EESTI NSV TEADUSTE AKADEEMIA TOIMETISED. 26. KÖIDE
BIOLOOGIA. 1977, NR. 2

ИЗВЕСТИЯ АКАДЕМИИ НАУК ЭСТОНСКОЙ ССР. ТОМ 26
БИОЛОГИЯ. 1977, № 2

https://doi.org/10.3176/biol.1977.2.07

УДК 577.472/28/578.087.1

Aare MÄEMETS, Ain RAITVIIR

ON THE CLASSIFICATION OF ESTONIAN LAKES BASED ON THE ANALYSIS OF PRINCIPAL COMPONENTS AND COORDINATES

In order to understand the essence of lakes, it is necessary to classify them. Undoubtedly, a typology of lakes based on important abiotic and biotic parameters and reflecting the genesis and evolution of lakes is the only scientific basis for their protection and economic management. A typology of lakes also provides us with a basis for the evaluation of the intensity of the process of anthropogenic eutrophication and for the understanding of its directions.

In the process of the classification of Estonian lakes, a typology of lakes has been created (Mäemets, 1965, 1974, etc.). On the one hand, it is based on the classical Naumann-Thienemann-Järnefelt's typology and, on the other, it also takes into account L. Rossolimo's accumulation types of lakes (Rossolimo, 1964) and the stratification of lakes. Thus the accumulation type (the trophy of the lake) and the vertical thermal and hydrochemical stratification of the lake form the basis for the existing typology of Estonian lakes discussed in the present paper. A hypothesis, according to which a lake as an ecosystem that accumulates various substances during its life, is the main component of this basis. The quality of water and the changes in ecosystems under natural conditions of Estonia are connected with three main natural processes: 1. humification, 2. eutrophication, 3. alkalization.

Humification is the accumulation of humic substances by the surface waters.

Eutrophication is the accumulation of nutrients, especially phosphorus and nitrogen, from the environment, mostly by surface waters, and to a smaller extent by phreatic waters and by atmospheric precipitation.

Alkalization is the accumulation of calcium, and to a smaller extent, of magnesium, mostly by phreatic water.

The above-mentioned processes never occur in a pure form under natural conditions. Nevertheless, the dominating process may always be distinguished.

Combinations of the processes form a basis for the typology of lakes. The main accumulation types are as follows:

1. oligotrophic type — a weak accumulation of all substances;
2. eutrophic type — the accumulation of nutrients is dominating;
3. dystrophic type — the accumulation of humic substances is dominating;

4a. soft-water dyseutrophic subtype — the accumulation of humic substances and nutrients dominates;

4b. hard-water dyseutrophic subtype — the accumulation of calcareous and humic substances and nutrients dominates;

5. alkalitrophic type — the accumulation of calcareous substances dominates.

In the Estonian coastal region, halotrophic lakes with a strong influence of halogenes can be found, too.

In the further division of the main types, the anthropogenic agency has been taken into account. On this basis, several main types have been divided into typical and eutrophicated subtypes.

The important basis for typology is the vertical thermic and hydrochemical stratification. The circulation of substances and energy in lakes is highly dependent on the above factor. On the basis of stratification, the lakes can be divided into stratified and unstratified ones.

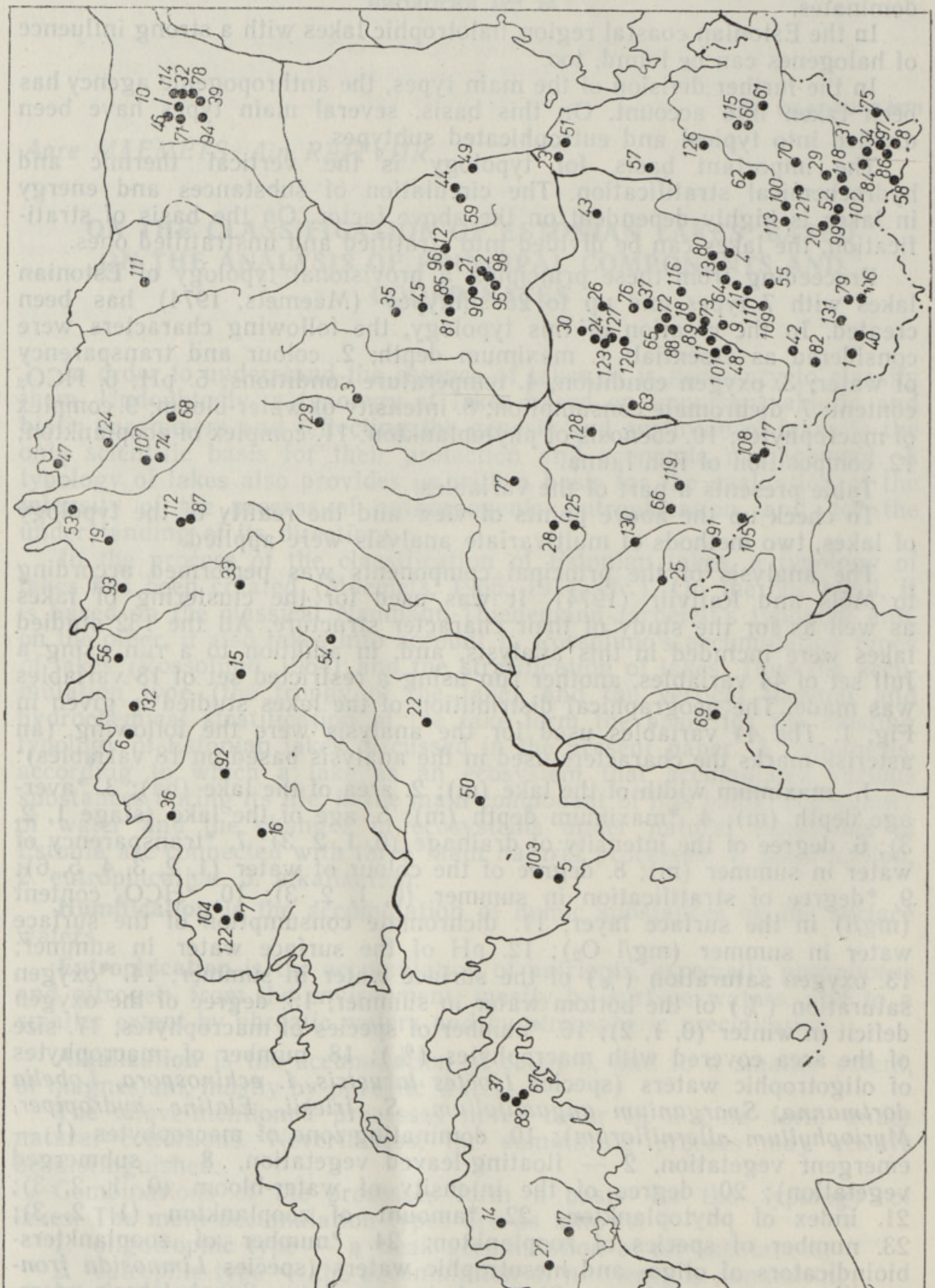
Proceeding from these principles, a provisional typology of Estonian lakes with 7 types and up to 25 subtypes (Mäemets, 1974) has been created. In the creation of this typology, the following characters were considered as essential: 1. maximum depth; 2. colour and transparency of water; 3. oxygen condition; 4. temperature conditions; 5. pH; 6. HCO_3 content; 7. dichromate consumption; 8. intensity of water-bloom; 9. complex of macrophytes; 10. coenosis of phytoplankton; 11. complex of zooplankton; 12. composition of fish fauna.

