TRENDS IN THE WATER CHEMISTRY OF HIGH ALTITUDE LAKES IN EUROPE

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(Accepted 14 April 2001)

Abstract. Here we present the chemical trends of seven high altitude lakes, analysed within the AL:PE and MOLAR Projects of the EU (1999) and selected on the basis of the availability of complete and reliable data for the period 1984–1999. The lakes are representative of the Scandinavian Alps, the Cairngorm Mountains in Scotland, the Alps and the Pyrenees. Significant trends were identified for some indicators of acidification, for instance pH and alkalinity, but not all lakes reacted similarly to decreasing depositions of sulphate and base cations. Differences in lake response are discussed in relation to recent variations of atmospheric deposition chemistry and associated changes in climatic conditions. Beside individual variations of the studied lakes, depending, among other things, on altitude and morphology, catchment characteristics and climate trends play a major role for the reaction of high altitude lakes on changes in atmospheric depositions.

Keywords: acidification, atmospheric deposition, remote lakes, trend, water chemistry

1. Introduction

Scientific studies within the MOLAR project (Measuring and modelling the dynamic response of remote mountain lake ecosystems to environmental change: A programme of Mountain Lake Research – MOLAR), were carried out between February 1996 and February 1999, and were funded within the EU Environmental and Climate Programme with assistance from INCO. Around 23 co-operative partners were involved in research at some of the most remote and least disturbed freshwater ecosystems in Europe, mainly located in the Alpine and Arctic regions. Although far from local sources of pollution, the ecology of these lakes is strongly influenced by the atmospheric deposition of pollutants (acidity and toxic air pollutants) and by climate change. Because of their sensitivity to anthropogenic influences, they are also excellent sensors of change and can be used to infer the

Water, Air, and Soil Pollution: Focus **2:** 75–89, 2002.

speed, direction and biological impact of changing air quality and climate (Patrick *et al.*, 1998).

Details of site descriptions, chemical methods and a summary of chemical results are given in a previous synthesis paper (The MOLAR Water Chemistry Group, 1999).

In this article we evaluate trends in the chemical composition of seven MOLAR lakes in relation to changes which occurred in atmospheric deposition chemistry and climatic variations during the period 1984–1999. These lake ecosystems are representative of different European areas (Figure 1), from the Scandinavian Alps (Stavsvatn) to the Cairngorm Mountains in Scotland (Lochnagar), to the Alps (Paione Superiore, Laghetto Inferiore, Lago di Latte, Schwarzsee ob Sölden) and the Pyrenees (Redó). Atmospheric deposition was collected at five different sites (Figure 1): the Norwegian sampling station of Mosvatn and the alpine stations of Reutte, Ritten, Domodossola and Piotta. Data collected at the Domodossola rain site were used in the case of Lake Paione, in spite of the difference in altitude between the sampling station and the studied lake (Table I), to provide a long data series. The validity of this selection was checked by comparing the chemistry of deposition collected at Domodossola with that collected at a site close to the lake over a short timescale. The results revealed only small differences in the values of the main chemical variables, so that data from the Domodossola station could be used to detect trends (Mosello *et al.*, 1999).

2. Results

2.1. LAKE WATER AND ATMOSPHERIC DEPOSITION CHEMISTRY

The main physical characteristics of the selected lakes and of the corresponding deposition sampling stations are shown in Table I. Sampling frequencies varied according to the accessibility of the lakes, from 1–2 to 12 or more samplings per year. Lake samples were considered to be representative of surface water (0–1 m). The hydrology of the lakes is strongly influenced by the long period of ice cover during the winter, with the period of maximum hydrological activity during the snowmelt, from April to July. Most of the watersheds of the lakes are formed of gneiss or granite, while two of them also contain small amounts of calcite and carbonate (Redó, Laghetto Inferiore). Bare rocks, moraine and debris are the main components of the drainage basin while soils are thin and constitute only a fraction of the whole watershed. The vegetation mostly consists of alpine meadows, but in a few cases a sparse cover of trees is present (Table I). Atmospheric precipitation was sampled weekly, and mean monthly and yearly averages of major ions concentrations were obtained by volume weighting. Mean pH values were calculated from the mean volume weighted H^+ concentration.

Procedures and methods employed for chemical analyses and quality assurance and quality control are described in Mosello and Wathne (1997). Mean concen-

