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MATTER FLUXES IN LAKE MATSIMÄE (CENTRAL ESTONIA) ESTIMATED FROM TRAPS AND SEDIMENT RECORDS

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To understand the mechanisms of the impact of external pollution on the state of lake ecosystems a comprehensive analysis of matter fluxes in Lake Matsimäe is presented. To study the biogeochemical cycling and deposition processes in the lake the atmospheric flux was estimated with Tauber traps, and sediment traps were used to collect sinking and recycling matter in the water. In addition, uppermost samples in sediment core were analysed. The amount and composition of dry matter, pollen and spherical fly-ash particles produced by combustion of fossil fuel were used as indicators. The obtained data show that redeposition in the deep and flat area is modest in L. Matsimäe. Geochemical and palaeobiological records allow reconstruction of the trends in the environmental conditions with resolution not less than 2–3 years.

Introduction

The information about the past environment has been widely used for understanding the main trends in the dynamics of natural conditions. The information (biological, geochemical, lithological) stored in cumulative deposits (peat, lake deposits) allows us to follow the changes in the processes having impact on the sediment deposition over certain time periods. So our previous studies in northeastern Estonia, where the human-induced disturbances during the last decades have been intense, demonstrated that it is possible to provide clear evidences about the impact caused by oil shale mining and processing [1]. As the palaeorecords reflect an integrated state of ecosystems that is influenced by both natural bio-geophysical and human-induced processes the problems arise in the interpretation of data. The problems involved are complicated due to the multitude of factors that determine the changes in the biogeochemical cycling in lakes and consequently in the chemical and biological composition of the sediments. Some advances have been made in the palaeoecological approach, in particular for studying long-term changes in water quality and the sedimentation regime. Experience shows that it is possible to separate layers in the lake and mire sediments corresponding to human impact of different character and intensity [2, 3].

Spatial and temporal patterns in the flux of sinking matter are central for understanding sediment formation processes that are very important for interpreting sediment data as well for estimating internal pollution fluxes in waterbodies. Our studies in the oil shale mining area demonstrated that the sedimentation in the lakes into which mining waters are led had increased, and the resuspension of sediments took place [1, 2]. The use of sediment traps is an important approach for measuring the flux of matter in the water column as well as the supply to the sediment surface [4].

In this research the palaeoecological-geochemical approach was used to study the formation and composition of sediments in dystrophic L. Matsimäe in central Estonia, far from industrial and agricultural areas. As the catchment of L. Matsimäe consists mostly of mires the internal processes should have more directly regulated the development of the lake. Weak human load and even lithological composition of sediments create also good prerequisites for the study of the fluxes of settling matter and redeposition processes in the lake.

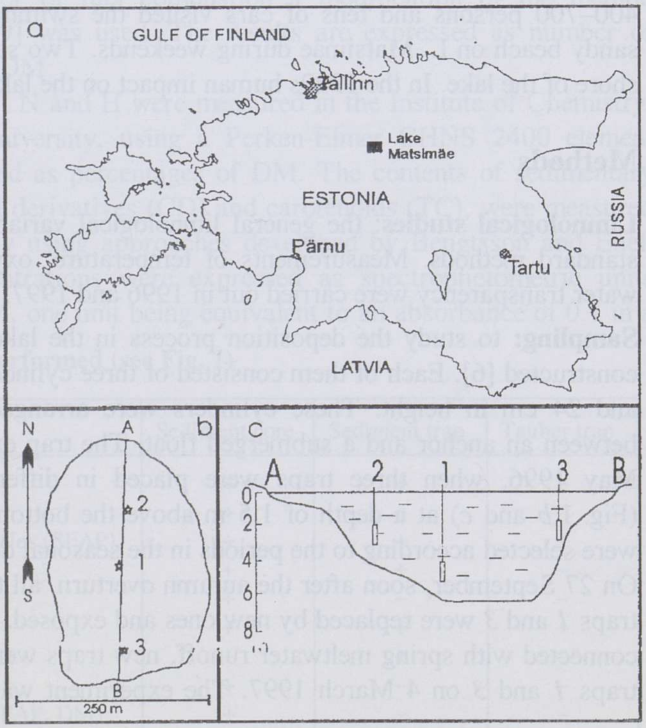

Fig. 1. Location of the study area (*a*), and sediment trap location in the lake (*b*) and on the profile AB (*c*)

Study Area

Lake Matsimäe (area 5.5 ha) is situated in central Estonia (longitude 25º31′ E, latitude 59º04′ N) in an area of the plain of the Baltic Ice Lake (Fig. 1,*a*). Now mires surround the lake except its west coast where the lake is dammed by an esker. The vegetation around the lake is mainly typical of ombrotrophic bogs and mixed forest on mineral soils. L. Matsimäe is a dimictic dystrophic lake, fed by humic waters from the catchment and by precipitation. The transparency of its brownish water is about 1 m with small seasonal variation. The lake is stratified in the summer. The greatest depth (8.1 m) has been measured quite close to the western shore. The thickness of the sediments is greatest (*ca* 4 m) in the northern part of the lake [5].