Table presents a part of the variables.

To check up the above points of view and the reality of the typology of lakes, two methods of multivariate analysis were applied.

The analysis of the principal components was performed according to Möls and Raitviir (1974). It was used for the clustering of lakes as well as for the study of their character structure. All the 132 studied lakes were included in this analysis, and, in addition to a run using a full set of 44 variables, another run using a restricted set of 18 variables was made. The geographical distribution of the lakes studied is given in Fig. 1. The 44 variables used for the analysis were the following (an asterisk marks the characters used in the analysis based on 18 variables):

1. maximum width of the lake (m); 2. area of the lake (ha); 3. *average depth (m); 4. *maximum depth (m); 5. age of the lake (stage 1, 2, 3); 6. degree of the intensity of drainage (0, 1, 2, 3); 7. *transparency of water in summer (m); 8. degree of the colour of water (1, 2, 3, 4, 5, 6); 9. *degree of stratification in summer (0, 1, 2, 3); 10. *HCO_3 content (mg/l) in the surface layer; 11. dichromate consumption of the surface water in summer (mg/l O_2); 12. pH of the surface water in summer; 13. oxygen saturation (%) of the surface water in summer; 14. *oxygen saturation (%) of the bottom water in summer; 15. degree of the oxygen deficit in winter (0, 1, 2); 16. *number of species of macrophytes; 17. size of the area covered with macrophytes (%); 18. number of macrophytes of oligotrophic waters (species *Isoëtes lacustris, I. echinospora, Lobelia dortmanna, Sparganium angustifolium, S. friesii, Elatine hydropiper, Myriophyllum alterniflorum*); 19. dominating zone of macrophytes (1 — emergent vegetation, 2 — floating-leaved vegetation, 3 — submerged vegetation); 20. degree of the intensity of water-bloom (0, 1, 2, 3); 21. index of phytoplankton; 22. *amount of zooplankton (1, 2, 3); 23. number of species of zooplankton; 24. *number of zooplankters-bioindicators of oligo- and mesotrophic waters (species *Limnosida frontosa, Holopedium gibberum, Simocephalus serrulatus, Scapholeberis microcephala, Acantholeberis curvirostris, Streblocerus serricaudatus, Ophryoxus gracilis, Alona rustica, A. karelica, Bythotrephes cederstroemi, Acanthodiaptomus denticornis, Heterocope saliens, H. appendiculata, Eurytemora lacustris, Cyclops scutifer*); 25. *amount of *Daphnia cucullata* (0, 1, 2, 3, 4, 5); 26. amount of *Daphnia cristata* (0, 1, 2, 3, 4, 5); 27. amount of

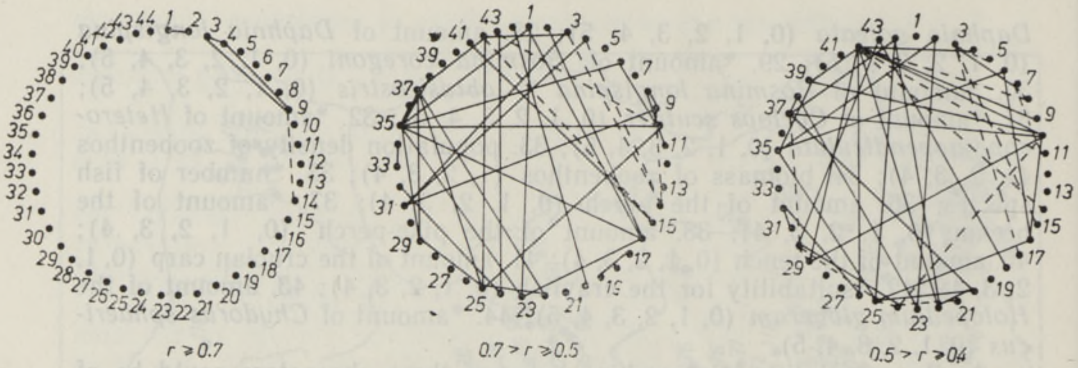

10
114
32
78
45
71
39
94
115
60
61
75
51
23
126
31
57
29
70
62
118
84
97
8
86
58
49
44
43
100
113
121
52
99
20
102
12
59
80
13
4
55
96
21
2
98
116
111
35
45
85
81
90
95
26
76
37
79
46
30
24
127
72
18
64
41
110
109
73
89
11
101
48
9
65
88
123
120
42
82
131
1
40
3
129
124
107
74
68
63
128
117
108
47
77
119
66
112
87
125
53
19
28
130
91
105
33
93
25
54
56
15
132
22
69
6
92
36
50
16
103
5
104
122
7
37
67
83
14
17
27

