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CORRELATIONS BETWEEN WATER QUALITY VARIABLES IN FINNISH LAKES

Jorma Niemi

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Relationships between chemical and biological water quality variables were investigated by applying linear correlation analysis to two series of data gathered from Finnish lakes. The first series consisted of chemical water quality variables and total phytoplankton biomass and phytoplankton divisions analysed in 136 lakes in 1977. The second consisted of chemical water quality variables analysed in 160 lakes during the period 1976–1981. In both series the strongest correlations between chemical state variables were found between alkalinity and conductivity, colour and iron, colour and COD, iron and COD and turbidity and total phosphorus. The strongest correlations between biological state variables and between biological and chemical state variables were found between *Chrysophyta* and total phytoplankton and chlorophyll-a and total phytoplankton. Chlorophyll-a had a fairly strong correlation with *Chlorophyta,* total residue, *Cyanophyta,* total nitrogen, alkalinity and total fixed residue.

Index words: Correlation analysis, water quality, nutrients, lakes.

1. INTRODUCTION

Relationships between water quality variables have previously been calculated from limnological data. Sakamoto (1966) and Dillon and Rigler (1974) investigated the relationships between phosphorus and chlorophyll-a and Paloheimo and Zimmerman (1983) studied phosphorus–phytoplankton relationships. Laaksonen (1970) presented relationships between several water quality variables in Finnish lakes. Canfield and Bachman (1981) and Lambou et al. (1982) investigated the relationship between chlorophyll-a and secchi disk depth on the one hand and the trophic state of a lake on the other. In addition, indices calculated on the basis of water quality variables have been developed (Washington 1984, Malin 1984). Relationships between water quality variables and between nutrient loadings and water quality data have also been determined (e.g. OECD, 1982).

The water quality of Finnish water bodies has been regularly monitored since the end of the nineteen-sixties and the results have been stored in data banks. This considerable store of information should be analysed and used in mathematical models or developed into indices in order to be used more effectively in decision making. The work reported here was an attempt to analyse part of the data using linear correlation analysis. The objective was to investigate correlations between chemical and biological water quality variables measured from a large number of lakes. Special emphasis was laid on calculating the correlations between the biological and other water quality variables in order to investigate whether the trophic state of a lake could be estimated solely on the basis of chemical variables. If strong correlations were found it should further be considered whether measurement of all the strongly correlated variables from the same samples is necessary in monitoring programmes. Nutrient loadings entering the lakes were not considered.

2. MATERIALS AND METHODS

Linear correlation analysis was applied to two series of data without transformations using BMDP library programs and an Eclipse MV/6000 computer. The first series, entitled surface data, was gathered in 1977 from 136 lakes sampled three times during the summer. Samples representing a water layer from 0 to 2 meters were analysed for chlorophyll-a, phytoplankton species, biomasses of phytoplankton divisions and chemical water quality variables (Table 1). The second series, entitled comparison data, consisted of water quality data analysed in 1976—1981 from vertical series of water samples of 160 lakes and it included only chemical water quality variables and chlorophyll-a (Table 2). From this material the mean values of water quality variables were calculated for the whole lake by weighting the vertically measured concentrations with their respective volumes using the method presented by Lappalainen (1976). The first series was used for calculating the correlations between chemical and between chemical and biological water quality variables and the results obtained were compared with the corresponding correlations calculated from the second material, when available.

Table 1. Dimensions, frequencies, means, standard deviations and smallest and largest values of the water quality variables in the surface data.

