Seasonal dynamics of subarctic Lake Saanajärvi in Finnish Lapland

Article · January 2000

DOI: 10.1080/03680770.1998.11901284

3 authors:

Sanna Sorvari
Finnish Meteorological Institute
32 PUBLICATIONS **2,307** CITATIONS

Milla Rautio
University of Québec in Chicoutimi
88 PUBLICATIONS **3,478** CITATIONS

Atte Korhola
University of Helsinki
189 PUBLICATIONS **9,335** CITATIONS

Verh. Internat. Verein. Limnol.	27	1–6	Stuttgart, November 1999

Seasonal dynamics of the subarctic Lake Saanajärvi in Finnish Lapland

Sanna Sorvari, Milla Rautio and Atte Korhola

Introduction

The numerous lakes and ponds in northern Finland are of great importance for the local people as well as for the general ecology of the area, yet little is known about the physical, chemical and biological nature of these small freshwater ecosystems. For example, there is no published work which describes complete annual cycles of physical and chemical variables in a subarctic lake in Finnish Lapland. The purpose of this paper is to produce data on such seasonal variability in Lake Saanajärvi, a small clear lake near the Kilpisjärvi Biological Station in the most arctic part of Finland. The lake is the Finnish site in the European-wide research project, "Mountain Lake Research" (MOLAR), funded by the European Community. The site has been monitored for physical, chemical, biological and sedimentological features since 1996.

Saanajärvi (69° 05' N, 20° 87' E) is situated in the northwestern part of Finnish Lapland, about 50 km from the Arctic Ocean (Fig. 1). The region lies in the transition between the North Atlantic oceanic climate and the Eurasian continental climate. The mean annual temperature in the area is –2.6 °C, mean annual precipitation is 422 mm, and the growing season is about 100 days (JÄRVINEN 1987). Despite the low precipitation, the soil maintains its moisture due to the low evaporation. The bedrock consists of Palaeozoic Caledonian schist and gneiss, underlain by sedimentary rocks and dolomitic limestones. Lake Saanajärvi is located between two fjells in the treeless tundra at 679.4 m above sea level. It is a small, clear, nutrient-poor subarctic lake with a surface area of 62.0 ha, a catchment area of 460.6 ha and a maximum depth of 24.0 m. The lake is elongated along a SE–NW axis; its maximum length is 1,400 m and the maximum width is 750 m. The lake margins are generally steep, and the shoreline is rocky. Except for some water mosses near the outlet there are no macrophytes in the lake. The catchment is covered mostly by bare rocks; the relatively diverse subalpine vegetation includes *Viola biflora, Ranunculus nivalis, R. glacialis, Saxifraga oppositifolia, S. aizoides, Cassiope tetragona, Diapensia lapponica* and *Betula nana*. No direct human activity occurs near the lake. However, in 1993 and 1997, arctic charr (*Salvenius alpinus*) was stocked in the lake for recreational purposes. More details of the chemical and physical characteristics of the lake and its catchment are given in Table 1.

Methods

Altogether 25 water profiling samples were taken with a Limnos-type water sampler from the deepest point of the lake at depths 0 (or ice base), 2, 4, 6, 8, 10, 12, 16, 20, 23 (or 1 m from the sediment surface) m. During the open-water periods, sampling frequency varied. In 1996 (July 4th to September 24th) the lake was sampled twice a month, and in the summer of 1997 the lake was at first sampled intensively once a week (June 10th to August 13th) and then on a monthly basis (August 13th to September 25th). During the ice-cover period, a complete sampling was performed every second month.

