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Nordic Hydrology 11, 1980, 25-32

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Acidification in 50 Norwegian Lakes

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In 50 lakes in south-eastern Norway hydrogen-ion concentration (pH) and total hardness (°dH) were measured in surface water in the 1950's and then once again 10 years later. Significant acidification was observed. In the total material average pH dropped from 7.0 to 6.8. The lakes were grouped into a low-total-hardness (0-1°dH) and a high-total-hardness group (>1°dH). [1°dH = 10 mg »CaO«/1]. In the low-total-hardness group average pH had dropped from 6.6 to 6.3 and the average H^+ concentration increased with 4.33 . 10^{-7} mol/1. In the high-total-hardness group significant acidification could hardly be traced. The data confirm previous observations that also lakes which in previous years had pH close to the neutral point have become acidified. Total hardness showed no significant change.

Acidification seems to occur most frequently in lakes with total hardness ≤1°dH. Such lakes are present all over Norway and are dominant in many areas.

Introduction

In South Norway several hundred lakes have lost their population of brown trout (*Salmo trutta* L.) during the last decades while in other lakes the population has diminished. Populations of salmon (*Salmo salar* L.) are also nearly eliminated in several rivers (Jensen and Snekvik 1972, Lande 1972, Leivestad et al. 1976, Wright and Snekvik 1978).

The main hypothesis for explaining these changes in fish stocks is that of acidifi-

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cation of water courses. Regional acidification of freshwater seems to be caused mainly by atmospheric deposition of acidifying components in areas with low neutralizing capacity (granitic and gneissic bedrock, sparse soil cover), cf. Gjessing et al. (1976), Seip and Tollan (1978), and Wright and Snekvik (1978).

Historical changes in the pH of Norwegian lakes is treated by Wright (1977). His material comprises 128 lakes from southern Norway where pH was measured in the 1920's, 1930's, and 1940's, and then remeasured during the 1970's. 63% of the lakes had become more acid in the sense that their pH was 0.25 units or more lower, while only 12% had become less acid. This material is the major direct documentation of long-term changes in pH in Norwegian lakes (cf. also Snekvik 1972, Gjessing et al. 1976, and Henriksen 1979 a, b).

Acidification has vast practical implications. Documentation of long-term changes of hydrogen-ion concentration in lakes is therefore important. The present article describes pH-changes in 50 Norwegian lakes which were first sampled in the 1950's and then 10 years later.

Material and Methods

Field work for a project studying the relation between environmental factors and geographical distribution of bottom animals in fresh water in Norway was carried out 1953-73 (J. Økland and K.A. Økland 1979). About 1,500 localities were investigated, most of them lakes. Ten environmental parameters were registered (e.g. pH, total hardness) and several groups of bottom animals collected. Each locality was usually investigated once, during summer. Measurements of pH and total hardness were made in water samples from the surface. Before 1958, pH was measured colorimetrically with a Hellige comparator. In 1958 and later, the measurements were made electrometrically with a battery instrument Metrom E-280 from the firm Metrom AG, Herisau, Switzerland. The accuracy of the observations is estimated at ± 0.1 pH. Total hardness was measured by EDTA titration.

In south-eastern Norway, delimited as shown in Fig. 1, about 600 lakes were investigated. For 585 of them observations of both total hardness and pH were available (Fig. 2 A). Total hardness was 0.05-20.80° dH (1° dH = 10 mg »CaO«/1) and pH 4.4-8.8.

The material for this paper comprises all lakes from south-eastern Norway investigated twice. The first period of investigation was 1953-57, later termed period 1. The second period of observation was 1963-70, later termed period 2. Values for total hardness and pH in these lakes are indicated in Fig. 2B. In period 1 total hardness was 0.15-10.30° dH and pH 6.0-8.4.

The lakes were distributed all over south-eastern Norway, in the following areas:

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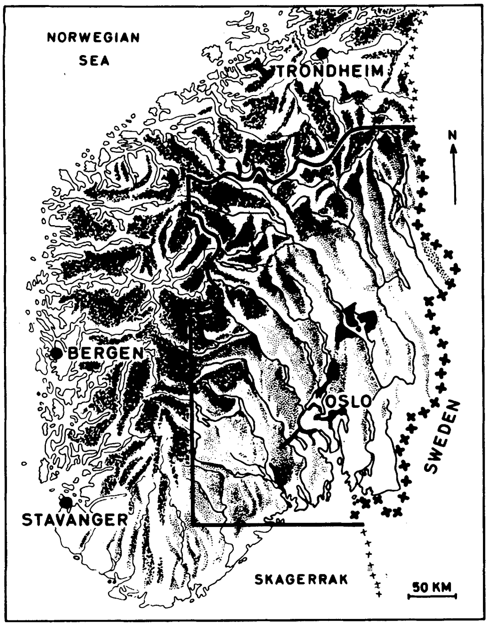

Fig. 1. Sketch map of southern Norway indicating the extent of study area No. I, south-eastern Norway. This area is delimited by the border with Sweden and by arbitrary lines towards south, west, and north, waters running westwards and northwards being excluded. From J. Økland and K. A. Økland 1979.