As L. Matsimäe is situated in an area of an extensive system of mires the human impact on it was and is rather modest. In the first half of the 20th century agricultural activity started to decline and nowadays the former fields are covered with forest. The area became of economic interest again at the end of 1940s when the esker, west from the lake started to be mined for gravel. The gravel pit was used up to the end of the 1950s. The mined area was more than 17 ha and consisted mainly of forested areas and in some agricultural land. Today the area is covered with pine forest. In the 1950s the western coast and part of the litoral were covered with sand and a summer swimming pool was established here. A new road, bus connection and an aesthetically valuable recreation area caused an increase in popularity. Some 400–700 persons and tens of cars visited the swimming pool and artificial sandy beach on L. Matsimäe during weekends. Two saunas were built on the shore of the lake. In the 1990s human impact on the lake has been decreasing.

Methods

Limnological studies: the general limnological variables were measured by standard methods. Measurements of temperature, oxygen content, pH, and water transparency were carried out in 1996 and 1997.

Sampling: to study the deposition process in the lake, sediment traps were constructed [6]. Each of them consisted of three cylinders, 4.3 cm in diameter and 24 cm in height. These cylinders were arranged on a rope stretched between an anchor and a submerged float. The trap experiment began on 22 May 1996, when three traps were placed in different parts of the lake (Fig. 1,*b* and *c*) at a depth of 1.5 m above the bottom. Observation periods were selected according to the periods in the seasonal development of the lake. On 27 September, soon after the autumn overturn, all traps were emptied and traps *1* and *3* were replaced by new ones and exposed. To study the processes connected with spring meltwater runoff, new traps were placed from ice near traps *1* and *3* on 4 March 1997. The experiment was finished on 29 April

1997. The year of the trap experiment 22.05.1996–29.04.1997 was distinguished for three periods important in the seasonal changes of the lake: 22.05–27.09 (period I) summer stratification and autumn overturn; 27.09–04.03 (period II) late autumn and ice covered winter period (pollen-free); 04.03–29.04 (period III) ice breaking and intensive meltwater runoff.

The sediment-coring site is close to the trap *1* (Fig. 1,*b* and *c*). Sampling was done in March 1996 with a modified Livingstone-Vallentyne piston corer. Sampling was continuous with intervals of 1 cm. As our historical records cover mainly the last one hundred years, only data for the top 20 cm of the core are presented. The visual lithology of the core was recorded in the field.

Modified Tauber trap [7, 8] was used to find out the influx of pollen and spherical fly-ash particles (SFAP) from the atmosphere. The trap consisted of a 10-litre bucket covered with a collar having a 7 cm diameter hole, which sheds rain and isolates the trap from the surrounding vegetation. The trap was placed about 100 m to the east from the lake and the exposition time covered period I in 1996 (22.05–27.09) and period 29.04–14.11 in 1997.

Sample analyses: comprehensive analyses of the samples from the sediment core and sediment traps were performed (Table 1). To determine the mass of dry matter (DM), the samples were dried at 105 ºC until a stable weight was reached. The content of organic matter was measured by loss-on-ignition (LOI) at 550 ºC as well calculated by multiplying the carbon content with 1.6 and expressed as percentages of DM. For determining the distribution of SFAP as an indicator of fuel combustion a modification of the method suggested by Rose [9] was used. The results are expressed as number of particles per gram of DM.

The contents of C, N and H were measured in the Institute of Chemistry, Tallinn Technical University, using a Perken-Elmer CHNS 2400 element analyser and presented as percentages of DM. The contents of sedimentary pigments, chlorophyll derivatives (CD) and carotenoids (TC), were measured spectrophotometrically using approaches developed by Bengtsson and Enell [10]. Pigment concentrations were expressed as spectrophotometric units (PU) per gram of DM, one unit being equivalent to an absorbance of 0.1 in a

Table 1. **Analyses Performed (see Fig. 1)**

Analysis	Sediment core	Sediment trap	Tauber trap
Dry matter (DM)	+	+	–
Organic matter (LOI)	+	–	–
Spherical fly-ash particles (SFAP)	+	+	+
C, N, H	+	+	–
Pigments	+	–	–
Pollen	+	+	+
Charcoal particles (CP)	+	+	–
Diatoms	+	–	–
Dating (^{210}Pb, ^{137}Cs, SFAP, DM)	+	–	–

1 cm quartz cuvette. Results are discussed in more detail in [11].