Samples were analysed for major ions, SO_4, Cl, NH_4-N and NO_2-N in the Laboratory of Physical Geography using standard methods of the National Board of Waters in Finland and MOLAR water chemistry protocols. Total organic carbon (TOC) was measured at the Lammi Biological Station using the method of SALONEN (1979). Oxygen, pH, temperature and conductivity were measured in the field using equipment from HANNA Instruments. Alkalinity was measured within 24 h in the laboratory using the one-point titration method. For chlorophyll-*a* determination, 2–3 L of water were filtered through a GF/C Whatman filter in the field; the filters were immediately frozen for further analysis. In the laboratory, chlorophyll-*a* was extracted in 90% acetone overnight at room temperature in the dark. After the extraction, samples were filtered and measured for absorbance at the following wavelengths: 750, 663, 647, 630, 480, 430 and 410 nm. The chlorophyll-*a* concentrations were calculated after

0368-0770/99/0027-0001 $ 1.50

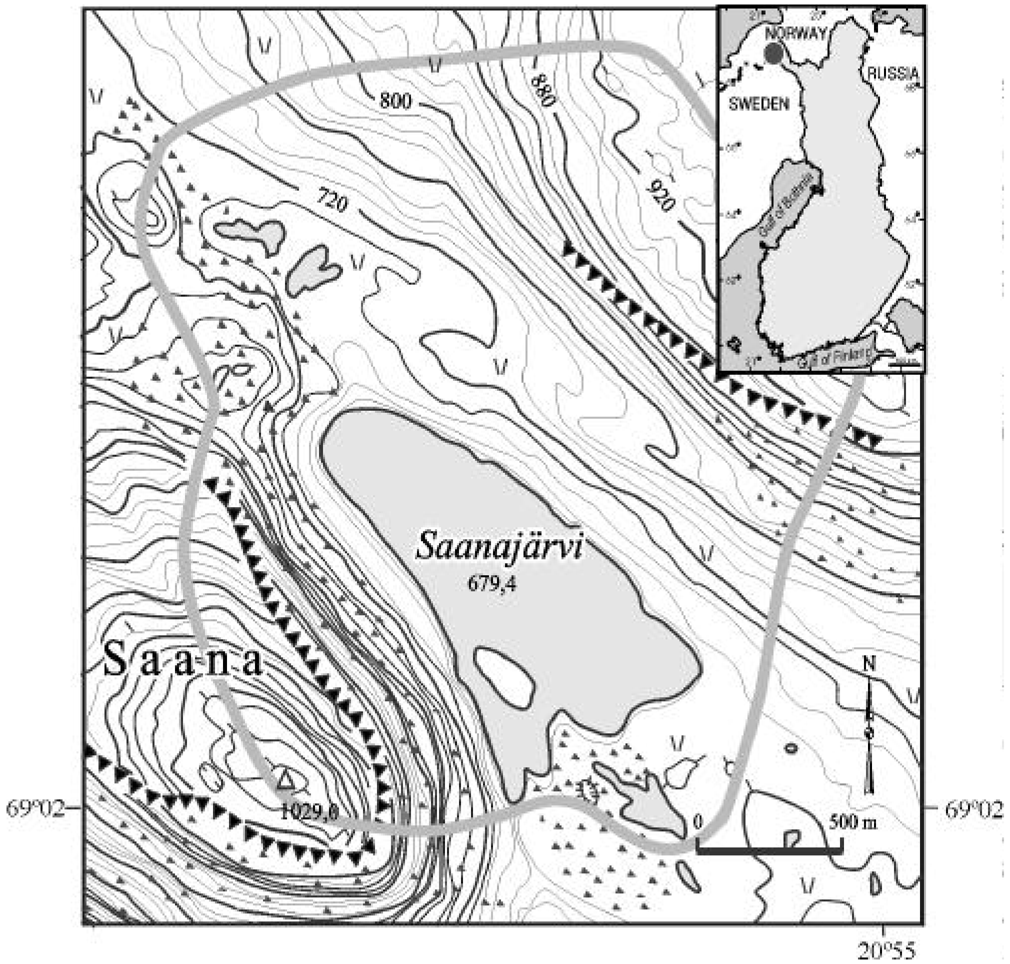

Fig. 1. Location of Lake Saanajärvi in the far north of Finnish Lapland, showing the catchment boundary.

Jefferey & Humphrey (1975).

Principal components analysis (PCA) was used to systematize and intepret the major patterns of variation in the chemical and physical data. All environmental variables were tested for skewness and, if necessary, transformed according to the closest Gaussian distribution. The PCA was implemented using the computer program CANOCO, version 3.10 (Ter Braak 1988, 1990), and the computer program CALIBRATE (S. Juggins & Ter Braak, unpublished program) was used for data transformation.

