HOLOCENE LACUSTRINE MICROFOSSILS AND ENVIRONMENTAL CHANGES

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ALHONEN, P., 1986: Holocene lacustrine microfossils and environmental changes. *Bull. Geol. Soc. Finland 58, Part* 1, 57—69.

This review is concerned with the biostratigraphical use of the lacustrine microfossils such as diatoms, blue-green and green algae, Mallomonadaceae, Cladocera and larval insect remains preserved in lake sediments and their value as bioindicators of Holocene environmental changes in Finland.

From lake sediment studies discussed in the text it can be concluded that the lacustrine microfossils are useful for the reconstruction of typological and water-level changes in lakes, catchment conditions and climatic fluctuations. They can also give profitable information for examing the cultural eutrophication and acidification of lakes.

In the light of the microfossil studies the most significant natural development of Finnish lakes has been a typological succession from the mineroeutrophic (argillotrophic or pelotrophic) state towards more dysoligotrophic conditions. This meiotrophication process is strictly related to the influence of environmental humic substances on the limnology of lakes. To analyze microfossils is still the most important key for the characterization of lacustrine environments during the Holocene.

Key words: fossil diatoms, Cladocera, blue-green and green algae, chironomids, palaeolimnology, Holocene lake development, climatic changes.

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Introduction

Several Quaternary palaeolimnological and microfossil studies of lake sediments in Finland have been focused on different problems of environmental reconstruction since the end of 1960s. Considerable progress has been made in the works of the 1970s and early 1980s, when some integrated sediment stratigraphical studies have been carried out to determine the developmental course of cultural eutrophication in certain small lakes as a result of agriculture, sewage and industrial effluents. Alhonen (1979a, 1979b and 1983) has briefly reviewed the problems of these studies, and a considerable part of this work in currently in progress.

The present review is concerned only with the biostratigraphical use of the remains of certain organisms preserved in lake sediments and their value as bioindicators of environmental changes during the Holocene. At the microscopical level the most abundant plant and animal remains in lake sediments are those of diatoms and certain other algae, chydorid and planktonic Cladocera as well as midge larvae. However, virtually all taxonomic groups of animals living in inland waters leave often some morphologically indentifiable remains in their deposits. Here I shall only discuss the microfossil groups, which have been studied in Finland with exception of pollen and spores including those of aquatic plants. Their stratigraphical use is based on a number of case-history studies of particular lakes. The references of this review are by no means complete, especially concerning their internationality. Thus the main literature is based on Finnish investigations.

Diatoms

Diatoms (class Bacillariophyceae) are useful environmental indicators. Therefore the diatom stratigraphy of lacustrine sediments has currently wide use in Quaternary research in Finland. With respect to the problems of lake isolation from the various stages of the Baltic Sea the relationship of the diatom flora to the salinity of the water is most important. In addition to the pollen stratigraphy diatom fossils have been used for determining Yoldia, Ancylus, Mastogloia and Litorina sediments in the Baltic history. Alhonen (1971a) has discussed their ecological importance in these studies (see also Eronen 1974).

Another important point for the application of diatom analysis is its use in elucidating the trophic history of lakes including cultural eutrophication as summarized by Alhonen (1979a). The changes in the composition of the diatom flora during the ontogeny of a lake reflect its typological development. In the interpretation of the diatom diagrams of seven inland lakes in south-western Finland Alhonen (1967, 1970a) applied the pH requirements of the diatom flora. In the diagrams the frequency percentages of each species were given as a separate column with the Holocene pollen zones for comparison the synchronous environmental changes in the lakes studied. These diagrams also show the stratigraphical isolation contact. Later (see Alhonen 1972) the diatom flora was arranged on the basis of different sources of pH ecological information into three groups, viz. alkaliphilous (including alkalibiontic), indifferent and acidophilous (including acidobiontic) in order to elucidate more accurate the long-term typological dynamics of the lake since its isolation. Because the diatoms seem to have a good correlation with pH of the water of recent lakes, their deposited assemblages can serve as palaeoecological pH-meters.

In the interpretation of lake development the biotope diagram constructed according to the habitat ecology of the diatoms was also used in order to show the changes in the water level (Alhonen 1972, Fig. 6). It had earlier become clear that the bathymetrical development of the lake seemed to reflect in the diatom stratigraphy (Alhonen 1970a). The planktonic/littoral diatom ratio has not been widely applied in the core studies of lake sediments in Finland. However, Koivo (1978) showed that the ratios of P/L and the mean and maximum depths are significantly higher for a shallow lake than for a deep lake.