Østfold: 5 lakes in Idd, Øymark, Trøgstad and Ski, 37-131 m above sea level.

Akershus: 2 lakes in respectively Søndre Høland and Nannestad, 164-299 m above sea level.

Southern Hedmark: 7 lakes in Eidskog, Vinger, Elverum, Nes and Ringsaker, 144-381 m above sea level.

Northern Hedmark: 3 lakes in Trysil and Sollia, 460-701 m above sea level.

Southern Oppland: 14 lakes in Lunner, Gran, Brandbu, Fåberg, Torpa, Etnedal, and Ringebu, 146-1052 m above sea level.

Northern Oppland: 9 lakes i Øystre Slidre, Vågå, Lom, and Dovre, 906-1397 m above sea level.

Vestfold: 1 lake in Hof, 86 m above sea level.

Coastal areas of Telemark: 7 lakes in Gjerpen, Bamble, Sannidal and Skåtøy, 2-63 m above sea level.

Interior Telemark: 2 lakes in respectively Lårdal and Rauland, 646-909 m above sea level.

Both series of observations were taken during summer (1 June to 30 September). There was no bias with regard to sampling dates when comparing the two sampling periods. The span of years within each sampling period reduces the effect of annual climatic variations within the period, i.e. within both periods some summers were hotter and dryer than others.

Changes from period 1 to period 2 in pH, °dH, H^+ concentration, and % change in H^+ were tested using one-tailed T-tests. The zerohypotheses »no acidification« was tested against the alternative »acidification«.

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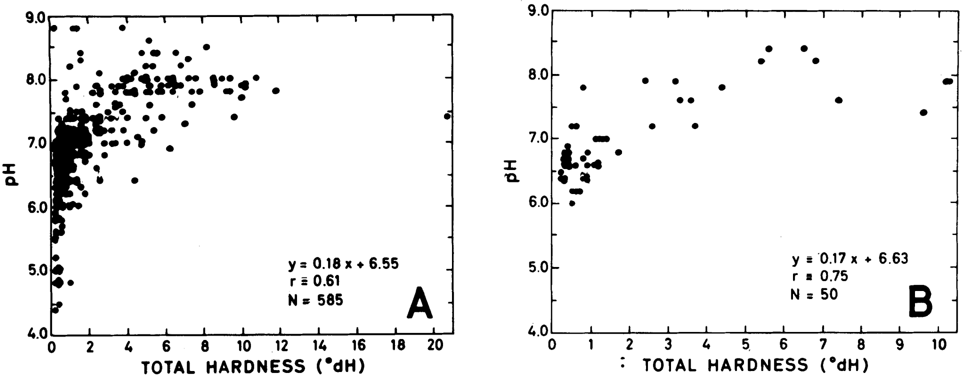

Fig. 2. (A): Total hardness and hydrogen-ion concentration (pH) in 585 lakes investigated 1953-70 in south-eastern Norway. (B): Same as in (A), indicating values for 50 lakes which were investigated twice. Values in (B) are from the first investigation period (1953-57). Note stretched scale for total hardness in (B).

Results

Fig. 3 shows pH for period 1 (1953-57) along the *x*-axis and for period 2 (1963-70) along the *y*-axis. Solid line marks expected position for dots for a given lake if values are the same in the two periods. Especially to the left in the diagram there is a tendency for the dots to be located below the line, signifying that pH has been lowered. This tendency is present at least up to c. pH 7.2.

Column C in Table 1 shows that average pH decreased from 7.01 in period 1 to 6.81 in period 2. This change is statistically significant. Accordingly an acidification has taken place, defined as a relative increase of H^+ concentration. Considering absolute increases in H^+ concentration, acidification is also significant. This concentration increased from 2.02 to 4.66 (10^{-7} mol/1), implying a 164% relative change in H^+ concentration.