Results and discussion

Physical features

Saanajärvi is a typical dimictic lake with a relatively regular pattern of stratification. Annual cycles in the lake were almost identical in the two sampling years. The lake is covered by ice for about 9 months (Fig. 2). In 1996, the ice break-up took place on 27th June, whereas in 1997 it occurred on 7th July. After a brief vernal overturn, the lake became thermally stratified for a few weeks. Heating of the epilimnetic water closely followed air temperature, the thermocline lying at depths of 4–6 m in early summer, 6–8 m in mid-summer and 8–10 m before autumnal overturn (September 10–15). Maximum surface-water temperatures of 14.5 and 15.4 °C were reached in early August in 1996

Table 1. Minimum, maximum, mean and median values of physical, chemical and biological data for Saanajärvi. Upper water column includes values from 0 to 8 m and lower water column from 10 to 23 m during the sampling period 1996–1998 (June 4th 1996 to May 13th 1998).

Parameters	Upper water column				Lower water column			
	Min.	Max.	Mean	Median	Min.	Max.	Mean	Median
Temperature	-0.2	14.6	5.2	4.3	0.9	10.6	4.30	4.7
pH	5.4	7.9	6.91	7	6	7.5	6.79	6.8
Conductivity (µS/cm)	24.5	32	27.5	27.4	18.1	62	26.94	26.7
Alkalinity (µeq/L)	141.1	210.7	163.1	157.32	143.1	210.7	159.7	157.3
Tot. P*	2.0	5.0	4.0	4.0	2.0	5.0	3.9	4.0
Tot. N*	103.0	141.0	120.8	122.00	99.0	157.0	129.0	129.0
NH_4-N (µg/L)	0.0	68.9	10.6	9.30	0.0	26.5	8.3	8.21
NO_3-N (µg/L)	0.0	383.5	35.3	24.38	0.0	202.5	39.6	35.64
Ca (mg/L)	0.54	3.68	2.94	3.00	2.73	4.96	3.04	3.0
Mg (mg/L)	0.15	0.84	0.66	0.66	0.60	1.13	0.68	0.66
Na (mg/L)	0.46	3.01	1.15	0.24	0.99	1.35	1.11	1.07
K (mg/L)	0.05	0.46	0.24	1.16	0.21	0.38	0.24	0.24
SO_4 (mg/L)	0.8	7.24	3.96	3.97	2.04	6.52	3.96	3.85
Cl (mg/L)	0.6	6.43	1.71	1.67	0.62	2.93	1.62	1.6
Chlorophyll-*a* (µg/L)	-0.02	1.93	0.73	0.711	-0.29	1.75	0.59	0.48

*Parameters are measured during the open-water period in 1996.

and in late July in 1997, respectively, and the autumnal overturn started when the temperature of the epilimnion was ca. 8 °C (Fig. 2). The autumnal mixing period in the lake is relatively long (≈50 days) and is characterized by the phytoplankton maximum. A relatively large volume of water as well as strong and constant winds are apparently the main driving forces in maintaining the autumnal mixing. The lake starts to freeze at the end of October when the temperature of the water column is around 3 °C. The total range of the epilimnetic temperature in the study period was from –0.2 to 15.4 °C.

After the establishment of the ice-cover on the lake, the ice thickness increases linearly with time during the first part of the freeze period. A slight variability in the freezing rate between the two sampling years is apparently related to variation in snow cover and water temperature. However, the ice reached its maximum thickness of ≈1 m near May 15 in each monitoring year. The isotherms (Fig. 2) suggest a general cooling of the water column until mid-February, after which the temperature started to increase. Thus, the lake apparently loses heat over a great part of the winter.