Diatoms response sensitively to human disturbance in lakes. The use of some indicator species for a study of the course of cultural eutrophication recorded from sediments can be significant, but the application of the pH requirements of the diatom flora seems to be most suitable (Fig. 1). The interpretation of the stratigraphical floral changes can succesfully be linked to the history of eutrophication and pollution of the lake (Alhonen 1979a). It has been argued in the literature (see Stockner and Benson 1967 and Stockner 1972) that a shift from the Centrales to the Araphidineae diatoms indicates eutrophication of the lake. The application of the Araphidineae/ Centrales (A/C) ratio as an indicator of the trophic status of the lake has not so far been sufficiently tested in Finland by e.g. examining surface sediment diatom assemblages in different lakes. Although the A/C ratio does not appear to be in every case valid, it very often can be correlated with environmental changes in lakes and in the catchment areas. Certain centric diatoms

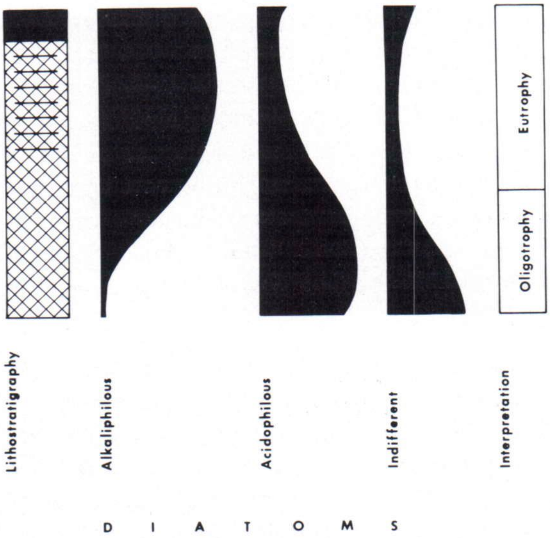

Fig. 1. Schematical diagram showing the changes of the pH ecological groups of the diatom flora during the cultural eutrophication of a lake (From Alhonen 1979, Fig. 3).

(*e.g. Stephanodiscus* and *Cyclotella*) can limit the use of the A/C index (see Brugam 1979). Howewer, M. Tolonen (1978) has calculated Araphidineae/Centrales ratio of diatom assemblages in her study on palaeoecology of Lake Ahvenainen in southern Finland. In the topmost part of its lithostratigraphy representing eutrophication of the lake the A/C ratio clearly had risen (see M. Tolonen 1978, Fig. 3).

Koivo (1976) examined species diversity using Shannon's entropy function in her studies on Holocene diatom communities of three sediment profiles from the Finnish Lake District. The results were compared with their biostratigraphy. The Holocene pollen zonation was used as a relative chronology of the sediments. As indicated by the species diversity the diatom communities in the developmental history of Lake Konnevesi, Kaipiolampi pond and Isosuo bog consisted first of only few species, when environmental conditions were characterized by cold water and limited nutrient budget. Later a trend to higher total diversity followed the isolation of the lake basins from the Baltic, as could be expected. Most diatom taxa have then been littoral forms, which occur in oligotrophic and acid waters.

Donner *et al.* (1978) calculated in addition to the percentage diatom diagram the number of frustules per 1 cm^3 wet sediment using exotic *Lycopodium*-spore tablets. The results suggest that the fluctuations in the total number of frustules seem to reflect trophic status of the studied lake Työtjärvi in southern Finland.

In addition to this discussion it might be noticed that diatoms are important algal component in varved lake sediments as shown by Simola (1977 and 1979).

Other algae

Of the other algal remains than diatoms colonies of blue-green algae (*e.g. Gloeotrichia*) and green algae of the genus *Pediastrum* can be recovered from Finnish lake sediments. In the uppermost 15 cm of the lithostratigraphy of Gallträsket, a small lake with human disturbance in southern Finland, *Gloeotrichia*-algae occur abundantly and they are related to the recent pollution of the lake (Alhonen 1972).

Salmi (1963) and Lappalainen (1970) have reported *Pediastrum*-algae in the sediments of lake and bog environment in Finnish Lapland. Their distribution in the lithostratigraphy seems to be connected with the climatic conditions and calcareous depositional environment.

Alhonen and Ristiluoma (1973) used *Pediastrum* fossils to reconstruct past limnology in a Holocene core from southern Finland. The investigated site lies close to the coast of the Litorina Sea. Therefore it was concluded by Alhonen and Ristiluoma (1973) that the proximity of the transgressive sea and the moist Atlantic climate have made the physico-chemical conditions in the lake phase of this environment favourable for the growth of *Pediastrum*-algae.

The siliceous scales of Mallomonadaceae (Chrysophyceae) are well preserved in lake sediments and are, therefore, useful environmental indicators. M. Tolonen (1978) reports the occurrence of *Mallomonas* in connection with the diatom and ignition loss stratigraphy of Lake Ahvenainen. It seems that *Mallomonas* scales or shell spicules are related to an oligotrophic phase of the lake. It should be mentioned in this connexion that Battarbee et al. (1980) have described mallomonadacean assemblages in the micro-laminated sediments of a small lake in Finnish North Karelia. In addition to this, the results of Smol *et al.* (1984a and 1984b) demonstrate that the distribution of certain *Mallomonas*-species is also closely related to lakewater pH giving evidence of recent acidification. Unfortunately such studies are so far lacking in Finland, but together with diatoms they should utilize palaeolimnological interpretations of lakes.