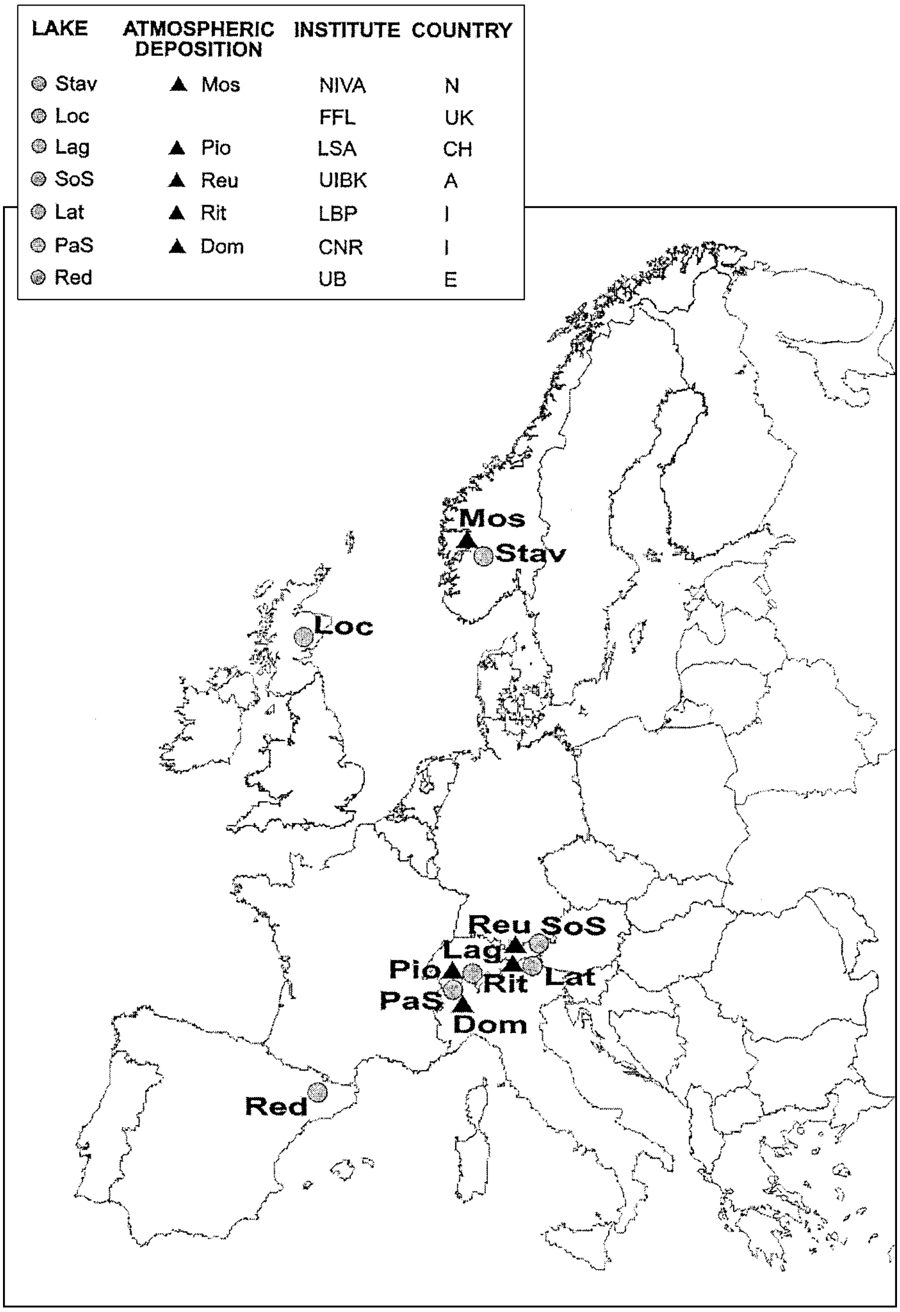

Figure 1. Lakes and atmospheric deposition sampling sites. NIVA: Norwegian Institute for Water Research, Oslo. FFL: Freshwater Fisheries Laboratory, Pitlochry. LSA: Laboratorio Studi Ambientali, Lugano. UIBK: University of Innsbruck. LBP: Laboratorio Biologico Provinciale, Laives. CNR: Istituto Italiano di Idrobiologia, Verbania Pallanza. UB: University of Barcelona. See Table I for the other acronyms.

TABLE I

Morphometric and hydrological characteristics of the selected MOLAR lakes

Lake (acronym)	Atm. deposition sampling station (acronym)	Station altitude m a.s.l.	Lake altitude m a.s.l.	Catchment area km^2	Lake area ha	Max depth m	Mean depth m	Volume m^3 10^6	Precipitation mm yr^{-1}	Retention time d	Annual runoff L sec^{-1} km^{-2}	Ice free period	Geology	Soil	Vegetation
Stavsvatn (Stav)	Møsvatn (Mos)	940	1053	2.43	40.0	17.0	6.2	2.50	1000	380	31	June–September/ October	Granite	Alpine soils and peat	Rocks, pasture, alpine heath, some birch trees
Lochnagar (Loc)			785	1.02	9.8	24.0	8.4	0.82	1034	315	30	ca. 8 months	Granite	Peat and alpine soil	Dwarf shrub (alpine) heath, bare rock
Laghetto Inferiore (Lag)	Piotta (Pio)	1007	2074	1.78	4.8	33.0	10.6	0.65	2300	55	60	July–October	Gneiss alkalipheldspat, anphibolite, presence of carbonate	Podsol 7%	Rocks and debris, some hay meadows and sparse shrubs
Schwarzsee ob Sölden (SoS)	Reutte (Reu)	930	2799	0.14	3.4	18.0	10.0	0.34	–	–	–	July/August–October	Gneiss, granite, diorit	Bare rocks, thin alpine soil	Rocks, alpine mats
Lago di Latte (Lat)	Ritten (Rit)	1780	2540	0.65	2.3	12.3	5.3	0.13	1000	71	31	July–October October	Gneiss	Alpine soil	Bare rocks, alpine pasture, permanent ice
Paione Superiore (PaS)	Domodossola (Dom)	270	2269	0.55	1.4	11.5	5.1	0.07	1400	33	44	August–October	Gneiss Gneiss Gneiss	Alpine soil	Rocks and debris, some hay meadows
Redó (Red)			2240	1.55	24.0	73.0	32.0	7.75	1300–1500	1217–1404	41–48	June–December	Granodiorite, rocks bearing calcite	Bare rocks, ranker soil	Festuca eskia fields, few mosses

