VESIENTUTKIMUSLAITOKSEN JULKAISUJA
PUBLICATIONS OF THE WATER RESEARCH INSTITUTE **49**

VESIHALLITUS—NATIONAL BOARD OF WATERS, FINLAND
Helsinki 1982

Tekijät ovat vastuussa julkaisun sisällöstä, eikä siihen voida vedota vesihallituksen virallisena kannanottona.

The authors are responsible for the contents of the publication. It may not be referred to as the official view or policy of the National Board of Waters.

ISBN 951-46-6722-0
ISSN 0355-0982

Helsinki 1983. Valtion painatuskeskus

THE EUTROPHICATION OF SOME PELOTROPHIC LAKES; A PALAEOLIMNOLOGICAL STUDY

Olavi Sandman

SANDMAN, O. 1982. The eutrophication of some pelotrophic lakes; a palaeolimnological study. Publications of the Water Research Institute, National Board of Waters, Finland, No. 49.

Sediment samples were taken from three eutrofic lakes situated in southern Finland in order to clarify their recent evolution. The lakes chosen were lakes Bodominjärvi, Tuusulanjärvi and Ruokojärvi. The oligotrophic Lake Särkinen, situated in sandy soil between moraine deposits, was also included for purposes of comparison. In addition to short samples a long profile sample was also taken from Lake Bodominjärvi, representing the entire independent history of the lake. In addition to the pollen and diatom analyses carried out in this work, the samples were also analysed for organic matter, chlorophyll, pheophytin and in some cases copper and lead. The results were interpreted using numerical taxonomy.

Index words: Palaeolimnology, eutrophication, sedimentation rate, diatom analysis, numerical taxonomy, pelotrophy.

1. INTRODUCTION

Faunal and floral remains and inactive substances deposited on lake bottoms remain in place over long periods of time and thus reflect the prevailing conditions at the time of sedimentation. Examination of sediment profiles therefore provides information concenrning the evolution of the lake and factors affecting it.

The aim of this study was to clarify the process of eutrophication in modern times in south Finnish pelotrophic lakes. As a background to the study a long sediment monolith was taken covering the whole independent history of lake Bodominjärvi. Lake Särkinen, situating further north and in loamy surroundings, was chosen as a basis for comparison. In particular, the significance of mineral material and pelotrophy was discussed.

2. METHODS

The lakes investigated were lakes Bodominjärvi (Espoo), Tuusulanjärvi (Tuusula), Ruokojärvi (Kankaanpää) and Särkinen (Vuokatti) (Fig. 1). With the exception of Lake Särkinen the lakes are all surrounded by clay soils. The lakes are eutrophic and in need of preservation measures. A long profile was cored from Lake Bodominjärvi in 1969. All corings were carried out from the main deeps of the lakes.

Fig. 1. The lakes studied.

2.1 Field work

A monolith of length nearly 5 meters (A) was cored from the deep of Lake Bodominjärvi in March 1969 from the ice-bound surface of the lake using a tripod and a Kullenberg-Winterhalter device (Kukkonen 1973). The short sediment samples from lakes Bodominjärvi and Särkinen were cored with a Kajak-type gravity corer (Hakala 1971). The sample from Lake Tuusulanjärvi was cored with a piston corer, in which the motion of the coring pipe is generated hydraulically. The profiles were ca. 20 cm long and were cut into sheets of thickness 1 cm. The partial samples were stored in Nalgene plastic containers. The samples cored with the Kajak device had a diameter of only 4 cm. Therefore two profiles were taken, one for biological and one, after refrigeration, for physical and chemical analyses.

2.2 Laboratory analyses

The long profile

The long profile was stored in its plastic cover for 6 months. The sediment became partially dried and oxidized during preservation. Visual observations of the clay sediment were thus excluded. The separation of the partial samples was 10 cm, samples being taken from depths of 0–1 cm, 10–11 cm, 20–21 cm, etc.

Pollen analyses were carried out according to the method of Faegri and Iversen (1964). A total of 150 species of arboreal pollen were identified. This number was the basis from which all percentages were calculated.

The analyses of diatoms and loss-on-ignition were carried out in 1976 from dry samples. The diatom preparations were made using a modification of the method of Mölder (1943). The organic part of the samples was destroyed with 30 % perhydrol for 24 hours at 50°C. The diatoms were not concentrated by decanting. The mounting medium was Clophen-harpix and the number of diatoms counted was 200. Identifications were carried out according to the methods of Huber-Pestalozzi (1942), Hustedt (1930a, 1930b, 1959) and Schmidt et al. (1972). The analysis of loss-on-ignition was carried out by burning the predried (105°C) sediment in 600°C to constant weight.

The short samples

Microscopic analyses were carried out as described by Lundqvist (1927). Organic carbon was analyzed by dichromate-sulphuric acid burning (Erkomaa et al. 1977) and the analysis of loss-on-ignition was performed at 600°C. Chlorophyll a was measured accoring to the method of Strickland and Parsons (1968) from sediment samples from the lakes Ruokojärvi and Särkinen. In a later phase of the work this analysis was carried out using the method described by

Lorenzen (1967) (lakes Tuusulanjärvi and Bodominjärvi). The latter method allows measurement of both chlorophyll a and pheophytin. The chlorophyll a unit is not absolute and depends on the method used. Copper and lead were analyzed by nitric acid oxidiation under pressure. The measurement was made using an atomic absorption spectrophometer (Erkomaa et al. 1977).

2.3 Numerical taxonomy

Numerical taxonomy (Sneath and Sokal 1973), i.e. cluster analyses, is a numerical grouping method. It was used here to compare the parameters of separate sediment depths in order to clarify the history of lake eutrophication.

The quantitative primary analyses results were transformed into dichotomous form. The similarity coefficient was Simple Matching, SM (Sneath and Sokal 1973, p. 32) and the clustering was made using the Single Linkage method (Lockhart and Liston 1970, p. 52). The results of grouping were expressed as a phenogram.

3. LAKE BODOMINJÄRVI

Information

Lake Bodominjärvi is situated in Espoo, northwest of the town of Kauniainen and between the lakes Pitkäjärvi and Nuuksio. Lake Bodominjärvi belongs to the river Espoonjoki watercourse and receives water from the lakes Matalajärvi and Luukinjärvi, both of which are eutrophic (Westerling 1960).

The length of Lake Bodominjärvi is ca. 2.5 km and its breadth ca. 1.2 km (Fig. 2). The western and southern shores consist of moraine, while the eastern and northern shores are bounded by fields on clay ground. The area of the drainage basin at the outlet is 28.5 km^2, of which rock and hilly ground with forest account for about 54 %, field 26 % and watercourse 20 % (Hämäläinen 1968).

The volume of influent water is low, and the residence time of Lake Bodominjärvi is over 2 years. The lake is eutrophic and characterized by plankton blooms and occasionally anoxic deeps. As early as 1947 Järnefelt (1956) classified the lake as chtonioeutrophic with pelotrophic features.

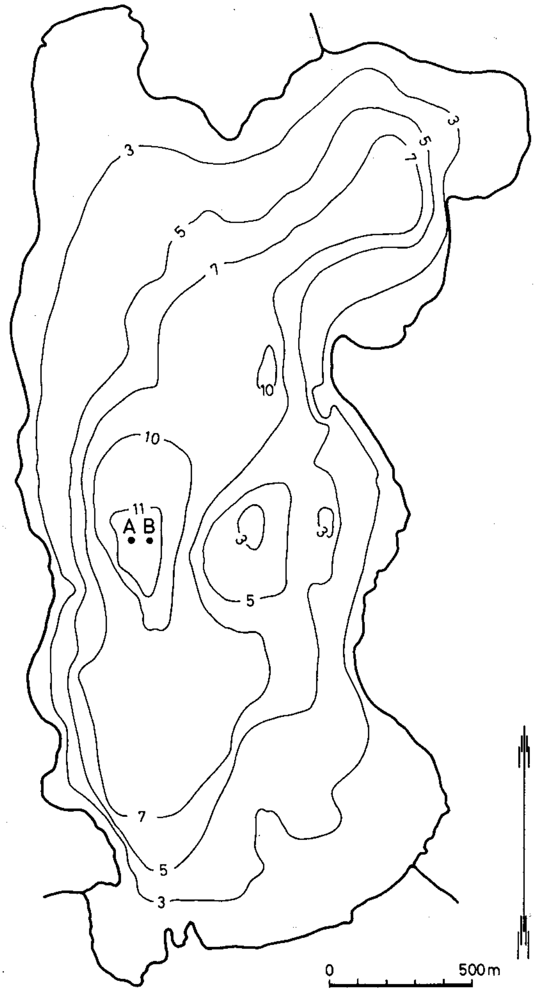

Fig. 2. Lake Bodominjärvi; the sampling stations are A and B. Depth in meters.

3.1 The long profile (Bodominjärvi A)

3.11 Analytical data

The pollen analysis (Fig. 3) was carried out for the dating of the long profile taken in 1969. The lower part of the pollen curve appears approximately to cover the Atlantic and Sub-Boreal periods (zones VI–VIII). The Atlantic period begins with the rise of Tilia in about 6 000 BC (Donner 1971, Fig. 1) and zone VIII ends at the descent of birch, alder, hazel and elm pollen.

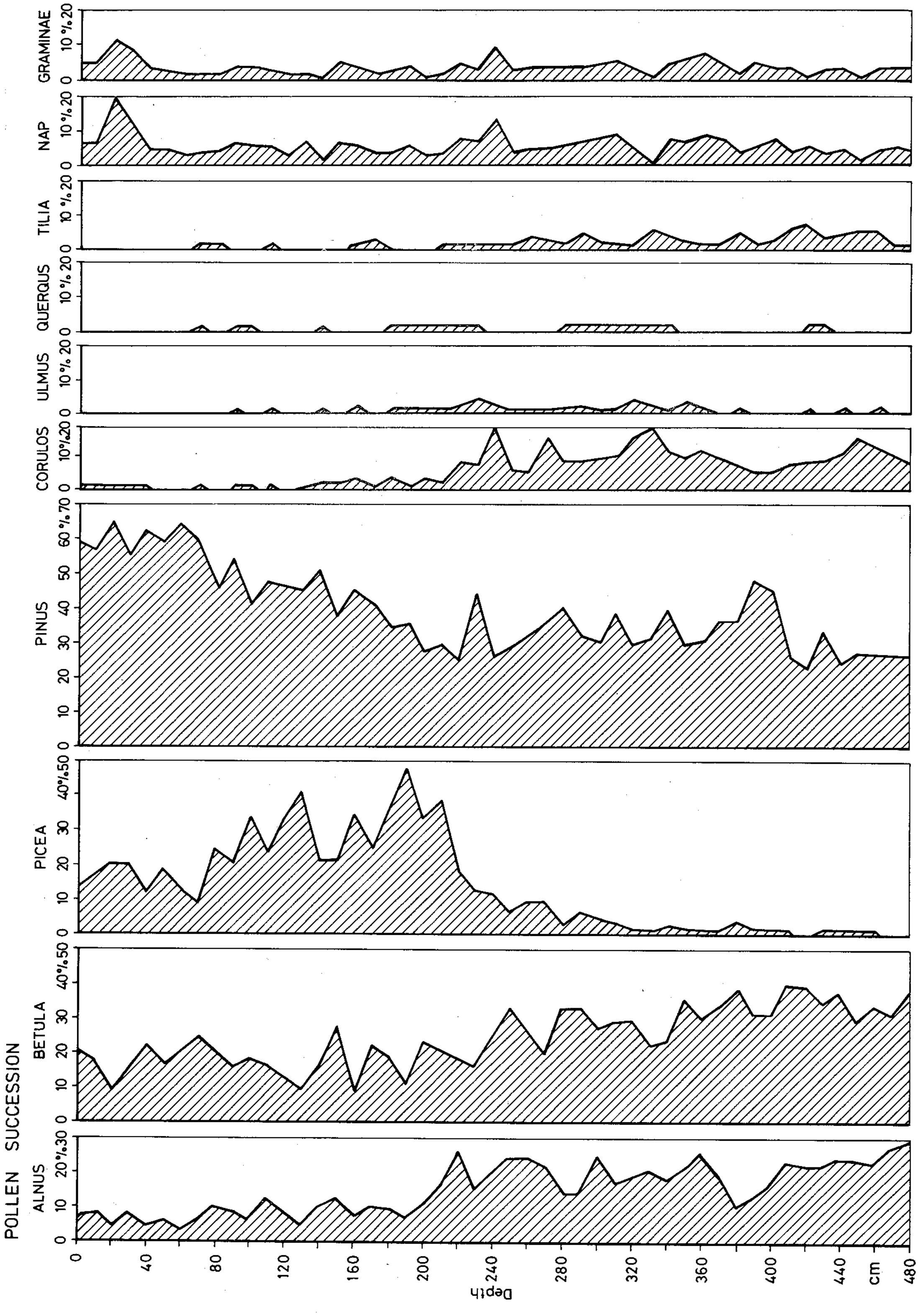

Fig. 3. Pollen diagrams, Lake Bodominjärvi A.