Cladocera

The various exosceletal fragments like head shields, shells, postabdomens, postabdominal claws and ephippia of Cladocera (Crustacea) occur abundantly in Holocene lake sediments in Finland (Alhonen 1967, 1969, 1970a, 1970b, 1971b and 1972). The families Sididae, Daphniidae, Bosminidae and Chydoridae are represented by the sufficient diversity of the morphological remains, and they have, therefore, a great role in palaeoecological and palaeolimnological studies.

The *Bosmina*-analysis of lake sediments in Finland was first applied by Alhonen (1967). His pioneering interpretations were based on the quantitative changes in the *Bosmina*-stratigraphy in order to reconstruct the limnological history of three inland lakes each representing different type (eutrophy, oligotrophy and dystrophy) at present. In later papers Alhonen (1970a, 1971b and 1972) identified the remains of the individual cladoceran species with the aid of the illustrations in Frey (1958, 1959, 1960 and 1962), Goulden (1964) and Whiteside (1970). The results were presented as percentage diagrams. Although the changes in the cladoceran stratigraphy are then relative they seem to be useful for interpreting the dynamics of the lake ecosystem during the Holocene. The ideal should be to present the biostratigraphy as annual influxes per cm^2 based on a detailed radiocarbon chronology or possible annual laminations of lake sediments. This method has so far been very little applied in Finland (see however K. Tolonen et al. 1976, Figs. 6 and 7).

The percentage composition of the cladoceran populations relates to the lake morphometry. Thus there is a clear relationship between the relative proportion of planktonic and littoral remains of Cladocera and the planktonic zone volume and the littoral floor area. Alhonen (1970a, 1970b, 1971b and 1972) found a close similarity among the planktonic/littoral percentages in the cladoceran stratigraphy of lake sediments. In comparing this P/L ratio with the Holocene climatic history it was possible to demonstrate that the water level fluctuations in principle correlated with dry and moist periods (see also Donner et al. 1978; Salomaa and Alhonen 1983). The occurrence of *Chydorus sphaericus* should, however, be considered in biostratigraphical investigations of lake sediments. It might also be presented in the plankton, especially in association with blue-green algae. Further it may be mentioned that although *Bosmina* and *Daphnia* are plankters they can also occur in the littoral zone. *Bosmina coregoni* var. *obtusirostris, B. c. longispina* and *B. c. longicornis* are found in a littoral plankton of oligotrophic Lake Pääjärvi in southern Finland (Kairesalo 1980). *Bosmina* species occasionally produced swarms of over 3000 animals per litre. Although the origin of the *Bosmina* swarms in the shallow littoral water is uncertain, it is clear that this phenomenon could alter the planktonic/littoral ratio of the cladoceran assemblages in lake sediments. The interpretative value of this ratio should, therefore, be tested in different sites of the lake basin and as a function of bathymetry (see Alhonen 1971b, Fig. 7). In any case the chydorids are adapted for life on submerged aquatic plants, bottom stones and sediments.

The interpretation of Cladocera as the indicators of lake productivity need more population ecological observations. In Finnish lakes *Ceriodaphnia* spp. and *Chydorus sphaericus* seem to be eutrophic (Järnefelt *et al.* 1963). Harmsworth and Whiteside (1968) did not find any clear relationship between the trophic level and chydorid remains in 19 Danish and 14 Indiana lakes. Among the zooplankton a shift from *Bosmina coregoni* to *B. longirostris* might indicate the eutrophication of a lake, but this problem is unsolved (see discussion in Brugam 1984: 216). In summary, environmental interpretations based on fossil cladoceran assemblages, however, provides valuable information on the palaeolimnological reconstructions.

Insect remains

Of the remains of insects the larvae of lacustrine Diptera are well preserved in lake sediments. Chironomids and chaoborids are most common and thus useful indicators of environmental conditions in lakes, particularly the trophic status and the oxygen concentrations.

There has been very little biostratigraphical application of chironomid remains to Holocene palaeolimnology in Finland. Alhonen and Haavisto (1969) have used the chironomid analysis to reconstruct the developmental history of Lake Otalampi in southern Finland. They described seven different midge groups, viz. Tanypodinae, Orthocladinae, Tanytarsarie, *Sergentia,* Chironomarie, Ceratopogonidae and *Chaoborus,* and interpreted their biostratigraphy. The total midge curve showed a maximum during the Holocene climatic optimum suggesting probably better limnological conditions in the lake than before and after it. More recently, Salonen *et al.* (1981) and Räsänen and Salonen (1983) have applied the midge analysis in connexion with palaeoenvironmental investigations in the vicinity of Piikkiö and Kakskerta island in SW Finland. Further, Kansanen (1985) analyzed subfossil remains of chironomids, chaoborids and ceratopogonids from four short cores of Lake Vanajavesi in relation to its pollution history.