For pollen analysis samples were boiled in 10 % KOH and treated with standard method of acetolysis [12]. Three tablets with the known content of *Lycopodium* spores were added to each sample at the beginning of laboratory treatment to calculate pollen concentration. In general, at least 500 arboreal pollen (AP) grains were determined under the microscope. The charcoal particles (CP) were counted from the same slides as pollen grains at a magnification × 400. The number of CP is expressed as concentration per DM.

The slides for diatom analysis were prepared according to Mannion [13] and mounted in Naphrax. The systematic was based mainly on Krammer and Lange-Bertalot [14].

For dating the core the ^{210}Pb method, some reference levels of the distribution of SFAP and ^{137}Cs, as well the changes in the mineral content caused by the building of the swimming pool were used. ^{210}Pb was measured at the Estonian Radiation Centre using an isotope dilution technique and ^{208}Po as a yield tracer [15]. ^{137}Cs was measured at the Estonian Radiation Centre using γ-spectrometry. To compile age-scales using SFAP distribution in lake sediment cores a reference layer from the time when a remarkable increase in the SFAP concentration started was used. Comparing curve of the SFAP distribution in lake sediments of northeastern Estonia with the oil shale combustion curve a sharp increase in both curves was dated to 1960 (SFAP-60). Fly-ash emission data for northeastern Estonia as well as for northwestern Russia available since 1960 [16] show that the increase in the SFAP concentration could be dated even earlier as due to the absence or poor cleaning devices the fly-ash emissions were much higher at that time compared with the amount of fuel combusted. Accounting also the fossil fuel combustion in Europe the rise in SFAP in the studied profile was dated at *ca* 1945–1950 (SFAP-45-50).

To date individual layers in sediment core, the weights of DM (constant weight at 105 ºC) for all sublayers above the reference layer were summed and the mean accumulation rate in mg cm^{-2} yr^{-1} was calculated. The age of every layer analysed was calculated by dividing the dry matter content in the relevant layer with the mean accumulation rate of matter (in figures these ages are designated as SFAP-1945-50 and SFAP-1960) [17]. In current study only SFAP, ^{137}Cs and mineral matter richer reference layers are used for compiling age-scale.

Results

Lake water: During the observation period (mainly 1996–1997) the pH of water was 5–6 and the Secchi transparency did not exceed 1 m. These data are similar to those measured by Mäemets [18] in 1976. The dissolved oxygen content was low in the near-bottom layers and at the end of the vegetation period (in September) oxygen was practically absent below 3 m.

Sediment Core

Sample composition: the sediments in the sampled core consist of dark-coloured gyttja without remarkable changes in the lithological composition. The water content in the upper layers is *ca* 98 % and decreases continuously up to the depth of 4–5 cm, reaching then a constant value of about 95 %. LOI values were mainly 80–90 % up to the depth of 7 cm, where also the content of mineral matter increases sharply (Fig. 2). The sediment density increases downwards, reaching constant values at depth 15–20 cm. The content of C is in correlation with LOI and has also lower values at depths 5–7 cm. The C/N ratio shows a slight but continuous tendency to increase with depth. SFAP distribution in the sediment core (Fig. 2) is typical of sediment sequences without remarkable near-surface turbulence. The sharp increase in the number of SFAP at the depth of 4–6 cm is connected with intensified fossil fuel combustion, which reached its maximum at the end of the 1970s – the beginning of the 1980s and then was followed by a reduction in emissions and a continuous decrease in SFAP in sediments [16].