TABLE II

Mean chemical characteristics (1998) of lake water and atmospheric deposition (conductivity μS cm^{-1} at 25 °C; concentrations μeq L^{-1}). Lakes: surface values (0–1 m); volume weighted mean concentrations in precipitation

	mm	pH[a]	Cond.	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Alk	SO_4^{2-}	NO_3^-	Cl^-
Lake													
Stavsvatn	–	6.05	9.0	1	3	40	8	21	3	22	29	4	14
Lochnagar	–	5.30	21.1	5	1	35	37	91	5	0	54	16	76
Lago Paione Superiore	–	5.60	10.9	3	4	43	8	11	7	8	36	28	5
Lago di Latte	–	6.22	19.3	1	5	101	13	16	8	78	59	15	4
Schwarzsee ob Sölden	–	5.92	17.2	1	0	80	27	17	3	11	104	7	2
Redó	–	6.14	10.4	1	1	72	7	13	1	49	26	11	11
Laghetto Inferiore	–	6.59	11.9	0	1	68	9	14	15	35	41	16	4
Precipitation amount and concentrations													
Møsvatn	783	4.79	–	16	10	4	2	6	1	–	16	14	8
Piotta	1258	4.90	19.5	13	27	13	4	8	1	2	26	24	5
Reutte	1574	5.23	–	7	21	16	3	4	2	–	6	19	7
Ritten	1052	5.09	9.4	8	26	15	6	3	2	–	26	21	6
Domodossola	1133	4.69	15.7	20	31	10	2	4	2	1	29	32	4

[a] Calculated from the mean volume weighed H^+ concentrations.

trations of major ions in surface water and atmospheric deposition are shown in Table II. The total ionic content of the lakes varies between 146 and 348 μeq L^{-1}; the highest value is that of Lochnagar, which has the greatest contribution from marine sources. The lowest alkalinity concentrations correspond to the lakes with pH below 6.0. The unusually high sulphate concentration at Schwarzsee ob Sölden indicates a large contribution from catchment weathering in addition to the atmospherically derived sources (Koinig *et al.*, 1997). Nitrate concentrations are very low (below 10 μeq L^{-1}) in the northernmost lake in Norway and in the Austrian lake, while the highest values (16–26 μeq L^{-1}) are found in the lakes in the Alps (Table II).

The wet deposition chemistry is quite similar at the four stations, with mean pH values ranging between pH 4.69 and 5.23, corresponding to an H^+ concentration ranging between 7 μeq L^{-1} (Reutte) and 20 μeq L^{-1} (Domodossola). The least polluted rain in terms of sulphate and nitrogen compound concentrations was collected at Reutte and Mosvatn, while the other sites were relatively similar, although Domodossola was the most polluted of the three (Table II).

2.2. LONG-TERM TRENDS

Statistical analysis to detect long-term trends was applied to the available chemical data of lake water and atmospheric deposition (Table III). The Kendall test was used in the former case because seasonality could not be considered, owing to the random sampling frequency (samples were taken in most cases during summer and with a different sampling frequency in the different years). The seasonal Kendall test (SKT) was used in the case of atmospheric deposition data, using the methods described by Hirsch *et al.* (1992) and Hirsch and Slack (1984).

Long-term trends in annual means of the main chemical variables in atmospheric deposition are shown in Figure 2. At all sites, pH increased significantly and sulphate decreased in the 1990s, as a consequence of reduced atmospheric emissions of sulphur compounds throughout Europe. Total inorganic nitrogen (NH_4^+ + NO_3^-) remained fairly constant or declined slightly at Ritten (Eastern Alps). Base cations declined significantly at the Domodossola, Piotta and Reutte sites (Figure 2, Table III).

Turning to the lake sites (Figures 3 and 4), the pH trend in three of the seven lakes (Laghetto Inferiore, Schwarzsee ob Sölden, Paione Superiore) showed a significant increase, but was in decline in Redó after 1986. Alkalinity increased in Stavsvatn, Lago di Latte and Paione Superiore with a high level of significance; the increase was less marked in Laghetto Inferiore and Redó. Interestingly, no significant alkalinity trend was found in Schwarzsee ob Sölden and Lochnagar; even though there was an increase in pH at the former site (Figure 3). Sulphate concentrations declined in all the lakes, with the exception of Lago di Latte and Schwarzsee ob Sölden. At the latter site sulphate concentrations increased sharply from 1992 (Figure 4). By comparison, nitrate concentrations do not show any

TABLE III

Trends of the main variables in lakes and atmospheric deposition

Lake	Test^b	Period	pH		SO_4^{2-}		NO_3^-		Base cations		Alkalinity	
			p level^c	B^d	p level^c	B^d	p level^c	B^d	p level^c	B^d	p level^c	B^d
Stavsvatn	KT	1986–1999	n.s.^{e}		**	–1.536	*	0.286	n.s.		**	1.186
Lochnagar	KT	1988–1999	n.s.		**	–1.067	*	0.667	**	3.222	n.s.	
Laghetto Inferiore	KT	1986–1999	*	0.046	*	–0.930	n.s.		n.s.		*	1.947
Schwarzsee ob Sölden	KT	1985–1999	**	0.037	**	5.801	*	–0.275	**	7.998	n.s.	
Lago di Latte	KT	1988–1999	n.s.		n.s.		**	–1.490	n.s.		**	4.188
Lago Paione Superiore	KT	1984–1999	**	0.032	**	–0.840	*	0.386	n.s.		**	0.682
Redó	KT	1984–1998	**	–0.033	*	–0.213	**	–0.638	*^{a}	0.860	*	1.019