Daphnia galeata (0, 1, 2, 3, 4, 5); 28. amount of *Daphnia longispina* (0, 1, 2, 3, 4, 5); 29. *amount of *Bosmina coregoni* (0, 1, 2, 3, 4, 5); 30. *amount of *Bosmina longispina* + *obtusirostris* (0, 1, 2, 3, 4, 5); 31. *amount of *Cyclops scutifer* (0, 1, 2, 3, 4, 5); 32. *amount of *Heterocope appendiculata* (0, 1, 2, 3, 4, 5); 33. population density of zoobenthos (1, 2, 3, 4); 34. biomass of zoobenthos (1, 2, 3, 4); 35. *number of fish species; 36. amount of the perch (0, 1, 2, 3, 4); 37. *amount of the bream (0, 1, 2, 3, 4); 38. amount of the pike-perch (0, 1, 2, 3, 4); 40. amount of the tench (0, 1, 2, 3, 4); 41. amount of the crucian carp (0, 1, 2, 3, 4); 42. *suitability for the crayfish (0, 1, 2, 3, 4); 43. amount of the *Holopedium gibberum* (0, 1, 2, 3, 4, 5); 44. *amount of *Chydorus sphaericus* (0, 1, 2, 3, 4, 5).

As the correlative relationships between these characters could be of some interest, they are briefly discussed. A survey of essential correlations between parameters is given in Fig. 2. All in all, 179 significant correlation coefficients ($r \geqslant 0.3$) were found between 44 parameters. Analysis of the correlation matrix showed that the highest correlation coefficients ($r \geqslant 0.7$) exist between directly interdependent abiotic factors such as the width of the lake and the area of the lake, average and maximum depth, degree of stratification and oxygen saturation of the bottom water. These correlations are in fact trivial ones. In the case of significant correlations between abiotic and biotic factors, the correlation coefficient is within the limits $0.65 \geqslant r \geqslant 0.3$, as well as in the case of significant correlations between biotic factors. There are several interesting interrelationships that could be pointed out. The numbers of plant and fish species are positively correlated. It is quite logical because the high number of plant species creates preconditions for the complexity of ecosystem structure that provides fish species with various ecological niches and wider food supply. The numbers of macrophyte species and the HCO'_3 content are

---

Fig. 1. Geographical distribution of the lakes investigated (List of lakes: *1* — L. Aheru, *2* — L. Elistvere, *3* — L. Endla, *4* — L. Erastvere, *5* — L. Ermistu, *6* — L. Harku, *7* — L. Hindaste, *8* — L. Hino, *9* — L. Inni, *10* — L Jaala, *11* — L. Juusa, *12* — L. Jōemōisa-Kaiu, *13* — L. Jōksi, *14* — L. Järise, *15* — L. Järlepa, *16* — L. Järveotsa, *17* — L. Kaarmise, *18* — L. Kaarna, *19* — L. Kahala, *20* — L. Kahrila, *21* — L. Kaiavere, *22* — L. Kaisma, *23* — L. Kalli, *24* — L. Karijärv, *25* — L. Kariste, *26* — L. Karujärv at Nōo, *27* — L. Karujärv, *28* — L. Karula, *29* — L. Kavadi, *30* — L. Keeri, *31* — L. Kirikumäe, *32* — L. Kirjakjärv, *33* — L. Kiruvere, *34* — L. Kisejärv, *35* — L. Kivijärv, *36* — L. Klooga, *37* — L. Kodijärv, *38* — L. Koigi, *39* — L. Konsu, *40* — L. Koobassaare, *41* — L. Kooraste, *42* — L. Korijärv, *43* — L. Kriimani, *44* — L. Kuningvere, *45* — L. Kuremaa, *46* — L. Kurtna, *47* — L. Käsmu, *48* — L. Kääriku, *49* — L. Lahepera, *50* — L. Lavassaare, *51* — L. Leegu, *52* — L. Liinjärv, *53* — L. Lohja, *54* — L. Loosalu, *55* — L. Lōōdla, *56* — L. Maardu, *57* — L. Mooste, *58* — L. Murati, *59* — L. Mustjärv at Kokora, *60* — L. Mustjärv at Nohipalu, *61* — L. Mustjärv at Orava, *62* — L Mustjärv at Tsolgo, *63* — L. Mustjärv at Valguta, *64* — L. Mutsina, *65* — L. Mōrtsuka, *66* — L. Mäeküla, *67* — L. Naistejärv, *68* — L. Tagajärv at Neeruti, *69* — L. Nigula, *70* — L. Noodasjärv, *71* — L. Nōmmejärv at Kurtna, *72* — L. Nōuni, *73* — L. Nüpli, *74* — L. Ohepalu, *75* — L. Pabra, *76* — L. Pangodi, *77* — L. Parika, *78* — L. Peen-Kirjakjärv, *79* — L. Pehmejärv, *80* — L. Piigandi, *81* — L. Pikkjärv at Kaarepere, *82* — L. Pikkjärv at Karula, *83* — L. Pikkjärv at Koigi, *84* — L. Preeksa, *85* — L. Prossa, *86* — L. Pullijärv, *87* — L. Purgatsi, *88* — L. Päidla, *89* — L. Pühajärv, *90* — L. Raigastvere, *91* — L. Ruhijärv, *92* — L. Ruiljärv, *93* — L. Rummi, *94* — L. Räätsma, *95* — L. Saadjärv, *96* — L. Saare, *97* — L. Saarjärv at Misso, *98* — L. Soitsjärv, *99* — L. Suurjärv at Rōuge, *100* — L. Tamula, *101* — L. Tornijärv, *102* — L. Tuuljärv, *103* — L. Tōhela, *104* — L. Tänavjärv, *105* — L. Tündre, *106* — L. Ubajärv, *107* — L. Udriku, *108* — L. Udsu, *109* — L. Uhtjärv, *110* — L. Uiakatsi, *111* — L. Uljaste, *112* — L. Urbukse, *113* — L. Vagula, *114* — L. Valgejärv at Kurtna, *115* — L. Valgjärv at Nohipalu, *116* — L. Valgjärv, *117* — L. Valgjärv at Koorküla, *118* — L. Vaskna, *119* — L. Veisjärv, *120* — L. Verevi, *121* — L. Verijärv, *122* — L. Veskijärv, *123* — L. Viisjaagu, *124* — L. Viitna, *125* — L. Viljandi, *126* — L. Viroste, *127* — L. Vissi, *128* — L. Vōrtsjärv, *129* — L. Väinjärv, *130* — L. Ōisu, *131* — L. Ähijärv, *132* — L. Ülemiste).



