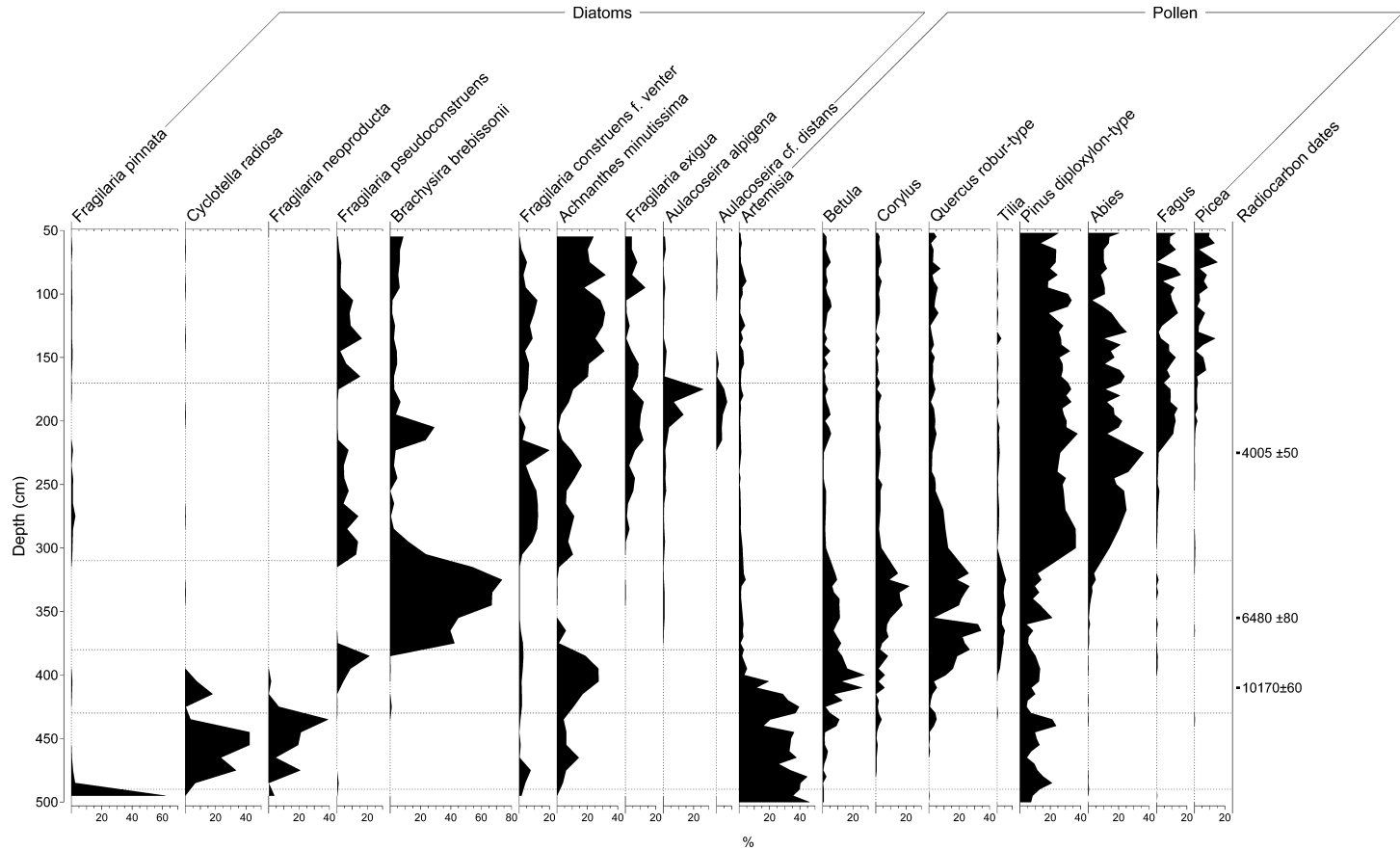


Fig. 3. Comparison of major diatom taxa with selected pollen types (data from Bozilova and Tonkov 2000) from the same sediment core of Sedmo Rilsko (Rila Mountains). Note that the top 50 cm (past ca. 1000 years) of the core are not shown.

of the circumneutral *Achnanthes minutissima* (see Fig. 2). It is unclear whether this change in sediment and diatom assemblages was caused by increased erosional input triggered by a wetter climate or by a decrease in in-lake productivity caused by a cooler climate. However, the diatom productivity as estimated by the biogenic silica concentration (Fig. 1) shows a twofold increase suggesting that the diatom productivity was silica-limited. Additional input of silica from the catchment may have allowed higher diatom productivity.