Variable	Dimension	Frequency	Mean	Standard deviation	Smallest value	Largest value
Turbidity	FTU	263	1.6	2.3	0.3	23.0
Suspended solids	mg l^{-1}	26	9.5	20.2	0.6	77.0
Conductivity	mS m^{-1}	260	6.7	3	2	26
Alkalinity	mmol l^{-1}	146	0.12	0.08	0.02	0.63
pH		270	6.9	0.5	5.3	9.7
Colour	Pt mg l^{-1}	68	51	45	10	300
COD	mg l^{-1}	265	10.1	6.5	3.2	80.0
Total nitrogen	$\mu g\ l^{-1}$	268	585	268	210.0	2000.0
Nitrite nitrogen	$\mu g\ l^{-1}$	255	1	2	0	23
Nitrate nitrogen	$\mu g\ l^{-1}$	262	92	115	0	850
Ammonia nitrogen	$\mu g\ l^{-1}$	263	24	62	0	850
Total phosphorus	$\mu g\ l^{-1}$	270	23	21	4	160
Phosphate phosphorus	$\mu g\ l^{-1}$	256	4	6	0	51
Iron	$\mu g\ l^{-1}$	12	262	217	69	720
Total residue	mg l^{-1}	253	58	31	13	280
Total fixed residue	mg l^{-1}	241	28	20	0	140
Chlorophyll-a	$\mu g\ l^{-1}$	273	6.3	7.8	0.6	77.0
Total phytoplankton	mg l^{-1}	273	1.06	1.93	0.04	16.94
Cyanophyta	mg l^{-1}	273	0.15	0.87	0.00	10.39
Chlorophyta	mg l^{-1}	273	0.10	0.53	0.00	7.23
Euglenophyta	mg l^{-1}	273	0.01	0.07	0.00	1.15
Chrysophyta	mg l^{-1}	273	0.57	1.35	0.00	14.80
Pyrrophyta	mg l^{-1}	273	0.23	0.30	0.01	3.13

Table 2. Dimensions, frequencies, means, standard deviations and smallest and largest values of the water quality variables in the comparison data. Values were obtained by weighting the vertically measured concentrations with their respective volumes (Lappalainen 1976) and they represent the average concentrations for the whole lake. The smallest and largest values are therefore approximate.

Variable	Dimension	Frequency	Mean	Standard deviation	Smallest value	Largest value
Turbidity	FTU	598	1.4	2.7	0.2	33.3
Conductivity	$mS\ m^{-1}$	793	6	3	2	21
Alkalinity	$mmol\ l^{-1}$	774	0.17	0.12	0.03	0.89
pH		817	6.9	0.4	5.7	8.8
Colour	$Pt\ mg\ l^{-1}$	631	46	34	0	268
COD	$mg\ l^{-1}$	808	8.8	4.7	2.0	59.0
Total nitrogen	$\mu g\ l^{-1}$	803	502	408	152	8600
Nitrate nitrogen	$\mu g\ l^{-1}$	165	100	118	0	747
Ammonia nitrogen	$\mu g\ l^{-1}$	181	39	87	1	861
Total phosphorus	$\mu g\ l^{-1}$	803	20	22	1	258
Phosphate phosphorus	$\mu g\ l^{-1}$	168	6	11	0	77
Iron	$\mu g\ l^{-1}$	732	289	388	4	2993
Chlorophyll-a	$\mu g\ l^{-1}$	358	7.7	11.3	1.1	130.0

3. RESULTS AND DISCUSSION

A correlation matrix was calculated from both data series. From these matrices the coefficients between the chemical water quality variables that were statistically significant ($P \leq 0.1$ %) and had in one or both of the two series an absolute value greater than 0.5 are presented in Table 3. The coefficients between the biological or between the biological and chemical water quality variables that were statistically significant ($P \leq 0.1$ %) and had in one or both of the two series an absolute value greater than 0.5 are presented in Table 4.

Correlation analysis measures relationships between the distributions of two variables. High correlation between the variables does not necessarily imply that they have a causal relationship, although an indication of such a relationship may be obtained.

Of the chemical state variables, high correlations were found between total fixed residue and total residue ($r > 0.9$). This was expected as both depend on the concentrations of dissolved and suspended materials in the water. Because of this high correlation it would not be necessary to carry out both of these measurements from the same samples. In both series of data the coefficients between colour and iron and between colour and COD were high ($r > 0.8$). The colour imparted to the water by iron and by humic materials may explain this relationship. In both series the coefficient between iron and COD was also fairly high ($r > 0.7$). This can be explained by the relations between iron, colour and COD discussed above. Fairly high coefficients were found in both series of data between turbidity and total phosphorus ($r > 0.6$), alkalinity and conductivity ($r > 0.6$) and pH and alkalinity ($r > 0.5$). Turbid waters contain suspended and dissolved materials containing phosphorus, which may explain the value of the first coefficient. The greater part of total phosphorus seems to be bound to suspended solids. On average the values of the correlation coefficients were stronger in the surface material than in the comparison material. This is explained by the fact that standard deviation increases with increasing number of observations. The correlations observed between the chemical water quality variables bear a close relationship to the values calculated on the basis of larger materials in Finland (Laaksonen 1970). It should be considered weather it is necessary to determine all of the strongly correlated variables, e.g. colour, iron, total residue and total fixed residue, of the same water samples.