$r \geq 0.7$ $0.7 > r \geq 0.5$ $0.5 > r \geq 0.4$

Fig. 2. Main correlations between the variables of lakes (continuous line — positive correlations; broken line — negative correlations).

positively correlated with the area of the lake, and the abundance of bream with that of the water-fleas *Daphnia cucullata* and *Bosmina coregoni*, or the abundance of *Cyclops scutifer* with the degree of stratification, etc. High negative correlations exist between the HCO'_3 content and abundance of *Holopedium gibberum*; between the degree of the oxygen deficit in winter and suitability for the crayfish, etc. The majority of biotic correlations are caused by the coexistence of species complexes with similar abiotic needs in the lakes belonging to the same type.

In the analysis of components (based on 44 variables), the first five principal components making up 51.34 per cent of the total variation, were interpreted.

The first principal component accounts for 19.33 per cent of the total variation. It could be named the component of trophy. It describes lakes in terms of the number of fish and macrophyte species, suitability for the crayfish, degree of mineralization, abundance of the bream, *Daphnia cucullata*, zooplankton, *Bosmina coregoni* and *Bosmina longispina + obtusirostris*. All the listed variables have high positive weights, except the last one (abundance of *Bosmina longispina + obtusirostris*), which has a highly negative weight. This component gives highly positive markings to eutrophic lakes, separating them from the dystrophic, oligotrophic and dyseutrophic ones which are characterized by negative and highly negative markings.

The second principal component accounts for 12.8 per cent of the total variation. It is the component of stratification. The component gives positive markings to lakes which are shallow, unstratified, rich in O_2, with a low transparency of water in summer, having *Chydorus sphaericus* in great numbers and *Heterocope appendiculata, Cyclops scutifer* and oligo- and mesotrophic zooplankton complex in small numbers. Lakes with opposite values in these characters get negative markings. This component, on the one hand, separates the dystrophic and oligotrophic lakes from dyseutrophic ones, and, on the other, the mesotrophic, stratified eutrophic and typical eutrophic lakes from each other.

The third principal component (7.6% of the total variation) is the component of overgrowth and age. Aged lakes are characterized by rich macrophyte vegetation and zoobenthos numbers and biomass, high transparency and light colour of water, abundance of the crucian carp while *Chydorus sphaericus* is almost absent. The other end of the component indicates lakes poor in vegetation and zoobenthos.

The fourth principal component (6.8% of the total variation) is first of

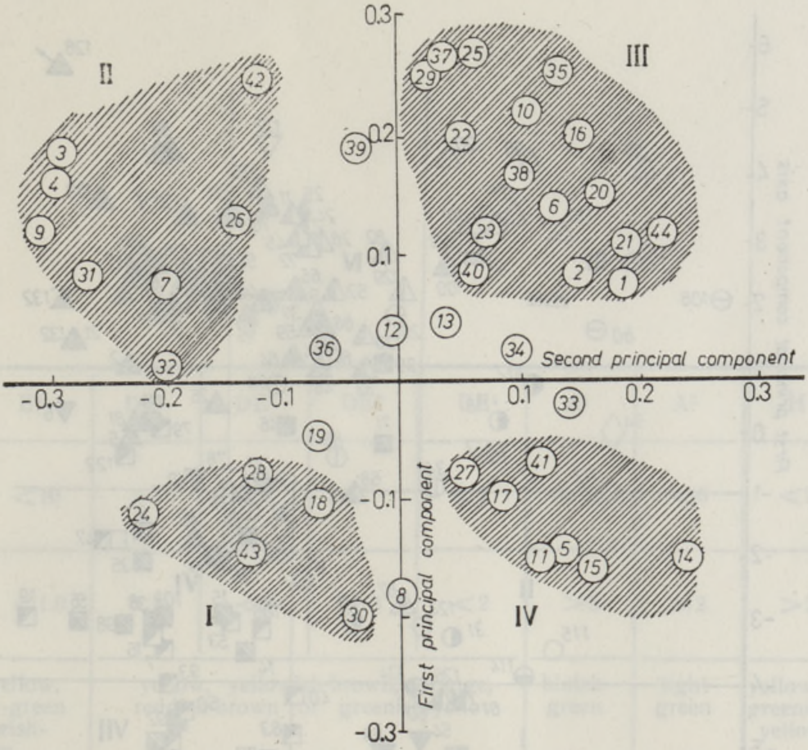


Fig. 3. Clustering of characters based on their coefficients in the first and second principal components. I — parameters of oligo- and dystrophic lakes, II — parameters of lakes with mesotrophic features, III — parameters of eutrophic lakes, IV — parameters of dyseutrophic lakes. The numbers of the parameters are the same as in the list of characters (p. 139 and 141).

all connected with the size of lakes. The number of zooplankton species, species of oligo- and mesotrophic zooplankton, abundance of *Bosmina longispina + obtusirostris, Holopedium gibberum*, the perch and the pike-perch are significant in this component.