The exact siting of the zone boundary XIII/IX on the Lake Bodominjärvi pollen curve is difficult to specify. The maximum of Picea at the sediment depth of 190 cm is particularly clear and can be dated to about 1 500 BC (Aartolahti 1966, Donner 1972). Due to the small amount of counted non-arboreal pollen, it is difficult to discern any »fingerprints» of human activities.

The results of the diatom analyses are presented in Figure 4 (Bodominjärvi A). The distribution of 100 % has been divided into alkaliphilic and alkalibiontic diatoms, Tabellaria fenestrata, indifferent diatoms and acidophilic and acidobiontic taxa (see Meriläinen 1967). The eutrophic diatoms decrease from 390 cm to 130 cm, while the proportion of oligotrophic diatoms correspondingly increases. The changes in diatom diversity are slight. The somewhat higher diversity at 370 cm and 380 cm results from the presence of halophilic and halobiontic diatoms in these deposits.

The upper part of the diagrams, from 120 cm to the sediment surface, indicate a shift to more

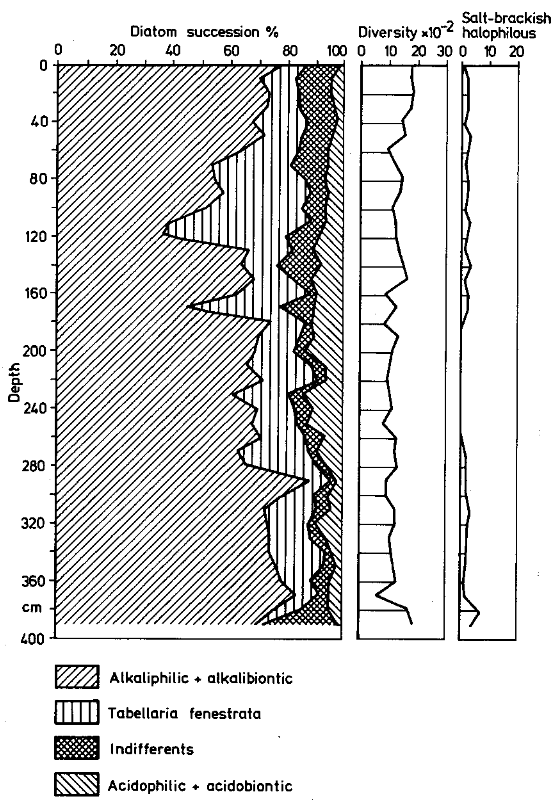

Fig. 4. Diatom diagram, Lake Bodominjärvi A. Diatom diversity = number of species/number of individuals.

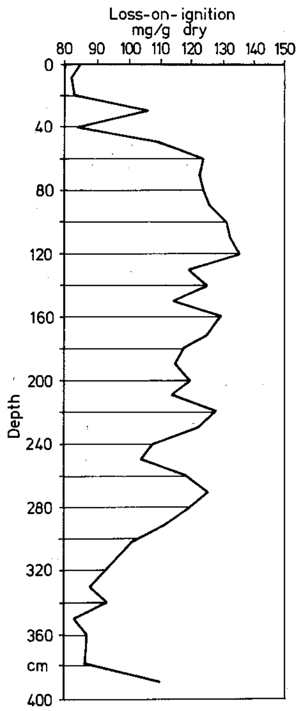

Fig. 5. Loss-on-ignition, Lake Bodominjärvi A.

alkaline (eutrophic) states. Tabellaria fenestrata may also indicate considerable eutrophy. The loss-on-ignition was analyzed from dried samples taken in 1969. The results (Fig. 5) are however obviously reliable, despite the stored age of the samples.

The peak of organic matter at the sediment depth of 390 cm originates from the formation period of the lake. The same phenomenon can be seen in Lake Gallträsk (Alhonen 1972, p. 26). The values of loss-on-ignition begin to increase at a depth of 330 cm and this increase continues to 270 cm, after which the values remain approximately constant for some time before rising to a maximum at a sediment depth of 120 cm. The curve then slopes gently down between the depths of 120 and 60 cm and more steeply between 60 cm and the sediment surface.

The value of loss-on-ignition depends not only on the content or organic matter. Slashing and burning of forests increase erosion and the proportion of mineral material in the sediment. Tolonen et al. (1975) dated the beginning of slashing and burning in southern Finland to the years 700—800 B.C. Increase in the amount of mineral material near the sediment surface has been found at least in the following southern Finnish lakes: Otalampi (Alhonen and Haavisto 1969), Pyhäjärvi (Kukkonen and Tynni 1970), Gallträsk (Alhonen 1972), Lohjanjärvi (Kukkonen 1973), Lojärvi and Lappböleträsk (Tolonen et al. 1975).

3.12 Dating

Lake Bodominjärvi is situated at a height of 22.8 m above sea level. According to the curves presented by Eronen (1974), the isolation of Lake Bodominjärvi occurred at the final phase of the Litorina sea, ca. 3 000 B.C.

In the sediment profile of Lake Bodominjärvi the maximum of loss-on-ignition and the minimum of eutrophic diatoms both occur at a depth of 120 cm. The dramatic fall in loss-on-ignition from 60 cm to the sediment surface, a sign of decreasing productivity of the lake, is not accompanied by corresponding changes in the diatom flora. Thus the increase of alkalibiontic and alkaliphilic diatoms from 120 cm to the sediment surface may be a result of the high pH of water draining to the lake from slash and burn agriculture (Tolonen et al. 1975), and of the movement of nutrients caused by erosion.

A summary of available information concerning sedimentation rates in the long profile of Lake Bodominjärvi is presented in Figure 6. The beginning of the rapid increase in loss-on-ignition values at the sediment of 60 cm occurs about in the year 1870. The population of Finland increased nearly sixfold from 1720 to 1870 AD and agriculture therefore spread rapidly. The generalization of ditching and the development of draining techniques took place in the beginning of the nineteenth century (Soininen 1974).

3.13 The development of Lake Bodominjärvi and the effects of climate

Lake Bodominjärvi was eutrophic or mesotrophic even at its birth. The decrease in the quota of eutrophic diatoms occurred as the climate became colder. The climate worsened during the whole Subboreal (Liljeqvist 1970), a temperature minimum occurring at 600–400 B.C. A warmer period began in ca. 1000–1200 AD,

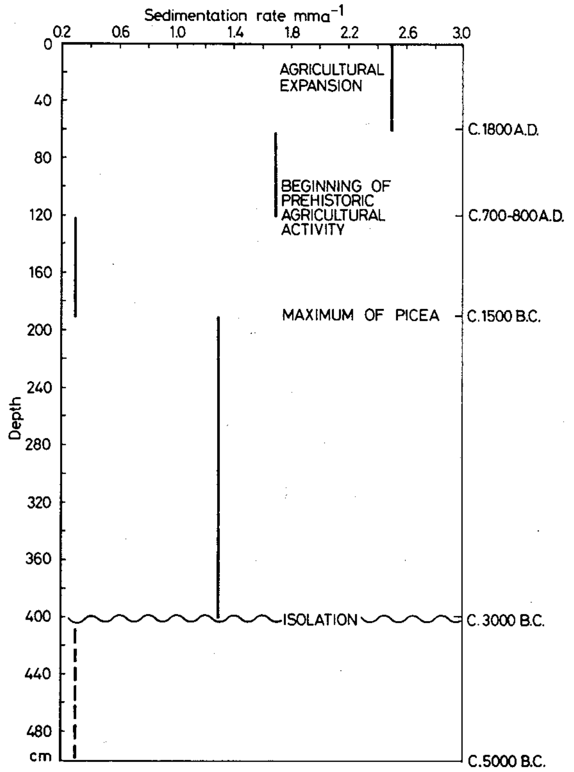

Fig. 6. Sedimentation rates and the corresponding historical interpretations in the sediment core, Lake Bodominjärvi A.

but by about 1300 climate worsened again. This situation lasted until the beginning the nineteenth century. From about 1850 to the nineteen–fourties the weather became warmer.

The effects of man can be seen from the sediment depth of 120 cm upwards, corresponding partly with the influence of the colder climate. Immediately after the isolation of the lake the proportions of eutrophic and oliggotrophic diatoms are nearly the same as at the sediment surface. The influence of climate is also more significant than that of agriculture.

The effects of man appear to be most obvious in the growing proportion of minerogenic matter, a sign of field erosion. The loss-on-ignition decreases in spite of the increasing nutrient level in the lake water. It is obvious that the rapid sedimentation rates of Lake Bodominjärvi result only from the high amount of minerogenic matter, which can mask the increase of allochtonous organic matter in the sediment.

3.2 The sample from the sediment surface (Bodominjärvi B)

3.21 Analysis results

The sediment sample Bodominjärvi B was cored in August 1976. The length of the profile was 21 cm and sample color was a smooth dark gray. The results of the diatom analysis are shown in Figure 7. The curves run rather smoothly to 21–12 cm, after which the proportion of alkaliphilic, alkalibiontic, acidophilic and acidobiontic diatoms diminishes and that of indifferent diatoms increases towards the surface of the sediment. In general, the diatom diversity increases sligthly towards the sediment surface.

The amounts of lead and copper in the sediment of Lake Bodominjärvi are presented in Figure 7. The amount of lead increases slightly to the sediment surface, while the copper content increases steeply from 11 cm, with a maximum at 8–5 cm. After this maximum, the amount of copper decreases to the sediment surface. The high amounts recorded result from the $CuSO_4$-treatment applied during the years 1964–1976.

The developments of loss-on-ignition and organic carbon values are presented in Figure 8. The curves increase to 14–13 cm, after which they level off and in the case of organic carbon even decrease. A slight increase in organic matter begins at about 8 cm.

The pigment results from Lake Bodominjärvi (B) are shown in Figure 8. The amount of chlorophyll increases from 8 cm to the surface of the sediment. The same feature also appears in the pheophytin values. The variation of the ratio between chlofophyll a and pheophytin reflects the varying levels of pheophytin at 21–11 cm. The increase at 2–0 cm probadly represents the change from chlorophyll to pheophytin.