Atmospheric deposition	Test^b	Period	pH		SO_4^{2-}		TIN^f		Base cations	
			p level^c	B^d	p level^c	B^d	p level^c	B^d	p level^c	B^d
Mosvatn	SKT	1993–1999	**	0.050	n.s.		n.s.		n.s.	
Piotta	SKT	1990–1999	**	0.068	**	–2.375	n.s.		*	–2.283
Reutte	SKT	1984–1999	**	0.048	**	–0.936	n.s.		**	–3.894
Ritten	SKT	1990–1999	**	0.043	*	–1.062	*	–1.856	n.s.	
Domodossola	SKT	1986–1999	**	0.032	**	–2.747	n.s.		**	–0.981

[a] Trend analysis performed on calcium concentrations. [b] KT: Kendall test; SKT: Seasonal Kendall test. [c] Probability level: * < 0.01; ** < 0.001. [d] B: Kendall slope estimator. [e] n.s.: Not significant trend. [f] TIN = total inorganic nitrogen ($NH_4^+ + NO_3^-$).

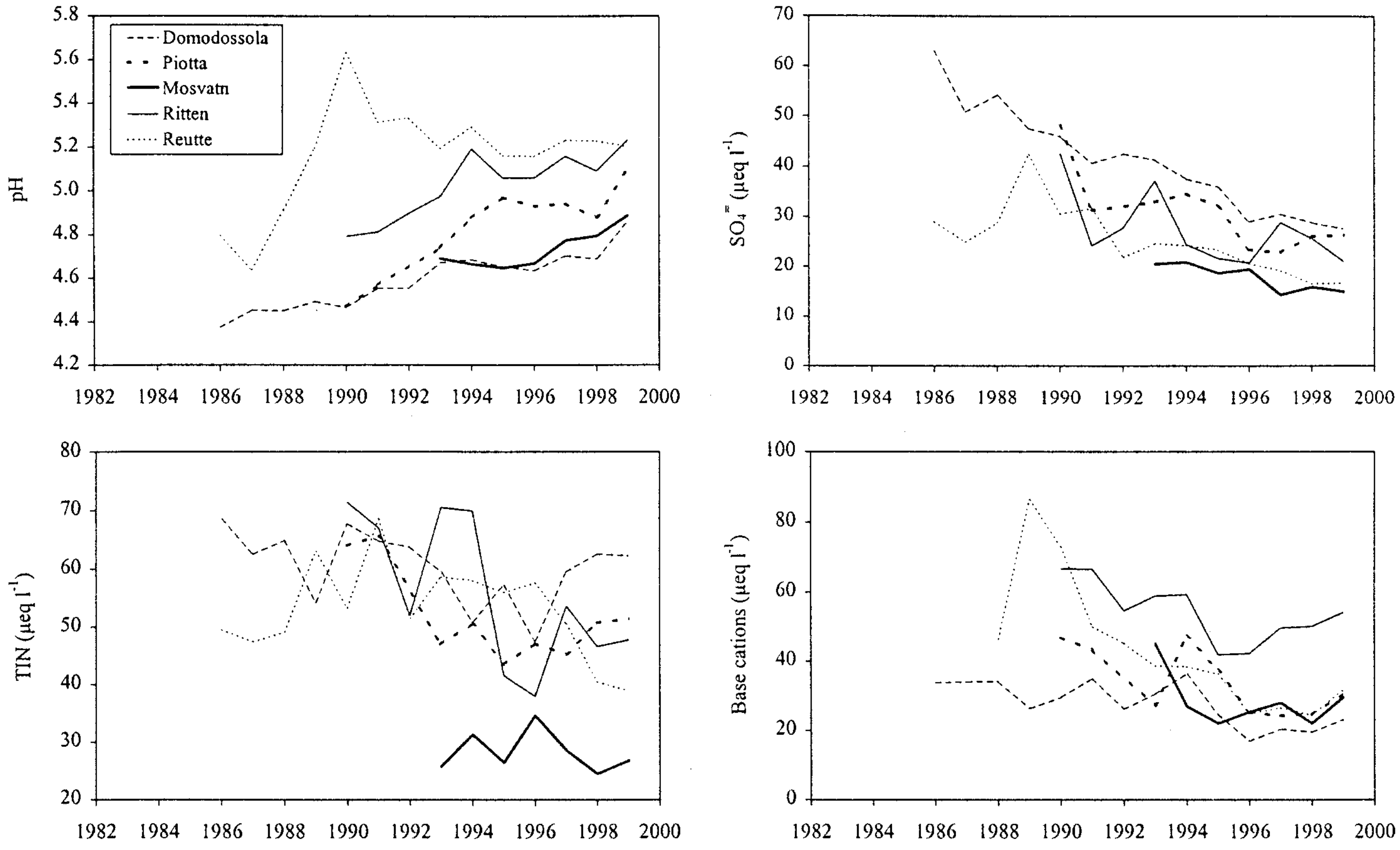

Figure 2. Trend of the atmospheric deposition chemistry at the sampling sites. TIN: total inorganic nitrogen ($NH_4^+ + NO_3^-$).