The fifth principal component (4.8% of the total variation) describes the deficit of O_2 in the bottom layers of lake water. It is connected with the age and stratification of lakes. In lakes with a low O_2 content near the bottom there are few perches and roach, many crucian carps and *Daphnia longispina*. The abundance of *Daphnia galeata* is low.

A plotting of variables against the 1st and 2nd principal components resulted in an interesting picture (Fig. 3). It turned out that variables characteristic of similar ecosystems are grouped in neighbouring areas in the graph (striped areas). So the first group consists of variables characteristic of oligotrophic and dystrophic lakes — *Holopedium gibberum, Daphnia longispina, Bosmina longispina + obtusirostris,* the macrophytes of oligotrophic waters and species of the zooplankton of oligo- and mesotrophic waters.

Group II is made up of variables which have positive weights in lakes with mesotrophic features. These are the big average and maximum depth, distinct stratification, high transparency, suitability for the crayfish, big amounts of *Cyclops scutifer, Daphnia cristata* and *Heterocope appendiculata*.

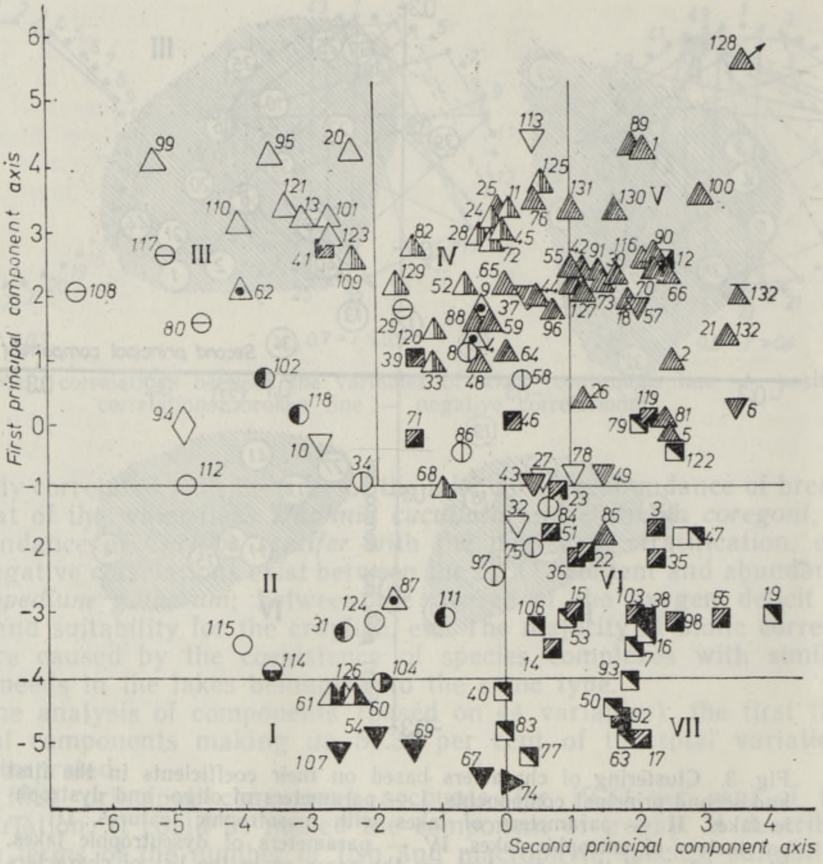


Fig. 4. A principal component clustering of Estonian lakes.
Symbols see in Fig. 5.

Variables with high positive weights characteristic of eutrophic lakes form Group III. They are great amounts of the bream, *Daphnia cucullata, Bosmina coregoni,* zooplankton, pike-perch, tench and *Chydorus sphaericus,* HCO'_3 content, number of species of fishes and macrophytes, intensive drainage, intensive water-bloom, large area and width of the lake.

Variables which have high positive weights in dyseutrophic lakes belong to Group IV: great amounts of *Daphnia galeata* and crucian carp, an area covered with macrophytes, dichromate consumption, O_2 deficit in layers near bottom, "winter kill", and age of the lake.

Some parameters, such as pH, O_2 content of the surface water, population density and biomass of zoobenthos, abundance of the perch, etc., are not particularly characteristic of any lake type and in the diagram they do not belong to any character complexes determining lake types.

Results of the principal components analysis are presented in Fig. 4. This diagram, plotted against the first and second principal component, was most readily interpreted in the terms of the A. Mäemets (1974) typology, and presents the results of an analysis carried out on the basis of 44 parameters. As the comparison of the results of the analysis on the basis of 44 and 18 parameters with the typology of lakes offered by A. Mäemets (1974) reveals, coincidence is marked, especially in the case of the analysis on the basis of 44 parameters. An attempt to reduce the

