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POLLEN INFLUX IN LAKE MATSIMÄE AND ITS CATCHMENT

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Abstract. Pollen distribution and pollen influx (number of pollen grains/cm^2 per exposition period) were studied in Lake Matsimäe sediments and in its catchment. For this pollen analyses from sediments, sediment traps as well as from a Tauber trap were used. The results obtained demonstrate that the percentage composition of the pollen sedimented both on land and in the lake and pollen influx rates for the same period were comparable during the vegetation period. Differences occur between the sediment traps during the overturn period in late autumn and early spring. The influence of the resuspension was much higher in the sediment trap closer to the lake shore. In the centre of the lake, pollen distribution was more even, allowing for forming a hypothesis about a constant annual pollen influx. The constant pollen influx rate can be used to construct a depth–age scale. The first results of such investigations are promising.

Key words: pollen analysis, pollen influx, lake sediments.

INTRODUCTION

To evaluate the state and dynamics of an ecosystem, it is essential to know its long-term development trends. The same is true for the description of structural changes in the system, for the observation of the reaction to some stressor, and for the explanation of the self-restoration capability of the ecosystem. Information on these changes is preserved in bog and lake sediments, allowing for the description of both natural and human impacts throughout hundreds and thousands of years (Smol, 1992). Pollen analysis is a tool widely used to assess the past anthropogenic impacts on the environment. This method helps to estimate the land use changes resulting in land cover changes that affect biodiversity and global climate change.

In the recent decades, pollen analysis data have been presented not only in terms of percentages of different pollen types but also as pollen influx, i.e., the annual number of pollen grains per square centimetre. To achieve this, the knowledge of pollen concentration per volume or weight unit and the sediment formation time is required. For finding pollen concentration, a certain number of tracers is added to the sample, followed by appropriate calculations.

In spite of long-term research, many questions are still not explicitly answered. For instance, which part of pollen reaches lake sediments, whether that part is comparable to the part falling on the land surface, and to what extent the pollen influx rate depends on the vegetation surrounding the lake and on the morphometry of the lake. Difficulties are faced in comparing surface samples from within the stand of vegetation with samples from lake sediments, considering the transport of pollen to the site of deposition and the subsequent amalgamation of spectra from a mosaic of vegetation communities (Davis, 1968).

Although there exists an enormous reservoir of pollen that is potentially available for aerial transport over lake surfaces, pollen influx in lakes varies also with factors not associated with the surrounding vegetation. These include sedimentary processes within the lake and differences between the lakes due to their size and morphometry. Earlier investigations, focused on a longer age scale involving thousands of years (Punning & Koff, 1997), demonstrate that pollen records depend beside the vegetation also on the changes of landscape structure. Being dependent on the variations in the surface area of lakes or bogs, pollen influx rates also vary. Because of the adjacent forest line, smaller sites had higher pollen influx rates than larger ones. According to the results from sediment traps Bonny (1978, 1980) concluded that a small lake will probably receive per unit area significantly more pollen from the vegetation surrounding it than will a lake of greater radius, where part of the water surface lies beyond the deposition range of most of the local pollen. The mean annual rates of arboreal pollen (AP) deposition in the centre of a lake are roughly inversely proportional to the distance from the nearest trees. Pennington (1974) emphasizes that the pollen deposition rate is thus a function of lake size and morphometry, and not only a function of the composition and structure of the local vegetation.

However, in addition to fluctuations shown on the diagrams of pollen influx rates, in certain periods constant influxes can be distinguished. If the bog has not undergone any major changes (e.g., changes in size, hydrothermic conditions, and human impact), the assumption of constant pollen influx may be used to increase time-scale precision. To reconstruct the time scale, Middeldorp (1982) assumed a constant pollen influx over a given interval in peat bogs. Based on the cumulative pollen curve used in the Niinsaare bog (Punning et al., 1993) it was shown that under certain conditions pollen influx can be considered constant in Estonian bogs.