Much valuable taxonomical information on chironomid remains of European species has been given by Hofmann (1971). Later, he also described a procedure with flow chart of preparation of the sediment samples for chironomid analysis (see Hofmann 1979). In the biostratigraphical interpretation a separation of the typical littoral species from profundal taxa is recommended. The littoral chironomid fauna under certain conditions is coldstenothermal and the occurrence of such chironomids is thus not related to the trophic states. As pointed by Hofmann (*cf.* 1979) the lake typology based on the profundal midge fauna might be applied only to deep stratified lakes.

To sum up, the analysis of chironomid remains of Finnish lake sediments still need more work. This group of animal microfossils is, however, no doupt very potential (*cf.* Kansanen 1985). In biostratigraphical investigations of lakes, as their taxonomical and ecological study in developed, it will contribute to the accurate of our palaeolimnological reconstructions.

The use of aquatic microfossils in Holocene lake sediment studies: examples from Finland

Different microfossil analyses of lake sediments have often be used as the main means for reconstructing the evolution of lakes. Although in many cases their utility needs further exploration, certain examples of the use of aquatic microfossils in palaeolimnological studies can be given. First aim of Finnish palaeolimnology was to interpret the Holocene typological development of a eutrophic, an oligotrophic and a dystrophic (polyhumous) lake (Alhonen 1967; see also Alhonen 1983). The history of dystrophy still is an important subject in Finland, and this process can be shown on the biostratigraphical basis. As a good example of the Holocene lake dystrophication is Lake Kyrösjärvi in southwestern Finland (Alhonen 1967). The diatom fossils show that after isolation from the Ancylus Lake Kyrösjärvi was at first eutrophic (mineroeutrophic) in its limnological type. Since the Atlantic period the typological development of Lake Kyrösjärvi has been towards more acid and dysoligotrophic conditions, and so to its present stage. The contemporaneous decline in the quantitative *Bosmina* curve indicates an intensive effect of humic substances on lake productivity by diminishing the trophogenic layer. At the present oligotrophic Lake Sarkkilanjärvi and eutrophic Lake Jalanti have not undergone any great typological change during their Holocene developmental history (see Alhonen 1967).

In the study on the palaeolimnology of four other lakes in south-western Finland Alhonen (1970a and 1970b) applied biostratigraphical methods to solve their limnological history and the development of the lake ecosystem in general. The lakes studied, Telkko, Särkijärvi, Järvenkylänjärvi and Leppäsjärvi, are all of the same age isolated from the Ancylus Lake. From the palaeolimnological point of view their typological development seems to be mainly oligotrophic. Leppäsjärvi is, however, today a polyhumous lake, which can also be interpreted as an example of lake dystrophication. More or less similar results have been obtained from the diatom and *Bosmina* stratigraphy of Lake Inari, Finnish Lapland, when comparing them with the lakes in south-western Finland (Alhonen 1969). However, it is possible that this large northern lake was in its initial stage to some degree more productive than later. Some alkaliphilous species occurred then in the diatom association and the *Bosmina* production increased. During the later history of Lake Inari it does not show any greater fluctuations (Alhonen 1969).

During its developmental history of Lake Otalampi (Alhonen and Haavisto 1969) the remains of subfossil *Bosmina* together with the biostratigraphy of the larvae of Diptera probably show a natural meiotrophication after the culmination of the Flandrian climatic optimum. However, Lake Otalampi has slightly eutrophicated again towards its present limnological state.

The sediment history of a 100 year old pond in eastern Finland formed in connexion with the drainage of Lake Höytiäinen in 1859 shows a dystrophication on the basis of the decline in the amount of *Bosmina* remains in the investigated core (Hyvärinen and Alhonen 1970). The planktonic/littoral ratio of the cladoceran stratigraphy shows the same trend; therefore the changes in P/L ratio can here be interpreted by increased humic substances rather than by fluctuations in bathymetry (see Hyvärinen and Alhonen 1970: 413—414).

The kettle-hole pond Hyrynlampi (Alhonen 1971b) between the Salpausselkä endmoraines south-west of the willage of Läyliäinen in the parish of Loppi has been limnologically more or less oligotrophic during its Holocene development. The significance of its cladoceran stratigraphy will be discussed later in the text.

Salomaa and Alhonen (1983) have examined diatom and cladoceran assemblages of the sediment core taken from Lake Spitaalijärvi in Lauhanvuori, western Finland. This small lake, now very acid, was isolated from the Ancylus Lake about 9000 B.P. It was during the first few hundred years probably eutrophic with alkaliphilous diatom flora. The later development of Lake Spitaalijärvi has clearly directed on the ultra-oligotrophy as was indicated by the appearance of the acidobiontic forms *Tabellaria binalis* and *Semiorbis hemicyclus* (Fig. 2). This lake is an interesting and very representative example of natural meiotrophication or acidification, the main reason of which can closely be correlated to highly siliceous quartz sandstone of its environment.