The mean Secchi disc transparency of the lake was 8.5 m, with a range from 5.7 to 10.4 m. High Secchi values were found in spring during the vernal mixing period immediately after the ice break-up. This finding is in contrast to more humic lakes in southern Finland where Secchi transparency is usually lowest in spring when the dark hypolimnetic water from the winter stagnation period is mixed into the entire water column (Ilmavirta 1988). In general, Secchi values were negatively correlated to chlorophyll-*a*, with lowest values during the production maxima in late spring and autumn. Highest Secchi transparencies were observed during the mid-summer (early August), when primary production was mainly concentrated near the metalimnion, presumably due to photo-inhibition near the lake surface (Bretschko 1995).

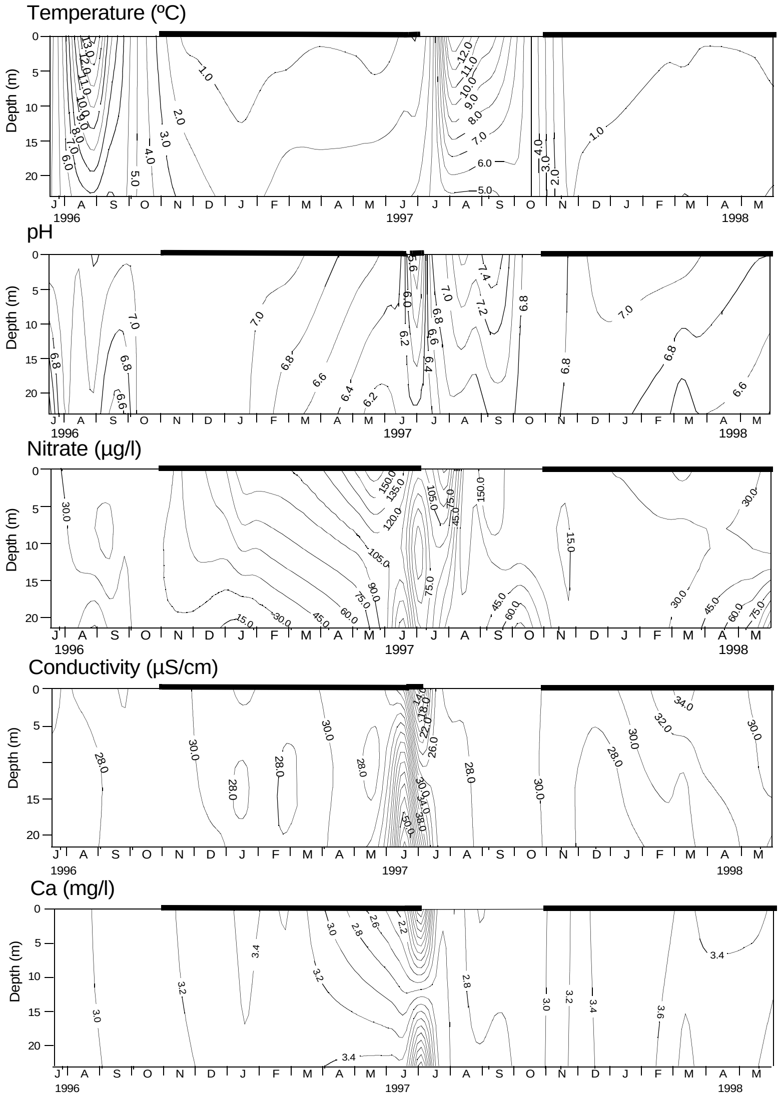

Fig. 2. Seasonal succession of water temperature and some chemical parameters in Lake Saanajärvi, July 4th 1996 to May 13th 1998. The duration of the ice-cover period is indicated by a black bar.

Water chemistry

Although the lake is ultra-oligotrophic, the bottom waters of Saanajärvi suffered from oxygen depletion before the spring mixing. The long winter, the small volume of the deep basin, and probably also respiration by the benthic community and zooplankton cause high oxygen consumption in the deeper parts. During the open-water period the lake is almost fully saturated with oxygen.