The main aims of this research were to determine how the pollen is distributed in the surface of an open bog close to a lake and in the sediment traps installed in the lake; how the mean annual pollen influx is formed in sediments. Based on earlier experiences (Punning et al., 1993), a tentative hypothesis was formulated: if during a certain period no significant changes take place in forest and land management, in the water level of a lake, and in its inflow and outflow regime, pollen influx rates in the lake sediments will be constant. By measuring the pollen concentration known in a particular sediment layer and dividing it by the amount of mean annual pollen influx, it is possible to determine the time of the formation of that layer. This approach has not yet been used to lake sediments, and therefore we were interested whether it can be used in the upper layers, where age determination with other methods is complicated.

STUDY SITE

Lake Matsimäe, with an area of 5.5 ha in Central Estonia, 8 km northwest of the village of Anna (longitude 25°31' E, latitude 59°04' N) in Järva County was selected as our study site. The lake surface is 77 m above sea level (Kask, 1964) and the lake is mainly precipitation fed. This lake is 340 m in length and 230 m in width; its shape is quite even and the shoreline not jointed. Sediments are evenly distributed in the deeper central part and close to the eastern shore. The western shore is steeper, and the thickness of sediments is smaller there (Saarse, 1994). The greatest depth of water (8.1 m) was measured quite close to the western shore (Mäemets, 1977).

In terms of landscape region, this lake is part of Kõrvemaa, an area characterized by little human impact, where large bogs and swamps, tree-covered eskers, and numerous lakes predominate. The lake is surrounded by an open stretch of bog pine trees; on the esker west from the lake birches, alder, and spruces are found. On the same esker, the area's only farm with a garden and a fallow field is located. Older maps give evidence of a larger farm. In 1961, a gravel quarry was opened there covering 8.2 ha, which operated for five years. When the quarry was shut, pine trees were planted there.

METHODS

The results of pollen analysis from two types of pollen traps and a sediment core were used to investigate the annual pollen influx:

1. The standard Tauber type trap (Tauber, 1974; Hicks & Hyvärinen, 1986) was used for pollen trapping from the atmosphere to the surface of the peat bog. In fact, the trap was a 10-litre bucket covered with a collar with a hole 7 cm in diameter, shedding rain and isolating the trap from the surrounding vegetation. The trap was placed in an opening inside bog vegetation.

2. The sediment trap for studying the deposition process in the lake was constructed according to Pennington (1974). It consisted of three cylinders, each 4.5 cm in diameter and 24 cm in height. The traps were arranged on a rope stretched between an anchor and a submerged float. The traps were placed in different parts of the lake (Fig. 1) at depths of 1.5 m above the bottom. Sampling points I and II were placed near the centre of the lake and point III closer to the shore to allow the observation of the effect of shore vegetation on the formation of the pollen spectrum. Sediment traps were exposed at various times (Table). The first observation period covered the main flowering time in summer 1996 (22 May 1996 to 29 September 1996), typical of distinctive water stratification in the lake. The second period comprised the autumn overturn, the winter season, when the lake was covered with ice, and the early spring overturn (10 October 1996 to 29 April 1997). The third observation period (5 March 1997 to 29 April 1997) incorporated the early spring flowering period, when the traps were placed into the lake immediately before ice-breaking and were removed before the period of pine flowering. Thus, an annual pollen cycle in the formation of lake sediment was covered.

3. Samples from the upper part of lake sediments were obtained using a modified Livingstone–Vallentyne piston corer from the deepest part of the lake (Fig. 1). Sampling was continuous, with the sampled layer 1 cm thick.