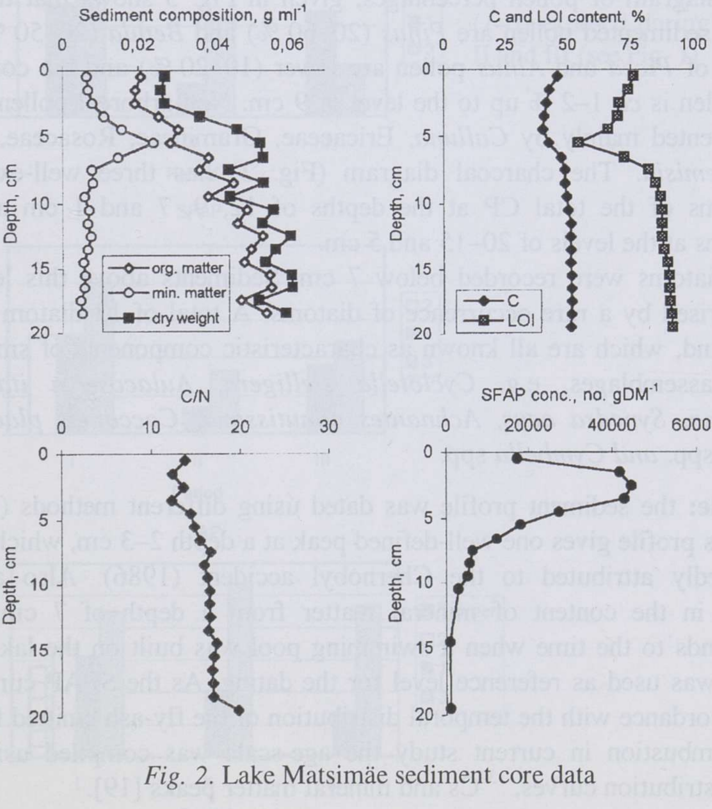

Fig. 2. Lake Matsimäe sediment core data

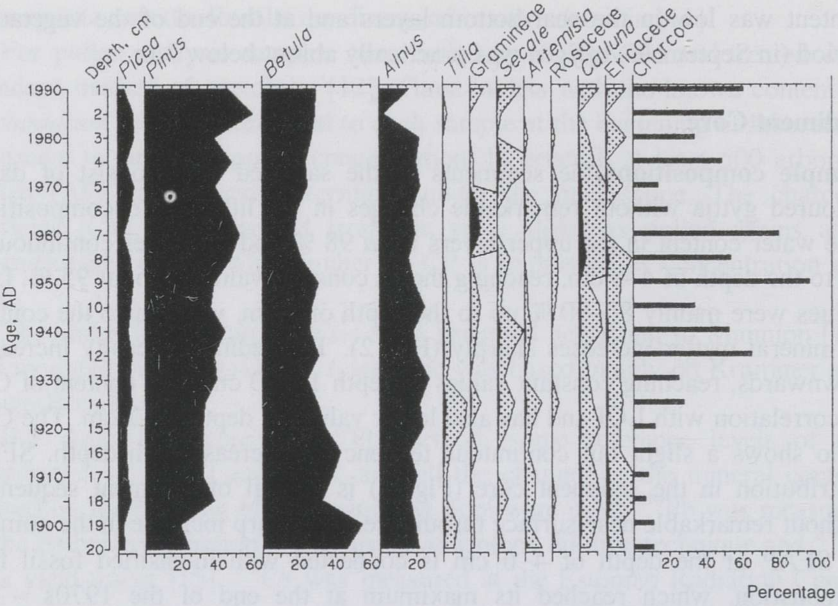

Fig. 3. Pollen and charcoal percentage diagram from L. Matsimäe sediment core

The diagram of pollen percentages, given in Fig. 3 shows that the main types of sedimented pollen are *Pinus* (20–60 %) and *Betula* (20–50 %). The contents of *Picea* and *Alnus* pollen are lower (10–20 %) and the content of *Tilia* pollen is *ca* 1–2 % up to the level of 9 cm. Non-arboreal pollen (NAP) is represented mainly by *Calluna,* Ericaceae, Gramineae, Rosaceae, *Secale* and *Artemisia.* The charcoal diagram (Fig. 3) has three well-expressed maximums of the total CP at the depths of 12, 9, 7 and 1 cm and two minimums at the levels of 20–15 and 5 cm.

No diatoms were recorded below 7 cm. Sediments above this level are characterised by a rare occurrence of diatoms. A total of 13 diatom species were found, which are all known as characteristic components of small lake diatom assemblages, e.g. *Cyclotella stelligera, Aulacoseira italica v. tenuissima, Synedra acus, Achnantes minutissima, Cocconeis placentula, Eunotia* spp. *and Cymbella* spp.

Age-scale: the sediment profile was dated using different methods (Fig. 4). The ^{137}Cs profile gives one well-defined peak at a depth 2–3 cm, which can be undoubtedly attributed to the Chernobyl accident (1986). Also a sharp increase in the content of mineral matter from a depth of 7 cm, which corresponds to the time when a swimming pool was built on the lake (early 1950s), was used as reference level for the dating. As the SFAP curve is in good accordance with the temporal distribution of the fly-ash emitted from oil shale combustion in current study the age-scale was compiled using two SFAP distribution curves, ^{137}Cs and mineral matter peaks [19].