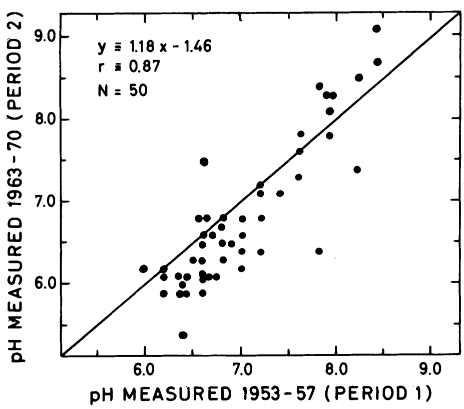

Fig. 3. Hydrogen-ion concentration (pH) in 50 lakes in south-eastern Norway. x-axis: values measured in period 1, y-axis: values measured in the same lakes in period 2. Solid line: position for dots if no change from period 1 to period 2.

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Table 1 Some environmental parameters in 50 lakes in south-eastern Norway first measured in 1953-57 and then later in 1963-70. The lakes are grouped into two categories of total hardness. For each parameter is indicated mean value, standard deviation, and standard error of the mean. Asterisks mark significant changes from period 1 to period 2.

Period	Parameter	A Low-total-hardness lakes (N=27) 0 - 1°dH			B High-total-hardness lakes (N=23) >1°dH			C All lakes (N=50) 0 - 11°dH		
		Mean	St. dev.	St. error of m.	Mean	St. dev.	St. error of m.	Mean	St. dev.	St. error of m.
Period 1: 1953-57	pH	6.62	0.37	0.07	7.47	0.58	0.12	7.01	0.64	0.09
	°dH	0.51	0.24	0.05	4.13	3.06	0.64	2.18	2.75	0.39
	H^+	3.13	2.15	0.41	0.71	0.83	0.17	2.02	2.06	0.29
Period 2: 1963-70	pH	6.30	0.43	0.08	7.42	0.86	0.18	6.81	0.86	0.12
	°dH	0.54	0.38	0.07	4.08	2.76	0.58	2.17	2.58	0.37
	H^+	7.46	7.48	1.44	1.37	1.81	0.38	4.66	6.37	0.90
Change in pH		-0.32*	0.41	0.08	-0.05	0.44	0.09	-0.20*	0.44	0.06
Change in °dH		0.04	0.27	0.05	-0.05	0.55	0.12	-0.01	0.42	0.06
Change in H^+		4.33*	7.13	1.37	0.66	1.50	0.31	2.64*	5.61	0.79
% change in H^+		233*	475	91	84	198	41	164*	378	53

H^+ concentrations are given as 10^{-7} mol/l St.error of mean = st.dev./$\sqrt{N}$

1°dH = 10 mg »CaO«/l * significant change, $P < 0.01$, one-tailed T-test

Fig. 4 shows values for total hardness for the same lakes for the two periods of investigation. The values are rather closely grouped around the solid line marking expected position if no change from period 1 to period 2 had taken place. A closer

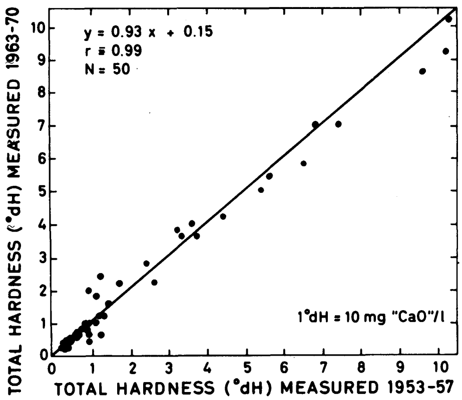

Fig. 4. Total hardness in 50 lakes in south-eastern Norway. x-axis: values measured in period 1 (1953-57), y-axis: values measured in the same lakes in period 2 (1963-70). Solid line: position for dots if no change from period 1 to period 2.

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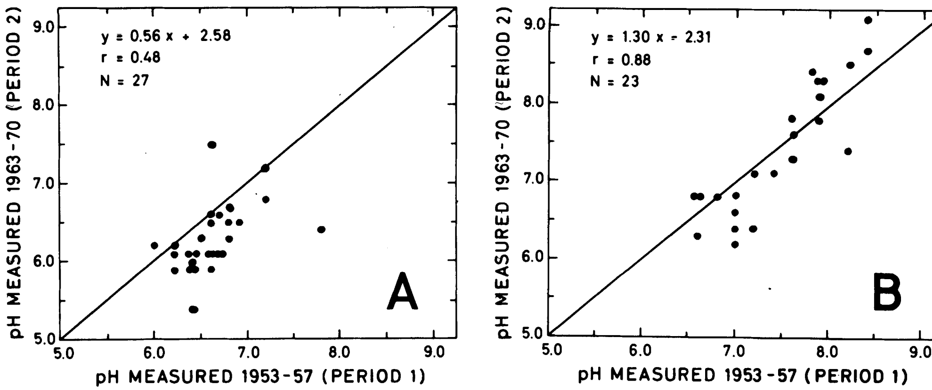

Fig. 5. Hydrogen-ion concentration (pH) in lakes in south-eastern Norway. x-axis: values measured in period 1, y-axis: values measured in the same lakes in period 2. Solid lines: positions for dots if no change from period 1 to period 2. (A): low-total-hardness lakes (0-1° dH) [1° dH = 10 mg »CaO«/1]. (B): High-total-hardness lakes (> 1° dH).

analysis of these values (column C in Table 1) shows no significant change (mean value 2.18° dH in period 1, 2.17° dH in period 2).