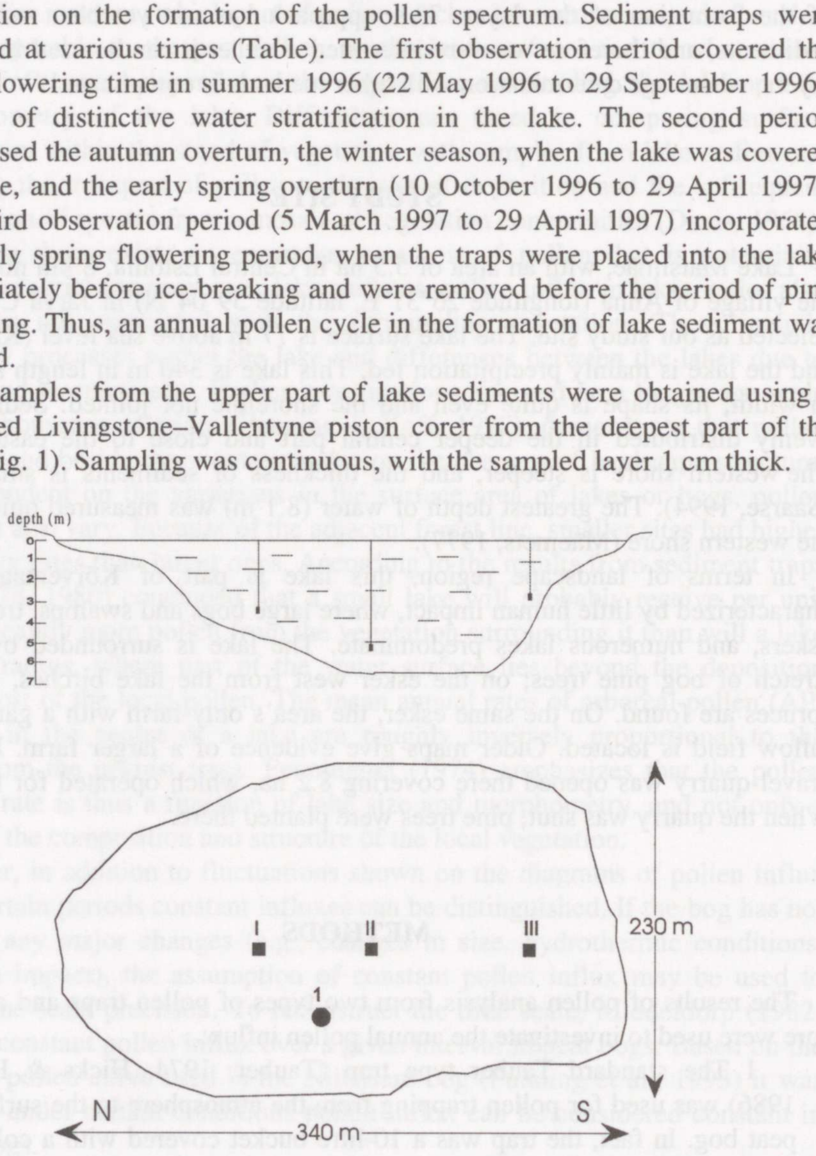

Fig. 1. Location of the sediment traps (I, II, III) and the studied core (1) in Lake Matsimäe.

Exposition period of sediment traps and arboreal pollen influx (number of pollen grains/cm²) in Lake Matsimäe during the period studied

Exposition period	No. of days	Trap	AP influx, grains/cm²
22.05.96–29.09.96	130	Tauber	7 200
		I/1	8 000
		II/1	8 500
		III/1	11 500
10.10.96–29.04.97	210	I/2	7 500
		III/2	20 700
05.03.97–29.04.97	53	I/3	1 500
		III/3	5 200

For pollen analysis from the sediment core, 50 mg of dried sample was boiled in 10% KOH and treated with standard acetolysis (Moore & Webb, 1978). Three tablets with the known content of *Lycopodium* spores were added to each sample at the beginning of laboratory treatment to calculate pollen concentration (Stockmarr, 1971). In general, at least 500 AP grains were determined under a microscope. The samples from the sediment traps and the Tauber traps were treated by the same standard analysis as pollen samples from sediments. Pollen influx rate was calculated for the Tauber and sediment traps on the basis of added and counted *Lycopodium* spores and divided by the area of the hole. The results were presented as the number of pollen grains per 1 cm² during the exposition period.

RESULTS AND DISCUSSION

In the bog surface, approximately 100 m from the lake, the Tauber trap was exposed together with the first series of sediment traps in the lake from May to September 1996. This period covers primarily the period typical of pollen production by Estonia's vegetation (Saar, 1996). Alder and hazel flower earlier; however, their proportion in Matsimäe vegetation is insignificant. Pine and birch were the groups of pollen predominating in the Tauber and sediment trap; spruce and alder were also found. The proportion of herbs was small.