The sediment history of Lake Työtjärvi situated in a shallow basin on the top of the first Salpausselkä (see Donner et al. 1978) shows at first an alkaliphilous (more or less eutrophic)

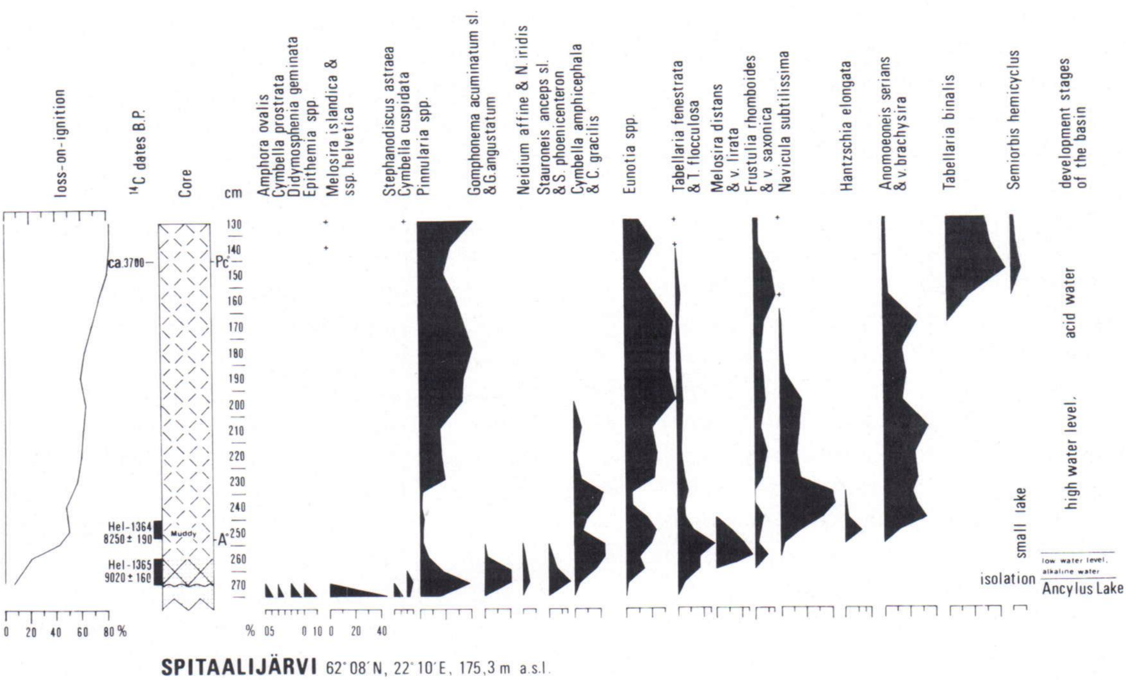

Fig. 2. Diatom stratigraphy (selected species) of Lake Spitaalijärvi (Lauhanvuori, western Finland) showing the isolation of the lake and the ecological development of the diatom flora (From Salomaa and Alhonen 1983, Fig. 3).

phase according to fossil diatom assemblages and thereafter at the beginning of the Atlantic Chronozone its water became acid. Later, during the Subatlantic Chronozone eutrophication of the lake started at least partly as a result of the activity of the Iron Age settlement in the catchment. This trend in the typological development was, however, temporary, because Lake Työtjärvi seems now to be more or less oligotrophic. The meiotrophication of the lake during the Middle Flandrian is most likely controlled by the humic substances, which have been washed from the adjoining mire Varrassuo into the lake. They are both at a level which emerged during the drainage of the Baltic Ice Lake to the level of Yoldia Sea at about 10200 years ago. Thus, the organic sediments (clay-mud and mud) in Lake Työtjärvi basin have been formed shortly after the beginning of the Holocene. The oldest radiocarbon date from Työtjärvi core is 9020 ± 190 B.P. (Donner *et al.* 1978: Appendix II).

Kukkonen and Tynni (1970) examined the typological history of Lake Pyhäjärvi in South Finland during past 3700 years. According to the fossil diatom flora the lowermost part of the investigated sediment core, 290 cm in length, was deposited in more or less eutrophic conditions, as does its topmost part. Before the terminal eutrophication, partly as a result of human activities in the catchment, Lake Pyhäjärvi was distinctly dystrophic and thus meiotrophicated. It should be mentioned already here that the dating of its sediments was for the first time in Finland based on varved gyttja-clay which has been assumed to be annual. Concerning eutrophication of Lake Pyhäjärvi in the diatom stratigraphy *Tabellaria fenestrata/Cyclotella kützingiana*-plankton was then replaced by *Melosira italica, M. ambigua* and *Stephanodiscus astraea* (Kukkonen and Tynni 1970, Fig. 11).