Values of some important variables of Estonian lake types and subtypes

Lake Type or Subtype	O^1	O^2	O^3	O^4	SD^1	SD^2	SD^3	SD^4	D^1	D^2	D^3	D^4	E^1	E^2	E^3	E^4	E^5	E^6	DE^1	DE^2	DE^3	DE^4	A^1	A^2	H
Maximum depth (m)	>30	7—12	25—30	<12	7—18	<7	>7	<7	5—20	>5	4—8	<2	7—30	<7	15—38	<10	>10	<10	>7	<7	>7	<7	3—8	<3	<2
Transparency of water (m) in summer	6.6—8.0	4.0—8.8	3.0—5.0	2.0—4.0	2.0—4.0	1.0—4.0	2.0—5.0	1.0—4.0	<1.5	0.5—1.0	<1.5	<1.5	0.5—2.5	0.4—1.0	2.0—6.5	<3.0	<2.0	<1.0	<3	<2	1—3	<2	>5	>2	>2
Colour of water in summer	light-green or bluish-green		yellow, yellowisch-green, greenish-yellow or light-green		yellow, yellowish-brown, brownish-yellow or greenish-yellow				brownish-red or reddish-brown				yellowish-green or brownish-green		greenish-yellow, yellowish-green		greenish-yellow, yellowish-green or yellowish-brown		yellow, yellowish-brown, orange, reddish-brown or greenish-yellow				bluish-green	light-green	yellow or greenish-yellow
pH (in summer)	7.2—7.5	6—7	7.3—8.4	6—8	6—7	5—8	7—8	5—8	4.5—6	4—6	4—6	4—6	7—9.2	7—9.2	7—9	7—9	7—9	8—9	6—>9	6—>9	7—9	7—9	>8	>8	>8
HCO_3 content (mg/l)	<20	<30	20—70	<80	<30	<80	<80	<80	<6	<6	<6	<6	<80	<80	>80	>80	>80	>80	6—80	6—80	>80	>80	>200	>200	>80
Dichromate consumption (mg of O_2 per litre in summer)	<20	<12	<20	12—25	15—35	15—35	20—35	15—35	>60	50—100	>35	>35	<35	<35	<35	<35	<35	<35	>35	>35	>35	>35	<15	<15	
Degree of stratification in summer	high	very low	high	very low	high	low	high	low	high	very high	low	very low	very high	low	very high	low	high	high	very high	low	very high	low	average	very low	very low
Water-bloom in summer	very weak or weak	very weak or absent	weak or average	average	very weak		average or strong		very weak or absent	weak or absent	absent		strong or very strong		weak or average	average or strong		strong	weak or average	average or strong	weak or average	average or very strong	absent		very weak or absent

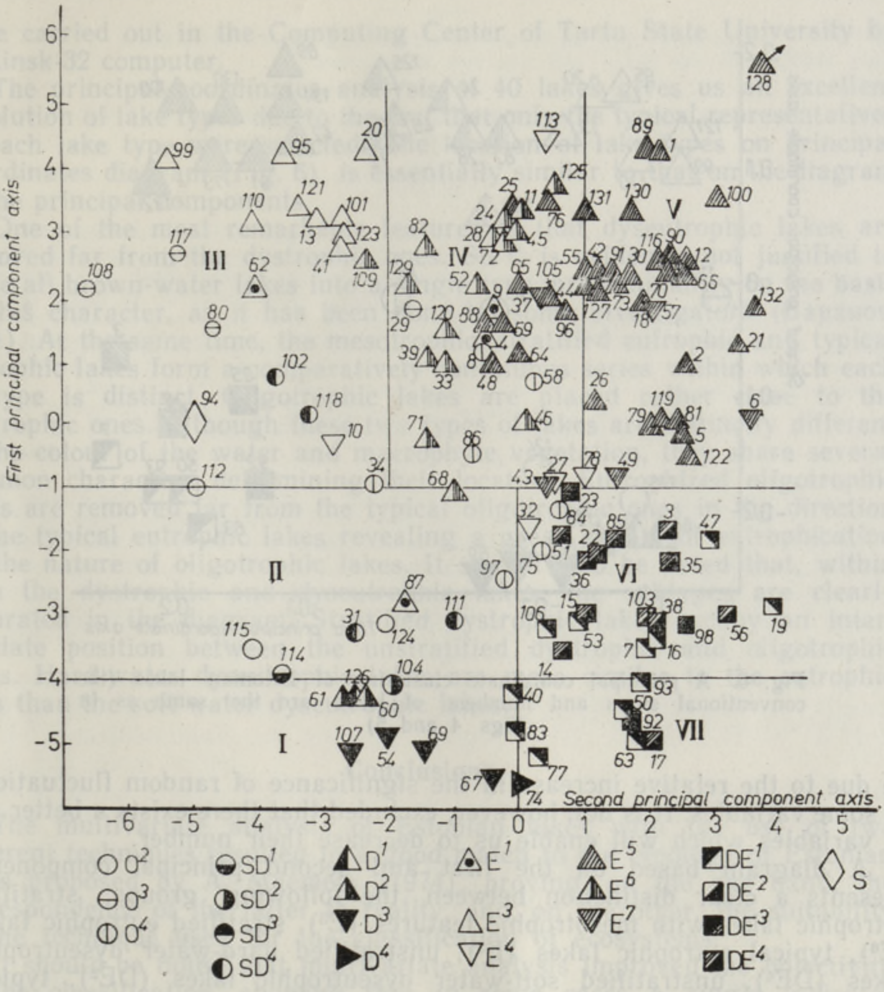


Fig. 5. The same clustering of lakes that in Fig. 4, but with changed conventional signs for the lakes whose type was re-evaluted as a result of the multivariate analysis.