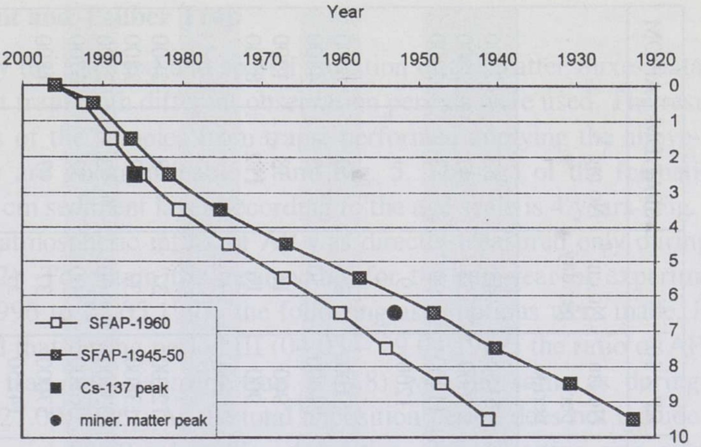

Fig. 4. Depth-age diagrams for upper part of L. Matsimäe sediment core. ■ – 1986 level marked with ^{137}Cs peak, ● – reference level marked by higher content of mineral matter (early 1950s)

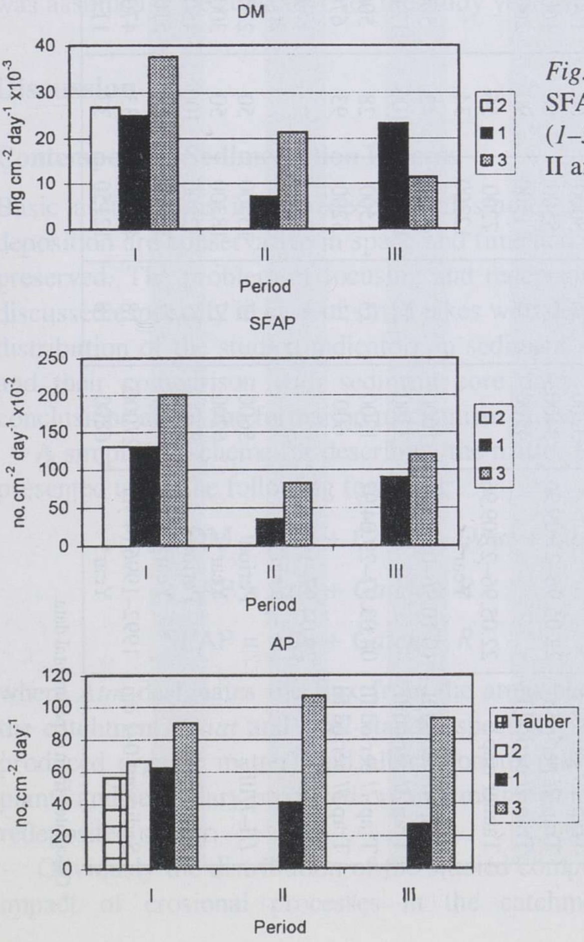

Fig. 5. The content of DM, SFAP and AP in sediment traps (*1–3*) exposed during periods I, II and III (see Fig. 1)

Table 2. **The Results of Analyses of Trap and Sediment Samples (See Fig. 1)**

Sample	Exposition period	DM × 10^{-3}		AP		SFAP × 10^{-2}		CP × 10^{-1}		SFAP/DM	AP/DM
		mg cm^{-2} per period	mg cm^{-2} per day	No cm^{-2} per period	No cm^{-2} per day	No cm^{-2} per period	No cm^{-2} per day	No cm^{-2} per period	No cm^{-2} per day	No mg^{-1}	
Trap *1* / period I	22.05.96–27.09.96	3200	25	8000	62	17000	130	6100	48	53	2500
Trap *2*/ period I		3400	27	8500	66	16000	130	7000	55	47	2300
Trap *3*/ period I		4900	38	11500	90	26000	200	11400	90	53	2300
Tauber trap	22.05.96–27.09.96			7200	56			1200	9		
	Year*			12300	34						
Trap *1*/ period II	10.10.96–04.03.97	1000	7	6000	42	5000	35	5100	35	50	6000
Trap *3*/ period II		3200	22	15500	106	12400	85	21000	150	40	4800
Trap *1*/ period III	04.03.97–29.04.97	1300	23	1500	28	5000	90	900	16	38	1200
Trap *3*/ period III		600	11	5200	93	6700	120	900	16	112	8700
Tauber trap	29.04.97–14.11.97					13800	70	1300	6		
	Year*					26000	70				
1/I–*1*/III	Period	5600	17	15500	50	27000	80	12100	37	48	2800
	Year*	6200	17	18300	50	30000	80	13800	37	48	2800
3/I–*3*/III	Period	8700	27	32200	100	45000	140	33300	100	52	3700
	Year*	9800	27	36500	100	51000	140	36500	100	52	3700
Sediment 0–1 cm	1992–1996 (4 yr)	27000	18	48600	33	47000	32	57000	37	17	1800
	Year*	6800	18	12150	33	11750	32	14250	37		

* Calculated from experimental data.