Lake water pH was almost constant throughout the year (mean pH = 7.1), except for a very short period in the spring when acid meltwaters drained into the lake (Fig. 2). Although the study area is considered one of the cleanest areas in Europe, the area receives small amounts of acid fallout throughout the year (Järvinen & Vänni 1990). In winter these acid compounds are stored in the snow pack making the pH of the spring meltwater very low (pH 4–5). In the study period, pH in the lake varied between 5.4 and 7.6. Primary production apparently caused seasonal pH variations in accordance with some small southern Finnish forest lakes where a close correspondance between pH and primary production has been noted (RASK et al. 1985). The average pH was slightly lower in the hypolimnion, which may be attributed to the accumulation of ions in the lower layers during winter as well as during thermal stratification. Alkalinity was more or less stable throughout the years varying from 141.1 to 210.7 µeq/L (mean 161.4 µeq/L). In general, alkalinity values were distinctly higher in Saanajärvi compared with those reported from other Lapland lakes (WECKSTRÖM et al. 1997, BLOM et al. 1998). This feature is probably related to the more alkaline local bedrock at Saanajärvi.

Conductivity was low and stable for most of the year (mean 27.6 µS/cm, range 8.5–45.1 µS/cm). However, during the oxygen depletion period in the spring, the values increased twofold in the hypolimnion, presumably due to a release of ions from lake surface sediments (Fig. 2). Immediately after this, lower conductivities were observed in the surface waters because of the dilution effect caused by meltwaters. Concentrations of Ca, Mg and K reached maxima under late spring ice, whereas Na concentrations were highest during the mid-summer. Otherwise the trends in base cations followed the pattern observed for conductivity. The sulphate maximum occurred during the snow melt period. Atmospheric sulphur dioxide concentrations in Lapland are highest in winter, causing a considerable shock effect on lakes when the acid compounds accumulated in snow are liberated as the snow melts (KÄHKÖNEN 1996). TOC was close or lower than the detection limit (1 mg/L) throughout the investigation period.

The nutrient status of Lake Saanajärvi is extremely low which is typical of lakes in northern Finland (FORSIUS et al. 1990). PO_4-P is below the detection limit of 1 µg/L, nitrate (NO_3-N) varies from 0 to the spring maximum of 383.5 µg/L and ammonium (NH_4-N) from 0 to 68.9 µg/L. The main source of inorganic nutrients in Saanajärvi is melting snow from the catchment which together with the nutrient release from the sediment under anoxic conditions causes the nutrient concentrations temporally to increase several-fold in spring in comparison to other seasons (Fig. 2). In particular during the time of the most intensive plankton production in autumn the water column lacks NO_3 due to biological uptake.

PCA classifies the surface-water samples into four distinct groups (Fig. 3). The first group represents spring samples, which are determined by high concentrations of NO_3. The second group is associated with higher summer surface temperatures, and the third group is correlated with low concentrations of NH_4-N. The fourth group is characterized by higher concentrations of ions in winter. The plotting of samples representing different years close together indicates great stability in seasonal dynamics. In the PCA biplot, high positive correlations among the variables themselves are distinguished by acute angles between the arrows representing the variables. This is evident among base cations, sulphate, chloride,

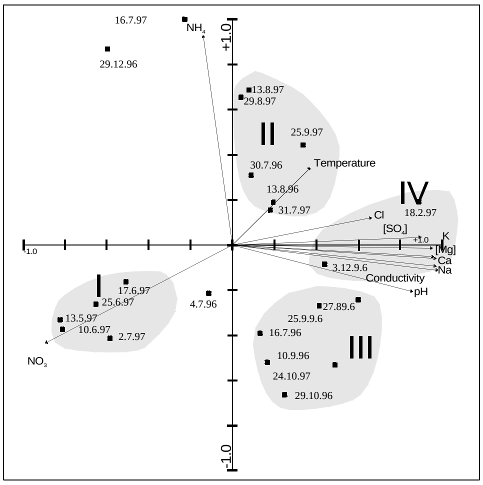

Fig. 3. The principal components analysis (PCA) ordination biplot of measured environmental variables and epilimnetic samples in Lake Saanajärvi. Four limnochemical groups, discussed in the text, are marked in the diagram by I–IV.

conductivity and pH, which are all strongly correlated with the PCA axis 1. The high positive correlations among these variables are typical of waters in Lapland (Blom et al. 1998).