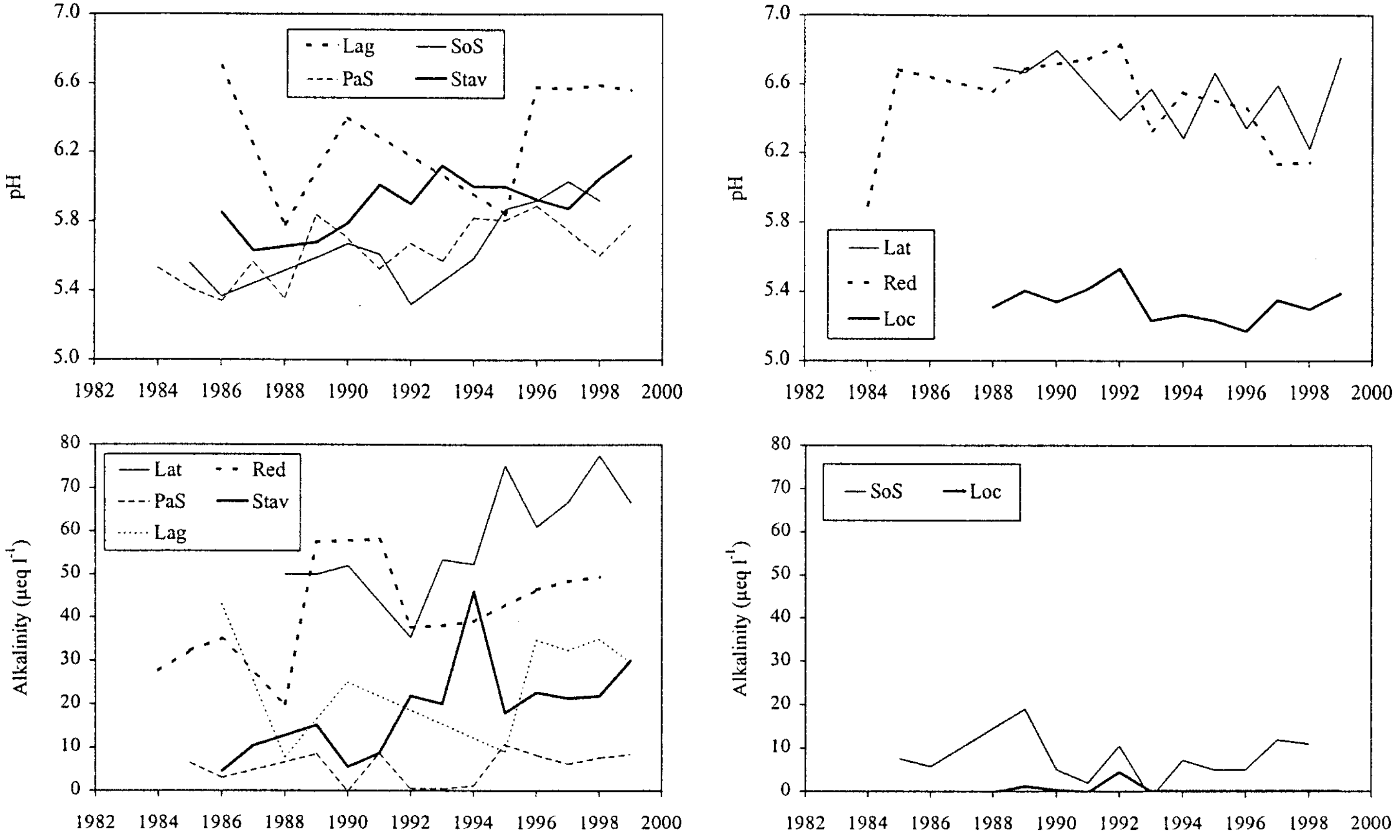

Figure 3. Long-term trends of pH and alkalinity in lake water.