Sediment and Tauber Trap

To study the seasonal and spatial variation of the matter fluxes data from the sediment traps with different observation periods were used. The results of the analyses of the samples from traps, performed applying the above-described methods are given in Table 2 and Fig. 5. The age of the formation of the upper 1 cm sediment layer according to the age scale is 4 years (Fig. 4).

The atmospheric influx of AP was directly measured only during period I (Table 2). To obtain the mean value for the full year of experiment (from 22.05.1996 to 22.05.1997) the following assumptions were made. First were assumed that during period III (04.03 – 29.04.1997) the ratio of AP flux into Tauber trap and sediment trap 1 (0.8) was the same as during period I (22.05–27.09.1996). As the total exposition period does not include May, the most crucial for *Betula* pollen deposition, its proportion was calculated as long-term mean (30 %) in sediments. That gives 12,300 as the annual AP influx to the Tauber trap in 1996–1997. For calculating yearly influx of SFAP the obtained daily influx for spring-autumn 1997 (70 particles per cm^2) was assumed to be constant over the study year (Table 2).

Discussion

Contemporary Sedimentation Process

Basic assumptions in palaeoecological studies are that the mechanisms of deposition are conservative in space and time and that primary information is preserved. The problem of focusing and redeposition of sediments is widely discussed especially in case of small lakes with deep slopes [20]. The seasonal distribution of the studied indicators in sediment and Tauber traps (Table 2) and their comparison with sediment core data allowed us to draw some conclusions about the formation mechanism of the sediment in L. Matsimäe.

A simplified scheme for describing the matter fluxes into sediments can be presented using the following formulas:

$$\mathrm{DM} = Atm + Catch + Oaut + Oall + R$$

$$\mathrm{AP} = Atm + Catch + R$$

$$\mathrm{SFAP} = Atm + Catch + R$$

where *Atm* designates the flux from the atmosphere, *Catch* is the flux from the catchment, *Oaut* and *Oall* stand respectively for autochthonous (primary produced organic matter) and allochthonous (also remains of higher littoral plants and secondary produced organic matter in lake) and *R* is suspended and redeposited matter.

Obviously the distribution of the studied compounds is connected with the impact of erosional processes in the catchment and atmospheric and hydrospheric transport of mineral matter, pollen and SFAP. The complicated process of sediment resuspension and redeposition is reflected in the seasonal variation of influxes of different indicators in the sediment traps. Analysis of these data must be done taking into account the atmospheric flux into Tauber trap, vertical and horizontal convection currents in the lake and naturally the ice cover, which isolated the lake from direct atmospheric influx from December 1996 until April 1997.

The mineral matter in DM consists mainly of fluxes from the atmosphere and the catchment. Using C and LOI values and C/N data (Fig. 2) of the settled matter in traps, it is possible to estimate the proportion of total organic matter and its allochthonous part [11]. The calculations show that the share of Oaut is from 60 % (sediment traps) up to 75 % (upper sediment layers). On the basis of the obtained data it is possible to calculate mean DM fluxes (Table 3).

Table 3. **The Fluxes of DM, mg cm^{-2} yr^{-1} × 10^{-3}**

Sample	DM	Mineral matter	Organic matter	
			Autochthonous	Allochthonous
Trap *1*	6200	2400	2400	1400
Trap *3*	9800	4500	4000	1300
Sediment, 0–1 cm	6800	1500	3500 0	180

Table 4. **The Fluxes of SFAP, No cm^{-2} yr^{-1} × 10^{-2}**

Sample	*Atm*	*Catch + R*	Total
Tauber trap	26,000	–	26,000
Trap *1*	26,000	4,000	30,000
Trap *3*	26,000	25,000	51,000
Sediment 0–1 cm	26,000	?	11,750

The yearly flux of DM into sediment trap *1* is rather close to the yearly amount of deposited matter during the last decades. The difference between the total amounts and composition of fluxes into traps *1* and *3* is significant. The 1.6 times greater amount of total DM in trap *3* (Fig. 5) and higher content of mineral matter in it indicate to intensive erosion and resuspension of matter in the near-shore area. The proportion of planktonic organic matter is also the biggest in this trap.

As to AP and SFAP, the fluxes into the Tauber traps reflect the atmospheric input (*Atm*). It is more complicated to differentiate between *Catch* and *R*. As L. Matsimäe is mainly surrounded by mire and no streams flow into the lake, particulate matter can be carried to the lake only with meltwater in early spring when the surface is still frozen. Otherwise the mire surface is a good filter for particles. Especially remarkable is the impact of catchment and erosional effects on the fluxes into sediment trap *3* placed near the shore. Assuming that the atmospheric influxes were comparable in different years it is possible to roughly estimate the SFAP fluxes into different collectors (Table *4*).