According to the percentage composition of pollen (Fig. 2), no substantial differences exist between the three sediment traps I/1, II/1, and III/1 and the Tauber trap, which were all exposed in the same period during summer 1996. *Pinus* pollen is predominant (50–60%), next comes *Betula* pollen (20–30%)

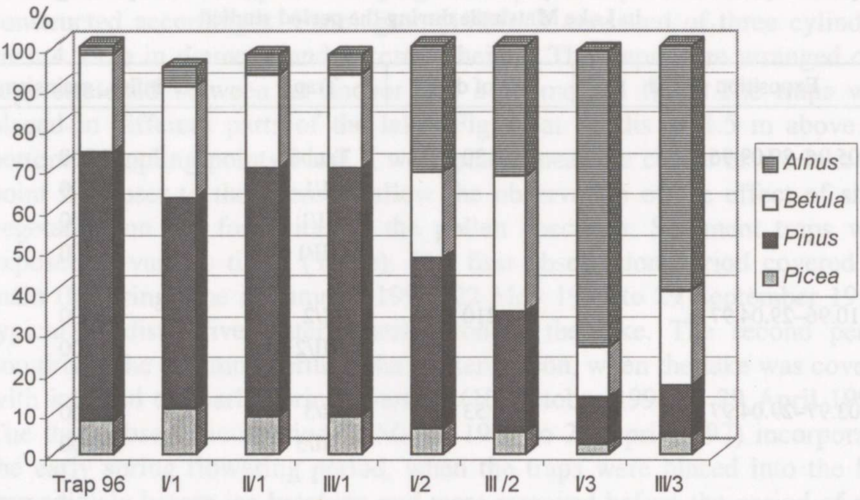

Fig. 2. Pollen percentages in sediment traps I/1, II/1, and III/1 and Tauber trap exposed during the period 22.05.96–29.09.96; in sediment traps I/2 and III/2 during the period 10.10.96–29.04.97; in sediment traps I/3 and III/3 during the period 05.03.97–29.04.97.

while *Alnus* and *Picea* (both about 10%) have lower occurrence. The results obtained demonstrate that the pollen composition is similar in the material sedimented on land surface and near the bottom in different parts of the lake.

One of the significant factors influencing the formation of lake sediments is resuspension. Resuspension has a greater effect in spring and autumn when vertical mixing processes take place in the water (Mieszczankin, 1997). As a result, very soft layers of sediment might be partly carried away, driven into a new cycle. Furthermore, depending on the morphometry of the lake, focusing of the sediment may take place in the deeper part of the lake. Basins shaped like hyperboloids or frustrums may introduce much greater distortion than basins conforming to ellipsoid or sinusoid shape (Lehman, 1975). Lake Matsimäe falls under the latter type, and thus the effect of focusing is smaller.

The pollen spectra obtained from the analysis of the material in sediment traps I/2 and III/2 (Fig. 2) reflect periods from late autumn up to early spring, e.g. the periods when the pollen production is generally absent except the *Alnus* and *Betula* flowering period in early spring. However, these samples contain a relatively high proportion of pine pollen. As is known, in Estonia *Pinus* and *Picea* flower in late May (Saar, 1996). Thus, in the sediment traps I/2 and III/2 (Fig. 2), part of pollen can be tracked down to the previous season. The fact that *Alnus* and *Betula* pollen had been produced in the new season is proved by the results of our spring observation period (I/3 and III/3) (Fig. 2), where *Alnus* pollen percentage in the sediment trap increased up to 73% in trap I and to 60% in trap III. Also, in early spring samples, about 10–15% of resedimented *Pinus* pollen was found. However, the amount of annual pollen sedimentation can be evaluated only through the pollen influx rates.

Our comparison of pollen influxes is based on the data obtained from the Tauber and sediment traps exposed during the flowering period (Fig. 3). The values of *Picea* and *Alnus* influxes in the Tauber and sediment traps were comparatively similar. Regarding *Betula* and *Pinus*, the influx was slightly higher into trap III/1 placed nearshore. The distribution of influx for the AP was the most even in the Tauber trap and sediment traps I/1 and II/1 in the range 7200–8500 pollen grains/cm^2 during the exposition period. In sediment trap III/1, AP influx amounted to 11 500. This trap was placed close to the southern shore of Lake Matsimäe (Fig. 1). The increased pollen influx could be either an effect of the trees growing on the shore, from which abundant pollen fall into the water, or pollen may be washed in from the slope. As seen in Fig. 1, the slope of the lake is relatively steep, and thus, the reason may lie in the redistribution of the sediment.