Kukkonen (1973) concluded that there have been three typological changes during the history of Lake Lohjanjärvi: in its initial phase the lake was eutrophic with slightly alkaline water. Due to the influence of the allochtonous humus substances the limnological type of Lake Lohjanjärvi developed towards dysoligotrophy. After the beginning of the Subatlantic Chronozone its typology became more eutrophic, as it still is at present (see Kukkonen 1973, Fig. 26). This cultural eutrophication of Lake Lohjanjärvi has started already before the influence of industrial and domestic waste waters due to land use for agricultural purposes since Iron Age. A number of eutrophic (alkaliphilous) diatoms in the lithostratigraphy of the lake, especially in its topmost part such as *Stephanodiscus astraea, S. astraea* var. *minutula, S. dubius, S. hantzschii, Melosira granulata, M. granulata* var. *angustissima* and a halophilous form *Diatoma elongatum* var. *tenue* indicate a clear development towards eutrophy and pollution. It might be mentioned that the present limnological conditions in Lake Lohjanjärvi are particularly favourable to this halophilous diatom (Kukkonen 1973: 41).

The cultural eutrophication can also be recorded in a number of sediment cores. Besides Lohjanjärvi excellent examples are the lakes Gallträsket, Pitkäjärvi, Tuusulanjärvi, Lampellonjärvi and the waste area of southern Lake Saimaa as discussed by Alhonen (1979a). The first stage of this process is indicated by the appearance and increase of certain organisms, which are associated with eutrophic conditions (see Fig. 1). The recent pollution phase of Lake Iidesjärvi in the town of Tampere (South Finland) is successively characterized by alkaliphilous diatoms (Alhonen 1981). On the whole this lake has been productive since its isolation from the Ancylus Lake stage of the Baltic Sea.

The diatom stratigraphy of the sediments of Lake Enäjärvi in southern Finland studied by Alhonen (1982) shows that it has been mineroeutrophic since its isolation from the Ancylus Lake. *Melosira granulata, M. granulata* var. *angustissima, M. italica, M. ambigua* and *Cyclotella comta* have dominated in the plankton throughout its whole developmental history.

Simola (1983) studied a diatom stratigraphy in the surface sediments of Lake Polvijärvi in North Karelia. The results show that the diatom plankton succession from *Tabellaria flocculosa* through *Asterionella formosa* to *Melosira ambigua* and *Fragilaria crotonensis* reflects a cultural eutrophication of the lake. This development is contemporaneous with peatland draining and fertilizing in the catchment of Lake Polvijärvi. In addition to the final eutrophication of this lake an increased productivity can be observed in connexion with the slash-and-burn-cultivation in the area; it was characterized by *Asterionella formosa* in the diatom stratigraphy of bottom sediments (see Simola 1983, Fig. 5).

Ahtiainen *et al.* (1983) describe a diatom stratigraphy from Lake Sysmäjärvi, which is polluted by mining waste-waters. This lake is situated in North Karelia, near the town of Outokumpu. Its initial and middle stages after isolation from the Ancylus Lake were indicated by a *Melosira granulata* maximum (Ahtiainen *et al.* 1983, Fig. 2). This taxon is very common in eutrophic waters. Sewage and circumneutral waste-waters from the mining industry started a cultural eutrophication process in Lake Sysmäjärvi, but since 1938 highly acid waters have been discharged into the lake. Effect of neutralization of lake water by liming is clearly seen in the topmost sediments and is indicated by an increase of *Nitzschia plana* (Ahtiainen *et al.* 1983, Fig. 3).

It should be mentioned in this connexion that Räsänen and Salonen (1983) have found in Lake Kakskerranjärvi near the town of Turku that diatoms and chironomids are good indicators of environmental pollution in recently deposited lake sediments. Their data suggest that changes in land use has been most important factor affecting the alterations in the limnological development of the lake. Since 1920s the use of industrial fertilizers has led to its rapid pollution.

Biostratigraphical research has been applied on several lakes in the vicinity of Lammi Biological

Station (see Kukkonen and Tynni 1972, Alhonen and Vuorela 1974, Tolonen *et al.* 1976, Huttunen and Tolonen 1977 and M. Tolonen 1978). In their first stages these typical kettle-hole meromictic lakes (except of the shallow Lake Lamminjärvi: Alhonen and Vuorela 1974) have developed from a eutrophic state towards dysoligotrophy. A later eutrophication is most likely due to human influence and it has been dated by varved lake sediments. The slash-and-burn cultivation around Lake Lovojärvi in the parish of Lammi was started c. 1700 B.P. (Huttunen 1980).

The usefulness of bioindicators, especially diatoms, has been shown in the formation of annually laminated lake sediments (see Saarnisto *et al.* 1977, Simola 1977 and 1979) as mentioned shortly above. The different kinds of intra-annual rhytmic structures (see Reineck and Singh 1975: 108—113) can confuse the interpretation of laminations, and therefore the annuality of varved lake sediments must always be verified by the seasonal succession of e.g. diatom fossils (see Simola and Tolonen 1981).