It seems that the most important factor in the resuspension of SFAP is the transport of particles in the water together with the finest fraction of mineral matter. It is especially remarkable during the autumn overturn period (period II). This factor may cause also certain differences in the yearly fluxes to the sediments. The average annual influx of SFAP into trap *3* is 1.8 times higher than into trap *1*. At the same time the calculated annual accumulation of particles in the Tauber trap is similar to the sediment trap *1*. The big differences between the fluxes into the Tauber and sediment traps in 1996–1997 and in the sediments give evidence about complicated and not yet clear mechanisms in the formation of SFAP fluxes. The SFAP content in the upper 0.5 cm sediment sample taken in 1994 in the same area in L. Matsimäe as the 1996 core was twice as high. This supports the assumption about great temporal variability of SFAP in sediments caused by their good ability to migrate together with finest mineral particles.

The great differences in AP fluxes into sediment traps *1* and *3* (Fig. 5) suggest strong influence of the catchment, which is first of all expressed here by the direct fall of pollen from vegetation growing on the shore. The resuspension is more clearly expressed during periods II and III when the influx to the near-shore trap *3* is three times as high as into trap *1*. Assuming that differences between the numbers of AP in trap *1* and the Tauber trap during period I were caused by resuspension and differences between the AP in traps *1* and *3* by the catchment effect it is possible roughly estimate the AP fluxes (Table 5).

Table 5. **The Fluxes of AP, No cm^{-2} yr^{-1}**

Sample	*Atm*	*Catch*	*R*	Total
Tauber trap	12,300	–	–	12,300
Trap *1*	12,300	?	>2,000	18,300
Trap *3*	12,300	>3700	>15,500	36,500
Sediment 0–1 cm	12,300	–	?	12,150

The results of pollen analyses of the sediment traps were described in more detail by Koff [19]. The seasonal distribution of AP influxes differs from DM and SFAP data. Analysis showed that the main determinant in the AP influx rates in the conditions of the given natural environment and vegetation is *Pinus,* which is known by high pollen productivity, its pollen grains are supplied with aerial sacks, and they have the capacity of covering long distances. Thus, in the areas forested with pines, the quantity of *Pinus* pollen is relatively constant, forming a certain background. The production of *Betula* pollen could also be relatively high, but with pine predominating, this influx rate is lower. Alder is not a high pollen producer and high values of *Alnus* pollen are mainly associated with the local impact. Thus, the highest content of *Alnus* was found in trap *3*, located closer to the shore where alder is growing.

If we consider that main flowering time is covered by periods I (pollen of *Pinus, Betula, Picea*) and III (pollen of *Alnus* and *Betula*) [19] then the calculations show that about 65 % of annually sedimented AP in trap *1* and only 35 % of that in trap *3* are of direct atmospheric origin. The remaining part of AP in the traps has been redeposited. During period I the number of AP in trap *1* was quite similar to the number deposited into the Tauber trap. This means that in the deeper area of the lake the proportion of redeposited pollen is small during the time of high pollen production. During periods II and III the AP influx values in trap *3* exceeded those in trap *1* respectively 2.5 and 3.2 times (Fig. 5). The reason is a higher importance of the local pollen rain close to the shore and partly also horizontal wind transport. The up to two times higher AP/DM ratio during period II compared with period I indicates to essential differences in the pathways of pollen and DM in the lake, especially in autumn and winter. The differences in the annually deposited AP number per DM unit to traps *1* and *3* are about 30 %.

There is no evidence about forest fires in the vicinity of the lake during the study year and charcoal particles must have originated from fireplaces near the lake or have been transported by the atmosphere. The distribution of CP in traps is quite similar to that of SFAP and AP. The amount of CP accumulated into trap *3* is up to three times as high as of trap *1*. The influx into trap *3* was especially high during period II, which shows that charcoal particles have also high uptake ability during the autumn overturn and redeposition. The flux of charcoal particles is relatively slow in springtime, which shows their small inflow from the catchment by meltwater.

The content of AP and SFAP per unit of DM gave some additional information (*Table* 2) for the analysis of the pathways of various compounds. During periods I and II the AP/DM and SFAP/DM ratios in traps *1* and *3* are practically similar showing that the migration pathways for all compounds are similar. However, during period III the ratio SFAP/DM is ca 2.5 times and the AP/DM ratio even 7.3 times higher in case of trap *3* than in trap *1*. Thus, during this period the pathways of influxes are different: as the SFAP are mainly carried by meltwater from the catchment, pollen in sediment trap *3* might have originated from trees growing immediately on the shore in the vicinity of the trap.