It should be noted that according to the Estonian pollen calendar (Saar, 1996), periods 1 (22 May to 29 September) and 3 (5 March to 29 April) correspond to the pollen season. From 29 September to 5 March, local plants did not produce any pollen. These data combined, we can observe the percentage of primary and secondary pollen in the traps.

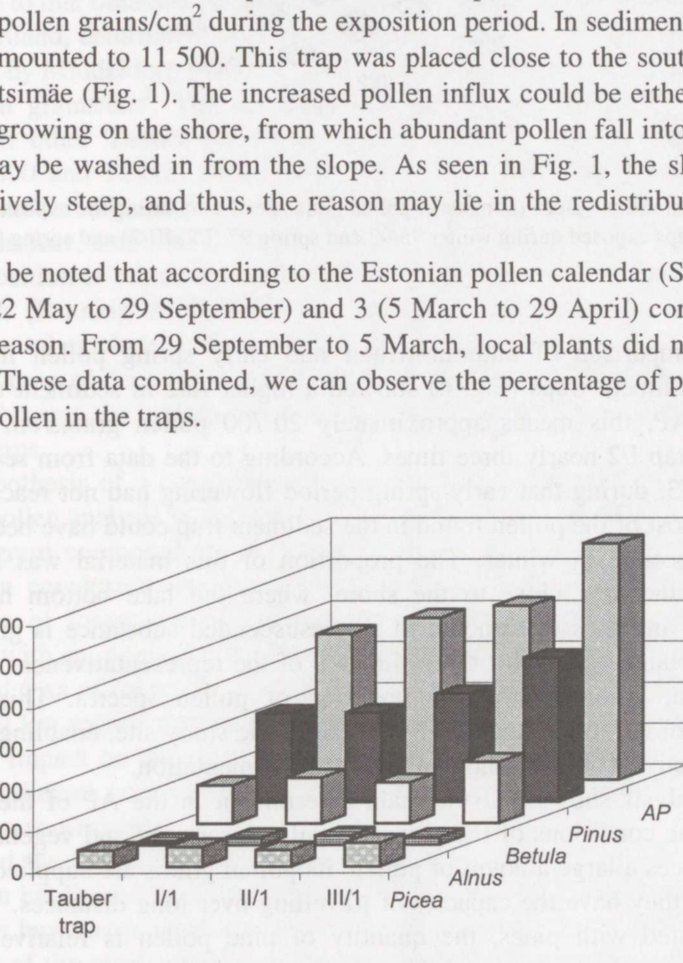

Fig. 3. Pollen influx values (number of pollen grains per 1 cm^2 during the exposition period) in sediment traps I/1, II/1, and III/1 and Tauber trap exposed during the period 22.05.96–29.09.96.

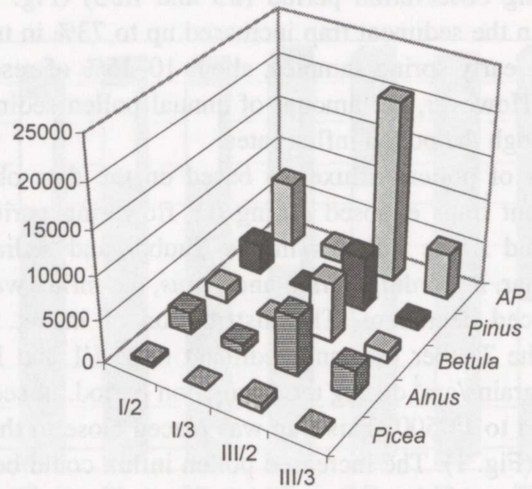

Fig. 4. Pollen influx values (number of pollen grains per 1 cm^2 during the exposition period) in sediment traps exposed during winter 96/97 and spring 97 (I/2, III/2) and spring 97 (I/3, III/3).