The strongest correlations between the biological and other water quality variables are presented in Table 4. The highest correlation was observed between *Chrysophyta* and iron. However, the coefficient was calculated solely on the basis of twelve observations and far-reaching conclusions cannot therefore be made. The strong correlation between *Euglenophyta* and ammonia nitrogen was due to two particularly high pairs of values included in the material. When these values were excluded the value of the correlation coefficient decreased and was no longer statistically significant. On the other hand the two high values were derived from real observations of two lakes and should therefore be included in the material. More observations of high concentrations of *Euglenophyta* and ammonia nitrogen are needed in order to obtain a more reliable

Table 3. Correlation coefficients between the chemical water quality variables calculated from the surface data (statistically significant ($P \leq 0.1$ %) and with an absolute value > 0.5) and the corresponding coefficients from the comparison data regardless of their absolute value, when available. n = number of observations.

	Correlation coefficients			
Variables	Surface data	(n)	Comparison data	(n)
Colour – Iron	0.93	(6)	0.90	(587)
Colour – COD	0.91	(68)	0.82	(630)
Total residue – Total fixed residue	0.91	(241)		
Turbidity – Total phosphorus	0.74	(261)	0.66	(592)
Iron – COD	0.72	(10)	0.76	(732)
pH – Alkalinity	0.72	(146)	0.56	(774)
Total residue – Conductivity	0.68	(247)		
Alkalinity – Conductivity	0.67	(147)	0.73	(752)
Total fixed residue – Conductivity	0.63	(236)		
Turbidity – Total nitrogen	0.57	(258)	0.43	(593)
Phosphate phosphorus – Total phosphorus	0.56	(256)	0.62	(165)
Total phosphorus – Total nitrogen	0.54	(266)	0.47	(798)
Total nitrogen – Conductivity	0.54	(256)	0.58	(786)
Total phosphorus – Iron	0.53	(251)	0.62	(728)
Turbidity – Alkalinity	0.52	(139)	0.61	(561)
Phosphate phosphorus – Ammonia nitrogen	0.52	(255)	0.52	(155)

Table 4. Correlation coefficients between the biological or between the biological and chemical water quality variables calculated from the surface data (statistically significant ($P \leq 0.1$ %) and with an absolute value > 0.5) and the corresponding coefficients from the comparison data, regardless of their absolute values, when available. n = number of observations.

	Correlation coefficients			
Variables	Surface data	(n)	Comparison data	(n)
Chrysophyta – Iron	0.87	(12)		
Euglenophyta – Ammonia nitrogen	0.82	(263)		
Chrysophyta – Total phytoplankton	0.80	(273)		
Chlorophyll a – Total phytoplankton	0.77	(273)		
Chlorophyll a – Chlorophyta	0.63	(273)		
Cyanophyta – Total phytoplankton	0.62	(273)		
Pyrrophyta – Euglenophyta	0.62	(273)		
Chlorophyll-a – Total residue	0.61	(253)		
Cyanophyta – Alkalinity	0.58	(146)		
Chlorophyll-a – Cyanophyta	0.58	(273)		
Chlorophyll-a – Total phosphorus	0.56	(270)	0.72	(348)
Chlorophyll-a – Turbidity	0.54	(263)	0.72	(291)
Chlorophyll-a – Total nitrogen	0.54	(268)	0.29	(347)
Chlorophyll-a – Alkalinity	0.53	(146)	0.64	(325)
Chlorophyll-a – Total fixed residue	0.51	(241)		
Total phytoplankton – Total phosphorus	0.50	(270)		

estimate of this correlation. The correlation may be real, as *Euglenophyta*-species grow well in waters with high concentrations of ammonia nitrogen, including waste waters. The high correlation between *Chrysophyta*-species and total phytoplankton reflects the great proportion of *Chrysophyta* in the total phytoplankton (Heinonen 1980). The coefficient between chlorophyll-a and total phytoplankton was fairly high. Various species of *Chrysophyta* e.g. diatoms contain only low concentrations of chlorophyll-a and probably because at this no strong correlation between chlorophyll-a and *Chrysophyta* was observed. The low concentrations of chlorophyll-a in species of *Chrysophyta* and their large proportion of total phytoplankton may explain the fact that the correlation between chlorophyll-a and total phytoplankton was only 0.77. Chlorophyll-a appeared to have a weak correlation with several chemical and biological water quality variables. There was a relatively high correlation between *Chlorophyta* and chlorophyll-a. The correlations between chlorophyll-a and total phosphorus (r=0.72) and turbidity (r=0.72) were fairly strong in the comparison data but weaker in the surface data. Moreover, the correlation between chlorophyll-a and alkalinity was stronger in the comparison data than in the surface data (r=0.53). Correlations between chlorophyll-a and total phosphorus and chlorophyll-a and turbidity are caused by intensive phytoplankton growth due to high nutrient concentrations.