Concurrent with the LOI decrease around 220 cm the pollen curve of *Fagus* increases (Fig. 3) giving evidence for the regional expansion of this tree. It is rather unlikely that beech grew in the catchment of Sedmo Rilsko. Given the coincidence in diatom assemblage change (e.g. increases in *A. alpigena*, *A. cf. distans*, *Pinnularia microstauron* and a decrease in *A. minutissima*) and the expansion of beech, it is likely that its expansion in the Rila Mountain region around 4500 cal. BP. was climatically triggered.

The topmost diatom assemblage zone D-6 (since ca. 3300 cal. BP) is dominated by the same set of diatoms as in D-3. However, according to the strongly increased biogenic silica content (Fig. 1) diatom productivity during this zone was at its peak.

Taxonomic diversity of the diatom assemblages in Sedmo Rilsko as assessed by rarefaction analysis (Fig. 1) shows low pre-Allerød values (D-1), intermediate diversities during the late-glacial and early Holocene (D-2 to D-4) and a higher diversity throughout the middle and late Holocene (D-5 and D-6). It is noteworthy that taxonomic diversity, as well as biogenic silica concentrations (Fig. 1), are generally lower during phases of increased occurrences of acidophilous and acidobiontic diatoms (D-4, second part of D-5) such as *B. brebissonii*.

Unfortunately, we cannot compare the late-glacial and Holocene development of diatom assemblages with the modern state and assess the amount and effect of anthropogenic acidification on the lake during the past century.

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APPENDIX

Diatom taxa encountered in the late-glacial and Holocene sediments of Lake Sedmo Rilsko (2095 m asl).

Achnanthes

- *altaica* (PORTEZKY) CLEVE-EULER
- *daonensis* LANGE-BERTALOT
- *didyma* HUSTEDT
- *flexella* (KÜTZING) BRUN
- *helvetica* (HUSTEDT) LANGE-BERTALOT
- *lanceolata* ssp. *frequentissima* LANGE-B.
- *lapidosa* KRASSKE
- *levanderi* HUSTEDT
- *linearioides* (LANGE-BERTALOT) LANGE-B.
- *marginulata* GRUNOW
- *minutissima* KÜTZING
- *minutissima* var. *scotica* (CARTER) LANGE-B.
- *oestrupii* (CLEVE-EULER) HUSTEDT
- *saccula* CARTER

- *subatomoides* (HUSTEDT) LANGE-BERTALOT
- *sucblandtii* HUSTEDT
- *ventralis* (KRASSKE) LANGE-BERTALOT

Amphora

- *pediculus* (KÜTZING) GRUNOW

Aulacoseira

- *albigena* (GRUNOW) KRAMMER
- cf. *distans* (EHRENBERG) SIMONSEN
- *valida* (GRUNOW) KRAMMER

Brachysira

- *brebissonii* ROSS
- *neosexilis* LANGE-BERTALOT

Cavinula (*Navicula* sensu lato)

- *pseudoscutiformis* (HUST.) MANN & STICKLE

Chamaepinnularia (*Navicula* sensu lato)

- *mediocris* (KRASSKE) LANGE-BERTALOT
- *schauppiana* LANGE-B. & METZELTIN
- *soebrensis* var. *bassiaca* (KRASSKE) L.-B.

Cocconeis

- *placentula* EHRENBERG

Cyclotella

- *radiosa* (GRUNOW) LEMMERMANN

Cymbella

- *affinis* KÜTZING
- *cymbiformis* AGARDH
- *elginensis* KRAMMER
- *gracilis* (EHRENBERG) KÜTZING
- *hebridica* (GRUNOW) CLEVE
- *helvetica* KÜTZING
- *microcephala* GRUNOW
- *naviculiformis* (AUERSWALD) CLEVE
- *perpusilla* CLEVE-EULER
- *reichardtii* KRAMMER

- *silesiaca* BLEISCH
- *subcuspidata* KRAMMER

Diadesmis (*Navicula* sensu lato)

- *gallica* var. *perpusilla* (GRUNOW) LANGE-B.