The comparison of autumn–winter and early spring pollen influx in the exposed sediment traps (Fig. 4) showed a higher rate in sediment trap III/2. In terms of AP, this means approximately 20 700 pollen grains/cm^2, exceeding sediment trap I/2 nearly three times. According to the data from sediment traps I/3 and III/3, during that early spring period flowering had not reached its peak and thus most of the pollen found in the sediment trap could have been refocused from the bottom in winter. The proportion of this material was significantly greater in the area close to the shore, where the lake bottom has a higher inclination and thus the amount of the resuspended substance is greater. Thus, the data obtained allow for the estimation of the representativeness of the study site chosen, based on the interpretation of pollen spectra. This is another indication of the importance of the choice of the study site, enabling an increase in the objectivity of information about lake sedimentation.

Our analysis shows that the main determinant in the AP of the tree pollen influx in the conditions of the given natural environment and vegetation is pine. Pine produces a large amount of pollen, its pollen grains are supplied with aerial sacks, and they have the capacity of travelling over long distances. Thus, in the areas forested with pines, the quantity of pine pollen is relatively constant, forming a certain background. The production of birch pollen could also be relatively high, but with pines predominating, its influx rate is lower. Alder pollen was reported at its highest aerial rate in Tartu by Saar (1996). In fact, alder is not a big pollen producer (Erdtman, 1969). Furthermore, high alder pollen percentage is associated with the local impact. Thus, its highest percentage was found in trap III, located close to the shore.

To calculate the annual pollen influx in the sediment, data from sediment trap I were used, because due to its location towards the central deeper part of the lake, the rate of redeposition and slope influx are lower there than in trap III. The results from sediment trap I are comparable with those from the Tauber trap exposed in the open bog close to the lake, allowing for a statement that the pollen aerial influx to the open bog environment is comparable to the quantity of AP pollen sedimented in the mid-lake bottom (Fig. 3). The annual pollen influx rate was obtained by summarizing the data of early spring and summer in sediment trap I where the rate was 9500 pollen grains/cm^2. This result is comparable to that obtained from Tauber traps by Hicks (1994) in a pine forest in northern Finland, determined as 4000–9000 pollen grains/cm^2. The annual influx determined by Middeldorp (1982) in peat in the Netherlands was slightly lower – 7000 pollen grains/cm^2. The annual pollen influx determined by the present author from other Tauber traps exposed in different sites in Estonia varies between 8000 and 12 000 pollen grains/cm^2. Thus, the annual influx of 9500 pollen grains/cm^2 obtained on the Matsimäe site correlates well with these results. Therefore, a conclusion can be drawn that in similar landscape structures pollen deposition is relatively similar in the collectors whose diameters exceed 200–300 m (Punning & Koff, 1997). Though a certain pollen redeposition undoubtedly takes place, it does not bring about balanced complete spectra, at least in the case of deep lakes with a strong stratification. Thus, we can assume that the influx into the bottom sediment is comparable to the relevant value in the sediment traps.

The hypothesis of a constant pollen influx was checked on the basis of the results of pollen analysis in the upper 32 cm sediment of Lake Matsimäe. From a pollen diagram composed by M. Kangur (unpublished, MS at the Institute of Ecology), a conclusion can be drawn that over the recent twenty years the composition of forests has not changed significantly. Changes have involved only herbs with an increase in Gramineae pollen rate after the quarry was opened in 1960 and 6 ha of forest was cut down. Surrounded by the forest from all sides within a 20 km radius, this small clear cut area does not, in general, have any substantial impact on the tree pollen influx. The samples analysed were taken from the sediment core close to sediment traps I and II, where the effect of redeposition was minimal.

Provided the amount of AP concentration in a sediment unit is known, this number can be divided by the amount of the annual constant sedimented pollen to calculate how many years are needed to form a 1 cm thick sediment. Further summation of the results yields the depth–age scale (Fig. 5). The scale obtained is in a relatively good correspondence with the time scale obtained based on ^{137}Cs and the distribution of spherical fly ash particles on the curves in the material taken from the same sediment core (Punning & Alliksaar, in press).