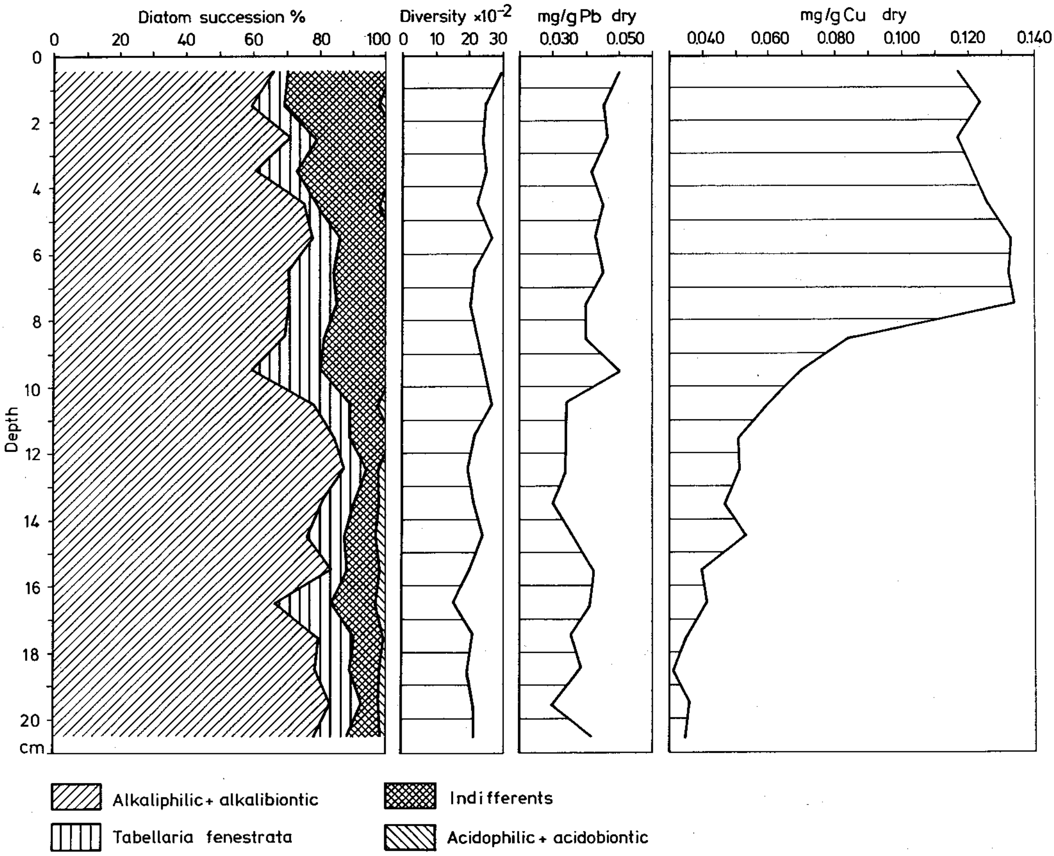

Fig. 7. Diatom diagram and Pb, Cu in the sediment, Lake Bodominjärvi B. Diatom diversity = number of species/ number of individuals.

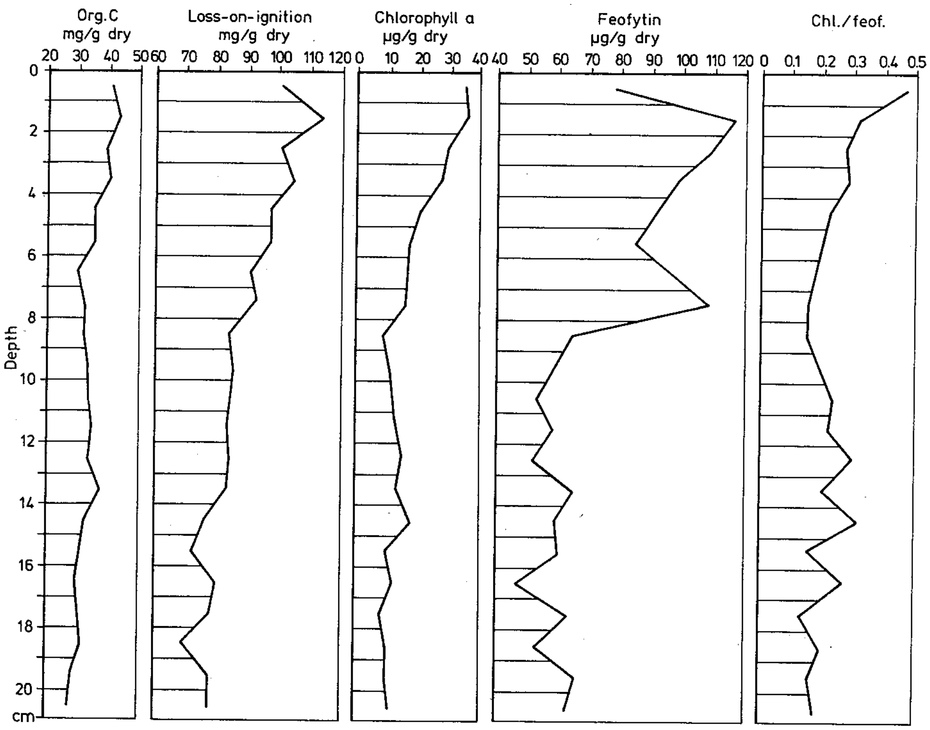

Fig. 8. Organic carbon, loss-on-ignition, chlorophyll a (Lorenzen) and pheofytin (Lorenzen) in sediment, Lake Bodominjärvi B.

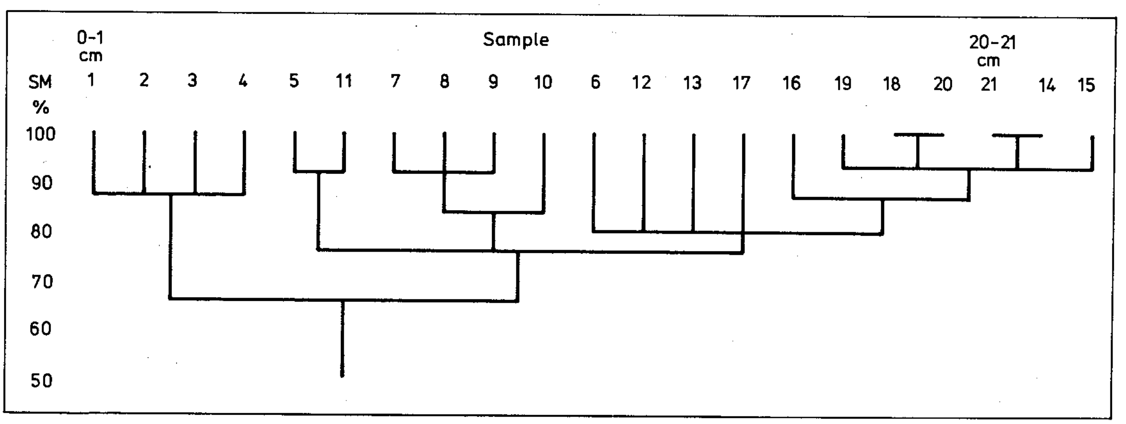

Fig. 9. Phenogram of the analysis results from Lake Bodominjärvi B. sediment depths 0–21 cm.

3.22 The evolution of the lake (Bodominjärvi B)

The phenogram (Sneath and Sokal 1973) from the analytical data of Lake Bodominjärvi (B) is presented in Figure 9. It can be seen that there is a clearly separate group consisting of the four highest centimeters 1, 2, 3, 4 (0–1 cm, 1–2 cm, 2–3 cm, 3–4 cm). It is possible that the algisidic copper sulphate hampers the interpretation of this phenogram. The proportion of alkaliphilic and alkalibiontic diatom taxa decreases from ca. 12 cm to the sediment surface, while that of the indifferent diatoms increases. The acidotrophic and acidobiontic diatoms also decrease from 12–10 cm to the sediment surface. Correspondingly the amount of sedimented copper (Fig. 7) increases from 11–10 cm upwards.

Iskandar and Keeney (1974) studied the sediments of lakes treated with copper sulphate. The surface sediments had predictably high copper contents. The maximal were unified to a single rounded peak rather than appearing as sharp discrete peaks. The smooth fall to the sediment surface remains unexplained. Lake Bodominjärvi was treated with copper sulphate for the first in 1964 (Hämäläinen 1968) and subsequently in the years 1966–1970. In 1967 the treatment was applied twice.

The maximum of copper correlates in all probability with the years 1966–1967. The average sedimentation rate would in this case be ca. 8 mm a^{-1}. The decrease in copper content towards the surface begins at 5 cm, and if this is assumed to have occurred after 1970 the corresponding minimum sedimentation rate is 10 mm a^{-1}.

The coordination of the two samples, Bodominjärvi A and B, is difficult. Samples taken with the large piston corer often lack the loose surface layer of the sediment (Dr. Esa Kukkonen, Geological Survey of Finland, personal communication).

4. LAKE TUUSULANJÄRVI

Lake Tuusulanjärvi is situated between the towns of Järvenpää and Tuusula, southwest of the centre of Järvenpää. The lake is part of the river Vantaanjoki watercourse. The area of lake Tuusulanjärvi is 6 km^2, its maximum breadth is ca. 1.5 km and its length ca. 8.1 km (Fig. 10). The theoretical residence time is 220 days.

The environs of Lake Tuusulanjärvi are characterized by dense population and intensive farming. Fields account for ca. 42 % of the drainage basin (Järnefelt 1921, Anttila 1967, Harjula 1971).

4.1 The sample from the sediment surface

As a preliminary operation Lake Tuusulanjärvi

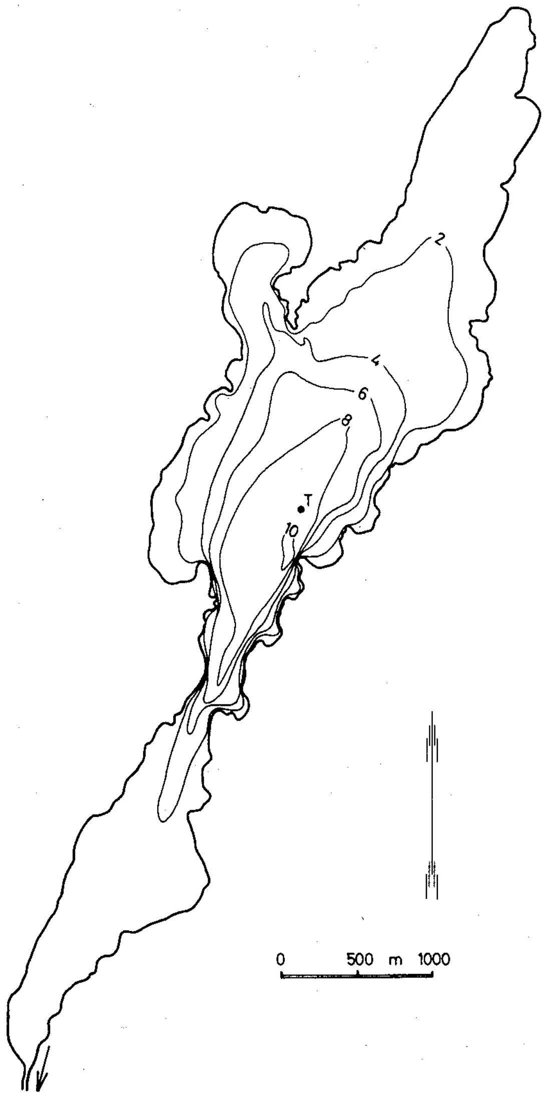

Fig. 10. Lake Tuusulanjärvi, the sampling station is T. Depths in meters.

was echosounded with an Atlas echograph (30 kHz). Gas was observed in the sediment at the northern part of the lake in water depths in excess of 1.5 m. The presence of gas was revealed by multiple echos. This observation was confirmed during coring as dubbles in water and cavities in sediment samples. The gas was odourless and almost certainly carbon dioxide.