(O^2 — unstratified oligotrophic lakes, O^3 — stratified eutrophicated oligotrophic lakes, O^4 — unstratified eutrophicated oligotrophic lakes, SD^1 — stratified semidystrophic lakes, SD^2 — unstratified semidystrophic lakes, SD^3 — stratified eutrophicated semidystrophic lakes, SD^4 — unstratified eutrophicated semidystrophic lakes, D^1 — stratified dystrophic lakes, D^2 — stratified dystrophic lakes without oxygen, D^3 — unstratified dystrophic lakes, D^4 — very shallow dystrophic lakes, E^1 — stratified soft-water eutrophic lakes, E^3 — stratified eutrophic lakes with mesotrophic features, E^4 — unstratified eutrophic lakes with mesotrophic features, E^5 — typical eutrophic lakes, E^6 — stratified eutrophic lakes, E^7 — hypereutrophic lakes, DE^1 — stratified soft-water dyseutrophic lakes, DE^2 — unstratified soft-water dyseutrophic lakes, DE^3 — stratified hard-water dyseutrophic lakes, DE^4 — unstratified hard-water dyseutrophic lakes, S — mesotrophic lake with siderotrophic features; I — region of dystrophic lakes, II — region of oligotrophic lakes, III — region of mesotrophic lakes, IV — region of stratified eutrophic lakes, V — region of typical eutrophic lakes, VI — region of hard-water dyseutrophic lakes, VII — region of soft-water dyseutrophic lakes; the numbers of lakes correspond to those in Fig. 1).

set of characters to 18, supposedly most important in describing lake ecosystems, resulted, however, in poorer resolution power. This seems to

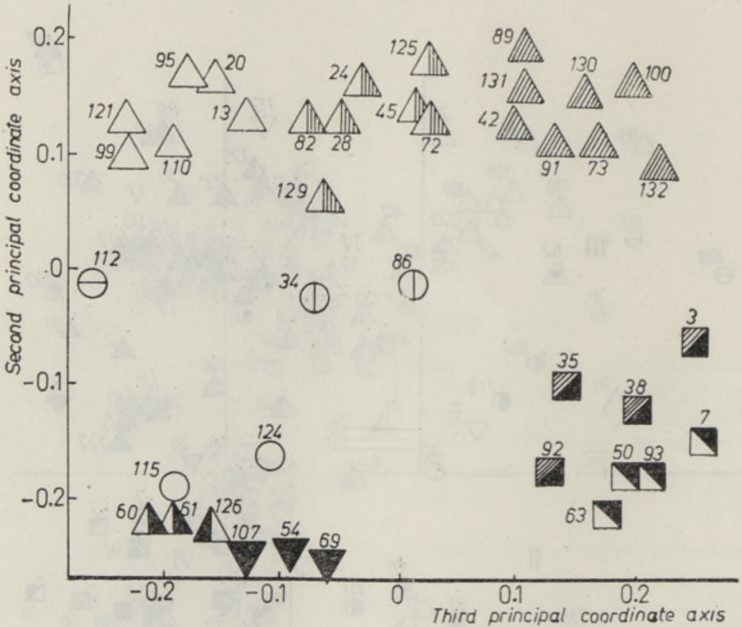


Fig. 6. A principal coordinate clustering of Estonian lakes (the conventional signs and numbers of lakes are the same as in Figs 4 and 5).

be due to the relative increase in the significance of random fluctuations of some variables. It is not, however, excluded that there exists a better set of variables which will enable us to decrease their number.

A diagram based on the first and second principal components presents a clear distinction between the following groups: stratified eutrophic lakes with mesotrophic features (E^3), stratified eutrophic lakes (E^6), typical eutrophic lakes (E^5), unstratified hard-water dyseutrophic lakes (DE^4), unstratified soft-water dyseutrophic lakes (DE^2), typical dystrophic lakes (D^3) and stratified dystrophic lakes (D^1, D^2). Partial overlapping occurs between oligotrophic, semidystrophic and soft-water eutrophic lakes. Some of the lakes classified by A. Mäemets differently from the computer belong to transition types and may well be classified as belonging to the type determined by the computer. In Figure 5 the lakes have been divided into groups where the corrections made by the computer have been taken into account.

In general, the diagram enables us to distinguish 7 areas corresponding to certain lake types or subtypes (see Figs 4 and 5). So in the present case the analysis of the principal components has served as an effective clustering technique of lakes.

Gower's principal coordinates analysis (Gower, 1966; Blackith and Reyment, 1970) has been proved to be a promising technique for the classification of various biological systems. In the present study, Gower's similarity coefficient $S_{ijk}=1-|x_i-x_j|R_k$ was computed; R_k is the range of character k. The association matrix of 40 typical lakes was computed, and its latent vectors were found. A diagram (Fig. 6) was plotted against the second and third principal coordinates since the first vector had similar elements relating to the mean value of all the elements of the association matrix. The small number of lakes included in the analysis of the principal coordinates was due to the capabilities of the computer. All computations were carried out in the Computing Center of Tartu State University by a Minsk-32 computer.

The principal coordinates analysis of 40 lakes gives us an excellent resolution of lake types due to the fact that only the typical representatives of each lake type were selected. The location of lake types on principal coordinates diagram (Fig. 6) is essentially similar to that on the diagram of the principal components.

One of the most remarkable features is that dyseutrophic lakes are removed far from the dystrophic ones. So it is evidently not justified to unite all brown-water lakes into a single type predominantly on the basis of this character, as it has been done by some investigators (Баранов, 1961). At the same time, the mesotrophic, stratified eutrophic and typical eutrophic lakes form a comparatively continuous series within which each subtype is distinct. Oligotrophic lakes are placed rather close to the dystrophic ones. Although these two types of lakes are distinctly different in the colour of the water and macrophyte vegetation, they share several common characters determining their location. Eutrophized oligotrophic lakes are removed far from the typical oligotrophic ones in the direction of the typical eutrophic lakes revealing a great impact of eutrophication on the nature of oligotrophic lakes. It should also be noted that, within both the dystrophic and dyseutrophic lakes, the subtypes are clearly separated in the diagram. Stratified dystrophic lakes occupy an intermediate position between the unstratified dystrophic and oligotrophic lakes. Hard-water dyseutrophic lakes are more similar to the eutrophic ones than the soft-water dyseutrophic lakes.