The main spatial regularity in the matter distribution in the lake is the largest amount of the studied indicators (DM, pollen, SFAP, CP) in trap *3* (Table 2; Fig. 5), which was exposed close to the shore. This is evidence of an important role of erosion and influx from the catchment in the matter cycling in the lake. As to temporal distribution of the flux, different indicators had different patterns. In period I up to half of the annual amount of DM and AP fluxes settled into sediment trap *3*. This is normal, because this is the time interval when the settling of planktonic matter takes place and also the period when most trees produce pollen.

The high proportion of SFAP can be explained by the small sizes of the particles and their longer retention time in the water column during the overturn periods. During period II the lake was mostly (from December up to the end of the period) covered with ice and atmospheric and catchment fluxes were practically absent. Therefore the redeposited matter plays the most important role in the total flux of suspended matter, accounting in the near-shore area for up to 30 % of the annually sedimented SFAP and up to half of AP. The flux during period III is mainly formed from the matter deposited into the lake surface and also on nearby catchment during the period of ice cover.

Sediment Records

The good temporal fit of the reference levels on the time–depth curve (Fig. 4) speaks about a rather even sedimentation rate of DM during the whole studied interval. The sediment composition in the core is also rather regular. Except the depth 3–7 cm, which has higher concentration of mineral matter, the core shows only a regular increase in the density of sediments caused by compaction and decreasing of water content downwards. Certain trends in the C/N ratio (Fig. 2) and pigment content from the depth of 7 cm upwards we correlate with the accelerated use of L. Matsimäe for recreational purposes [11].

The building of a sauna and a swimming pool may have caused an increase in nutrients and bioproductivity, which is reflected in the increase of the proportion of protein-rich plankton and pigments in sediments. The dating of the core shows that this event took place in AD 1955 (1953?) (depth 6–7 cm), which is in good accordance with the creation of a recreational area here. It is interesting to note that diatoms appear in sediments only from the depth of 7 cm. It is known that the main growth regulating factors of diatoms are turbulence, temperature and nutrients availability [21].

The most characteristic feature of the pollen diagram is a continuous increase in the proportion of *Pinus* and a decrease in *Betula* pollen from a depth of 20 cm upwards. Most probably it is connected with drainage of the surrounding mires for expanding pastures and improving the forest quality. According to the land use map for 1875 on the esker on the western shore of the lake was a narrow field with an area of approximately 15 ha following the shape of the esker. This means that the farm existed there already before 1875. In the upper part of the sediment the proportion of *Betula* pollen decreases at a depth 8–6 cm and a significant increase in *Gramineae* pollen can be observed at a depth of 6–7 cm. This level is dated as the 1950s and correlates with the construction of the swimming pool and recreation area on the shore suitable for the growth of birch.

Distribution of CP in the sediment core (Fig. 3) shows that the influx of charcoal particles was relatively low in the lower part of the core but it increased in the layers forming since 1940s. Assuming that an increase in the content of large charcoal particles is evidence of fires in the vicinity of the lake, we can say that major fires (or increase in human activity – households, camps, etc.) took place in the 1940–1945, 1955–1960 and 1980–1990. Most probably the presence of charcoal particles indicates intensification of forestry work and gravel mining in the middle of 20th century and burning branches and bushes. Further research is needed to ascertain whether the burning of forest or branches by clear cutting and making arable land were simultaneous or whether large charcoal particles have a tendency to sink deeper into sediment.

The temporal correlations between the main events affecting the lake ecosystem and changes in the sediment records are in good correspondence with our previous conclusions about the stabile sedimentation conditions in L. Matsimäe during the last decades.

Conclusions

Comprehensive study of the process of resuspension and spatial-temporal matter fluxes in the L. Matsimäe showed significant differences between various seasons and different morphological areas of the lake. During the summer stratification period mainly primary sedimentation took place. Based on the data from the sediment traps during this time, the DM, AP and SFAP fluxes in the lake are the most even. After the autumn overturn the sediment matter will suspend and distributed laterally. Approximately 30 % of annual sediment matter will redeposit during this period. Resuspension of sediments and their downward transport are more intensive during the autumn and spring overturns, especially near the shore. In deeper parts, their scope is smaller. Therefore, sampling in the central part of lake is very important for palaeogeographical reconstructions.

There are differences in the distribution and resuspension of different indicators. The SFAP have similar pathways with DM but pollen suspension seems to be bigger and it is possible that in near-shore areas the relative enrichment of sediment matter with pollen occurred.

As the study of the sedimentation processes demonstrated, in the deeper part of L. Matsimäe seasonal matter flows caused by resuspension and sediment focusing fluxes are essential and may cause serious smoothing of seasonal palaeoecological information. Redeposition, in any case in the deeper areas of the lake, does not affect the reliability of the reconstruction of the trends in the biogeochemical cycling of matter in the lake. This assumption is supported by good accordance between yearly influxes of DM and AP into Tauber and sediment traps with consequent mean annual values obtained by study of the sediment core.

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