There was no correlation between change in pH and change in total hardness from period 1 to period 2 (r = 0.07).

In order to investigate whether changes in pH depend on total hardness, the material was grouped into two parts: lakes with low total hardness (0-1° dH), and lakes with high total hardness (>1° dH). Fig. 5 A shows that of the 27 lakes with low total hardness 22 had become more acid, 3 had no change, and 2 had become less acid. Fig. 5 B shows that of the 23 lakes with high total hardness 11 had become more acid, 2 had no change, and 10 had become less acid.

A closer study of the changes in pH and total hardness for the two groups of lakes is given in Table 1. In the group of low-total-hardness lakes, mean pH decreased 0.32 units, from pH 6.62 to 6.30. Mean concentration of H^+ increased with $4.33 \cdot 10^{-7}$ mol/1. This is a relative increase of 233%. These changes were statistically significant.

In the group of high-total-hardness lakes, pH showed an insignificant decrease of 0.05 units, from pH 7.47 to pH 7.42. The increase in H^+concentration was small ($0.66 \cdot 10^{-7}$ mol/1).

Discussion

Documentation of long-term changes in hydrogen-ion concentration in Norwegian lakes is faced with a methodical problem: older records being based on measurements made colorimetrically while new observations are generally made electro-

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metrically (Wright 1977). The major pitfall of colorimetric measurements is registration of pH in poorly-buffered waters, the measurements tending to reflect the pH of the indicator rather than the pH of the water. The 50 lakes analysed in the present study are, however, not especially poorly buffered (mean value of total hardness of 2.18°dH). We shall therefore accept the two sets of data as suitable for comparison.

Problems of acidification have mainly been centered around changes in fish stocks and change in pH in very acid water (pH about 5.5-4.5). Wright (1977) however, shows that also lakes with neutral or slightly alcalic reaction have become acidified (cf. also Wright and Gjessing 1976). Observations from the present material corroborate the idea that lakes around the neutral point may become acidified.

Acidification is not restricted to extremely poorly buffered water. Owing to the correlation between content of calcium and content of bicarbonate/carbonate in most lake waters, we may use the content of calcium as a rough estimation for the buffer capacity. Henriksen (1979 a,b) shows that acidification may occur in lakes with up to about 6 mg Ca/l, i.e. 8.4 mg CaO/1. In relation to total hardness this means c. 1° dH since lake water also contains some magnesium. Wright and Gjessing (1976) regard lakes with electrolytic conductivity (κ_{20}) below 100 and especially those below 50 as having low buffer capacity, being vulnerable to acidification. This will generally cover lakes with total hardness up to c.2° dH, respectively 1°dH. This reasoning is based on the relation between electrolytic conductivity and total hardness in 619 Norwegian lakes (J. Økland unpublished). Evidence from the 50 lakes analysed in the present study also support the statement that acidification of lakes may occur in sites with total hardness up to at least 1° dH. Such lakes are present all over Norway and are dominant in many areas, cf. maps in J. Økland (1979), and a map of geographical distribution of pristine lakes with given values for electrolytic conductivity in Norway and Sweden presented by Wright and Gjessing (1976).

The general conclusion is that lakes with values for total hardness at least up to 1°dH (10 mg »CaO«/1) have been acidified and are vulnerable to acidification.

Acknowledgements

The Norwegian Research Council for Science and the Humanities (NAVF) has sponsored the field work. Calculations and statistical consultations have been carried out by the Norwegian Computing Centre (Mr. Dan Wøien, Mr. Vidar Berteig) as a part of the Norwegian interdisciplinary research programme »Acid Precipitation – Effects on Forest and Fish« (the SNSF-project). This is SNSF-contribution FA 50/79.

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Postscript

Acidification in lakes near neutrality has recently also been shown in Canada (Watt, W.D., Scott, D., and Ray, S. (1979) Acidification and other chemical changes in Halifax County lakes after 21 years. *Limnol. Oceanogr. 24(6),* 1154-1161).

Received: September 9th, 1979

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