Investigation of this material did not reveal particularly strong correlations between chemical and biological water quality variables. For example, no strong relationships were found between the phytoplankton divisions and individual water quality variables. This may be due to the fact that phytoplankton divisions are wide taxonomic units that do not seem to have clear relationships with water chemistry. Additional important factors that affect phytoplankton growth, such as light and temperature, were not considered in this work. If these factors were investigated together with chemical water quality variables, a better indication of the relationships between phytoplankton divisions and water chemistry might be obtained.

Time and space during which observations are carried out are important factors which affect the correlations between the observed water quality variables. Strong correlations may be obtained from materials gathered within certain characteristic time or space scales, while by using other scales the correlations become weaker of dissappear. Ducklow (1984) found that correlations between bacterial abundance and chlorophyll depended on the time and space scales used. He pointed out that in analysing the scales of variability of water quality variables the scales over which variables are not correlated may be as important as those over which they are significantly related.

The results obtained indicate that the trophic state of a lake as measured by phytoplankton biomass, species composition and chlorophyll-a cannot be estimated solely on the basis of chemical water quality variables, although some indications of the trophic state may be obtained. For the estimation of the behaviour of phytoplankton, simulation might be a more suitable method than calculation of the statistical relationships between phytoplankton and chemical water quality variables.

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TIIVISTELMÄ

Kemiallisten ja biologisten vedenlaatumuuttujien välisiä yhteyksiä tutkittiin soveltamalla lineaarista korrelaatioanalyysiä kahteen järviaineistoon. Työn tarkoituksena oli tutkia voitaisiinko järven trofiatasoa arvioida pelkästään kemiallisten vedenlaatumuuttujien avulla. Toinen aineisto sisälsi vuonna 1977 136 järvestä analysoidut kemialliset vedenlaatumuuttujat sekä kasviplanktonin lajiston ja kasviplanktonin pääryhmien biomassat. Toinen aineisto sisälsi vuosina 1976–1981 valtakunnallisista syvännehavaintopisteistä analysoidut kemialliset vedenlaatumuuttujat. Molemmissa aineistoissa vahvimmat kemiallisten vedenlaatumuuttujien väliset korrelaatiot havait-

tiin värin ja raudan, värin ja kemiallisen hapenkulutuksen, raudan ja kemiallisen hapenkulutuksen sekä sameuden ja kokonaisfosforin välillä. Vahvimmat biologisten vedenlaatumuuttujien sekä biologisten ja kemiallisten vedenlaatumuuttujien väliset korrelaatiot havaittiin *Chrysophyta*-pääluokan ja kokonaiskasviplanktonin sekä klorofyllin ja kokonaiskasviplanktonin välillä. Klorofyllillä oli verrattain vahva korrelaatio *Chlorophyta*-pääluokan, haihdutusjäännöksen, *Cyanophyta*-pääluokan, kokonaistypen, alkaliniteetin ja hehkutusjäännöksen kanssa.

Aineiston tarkastelu ei tuonut esille erityisen vahvoja korrelaatioita kemiallisten ja biologisten muuttujien välillä. Esimerkiksi kasviplanktonin pääluokkien ja yksittäisten vedenlaatumuuttujien välillä ei havaittu selviä yhteyksiä. Tämä johtunee siitä, että kasviplanktonin pääluokat ovat laajoja taksonomisia ryhmiä, joilla ei näytä olevan erityisen selviä korrelaatioanalyysissä esille tulevia yhteyksiä veden kemiaan. Tulokset osoittavat, että järven trofiatasoa ei voida määrittää pelkästään fysikaalis-kemiallisten vedenlaatumuuttujien avulla, vaikkakin joitakin viitteitä näin voidaan saada.

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