The 20 cm sediment profile was taken from the deep of Lake Tuusulanjärvi in May 1975.

The sediment of Lake Tuusulanjärvi was clayey and dark but no odour of hydrogen sulphide was detected.

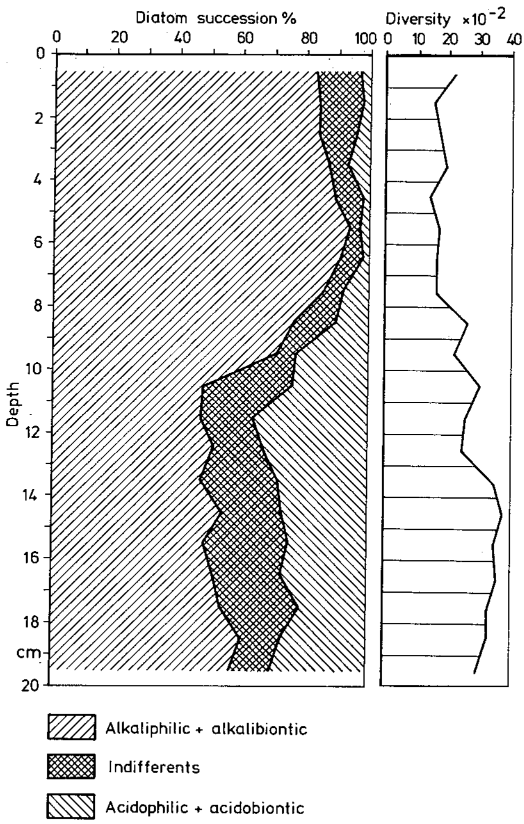

Fig. 11. Diatom diagram, Lake Tuusulanjärvi T. Diversity = number of species/number of individuals.

4.11 Analytical data

The diatom data are shown in Figure 11. The levels below a depth of 11 cm give an impression of a stable period. The trend is however perhaps towards a more acid environment. In the upper part, 11–0 cm, a clear change to eutrophy occurs, with a peak at 7–4 cm. Alkaliphilic and alkalibiontic diatoms account for 94 % of the total flora in these strata. Towards the sediment surface their amounts decrease.

The percentage changes in the amounts of Melosira ambigua and Stephanodiscus hantzschii are presented in Figure 12. The proportions of these species are inversely related. According to Pascher (1930) and Huber-Pestalozzi (1942) Stephanodiscus hantzschii is a typical diatom of strongly eutrophic waters, whereas Melosira ambigua thrives in somewhat more oligotrophic conditions. In the course of eutrophication the peak of M. ambigua is followed by a maximum of S. hantzschii. At the sediment surface M. ambigua again dominates indicating a recent trend towards decreasing eutrophy.

The period of accelerated eutrophication began in Lake Tuusulanjärvi during the years 1956–1957 (Anttila 1967). If the observed shift in the diatom data at 10 cm reflects the change described by Anttila, we arrive at a medium sedimentation rate of 5 mm/year. According to information obtained from Helsinki town water works (Tapani Vakkuri, personal communication) a recovering phase occurred in 1972–1973 after the eutrophication peak. The reason for this was in part the decrease in the sewage load from Tuusula and Järvenpää. An aeration experiment carried out in the winter of 1972–1973 prevented phosphorus mobilisation from the sediment.

The changes in loss-on-ignition and organic carbon data in the sediment core at 25 cm are shown in Figure 13. The quantity of organic carbon increases at a sediment depth of 13–12 cm. The curve of loss-on-ignition is unstable and the increase in organic matter slow. There is a distinct rise in both curves at a sediment depth of 5 cm, with a preliminary minimum at 7–5 cm. The change in the 5 cm sample was visually evident.

The chlorophyll data are shown in Figure 13.

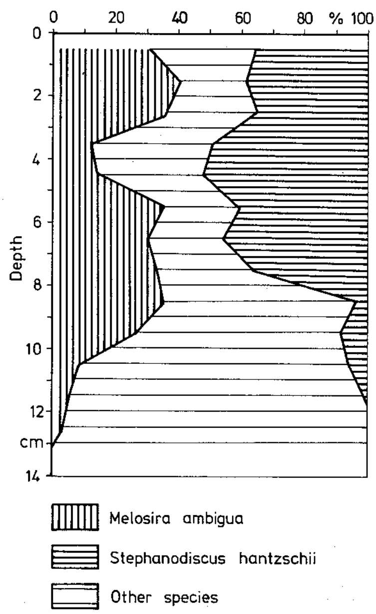

Fig. 12. Diatom diagram, Lake Tuusulanjärvi T; The proportions of Melosira ambigua and Stephanodiscus hantschii.

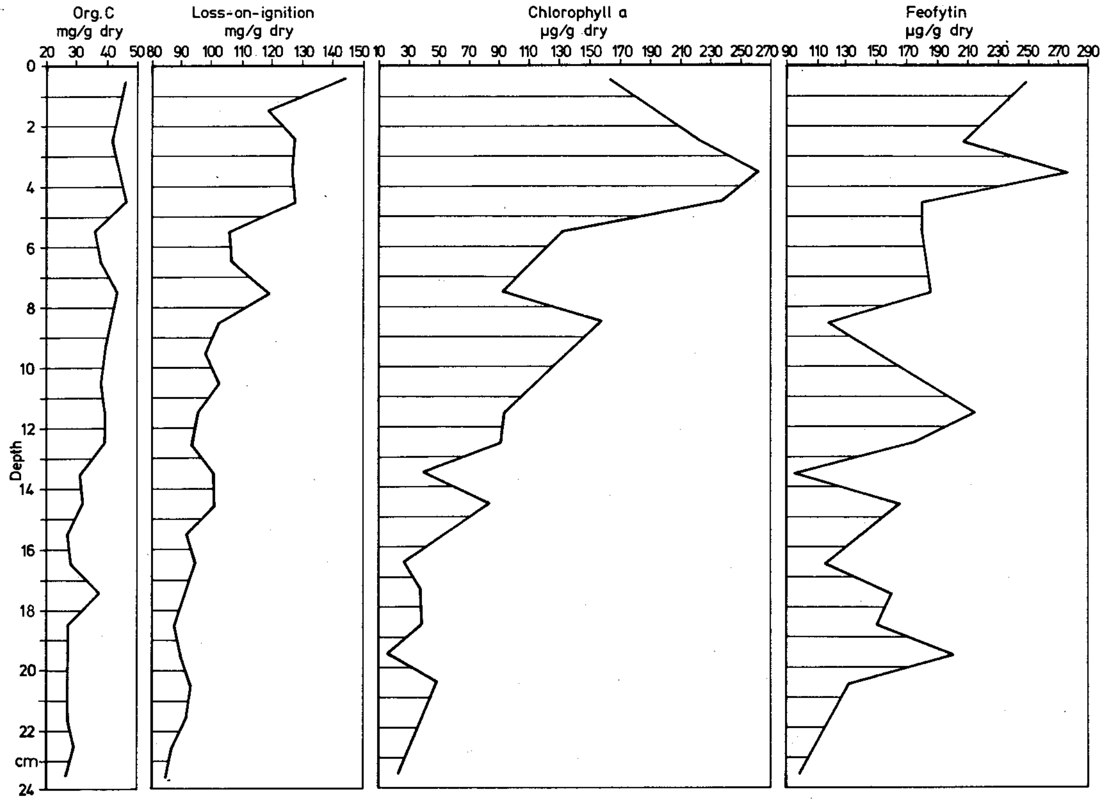

Fig. 13. Organic carbon, loss-on-ignition, chlorophyll a (Lorenzen) and pheophytin (Lorenzen) in sediment, Lake Tuusulanjärvi T.

Changes were recorded in chlorophyll a and pheophytin values. The chlorophylls decompose in the water phase and in the oxygenated upper layer of the sediment but not in the deeper levels of sediment (Vallentyne 1955). The observed changes therefore reflect the decrease in absolute chlorophyll levels or the increasing proportion of mineral material or both.

A pigment maximum occurs at 4—3 cm, followed by a clear fall in chlorophyll a values The pheophytin curve is unstable.

4.12 The evolution of the lake

The phenogram (SneathandSokal,1973)obtained from the analytical data of Lake Tuusulanjärvi sediments is shown in Figure 14. The phenogram is dichotomous, with the sediment depth of 9—8 cm mediating between the two peaks. There is little difference between the similarity levels. Differences less than 5 % are not taken into account.

The clearest picture of the recent evolution on Lake Tuusulanjärvi is provided by diatom analysis. The eutrophication process is accelerated from the sediment depth of 10—8 cm. On the basis of observations by Anttila (1967) we obtain a mean sedimentation rate of 5 mm/a for the 10—0 cm levels. Information obtained from Helsinki town water works (Tapani Vakkuri, personal communication) concerning the eutrophication peak in 1970 indicates a sedimentation rate to the topmost 5 cm sedimentlayer of nearly 10 mm/a. This rapid sedimentation rate arises partly from the loose consistency of the surface sediment.

There is some correspondence between the pigment- and loss-on-ignition results, but diatom analysis gives a rather different picture. It can however be established that the pigment maximum at 5—3 cm is almost at the same sediment depth as the Stephanodiscus hantzschii maximum and the maximae of loss-on-ignition and

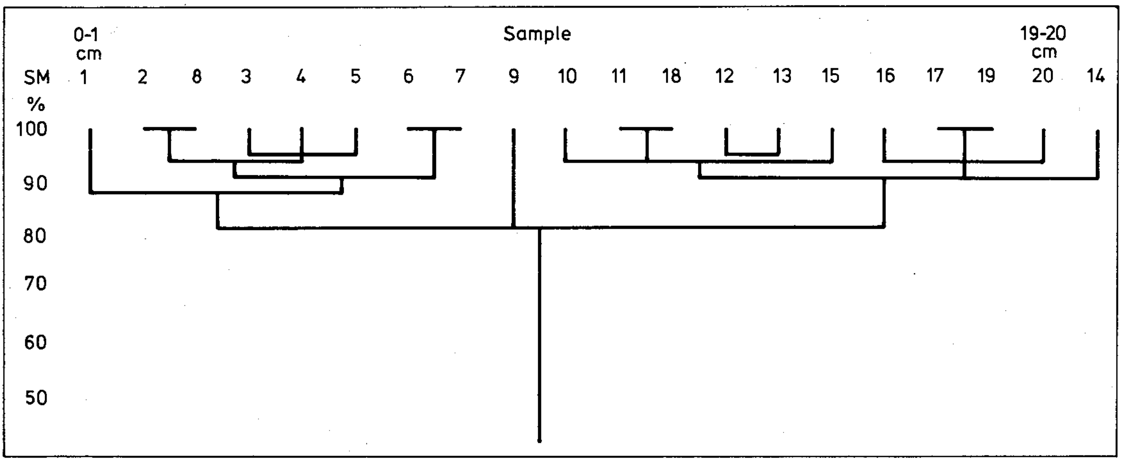

Fig. 14. Phenogram of the results from Lake Tuusulanjärvi T; sediment depths 0–20 cm.

organic carbon.

There is no decrease in the values of organic carbon and loss-on-ignition in the sediment depth 3–0 cm corresponding to that in the pigments. This feature points to the decomposition of pigments and the possible effect of aeration (Daley and Brown 1973). A slight recovery in the status of Lake Tuusulanjärvi is also possible, as the proportion of the eutrophic diatoms decreases at the sediment surface and Melosira ambigua and Stephanodiscus hantzschii fluctuate, indicating a slight healing of the lake.