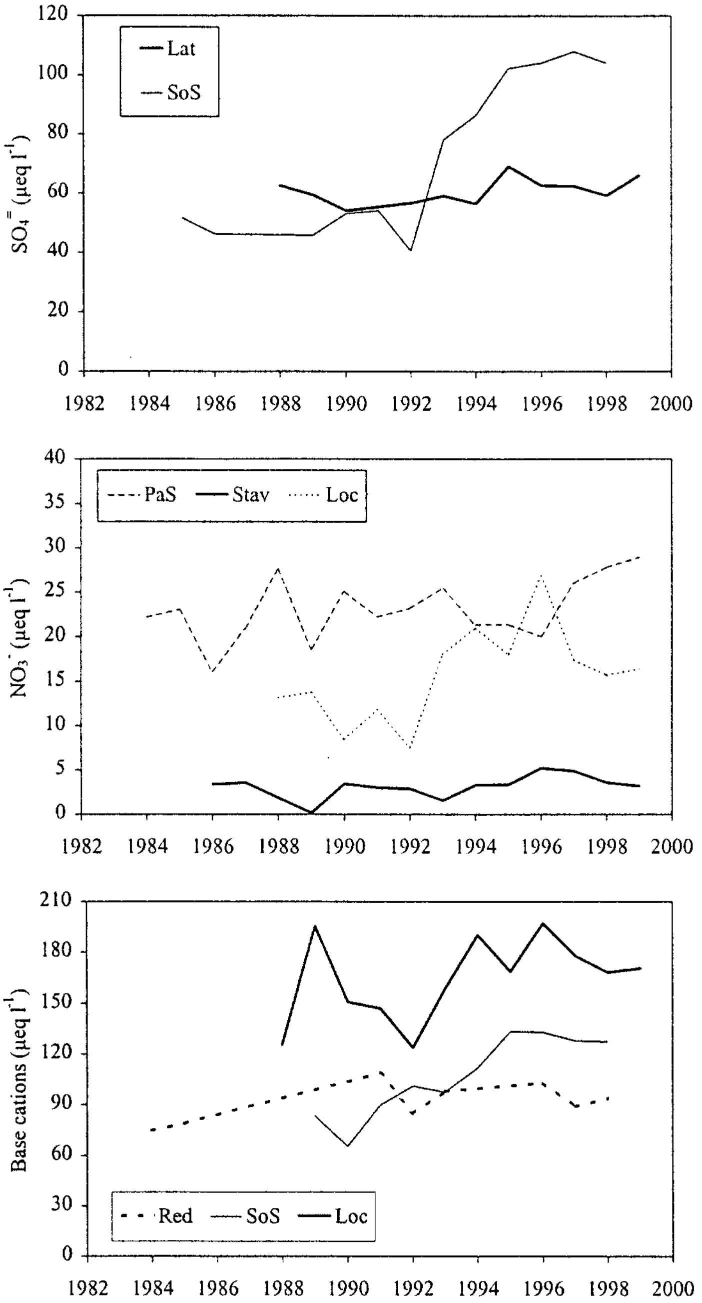

Figure 4. Long-term trends of sulphate, nitrate and base cations ($Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$) in lake water.

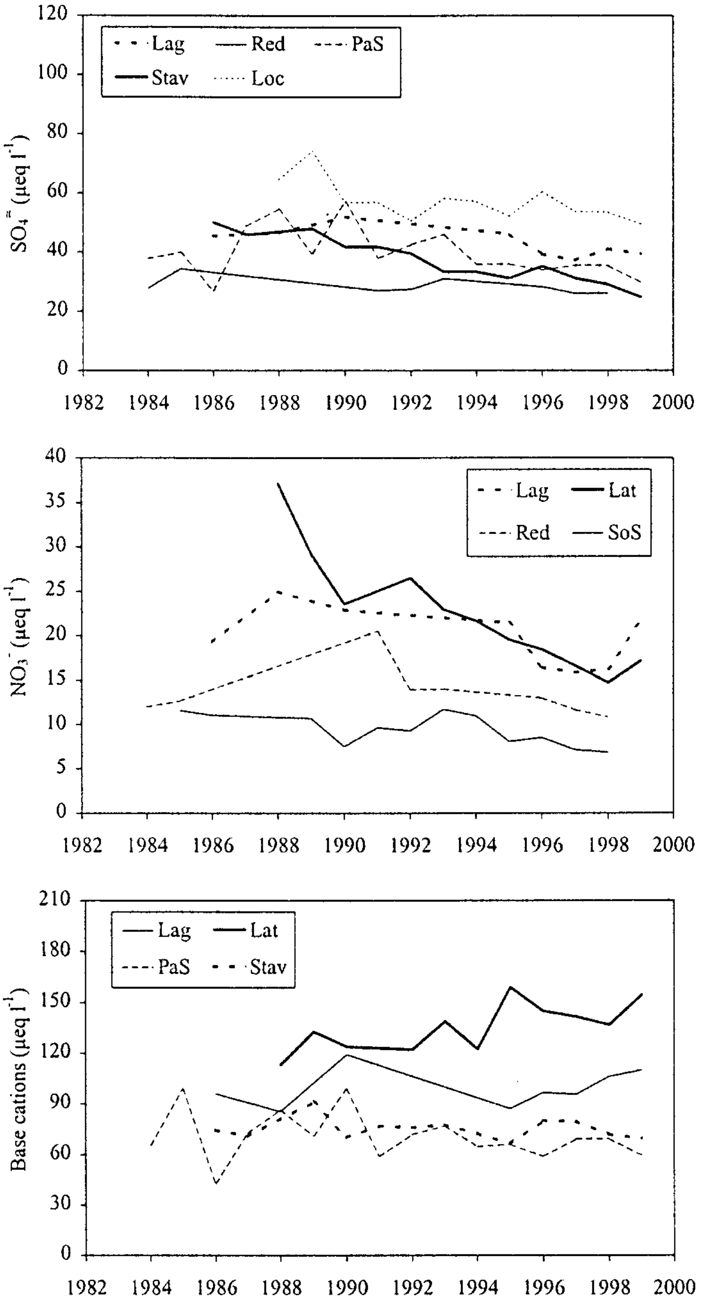

Figure 4. (Continued).