Diatoma

- *mesodon* (EHRENBERG) KÜTZING

Eunotia

- *bilunaris* (EHRENBERG) MILLS
- *diodon* EHRENBERG
- *exigua* (BRÉBISSON) RABENHORST
- *fallax* A. CLEVE
- *glacialis* MEISTER
- *implicata* NÖRPEL et al.
- *incisa* GREGORY
- *minor* (KÜTZING) GRUNOW
- *nymanniana* GRUNOW
- *paludosa* GRUNOW
- *praerupta* EHRENBERG
- *rhomboidea* HUSTEDT

Fragilaria

- *arcus* KÜTZING
- *bicapitata* A. MAYER
- *capucina* var. *gracilis* (OESTRUP) HUSTEDT
- *capucina* var. *rumpens* (KÜTZING) LANGE-B.
- *construens* f. *venter* (EHRENBERG) HUSTEDT
- *exigua* GRUNOW
- *nanana* LANGE-BERTALOT
- *neoproducta* LANGE-BERTALOT
- *oldenburgioides* LANGE-BERTALOT
- *opacolineata* LANGE-BERTALOT
- *parasitica* var. *subconstricta* GRUNOW
- *pinnata* EHRENBERG
- *pseudoconstruens* MARCINIAK
- *robusta* (FUSEY) MANGUIN
- spec. Nr. 5 Julma Ölkky
- *tenera* (W. SMITH) LANGE-BERTALOT

Frustulia

- *rhomboides* (EHRENBERG) DE TONI
- *rhomboides* var. *saxonica* (RAB.) DE TONI

Gomphonema

- *acuminatum* EHRENBERG
- *clavatum* EHRENBERG
- *gracile* EHRENBERG
- *hebridense* GREGORY
- *parvulum* var. *exilissimum* GRUNOW
- *pumilum* (GRUNOW) REICHARDT & LANGE-B.
- *sphenovortex* LANGE-B. & REICHARDT
- *truncatum* EHRENBERG

Luticola (*Navicula* sensu lato)

- *mutica* (KÜTZING) MANN

Navicula

- *angusta* GRUNOW
- *begerii* KRASSKE
- *cryptocephala* KÜTZING
- *exilis* KÜTZING
- cf. *fluens* HUSTEDT
- *laevissima* KÜTZING
- *levanderii* HUSTEDT
- *minima* GRUNOW
- *notha* WALLACE
- *psendolanceolata* LANGE-BERTALOT
- *pseudoventralis* HUSTEDT
- *radiosa* KÜTZING

Naviculadicta (*Navicula* sensu lato)

- *absoluta* (HUSTEDT) LANGE-BERTALOT
- *bryophila* (PETERSEN) LANGE-BERTALOT
- *digituloides* LANGE-BERTALOT
- *digitulus* (HUSTEDT) LANGE-BERTALOT
- *elorantana* LANGE-BERTALOT
- *fennica* (HUSTEDT) LANGE-BERTALOT
- *schmassmannii* (HUSTEDT) LANGE-B.
- *subtilissima* (CLEVE) LANGE-BERTALOT

Neidium

- *ampliatum* (EHRENBERG) KRAMMER
- nov. spec. 1 (cf. *bercynicum* A. MAYER)
- nov. spec. 2 (cf. *iridis* (EHRENBERG) CLEVE)

Nitzschia

- *acidoclinata* LANGE-BERTALOT
- *alpina* HUSTEDT
- *angustata* GRUNOW
- *gracilis* HANTZSCH
- *inconspicua* GRUNOW
- *perminuta* (GRUNOW) M. PERAGALLO
- *recta* HANTZSCH
- spec. Nr. 1 Julma Ölkky

Pinnularia

- *borealis* EHRENBERG
- *macilenta* EHRENBERG
- *microstauron* (EHRENBERG) CLEVE
- *microstauron* var. *rostrata* KRAMMER
- *schoenfelderi* KRAMMER
- *silvatica* PETERSEN
- *subanglica* KRAMMER
- *tirolensis* (METZELTIN & KRAM.) KRAMMER

Sellaphora (*Navicula* sensu lato)

- *pupula* (KÜTZING) MERESCHKOWSKY

Stauroneis

- *anceps* EHRENBERG
- *phoenicenteron* (NITZSCH) EHRENBERG

Stenopterobia

- *delicatissima* (LEWIS) BRÉBISSON

Tabellaria

- *floculosa* (ROTH) KÜTZING