5. LAKE RUOKOJÄRVI

Lake Ruokojärvi is situated south of the town of Kankaanpää, in the river Karvianjoki watercourse. The area of the lake is nearly 100 ha, its length is ca. 2.2 km and its breadth is about 0.2 km. The lake is shallow, with a mean depth of 1.9 m and a maximum of 4.1 m (Fig. 15). The theoretical residence time is about 170 days. The water flora is abundant, especially near the NW-shore and in the shallow Seppälänlahti bay. Fields account for 30 % of the drainage basin of Lake Ruokojärvi (Vesihallitus 1974).

Lake Ruokojärvi is a eutrophic lake, characterized by high primary production, high summer biomass levels and oxygen deficiency in winter. At times during late winter the whole watermass has been anoxic. The oxygen level is also on occasion low in summer.

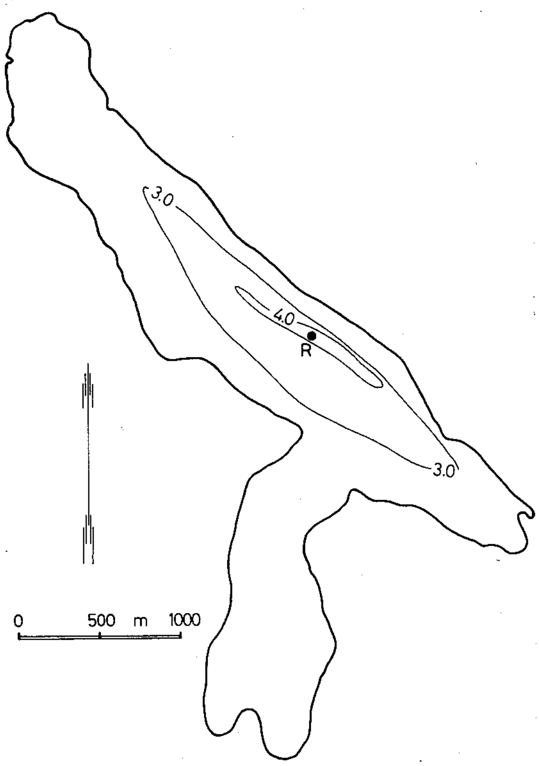

Fig. 15. Lake Ruokojärvi, the sampling station is R. Depths in meters.

5.1 The sample from the sediment surface

5.11 Analytical data

The coring was carried out in the late winter of 1974. The sediment monolith was clayey gyttja containing sulphides and its length was 18 cm. The proportion of alkaliphilous and alkalibiontic diatoms was about 90 % (Fig. 16). The run of the curve was smooth. The increase in mean alkalinity continued at least to a sediment depth of 10–9 cm. The possible changes to more acid conditions occurred at sediment depths of 6–5 cm and 1–0 cm.

The maximum of the dominating species, Melosira ambigua, occurred in the sediment depth 7–6 cm. Near the surface the proportion of Stephanodiscus astraea increased considerably, to a maximum at a depth of 3–1 cm. Stephanodiscus astraea is an alkalibiont, but M. ambigua also occurs in oligotrophic watercourses (Huber-Pestalozzi 1945).

A very sligth improvement in the status of the lake at the topmost centimeter appears to be genuine, as it was indicated by all the diatom parameters analyzed.

The variation in the values of loss-on-ignition and organic carbon in the 25 cm long sediment core is shown in Figure 17. In the nine-ten deepest centimeters there is a steady increase in the amount of organic matter. This increase is followed by an intermediate phase at 16–7 cm, perhaps due to the increased proportion of minerogenic matter. Visual observations indicated that the sediment was less clayey above 7 cm, and this was also confirmed by the loss-on-ignition curve.

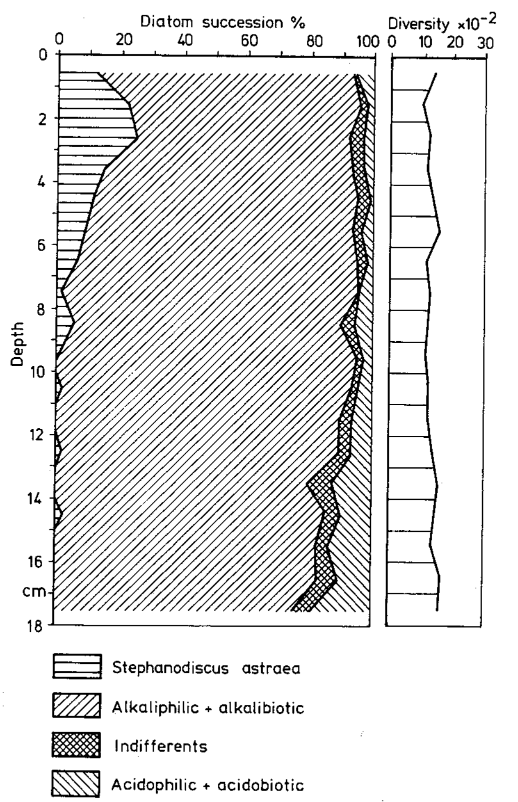

Fig. 16. Diatom diagram, Lake Ruokojärvi R.Diversity = number of species/number of individauls.

The chlorophyll analyses were carried out according to the method of Lorenzen (1967). The sediment profile was 25 cm long (Fig. 17). The chlorophyll curve resembled the corresponding curve of organic carbon, and increased steeply from a sediment depth of about 5 cm to the surface. It is possible that chlorophyll decompisition occurs mainly in the topmost 5 cm of the sediment. Influencing factors include oxygen and light (Daley and Brown 1973).

5.12 The evolution of the lake

Figure 18 is a phenogram of the similarities between the samples 1 (0–1 cm) to 18 (17–18 cm) (Sneath and Sokal 1973). The samples 1–7 (0–7 cm) are clearly distinct, indicating accelerated evolution of the lake due to human activities.

6. LAKE SÄRKINEN

Lake Särkinen is situated in the parish of Sotkamo, southeast of the Vuokatti village. Its length is ca. 2 300 m and breadth 700 m (Fig. 19). The residence time is about 2 years.

The surroundings of the lake are mainly pine forest and the soil is composed of sand and silt. The drainage basin is 3.8 km^2, of which about 8 % is cultivated. In the immediate vicinity of Lake Särkinen are situated the Vuokatti institute of athletics and a holiday centre of the state railways.

Lake Särkinen is a eutrophic lake characterized by waterblooms and anoxia of the deep water in winter. According to information obtained from the Kainuu water distric office (S-L. Markkanen, personal communication), the first clear signs of eutrophy appeared after the middle the nineteen-sixties.

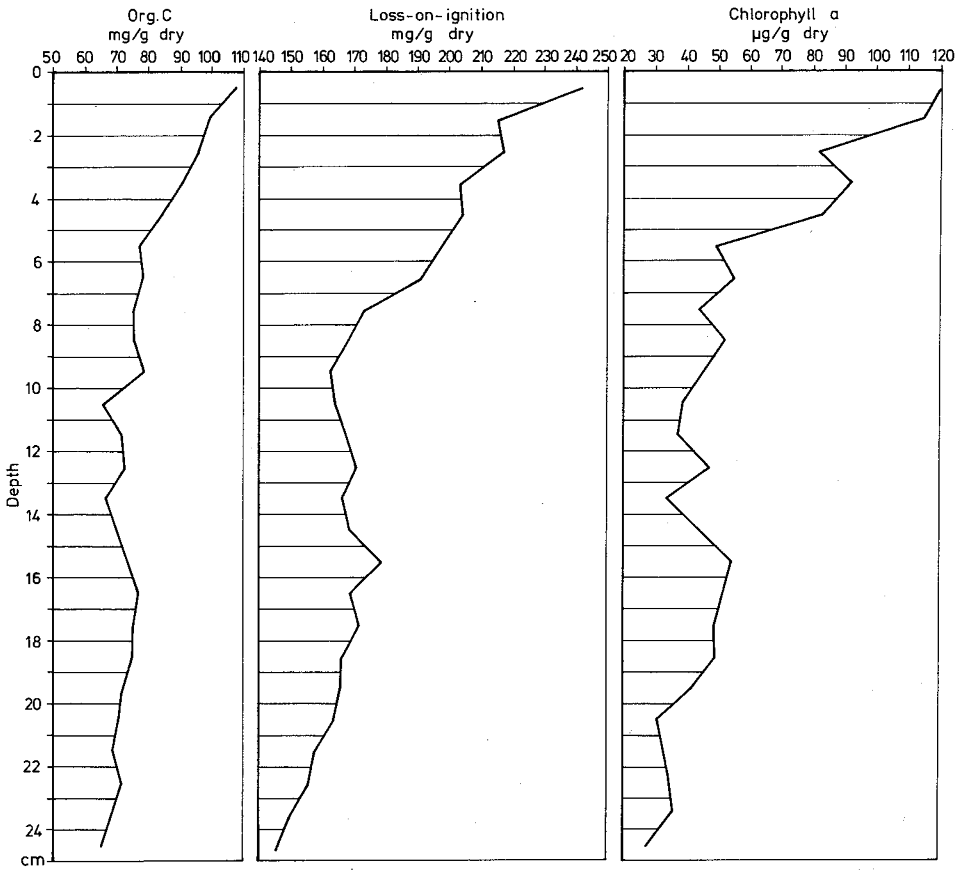

Fig. 17. Organic carbon, loss-on-ignition and chlorophyll a (Strickland and Parsons 1952) in sediment, Lake Ruokojärvi R.

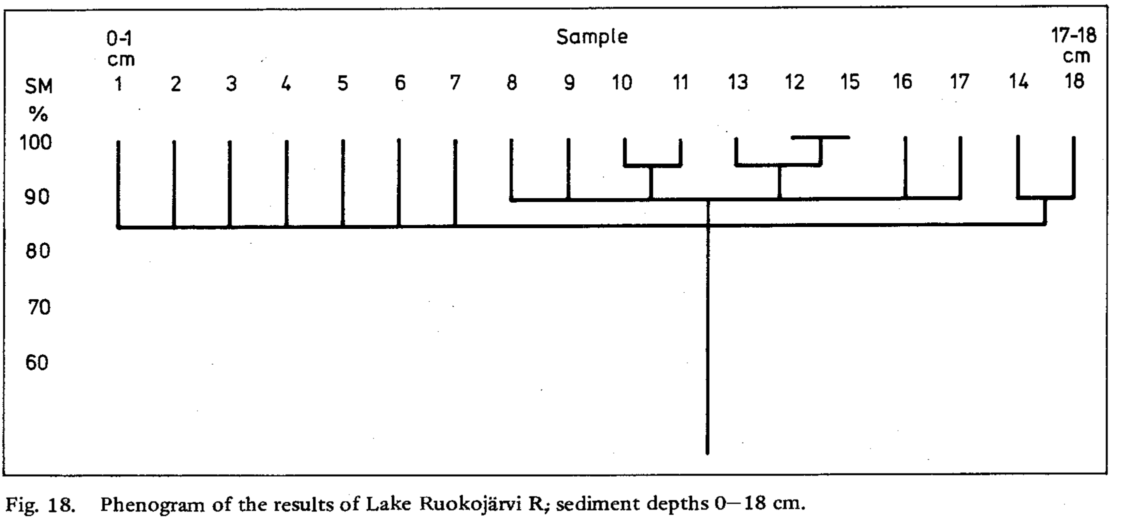

Fig. 18. Phenogram of the results of Lake Ruokojärvi R; sediment depths 0—18 cm.