Conclusions

The multivariate analysis of Estonian lakes with the use of two different techniques resulted in a good match to the typology of Estonian lakes proposed by A. Mäemets (1974), proving, on the one hand, the correspondence of the latter to reality, and, on the other, the suitability of the technique used for the classification of ecosystems.

It should be noted that multivariate analysis improved the objectivity of the classification, showing that in some cases a single indicator character is less significant than a larger set of ecological-biological characters.

The principal coordinates analysis proved to be an excellent ordination technique resulting in well-defined clusters in case of a somewhat idealized model.

The character analysis with the aid of principal components shows that there exist four character complexes which are related to a certain type of lake and so could be described as the determinants of lake types.

REFERENCES

Blackith, R. E., Reyment, R. A., 1971. Multivariate morphometrics. London—New York.

Gower, J., 1966. Some distance properties of latest root and vector methods used in multivariate analysis. Biometrica 53 : 325—338.

Mäemets, A., 1965. Eesti järvetüüpidest. Eesti Loodus 8 (4) : 201—209.

Mäemets, A., 1974. On Estonian Lake Types and Main Trends of Their Evolution. Coll: Estonian Wetlands and Their Life. Tln. : 29—62.

Баранов И. В., 1962. Лимнологические типы озер СССР. Л.

Academy of Sciences of the Estonian SSR,
Institute of Zoology and Botany

Received
Jan. 9, 1976

Aare MÄEMETS, Ain RAITVIIR

EESTI JÄRVEDE KLASSIFITSEERIMINE PEAKOMPONENTIDE JA PEAKOORDINAATIDE ANALÜÜSI ALUSEL

Resümee

A. Mäemetsa (1974) loodud Eesti järvede tüpoloogia objektiivsuse kontrollimiseks kasutati kaht paljumõõtmelise analüüsi meetodit: peakomponentide ja peakoordinaatide analüüsi. Peakomponentide analüüs põhineb 132 paremini uuritud Eesti järve materjalil (järvede paiknemist vt. joon. 1), kusjuures analüüsiti ühel juhul 44 ja teisel juhul 18 tunnust. Ilmekaimad tunnustevahelised korrelatsioonid on esitatud 2. joonisel. Peakomponentide analüüsiga selgitati 5 peakomponenti (moodustavad 51,3% koguvariatsioonist): esimene iseloomustab järve troofsust, teine vee stratifikatsiooni, kolmas kinnikasvamist ja vananemist, neljas järve suurust ning viies vananemist ja stratifikatsiooni.

Selgus ka, et sarnaseid ökosüsteeme iseloomustavad tunnused rühmituvad lähedastesse piirkondadesse (joon. 3). On võimalik eristada 4 tunnuserühma: 1. oligo- ja düstroofsete järvede, 2. mesotroofsete joontega järvede, 3. eutroofsete järvede ja 4. düseutroofsete järvede rühm.

Peakomponentide analüüsi tulemused näitavad, et kõige selgem rühmitumine saadi 44 tunnuse kasutamisel I ja II peakomponendi puhul, kusjuures ka kokkulangevus A. Mäemetsa Eesti järvede tüpoloogiaga oli kõige parem (joon. 4 ja 5). Väga hea rühmitumine ja kokkulangevus A. Mäemetsa tüpoloogiaga saadi Goweri peakoordinaatide analüüsi rakendamisel 40 tüüpilise järve puhul (joon. 6).

Eesti järvede paljumõõtmeline analüüs kahel eelnimetatud meetodil tõestas ühest küljest A. Mäemetsa tüpoloogia objektiivsust ja teisest küljest kasutatud meetodite sobivust ökosüsteemide klassifitseerimisel.

Eesti NSV Teaduste Akadeemia
Zooloogia ja Botaanika Instituut

Toimetusse saabunud
9. I 1976

Ааре МЯЭМЕТС, Айн РАЙТВИЙР

КЛАССИФИКАЦИЯ ОЗЕР ЭСТОНИИ НА ОСНОВЕ АНАЛИЗА ГЛАВНЫХ КОМПОНЕНТОВ И КООРДИНАТ

Резюме

Для проверки объективности типологии озер Эстонии, выработанной А. Мяэметсом (1974), использовались два метода многомерного анализа — анализ главных компонентов и анализ главных координат.

Анализ главных компонентов был основан на материале 132 комплексно исследованных озер (рис. 1) и проведен в двух вариантах (с 44 и 18 признаками). В ходе проверки между отдельными признаками обнаружены корреляции — наиболее тесные из них приведены на рис. 2. При этом анализе было установлено 5 главных компонентов, которые суммарно объясняют 51,3% тотальной изменчивости выборки. Первый компонент характеризует трофность озера, второй — стратификацию воды, третий — зарастание и старение озера, четвертый — величину озера и пятый — старение и стратификацию.

При изображении признаков на диаграмме в отношении их нагрузок по I и II главным компонентам выяснилось, что отчетливо выделяются группы признаков, определенных экосистем (рис. 3). Можно различить 4 группы признаков: 1) признаки олиго- и дистрофных озер, 2) признаки озер с мезотрофными чертами, 3) признаки эвтрофных озер и 4) признаки дисэвтрофных озер.

Результаты анализа главных компонентов показали, что наилучшая группировка озер наблюдается при I и II компонентах в случае использования 44 признаков, причем установлено хорошее совпадение с типологией А. Мяэметса (рис. 4 и 5). Четкая группировка озер и совпадение с типологией А. Мяэметса получено при анализе главных координат Гоуера у 40 типичных озер (рис. 6).

Многомерный анализ озер Эстонии названными методами доказал объективность типологии А. Мяэметса, а также пригодность использованных методов для классификации экосистем.

Институт зоологии и ботаники
Академии наук Эстонской ССР

Поступила в редакцию
9/I 1976