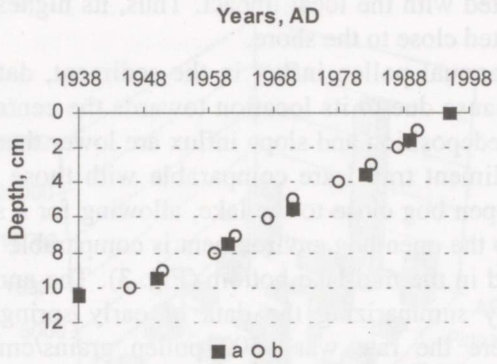

Fig. 5. Depth–age scale based on the spherical fly ash particles and ^{137}Cs data (a) and on the constant pollen influx data (b).

CONCLUSIONS

Based on the results of the investigation, the following conclusions can be drawn:

1. Annual tree pollen influx into the Tauber traps is comparable to the pollen influx in the flat deeper part of a lake and is approximately 9500 pollen grains/cm^2.

2. Data from sediment traps indicate that pollen sedimentation in a lake is more even during the period when the lake is stratified. During the autumn and spring overturn, pollen is transported together with the rest of sediment substance. Redeposition is more intensive on the shore, in deeper parts its scope is smaller.

3. If the vegetation surrounding the lake has not changed substantially, the AP influx to the lake sediment can be regarded as constant. Based on the pollen concentration in the sediment samples taken from a deeper part of the lake, the formation time of each sediment layer can be calculated, and the time scale determined adds to the methods of age determination, allowing for the specification of the dynamics of sedimentation and the conditions of changes.

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ÕIETOLMU SISSEKANNE MATSIMÄE JÄRVE JA SEDA ÜMBRITSEVALE ALALE

Tiiu KOFF

Töö põhieesmärk oli selgitada, kuidas jaotub atmosfäärist väljakantav õietolm järvevees sõltuvalt asukohast ja vee sügavusest ja järve äärsel lagerabal ning kuidas formeerub aasta keskmine õietolmu sissekanne settesse.

Uurimisobjektiks valiti Matsimäe järv (pindala 5,5 ha), mis asub Eesti keskosas, Voose-Matsimäe oosideahela lõunaosas, Järvamaal, Annast 8 km loodes. Settelõksud olid paigutatud järves kolme kohta 1,5 m kõrgusele põhjast. Proovipunktid I ja II asusid järve sügavamas osas, proovipunkt III kaldale lähemal. Settelõkse vahetati eri aegadel. Esimene vaatlusperiood hõlmas peamise õitsemisaja 1996. aasta suvel (22.05.96.–29.09.96), kui järv oli selgesti stratifitseerunud. Teine periood vältas hilissügisest kuni varakevadise vertikaalse segunemiseni (10.10.96.–29.04.97). Kolmas vaatlusperiood (05.03.97–29.04.97) langes kokku osaga teisest perioodist ja peegeldas peamiselt varakevadist õitsemist.

Raba pinnale, *ca* 100 m kaugusele järvest paigutati nn. Tauberi lõks, mis oli koos esimese seeria settelõksudega eksponeeritud maist septembrini 1996. Valdavalt leidus nii Tauberi lõksus kui ka settelõksudes männi ja kase õietolmu, veel esines kuuse ja lepa oma. Puude õietolmu sissekanne Tauberi lõksu oli võrreldav õietolmu sissekandega järve sügavamas, ühtlasema settimisega osas moodustades *ca* 9500 õietolmutera/cm^2-le.

Õietolmu settimine järves on settelõksude andmete alusel ühtlasem perioodil, kui järv on stratifitseerunud. Sügisese ja kevadise vee segunemise ajal võib aset leida ka sette, sh. õietolmu ümberpaiknemine. Ümbersettimine on intensiivsem järve kalda läheduses, järve sügavaimas osas on see väikseima ulatusega. Arvutused näitavad, et settiva puude õietolmu sissekanne on viimastel aastakümnetel olnud konstantne ja järve sügavamast osast võetud setteproovides sisalduva õietolmu kontsentratsiooni järgi on võimalik kindlaks teha iga settekihi moodustumise aeg. Sel viisil saadud ajaskaala on heas kooskõlas teiste meetodite abil saadud skaalaga.