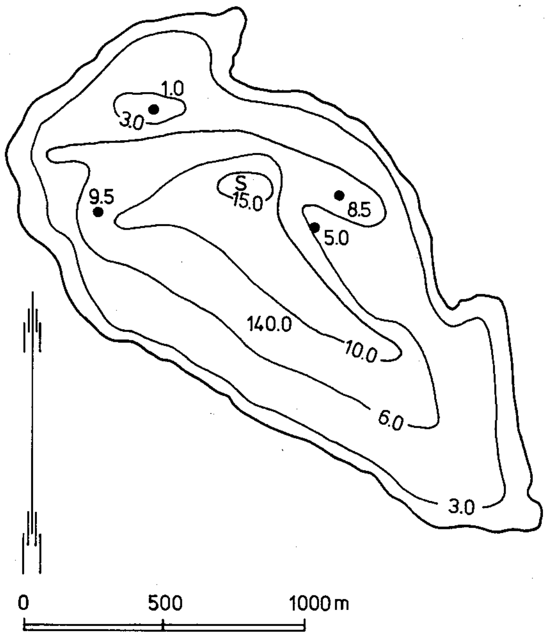

Fig. 19. Lake Särkinen; the sampling station is S. Depths in meters.

6.1 The sample from the sediment surface

6.11 Analytical data

The sediment sample from Lake Särkinen was taken in 1974. The profile was greenish brown in colour and visually homogenous.

The evolution of the diatom flora is shown in Figure 20. The proportions of alkaliphilic and alkalibiontic taxa vary. This result may partly be due to the high diatom diversity and the limited number (100) of diatom fossils counted. The evolution of the lake neverthless appears to proceed towards more eutrophic conditions.

The proportion of Tabellaria fenestrata may indicate an increasing but moderate eutrophication in a pelotrophic lake. The clear rise of T. fenestrata begins at a sediment depth of about 5 cm and continues to 3–2 cm. In the two top centimeters the proportion of diatoms reflecting stronger eutrophication, e.g. Asterionella formosa and Fragilaria crotonensis. increases to 79 %.

It is difficult to pinpoint the exact time of the beginning of severe eutrophication, but the sediment depth of 5 cm may be the nearest estimate. If the year ca. 1965 does in fact represent the start of more severe eutrophication we arrive at an aproximate sedimentation rate of about 5 mm/a for the topmost 5 cm.

The results of loss-on-ignition and organic carbon analyses are shown in Figure 21. The increase in the proportion of organic matter continues to ca. 20 cm, after which the values are almost constant to 12–11 cm. Thereafter occurs a steep decrease, to a minimum at a sediment depth of 6–5 cm. After this follows a rapid increase in organic matter to the sediment surface.

The decrease of 20 % to 6–5 cm can only result from the increased proportion of minerogenic matter. If it is assumed that the proportion of organic matter was constant, the increase in minerogenic matter must have been at least threefold and correspondingly that of the sedimentation rate nearly twofold. The causes of the increase in the proportion of minerogenic matter could be the construction of the Nurmes-Sotkamo railway and of the road from Vuokatti to Valtimo during the years 1924–1928. Later, erosion has been increased by the construction of the Vuokatti institute of

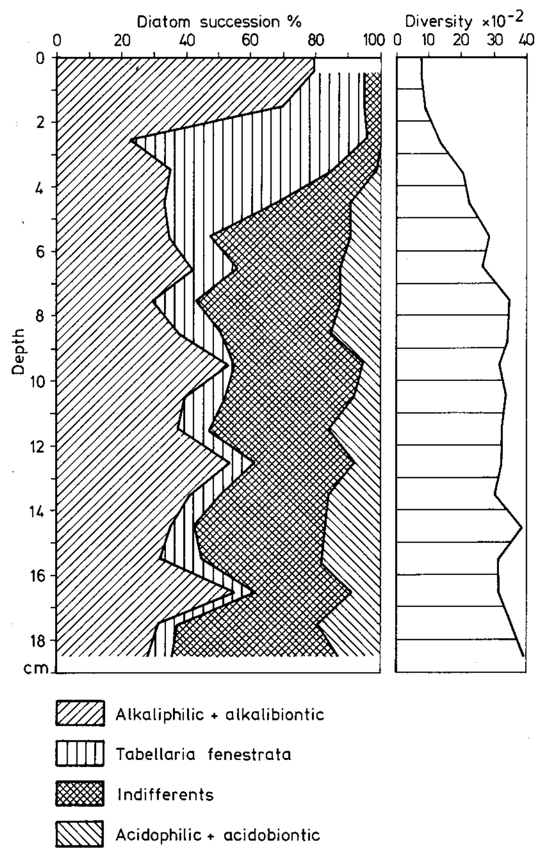

Fig. 20. Diatom diagram, Lake Särkinen S. Diversity = number of species/number of individuals.

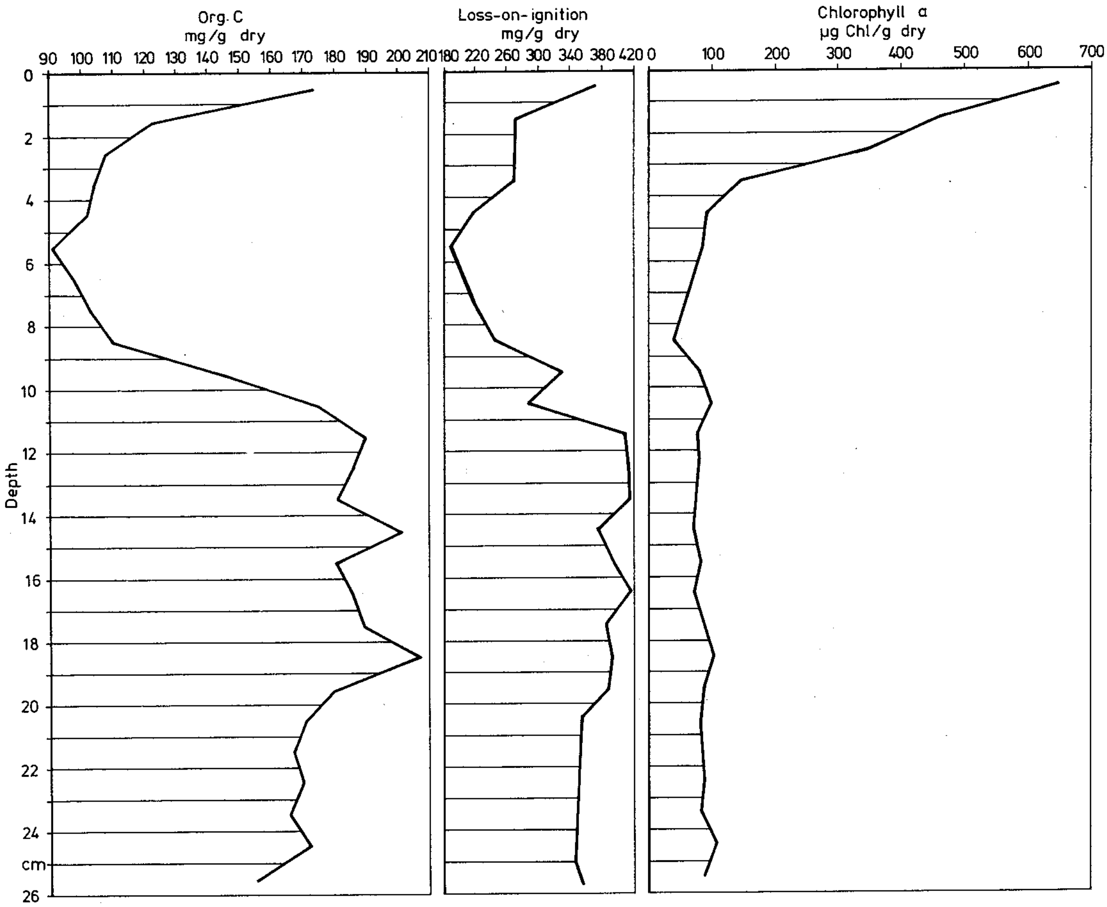

Fig. 21. Organic carbon, loss-on-ignition and chlorophyll a in sediment, Lake Särkinen S.

athletics in the years 1945 and 1972 of the holiday centre of the state railways in the years 1952, 1956 and 1959. Even in 1974 there was less organic matter in the surface of the sediment than in the sediment depth of 12—11 cm. It is apparent that the erosion is continuing. The effects of people using paths by the lake, and of the steep shores, promote the movements of sand and silt.

The results of chlorophyll analyses carried out according to the method of Strickland and Parsons (1972) are shown in the Figure 21.

6.12 The evolution of the lake

Figure 22 is a phenogram (Sneath and Sokal 1973) of the analyses results of Lake Särkinen sediments. In the phenogram, three groups are discernable: the 1, 2, 3 and 4 cm layers indicate rapid eutrophication 5, 6 and 7, 8, 9 cm indicate erosion, and 10—19 cm show slow eutrophication. The effects of man are of two kinds, namely eutrophication and erosion effects.

If the amounts of organic matter and chlorophyll are compared, it is noticed that the chlorophyll curve is very stabile to about 3 cm, after which a very clear increase occurs at the top level. There are two possible explanations for this observation: The organic matter may include a large proportion of alloctonous material or the powerful increase in primary production almost masks the influence of minerogenic matter. The former alternative is more probable. The proportion of organic matter in the sediment at a depth of 14—11 cm is nearly 40 % (loss-on-ignition mg/g).

Using the information given above, it is possible to calculate the approximate sedi-

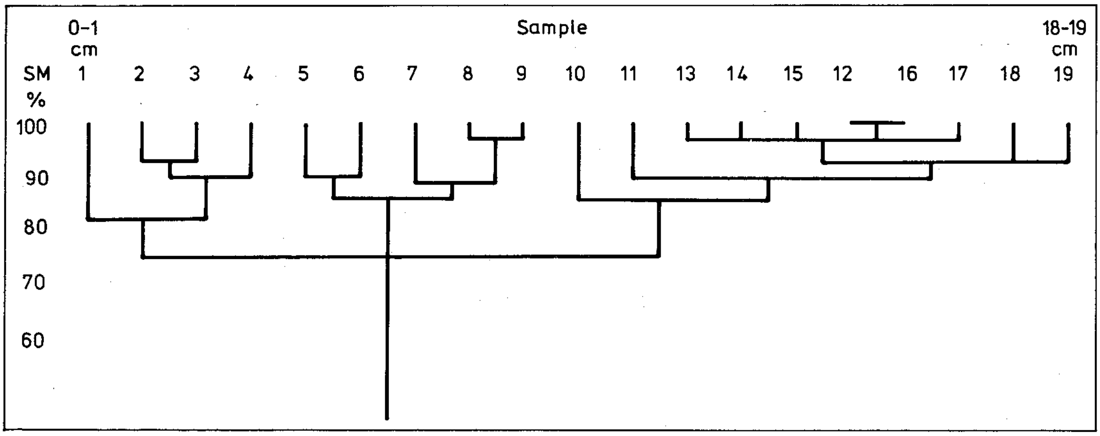

Fig. 22. Phenogram of the results in Lake Särkinen S; sediment depths 0—19 cm.

mentation rate. From the railway and road works in late 1920's we arrive at a mean value of 2 mm a^{-1} from ca. 11 cm to the sediment surface. From the accelerating sedimentation in the years ca. 1965 at the sediment depth of 5 cm we reach a sedimentation rate of 5 mm a^{-1}. From the estimate that the sedimentation rate should be doubled between the layers 12 cm—5 cm, we obtain inversely a maximum estimate for the sedimentation rate at the beginning of the twentieth century less than 0.7 mm a^{-1}.