The useful information can also be obtained from a diatom stratigraphy for examining the acidification of lakes by e.g. air-borne pollutants (see Tolonen and Jaakkola 1983). The topmost centimetres of the sediment cores in four small oligohumous forest lakes in the parish of Espoo (South Finland) were characterized by acidobiontic species, such as *Anomoeoneis serians, Navicula subtilissima, Actinella punctata, Eunotia exigua* and *Tabellaria binalis* (see Tolonen and Jaakkola 1983: 64).

Coastal lakes: a new application

Coastal lakes in Finland are transiet stages between the Baltic Sea inlets and true lakes (Lindholm 1982). They also include many man-made reservoirs and numerous archipelago waters almost isolated from the Baltic. Ahvenanmaa (Åland) offers good examples of these lakes, but along the coast of northern Baltic new lake basins are still formed as a function of land uplift.

Many coastal lakes are meromictic (Lindholm 1975). The presence of salt water of higher density is a prerequisite for meromixis. Lindholm (1982: 56) has summarized the main factors and mechanisms keeping coastal lakes meromictic. It should be also mentioned that the development towards increasing eutrophy in these lakes depends on increased water renewal time and temporary meromixis mobilizing nutrients from bottom sediments. Variations in salinity seem to be the most significant factor affecting changes in diatom communities in coastal lakes, and it can succesfully be followed from the diatom stratigraphy of sediment cores (see Räsänen 1983). The determination of lake isolation horizon on the basis of the deposited diatom assemblages is, however, often difficult. After the topographical »true» isolation of a lake basin from marine Baltic environment (see Ingmar 1975) the salinity conditions continue in meromictic coastal lakes, and the biological isolation occurs when the brackish stage in the lake basin is totally ended.

Lake microfossils and climatic changes

As mentioned above Cladocera can be divided ecologically into planktonic and substrate species. Hence, they are particularly well suited for interpretative studies of past fluctuations in water-level. Diatom fossils show a similar distribution. A good example of this is the study by Donner et al. (1978) on Lake Työtjärvi (see Fig. 3).

The planktonic/littoral ratio in the cladoceran stratigraphy and the changes in the biotope ecological groups of diatoms suggest that the basal sediments of Lake Työtjärvi in Preboreal and Boreal Chronozones were deposited in shallow water. At the beginning of the Atlantic Chronozone the rise of water-level took place. A similar feature has been detected by Alhonen (1970a, 1970b and 1972) in some other lakes in Finland. These show an increase in the proportion of the littoral cladoceran species in the Subboreal Chronozone.

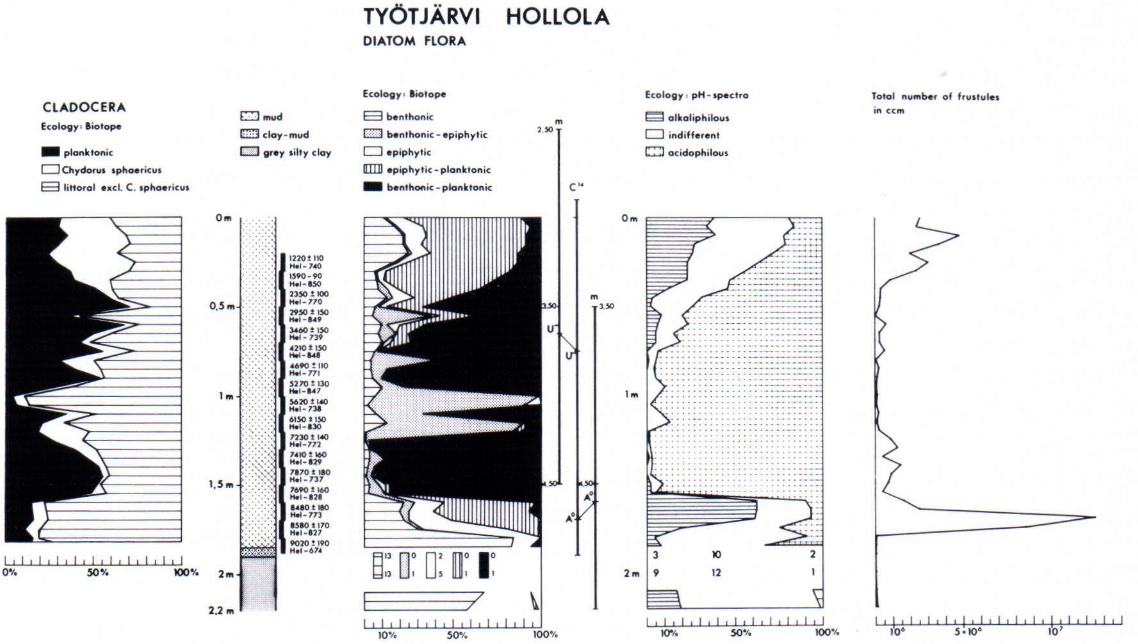

Fig. 3. Comparison between cladoceran and diatom stratigraphy of Lake Työtjärvi (on the top of the Salpausselkä I, near the town of Lahti) with radiocarbon dates. The biostratigraphy provides information both on the water-level changes and the eutrophication during the developmental history of the lake (From Donner *et al.* 1978).