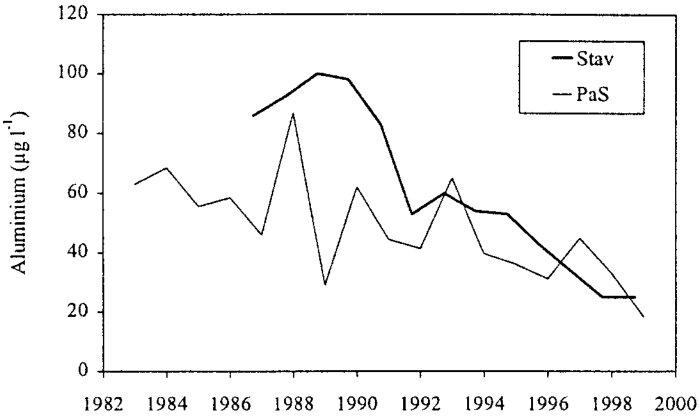

Figure 5. Long-term variations of aluminium concentrations in lakes Stavsvatn and Paione Superiore.

consistent trends: they increased significantly in Stavsvatn, Lochnagar and Paione Superiore, and decreased in Schwarzsee ob Sölden, Lago di Latte and Redó, while the trend is not statistically significant in the case of Laghetto Inferiore (Figure 4, Table III). Trend analysis of base cations was performed for six of the lakes: Lochnagar and Schwarzsee ob Sölden showed an increasing trend of base cations, while in the other lakes the trends were not significant. For Lake Redó only calcium and sodium concentrations were available: the trend analysis performed on calcium data showed a significant increase (Table III). The fact that base cations have generally decreased in precipitation seems to indicate that in the lakes where their concentrations have not changed or have slightly increased, weathering rates are higher, possibly as a consequence of warmer temperatures.

Figure 5 shows the long-term trend of declining aluminium in Stavsvatn and Paione Superiore based on annual average values; this indicates a steady recovery from acidification allied with increasing pH and alkalinity and declining sulphate concentration.

3. Discussion and Conclusion

The data from the precipitation network indicate a general decline in acidity, sulphate and base cations over most of Europe, which is corroborated by data from other precipitation networks (Schaug *et al.*, 1997; Barrett *et al.*, 2000). However, the response of high mountain lakes is rather variable and, in some cases, quite the opposite of the deposition trends. Results of the analysis of long-term trends of mountain lake chemistry show marked dissimilarities in the responses of lakes to the changes occurring in atmospheric deposition.

In agreement with the decreasing acidity of the atmospheric input, there are clear signs of recovery from acidification in some of the lakes: the pH and alkalinity trends of Laghetto Inferiore and Paione Superiore show a significant increase, although the relationship between these two variables does not match very well in the other lakes. While the pH trend in Stavsvatn is not significant, the recovery of the lake is evident in terms of increasing alkalinity and decreasing aluminium concentrations; this is due to the reduction of atmospheric deposition of sulphur over the whole region of South Norway (The Norwegian State Pollution Control Authority, 1999).

There appears to be no relationship between atmospheric input and lake response in the Austrian lake Schwarzsee ob Sölden, where sulphate concentration increased, in sharp contrast with the decreasing sulphate concentration in the atmospheric deposition of the Reutte site (Puxbaum, 1998). This behaviour, which is characteristic of a high number of mountain lakes in the Eastern Alps (Sommaruga-Wögrath *et al.*, 1997), can be explained by higher summer temperatures and consequently more intense weathering related to climate change, in particular the dissolution of easily soluble calcium and magnesium sulphate in the catchment. As shown by Beniston *et al.* (1997) the average air temperature at altitude stations in the Alps has increased by ca. 1 °C since 1985. Sommaruga-Wögrath *et al.* (1997) argued that the disappearance of permanent snowfields in the catchment of Schwarzsee ob Sölden – a typical feature of the 1970s, when also the lake itself had a permanent ice cover during some years – has led to a tremendous increase in the dissolution of minerals, indicated by a steady rise of silica concentrations in lake water. Pyrite oxidation, which produces sulphuric acid and thus enhances the weathering of silicate or carbonate minerals, could also account for the increased concentrations of sulphate, base cations and silica without any change in alkalinity (Wögrath and Psenner, 1995). Another striking case is that of Lago di Latte, where the sulphate trend is not significant in spite of a diminishing content in atmospheric deposition at Ritten. Enhanced weathering and increased biological activity induced by climate warming may account for this result, and also for the decrease in nitrate concentration, as in Schwarzsee ob Sölden, in agreement with the increased levels of primary production (Tait and Thaler, 2000).

In Lake Redó, the year-to-year variability was high because some of the yearly averaged data were biased by winter data, when the ice cover and melting snow with distinct chemical characteristics had a major influence on the surface waters. This uneven sampling frequency caused a departure from the general trend, which might override the signal of the processes. Despite this fact, decreasing sulphate concentration and pH, and increasing alkalinity trends were found to be statistically significant. Thus, whereas alkalinity seemed to respond to lower sulphate deposition as expected, pH had an opposite response. The apparent paradox of the pH and alkalinity trends may be explained by the increased concentrations of dissolved inorganic carbon measured in the lake water (Camarero, unpublished data), resulting in higher values of dissolved CO_2-carbonic acid. Since Redó acts as an heterotrophic system (Camarero *et al.*, 1999), higher respiration rates and, therefore, enhanced CO_2 production in the lake related to warmer periods is a possible explanation.

In other lakes, which are much more shallow than Redó, because of longer exposure to the atmosphere (i.e. a reduction of ice cover duration and longer mixing periods), the pH may become closer to the atmospheric equilibrium (i.e. it will rise), while in deep lakes CO_2 can accumulate at a faster pace when climatic conditions become more favourable.