Acknowledgements

This research was supported by the European Community "Environment and Climate Programme" under contract ENV4-CT95-0007 (MOLAR Project) and by the Academy of Finland (Grant 101 7383). We are grateful to the staff of the Kilpisjärvi Biological Station and The Finnish Forest Research Institute, Kilpisjärvi Branch, for their hospitality and logistic help, J. Virkanen and the staff of the Laboratory of Physical Geography for help in water chemistry analyses, S. Juggins and C. J. F. Ter Braak for providing a pre-release copy of their computer program CALIBRATE, K. Lehto for completing some of the drawings and J. Snyder for improving the English.

References

Blom, T., Korhola, A. & Weckström, J., 1998: Physical and chemical characterisation of small subarctic lakes in Finnish Lapland with special reference to climate change scenarios. – In: Lemmelä, R. (Ed.). *Proceedings of the 2nd International Conference on Climate and Water, Espoo, Finland, 17–20 August 1998* (in press).

Bretschenko, G., 1995: Opportunities for the High Alpine Research, the Lake "Vorderer Finstertaler See" as an Example (Kühtai, Tirol, 2237 m a.s.l.). – *Limnologica* 25: 105–108.

Forsius, M., Kämäri, J., Kortelainen, P., Mannio, J., Verta, M. & Kinnunen, K., 1990: Statistical lake survey in Finland: Regional estimates of lake acidification. – In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds): *Acidification in Finland*: 759–780. – Springer-Verlag, Berlin.

Ilmavirta, V., 1988. Acidic Lake lakeenjärvi, Eastern Finland: Phytoplankton succession and water chemistry. – *Verh. Internat. Verein. Limnol.* 23: 693–698.

Järvinen, A., 1987: Basic climatological data on the Kilpisjärvi area, NW Finnish Lapland. – *Kilpisjärvi Notes* 10: 1–16.

Järvinen, O. & Vänni, T., 1990: Bulk deposition chemistry in Finland. – In: Kauppi, P. et al. (eds): *Acidification in Finland.* – Springer-Verlag, Berlin Heidelberg.

Jefferey, S. W. & Humphrey, G. F., 1975: New spectrophotometric equations for determining chlorophyll a, b, c1 and c2 in higher plants, algae, and natural phytoplankton. – *Biochem. Physiol. Pflanzen* 167: 191–194.

Kähkönen, A.-M., 1996: The geochemistry of podzol soils and its relation to lake water chemistry, Finnish Lapland. – *Geol. Surv. Fin. Bull.* 385: 1–89.

Rask, M., Arvola, L. & Salonen, K., 1985: A note on the acidity in 54 small lakes in Evo forest area, southern Finland. – *Aqua Fennica* 15: 35–40.

Salonen, K., 1979: A versatile method for the rapid and accurate determination of carbon by high temperature combustion. – *Limnol. Oceanogr.* 24: 177–183.

Ter Braak, C. J. F., 1988: CANOCO – a FORTRAN program for canonical community ordination by [partial] [detrended] [canonical] correspondence analysis, principal components analysis and redundancy analysis (version 2.1). – *Agricultural Mathematics Group Technical Report LWA-88-02.* – Wageningen: Agricultural Mathematics Group. 95 pp.

Ter Braak, C. J. F., 1990: *Update notes: CANOCO version 3.10.* – Wageningen: Agricultural Mathematics Group. 35 pp.

Weckström, J., Korhola, A. & Blom, T. (1997). Diatoms as quantitative indicators of pH and water temperature in subarctic Fennoscandian lakes. – *Hydrobiologia* 347: 171–184.

Authors' addresses:

Sanna Sorvari, Milla Rautio, Atte Korhola, Laboratory of Physical Geography, Department of Geography, P.O. Box 9 (Siltavuorenpenger 20 A), FIN-00014 University of Helsinki, Finland.

Milla Rautio, Division of Hydrobiology, Department of Ecology and Systematics, P.O. Box 17 (Arkadiankatu 7), FIN-00014 University of Helsinki, Finland.