7. DISCUSSION

7.1 Comparison of the studied lakes

The phenogram of lakes Bodominjärvi and Tuusulanjärvi can be divided into two parts, while vigorous changes take place in the topmost 7 cm of Lake Ruokojärvi and the phenogram of Lake Särkinen is clearly in three parts. The quantities and evolution of the organic carbon and loss-on-ignition in lakes Bodominjärvi and Tuusulanjärvi are similar. However, in Lake Tuusulanjärvi the proportion or organic matter increases more steeply. This lake is heavily loaded with sewage, but in Lake Bodominjärvi a diffuse load is prevalent (M. Hämäläinen, Espoo town water works, personal communication). In both lakes the proportion of minerogenic matter in the sediment is high, about 90 % (900 mg/g dry sediment). This can mask changes in the organic matter.

The difference between maximum and minimum ignition losses as a percentage of the minimum is in Lake Bodominjärvi about 40 % and in Lake Tuusulanjärvi about 50 %.

The diatom analysis usually gives relevant information, but the species composition of Lake Bodominjärvi at the top of the sediment shows obvious deviation, possibly due to the copper sulphate treatments.

In the analyses results of the Lake Ruokojärvi sediments a regular and clear increase in loss-on-ignition is discernable when approaching the sediment surface. The increase is about 60 %, which is slightly higher than in lakes Bodominjärvi and Tuusulanjärvi.

The residence time of Lake Bodominjärvi is rather long, about 2 years, and the field percentage in the drainage basin somewhat lower compared with Lake Ruokojärvi. It is possible that the slow turnover of the water is in this case the factor causing increased nutrient levels in the sediment of Lake Bodominjärvi. The load to this lake is nearly totally diffuse.

The evolution of Lake Ruokojärvi is regular, as indicated by the diatoms analyses. The proportion of alkaliphilic and alkalibiontic diatoms in the topmost 10 cm of sediment is very high, in some samples over 90 %, which is almost the same as in Lake Tuusulanjärvi temporarily at a sediment depth of 6 cm. The diatom diversity is on average lower than in Lake Tuusulanjärvi and the more eutrophic status of Lake Ruokojärvi is also reflected by the minute portion of indifferent diatoms.

As was indicated in the preceding text, the field percentages and, correspondingly, the suspended solids loads are of the same class of magnitude in the different lakes.

The volume of Lake Tuusulanjärvi, 18.6 x 10^6 m^3 (Harjula 1971) is ten times greater than the 1.8 x 10^6 m^3 of Lake Ruokojärvi (Vesihallitus, Ruokojärven kunnostussuunnitelma 1974).

The residence times are of about the same magnitude in both lakes, so that the water volume entering Lake Tuusulanjärvi is about 10 times greater than that entering Lake Ruokojärvi. On the basis of information provided by Ojanen and Kenttämies (1977), it can be calculated that the phosphorus load to Lake Tuusulanjärvi is about threefold that to Lake Ruokojärvi. The dilution in Lake Tuusulanjärvi, as a consequence of the larger water volume is about 10 times greater, so that the phosphorus concentrations in Lake Ruokojärvi are about three times greater.

Lake Särkinen at Vuokatti is perhaps not a very suitable lake for comparison in the present study. It is situated further north than the other lakes and the surrounding soil is chiefly sand and silt. There are not many fields in the drainage basin of Lake Särkinen and the significance of sewage waters is therefore comparatively high. Anomalies due to unknown factors are evident. The possibility of comparison concerns primarily the earlier virgin state of the lake. There exist differences between the lakes Särkinen and Bodominjärvi in the fossil diatom flora. Lake Särkinen is primarily an oligotrophic lake, while Lake Bodominjärvi (A) has been eutrophic since its birth and even during cold climatic periods. Clay or its absence is perhaps a factor which governs the trophic status of lake in its natural state.

7.2 Factors affecting the interpretation and value of the parameters

The diatom analysis gives a somewhat different picture of the eutrophication of a lake than do the organic carbon and chlorophyll a contents. The erosion and the resulting growth of the proportion of minerogenic matter can significatly influence the proportions of carbon and pigments (Markereth 1966). Thus events in the drainage basin of a lake may be reflected in changes in the ratio of minerogenic to organic matter (see analysis results for Lake Särkinen).

The highest level of aerobic heterotrophic bacteria was recorded in the topmost centimeter of sediment in Lake Balaton (Olah 1973). The decomposition of organic matter continues in the surface layers of sediment and carbon dioxide is produced (Rich 1975). The increase in organic matter in the uppermost ca. 5 cm of sediment possibly reflects the mineralization of the organic compounds in the sediment.

The values of chlorophyll a often increase very steeply near the surface of the sediment. Factors increasing the decomposition of pigmenst include microbes, oxygen and light (Daley and Brown 1973).

Diatom analysis is the most useful parameter for elucidation of the evolution of a lake, but in order to arrive at a more complete picture some other parameters, depending on the amount of mineral matter, are also useful.

The loss-on-ignition and the organic carbon analyses are mutually correlated. The contemporaneous use of these parameters, however, lends more certainty to the interpretation of minor changes.

7.3 Clay and pelotrophy

In southern Finland, lakes are often situated in clay soils and are pelotrophic, shallow and eutrophic. The water of a pelotrophic lake is rich in electrolytes. The finegrained suspended minerogenic matter has a large surface, on to which microbes can adhere. Pelotrophy thus increases microbial populations, and the intensity of the decomposition of organic matter (Jannasch and Pritchard 1972). These clayey waters have never been oligotrophic.

The small clay particles in pelotrophic waters take up nutrients on their surfaces. The fixation of phosphate to clay particles is perhaps not an ion exchange reaction (Edzwald et al. 1976). The effective factors are possibly the mineralogic composition of the clay and the concentration of free metals.

A quartz suspension with particle size similar to that of clay cannot adsorb phosphorus from water. If the binding of phosphorus occurs adsorptively it is obvious that the phosphorus fixed by a particle in the water phase is directly or perhaps as a function of microbial activity, available to planktonic organisms.

Pelotrophic lakes, surrounded by clay fields are usually shallow and poorly stratified (Järnefelt 1956). Wind delays sedimentation and causes erosion and redeposition (Davis 1973). The mineralisation of the organic content is therefore enhanced. According to Berg (1970), merely agitation of the sediment can increase the oxygen demand tenfold.

8. SUMMARY

The purpose of this study was to clarify the eutrophication of pelotrophic lakes in southern Finland. Sediment samples were taken from three sewage-loaded lakes situated in claysoil areas: lakes Bodominjärvi (Espoo), Tuusulanjärvi (Tuusula, Järvenpää) and Ruokojärvi (Kankaanpää).

A long sediment profile containing the whole history of the independent lake was available for Lake Bodominjärvi. Further, a short profile from Lake Särkinen (Vuokatti), a kettle lake in the Kainuu province, was also available.

The parameters analysed from the long Lake Bodominjärvi profile (A) were pollen, diatom composition and loss-on-ignition. According to the results of the diatom analysis the trophic status of the lake has been almost constant throughout its history. Lake Bodominjärvi was already mesotrophic at its formation. The worsening of the climate, when the Atlantic period retired, caused a clear decrease in the alkalinity of the water.

The decrease in the loss-on-ignition and increase in alkaliphilic and alkalibiontic diatoms from the level of 120 cm to the sediment surface could have arisen from slashing and burning forestry carried out after ca. 700–800 B.C.

The impact of man becomes discernable in the growing proportion of minerogenic matter, reflecting increased erosion. This is in apparent contradiction to the diatoms, which indicate growing eutrophication. The erosion and the amount of minerogenic matter greatly affect the relative proportion of organic carbon.

In the short sediment sample from Lake Bodominjärvi (B), it can be seen that the increase in copper content and the exceptional changes in diatom flora occur in the same sediment strata. The alkaliphilic and alkalibiontic diatom taxa decrease and the diversity and the proportion of indifferent taxa increase. The sedimentation rate in the topmost 8 cm is almost 1 cm/year.

The sedimentation rate in Lake Tuusulanjärvi is very similar to that in Lake Bodominjärvi. The diatom diagram indicates a slight healing of the lake.

Lake Ruokojärvi is strongly eutrophic, even more markedly than Lake Tuusulanjärvi on the basis of diatom analyses. This observation supports calculations which show that the dilution rate is greater in Lake Tuusulanjärvi and that the phosphorus concentration is clearly higher in Lake Ruokojärvi.

Lake Särkinen is eutrophic lake loaded by the Vuokatti institute of athletics and by the holiday centre of the state railways. With the aid of indications appearing in the sediment of erosion caused by the construction of the Nurmes-Sotkamo railway and of the road from Vuokatti to Valtimo, a sedimentation rate lower than 0.5 mm/year is obtained for the early nineteen-hundreds. At the sediment depth of 11–5 cm a sedimentation rate of 1.5 mm a^{-1} for the nineteen-twenties is indicated. The signs of growing erosion from ca. 1965 indicate that the mean sedimentation rate in the top 5 cm has been about 5 mm a^{-1}. The clearly more oligotrophic character of Lake Särkinen and its rather high sensitivity to the eutrophying effect of the domestic sewage load can easily be discerned in comparison with Lake Bodominjärvi (A).

Suspended clay improves the growth environment of microbes and thus increases the rate of mineralization of organic matter. The significance of clay particles in promoting the movement of phosphus is an important but little-knwon phenomenon.

Pelotrophic lakes situated in clay soil are usually shallow and their water is poorly stratified. The effect of wind in slowing the sedimentation of fine particles and promoting resuspension is considerable. Pelotrophic lakes are even in their natural state considerably eutrophic and can absorb nutrient loads rather well.

ACKNOWLEDGEMENTS

I should like to thank prof. Pentti Alhonen and Dr. Reino Laaksonen for valuable advice during the course of this study. I am also indebted to the personnel of the Research Laboratory of the National Board of Waters for carrying out the chemical analyses. The English language of the text was revised by Mr. Michael Bailey.

Mikkeli, December 1982

Olavi Sandman

LOPPUTIIVISTELMÄ

Etelä-Suomen savisamenteisten järvien rehevöitymisen kulun selvittämiseksi otettiin pohjakerrostumanäytteitä neljästä saviseudulla sijaitsevasta asumisjätevesien kuormittamasta järvestä: Bodominjärvestä (Espoo), Tuusulanjärvestä (Tuusula) ja Ruokojärvestä (Kankaanpää). Bodominjärvestä oli käytettävissä myöskin itsenäisen järven koko historian sisältävä profiili. Lisäksi otettiin näytteitä Vuokatin Särkisestä, joka on harjukuoppaan syntynyt kainuulainen järvi.

Bodominjärvestä otetusta pitkästä sedimenttinäytteestä (A) tehtiin siitepölyanalyysi, piileväanalyysi ja polttoanalyysi.

Hehkutushäviöarvojen laskun ja veden emäksisyyttä indikoivien piilevälajien osuuden nousun alku 120 cm sedimenttisyvyydestä pintaa kohden voidaan tulkita kaskeamisesta johtuvaksi ja ajoittaa noin vuosiin 700—800 j.Kr. Piileväanalyysin tulosten perusteella havaitaan järven trofiatason pysyneen suhteellisen muuttumattomana koko näyteprofiilin käsittämän ajanjakson. Bodominjärvi oli jo syntyessään varsin runsasravinteinen, mesotrofinen. Ilmasto-olosuhteiden huononeminen lämpökauden väistyessä aiheutti veden emäksisyyden selvästi havaittavan vähenemisen. Kaskeaminen puolestaan käänsi järven kehityksen jälleen emäksisempään suuntaan. Ihmisen vaikutus näkyy selvästi mineraaliaineksen osuuden, so. eroosion kasvuna, mikä on näennäisessä ristiriidassa piilevien indikoiman veden ravinnepitoisuuden nousun kanssa. Kasvavan eroosion ja mineraaliaineksen määrän vaikutus suurelta osalta autoktonisen orgaanisen hiilen suhteelliseen määrään sedimentissä on merkittävä.