The upper planktonic maximum in the cladoceran stratigraphy of Lake Työtjärvi shows the development towards more pelagic environment. This is probably due to the high abundance of *Chydorus sphaericus* (Fib. 3), which is primarily a littoral species, but is considered here to be in plankton associated with bluegreen algal blooms. These have been assumed to occur during the eutrophication process in Lake Työtjärvi.

As pointed out by Digerfeldt (1972 and 1975) a water-level fluctuation indicates that a change in the moisture of climate has occurred. The climatic interpretation from certain microfossil assemblages of lake sediments seems to agree with moister and drier phases of Holocene climatic events especially in southern Finland and can also be correlated to some extend with palaeohydrological changes in Scandinavia (see Berglund 1983). Warm and dry conditions with low water-level is evident during 8000—9000 B.P. in Lake Työtjärvi. From about 8000 B.P. the water-level rose and remained high with possible minor fluctuations. There has been an apparent lowering in water-level at about 5000 B.P., but its evidence is not conclusive (see Donner *et al.* 1978: 277).

Conclusions

The present knowledge of Holocene palaeolimnological, palaeoecological and environmental changes in Finnish lakes rests essentially on microfossil studies. Diatoms and Cladocera are still the most significant groups, but the potential usefulness of the larvae of lacustrine Diptera, chrysomonads, rhizopod Protozoa, ostracods, sponges and possibly rotifers cannot be neglected. Besides terrestrial pollen they enable interpretations of typological development of lakes, catchment conditions, water-level changes and climatic fluctuations. It is very apparent that the results

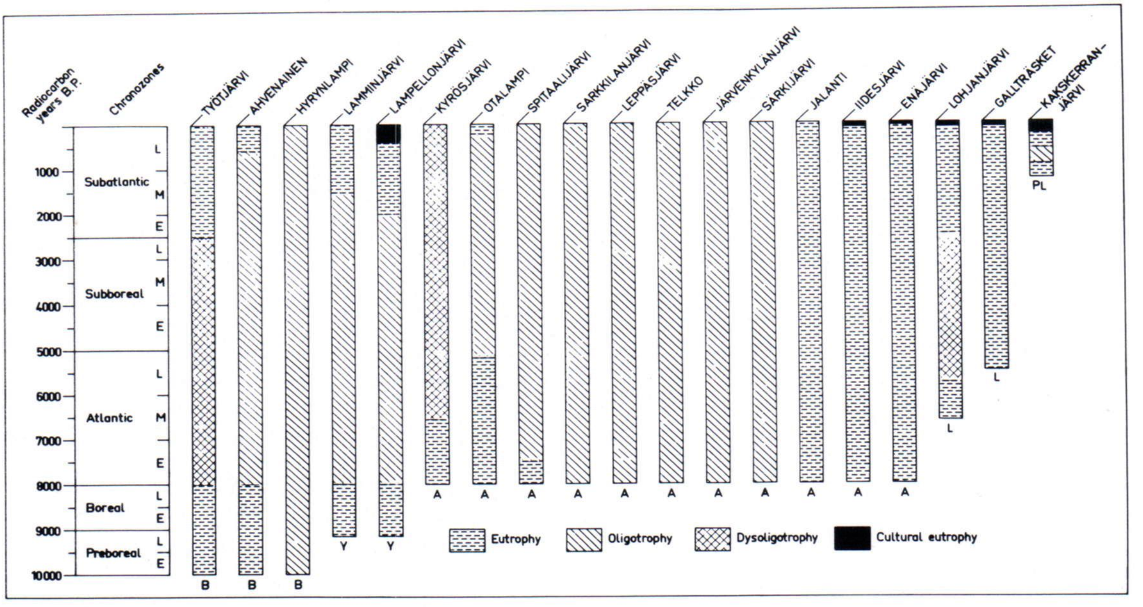

Fig. 4. Simplified scheme representing the interpretation of palaeolimnological events in the lakes discussed in the text (partly selected) related to Holocene chronozones and radiocarbon time scale (see Mangerud *et al.* 1974). The isolation of the lake basins are marked by B (= Baltic Ice Lake), Y (= Yoldia phase), A (= Ancylus Lake), L (= Litorina Sea) and PL (= post-Litorina Baltic).

derived from different microfossil biostratigraphies of lake sediments can solve many environmental problems, because bottom deposits store often a detailed history of the environment.

In the light of the microfossil studies the most significant natural development of Finnish lakes is a typological succession from the minero-eutrophic (argillotrophic or pelotrophic) state towards more dysoligotrophic conditions. As a matter of fact this progressive meiotrophication means dystrophication related to increasing humic substances leaching from sorrounded bogs and pedological changes of soil. A later cultural eutrophication was followed due to man's activities in the lake environment. The conclusions which can be drawn from palaeolimnological reconstructions based on microfossil assemblages as lacustrine bioindicators are summarized in Fig. 4.

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