The decline in sulphate concentration in Lochnagar can also be associated to a similar decline in atmospheric deposition, but for this lakes there were no trends in either pH or alkalinity. Climate influences might offer an explanation: during the past two decades, ice cover on the lake has declined, resulting in more frequent mixing and less chemical variability. The increasing nitrate trend appears to be a consequence of the warm dry summer of 1996, which mineralised soil nitrogen and produced elevated nitrate concentrations for about two years. Associated with this trend is an equivalent increase in ionic aluminium and base cations. Recently, nitrate concentrations have declined to pre-1995 levels.

Altogether, the chemical signal from atmospheric deposition (especially sulphate) appears generally to be detected in high mountain lakes. Some of them show clear signs of recovery from acidification in terms of decreasing acidity and sulphate, while others seem to stray from these trends. Altitude (and consequently temperature and ice cover duration), trophic degree, morphometry (especially size and depth) and catchment characteristics seem to play a dominant role for the observed differences. In addition, climate variability appears to introduce a greater degree of chemical variability (especially in nitrate, aluminium and base cations) which may mask trends resulting from emission reduction programmes.

Acknowledgements

The MOLAR project is funded within the European Commission Framework Programme IV: Environment and Climate with assistance from INCO. Contract No.: ENV4-CT95-0007/IC20-CT96-0021.

References

Barrett, K., Schaug, J., Bartonova, A., Semb, A., Hjellbrekke, A. G. and Hanssen, J. E.: 2000, *A Contribution from CCC to the Re-evaluation of the Observed Trends in Sulphur and Nitrogen in Europe, 1978–1998.* EMEP/CCC-REPORT 7/2000.

Beniston, M., Diaz, H. F. and Bradley, R. S.: 1997, 'Climatic change at high elevation sites: An overview', *Climatic Change* **36**, 233–251.

Camarero, L., Felip, M., Ventura, M., Bartumeus, F. and Catalan, J.: 1999, 'The relative importance of the planktonic food web in the carbon cycle of an oligotrophic mountain lake in a poorly vegetated catchment (Redó, Pyrenees)', *J. Limnol.* **58**, 203–212.

Hirsch, R. M. and Slack, J. R.: 1984, 'A nonparametric trend test for seasonal data with serial dependence', *Water Res. Resear.* **20**, 727–732.

Hirsch, R. M., Slack, J. R. and Smith, R.: 1982, 'Techniques of trend analysis for monthly water quality data', *Water Res. Resear.* **18**, 107–121.

Koinig, K. A., Schmidt, R., Sommaruga-Wögrath, S., Tessadri, R. and Psenner, R.: 1998, 'Climate change as the primary cause for pH shifts in a high alpine lake', *Water, Air, and Soil Pollut.* **104**, 167–180.

Mosello, R. and Wathne, B. M.: 1997, 'Surface Water. Chemical Analysis of Major Ions and Nutrients. Analytical Quality Control', in B. M. Wathne (ed.), *MOLAR. Measuring and Modelling the Dynamic Response of Remote Mountain Lake Ecosystem to Environmental Change: A Programme of Mountain Lake Research. MOLAR Project Manual*, NIVA Report 0-96061, pp. 24–45.

Mosello, R., Marchetto, A., Brizzio, M. C., Tartari, G. A. and Rogora, M.: 1999, 'Pluriannual evolution of the hydrochemistry of two alpine lakes (Lake Paione Inferiore and Lake Paione Superiore, Ossola Valley) in relation to atmospheric loads', *J. Limnol.* **58**, 43–49.

Patrick, S., Battarbee, R. W., Wathne, B. and Psenner, R.: 1998, 'Measuring and Modelling the Dynamic Response of Remote Mountain Lake Ecosystems to Environmental Change: An Introduction to the MOLAR Project', *Hydrology, Water Resources and Ecology in Headwater, Proc. of the Headwater Conference, Meran, Italy, April 1998*, IAHS Publ. 248, pp. 403–410.

Puxbaum, H., Simeonov, V. and Kalina, M. F.: 1998, 'Ten years trends (1984–1993) in the precipitatione chemistry in Central Austria', *Atmos. Environ.* **32**, 193–202.

Schaug, J., Semb, A., Solberg, S., Hanssen, J. E., Pacyna, J. M. and Hjellbrekke, A. G.: 1997, *Summary Report from the Chemical Co-ordinating Centre for the Fifth Phase of EMEP*, EMEP/CCC-REPORT 7/96.

Sommaruga-Wögrath, S., Koinig, K. A., Schmidt, R., Sommaruga, R., Tessadri, R. and Psenner, R.: 1997, 'Temperature effects on the acidity of remote alpine lakes', *Nature* **387**, 64–67.

Tait, D. and Thaler, B.: 2000, 'Atmospheric deposition and lake chemistry trends at a high mountain site in the Eastern Alps', *J. Limnol.* **59**, 61–71.

The MOLAR Chemistry Group: 1999, 'The MOLAR project: Atmospheric deposition and lake water chemistry', *J. Limnol.* **58**, 88–106.

The Norwegian State Pollution Control Authority: 2000, *Overvåking av langtransportert luft og nedbør. Atmosfærisk tilførsel (Monitoring of long range transported air pollutants and precipitation. Atmospheric deposition, 1999). Statlig program for forurensningsovervåking*. Rapp. 797/00 (in Norwegian).

Wögrath, S. and Psenner, R.: 1995, 'Seasonal, annual and long-term variability in the water chemistry of a remote high mountain lake: acid rain versus natural change', *Water, Air, and Soil Pollut.* **85**, 359–364.