Bodominjärvestä otetusta lyhyestä kerrostumanäytteestä (B) havaittiin sedimentin pintaa kohti nousevien kuparipitoisuuksien ja piilevästössä tapahtuneiden poikkeavien muutosten yhtäaikaisuus. Tapahtuneeseen alkalifiilisten ja alkalibionttisten piilevälajien osuuden laskuun liittyy diversiteetin ja indifferenttien lajien osuuden nousu. Kerrostumisnopeus ylimmän 8 cm alueella on vajaa 1 cm vuodessa.

Tuusulanjärven ylimmän 9 cm kerrostumisnopeus on samaa suuruusluokkaa kuin Bodominjärvessä. Piilevädiagrammi indikoi järven tilan lievää paranemista kuormituksen vähenemisen ja ilmastamisen vaikutuksesta.

Ruokojärvi todettiin voimakkaasti rehevöityneeksi. Veden korkeaa emäksisyyttä heijastavien lajien prosenttiosuuden ja orgaanisen aineksen osuuden minimit sijaitsevat likimain samassa sedimenttisyvyydessä. Ylimmän senttimetrin alueella on havaittavissa piilevästön mukaan järven tilan lievä paraneminen.

Piileväanalyysin tulosten perusteella Ruokojärvi on voimakkaammin rehevöitynyt kuin Tuusulanjärvi. Havaintoa tukee laskelma, jonka mukaan laimeneminen on Tuusulanjärvessä suurempien vesimäärien takia voimakkaampaa ja fosforimäärät Ruokojärvessä tilavuusyksikköä kohden selvästi suurempia.

Särkinen on Vuokatin urheiluopiston ja valtion rautateiden retkeilykeskuksen kuormittama rehevöitynyt järvi. Rautatien ja maantien rakentamisen sedimenttiin jättämiä jälkiä apuna käyttäen saadaan 1900-luvun alun vuotuiseksi kerrostumisnopeudeksi alle 0,7 mm ja välille 11—5 cm, so. 1920-luvulta lähtien vastaavasti 1,5 mm. Noin vuonna 1965 nopeutuneen rehevöitymisen jälkiä kiinnekohtana käyttäen saadaan ylimmän 5 cm:n alueen keskimääräiseksi sedimentoitumisnopeudeksi 5 mm vuodessa. Vertailussa Bodominjärvestä otettuun pitkään profiiliin (A), voidaan todeta järven selvästi karumpi perusluonne ja toisaalta herkkyys asumajätevesien rehevöittävälle vaikutukselle.

Numeerista taksonomiaa (cluster analysis) käytettiin tutkimuksessa eutrofoitumista heijastavien parametrien muutosten havainnollistamiseen.

Liettyneellä saveksella on merkitystä mikrobien elinmahdollisuuksia parantavana ja tämän seurauksena orgaanisen aineksen mineralisoitumista lisäävänä tekijänä. Fosforin sorptio savihiukkasiin on ilmeisen tärkeä, mutta suhteellisen vähän selvitetty ilmiö.

Savitasankojen ympäröimät pelotrofiset järvet ovat yleensä matalia ja niiden vesimassa heikosti kerrostunut. Tuulen vaikutus hienon aineksen kerrostumista hidastavana ja uudelleen suspensioon saattavana tekijänä on ilmeinen. Savisamenteisten järvien perustyyppi on runsasravinteinen ja niiden ravinnekuormituksen »sieto» on suhteellisen hyvä.

REFERENCES

Aartolahti, T. 1966. Über die Einwanderung und die Verhäufigung der Fichte in Finnland. Ann. Bot. Fennici 3:368–379.

Alhonen, P. 1972. Gallträsket: The geological development and palaeolimnology of a small polluted lake in Southern Finland. Comment. Biol. 57, 34 pp.

Alhonen, P. & Haavisto, M. 1969. The biostratigraphical history of lake Otalampi in southern Finland, with special reference to the remains of subfossil midge fauna. Bull. Geol. Soc. Finland 41:157–164.

Anttila, R. 1967. Tuusulanjärven hydrografian, kasviplanktonin ja kalaston kehitys vuosina 1893–1967 sekä niihin vaikuttaneet tekijät. Laudaturtyö, Helsingin yliopiston limnologian laitos. 155 p.

Berg, R.H. 1970. The oxygen uptake demand of resuspended bottom sediments. Envir. Protection. Agency, Water Pollution Control Research Series 16070 DCD. 38 pp.

Daley, R.J. & Brown, S.R. 1973. Experimental characterisation of lacustrine chlorophyll diagenesis. Arch. Hydrobiol. 72, 3:277–304.

Daley, M.B. 1973. Redeposition of pollen grains in lake sediment. Limnol. Oceanogr. Vol. 18, 1:44–52.

Donner, J.J. 1971. Towards a stratigraphical division of the Finnish Quaternary. Soc. Sci. Fenn. Comm. Phys.-Math. 41:281–305.

Donner, J.J. 1972. Pollen frequencies in the Flandrian sediments of Lake Vakojärvi. Soc. Sci. Fenn. Comm. Biol. 53, 19 pp.

Ezvald, J.K., Toensing, D.C. & Chi-Yew Leung, M. 1976. Phosphate adsorption reactions with clay minerals. Environ. Sci. Technol 10, 485–490.

Erkomaa, K., Mäkinen, I. &Sandman, O. 1977. Vesiviranomaisen ja julkisen valvonnan alaisten vesitutkimuslaitosten fysikaaliset ja kemialliset analyysimenetelmät. Vesihallituksen tiedotuksia 121, 54 pp.

Eronen, M. 1974. The history of the Litorina Sea and associated holocene events. Soc. Sci. Fenn. Comm. Phys. -Math. 44, 4:79–195.

Faegri, K. & Iversen, J. 1964. Textbook of pollen analysis. Munksgaard, Copenhagen. 237 pp.

Hakala, I. 1971. A new model of the Kajak bottom sampler, and other improvements in the zoobenthos sampling technique. Ann. Zool. Fenn. 8:422–426.

Harjula, H. 1972. Hiidenveden ja Tuusulanjärven rehevöitymisen kehitys pohjasedimenttien valossa. Lisensiaattityö. Helsingin Yliopiston limnologian laitos. 109 pp.

Huber-Pestalozzi, G. 1942. Das Phytoplankton des Süsswassers. Binnengewässer XVI, 2, 2:367–549.

Hustedt, Fr. 1930a. Bacillariophyta (Diatomeen). In: Pascher, A.: Die Süsserwasserflora Mitteleuropas. Jena. 462 pp.

Hustedt, Fr. 1930b, 1959. Die Kieselalgen Österreich und der Schweitz. In: Rabenhorst, L.: Kryptogamenflora von Deutschland, Österreich und der Schweitz. Leipzig. 920 pp, 736 pp.

Hämäläinen, M. A. 1968. Piirteitä rehevöityvän järven kehityksestä ja kuparisulfaatin välittömästä vaikutuksesta sen planktonkuvaan. Laudaturtyö. Helsingin yliopiston limnologian laitos. 63 pp.

Iskandar, K.I. & Keeney, D.R. 1974. Concentration of heavy metals in sediment cores from selected Wisconsin lakes. Envir. Sci. & Technol. 8, 2:165–170.

Jannasch, H.W. & Pritchard, P.H. 1972. The role of inert particulate matter in the activity of aquatic microorganisms, In: Detritus and its role in aquatic ecosystems. Mem. Ist. It. Idrob. 29, Suppl.:291–308.

Järnefelt, H. 1956. Zur Limnologie einiger Gewässer Finnlands XVI. Ann. Zool. Soc. Vanamo 17. 314 pp.

Kukkonen, E. 1973. Sedimentation and typological development in the basin of the Lake Lohjanjärvi, South Finland. Geological Survey of Finland, Bulletin 261. 67 pp.

Kukkonen, E. & Tynni, R. 1970. Die Entwicklung des Sees Pyhäjärvi in Südfinnland in Lichte von Sediment und Diatomeenuntersuchungen. Acta Bot. Fennica 90. 30 pp.

Liljequist, G.H. 1970. Klimatologi. Generalstabens litografiska anstalt. Stockholm: 395–400.

Lockhart, W.R. & Liston, J. ed. 1970. Methods for numerial taxonomy. Amer. Soc. Microbiol. 62 pp.

Lorenzen, C.J. 1967. Determination of chlorophyll and pheopigment: Spectrophotometric equations. Limnol. Oceanogr. 12:343–346.

Lundqvist, G. 1927. Bodenablagerungen und Entwicklungstypen der Seen. Binnengewässer 2. 124 pp.

Mackereth, F.J.H. 1966. Some chemical observations on postglacial lake sediments. Phil. Trans. R. Soc. (B) 250:165–213.

Meriläinen, J. 1967. The diatom flora and the hydrogen-ion concentration of the water. Ann. Bot. Fenn. 4, 1:51–58.

Mölder, K. 1943. Studien über die Ökologie und Geologie der Bodendiatomeen in der Pojo-Bucht. Ann. Bot. Soc, Zool. Bot. Fenn. Vanamo 18, 204 pp.

Olah, J. 1973. Bacterial gradients at the sediment: Water interface of shallow lakes. Ann. Inst. Biol. (Tihany) Hung. Acad. Sci. 40:219–225.

Pascher, A. ed. 1930. Die Süsswasser-flora Mitteleuropas, Heft 10. Bacillariophyta. Gustav Fischer, Jena. 466 pp.

Rich, P.H. 1975. Benthic metabolism of a soft-water lake. Verh. Intern. Ver. Limnol. 19:1023–1028.

Schmidt, A., Schmidt, M., Fricke, F., Heiden, H., Müller, O. & Hustedt, F. 1972. Atlas der Diatomaceen-kunde, Band I-IV. Nachdruck der Originalausgabe. Zentralantiquariat DDR, Leipzig. 468 Tafel.

Sneath, P.H.A. & Sokal, R.R. 1973. Numerical taxonomy. Freeman & Co, San Francisco. 573 pp.

Soininen, A.M. 1974. Vanha maataloutemme. Maaseutuja maatalousväestö Suomessa perinnäisen maatalouden loppukaudella 1720-luvulta 1870-luvulle. Maataloustieteellinen Aikakauskirja, Erikoisnumero. 46, 259 pp.

Strickland, J.D.H. & Parsons, T.R. 1968. A handbook of seawater analysis. Bull. Fish. Res. Bd. Can., Ottawa. 167: 185–206.

Tolonen, K., Siiriäinen, A. & Thompson, R. 1975. Espoon Lojärven pohjakerrostumien tulkinta ja paleomagneettinen ajoitus. Geology 27, No 8:97–102.

Vallentyne, J.R. 1955. Sedimentary chlorophyll determination as a paleobotanical method. Can. J. Bot. 33:304–313.

Vesihallitus, 1973. Vesiviranomaisten käyttämät näytteenottomenetelmät; sedimenttinäytteet. Vesihallituksen julkaisuja 6:22–24.

Vesihallitus, 1974. Ruokojärven kunnostussuunnitelma 1–10.

Westerling, H. 1960. Havaintoja Bodominjärven pohjaeläimistöstä kasvillisuusvyöhykkeen ulkopuolella sekä piirteitä järven kemiasta. Laudaturtyö. Helsingin yliopiston limnologian laitos. 47 pp.