Hydrology and Earth System Sciences, 5(3), *274–282* (2001) © EGS

Assessment of recovery of European surface waters from acidification 1970-2000: An introduction to the Special Issue

R.C. Ferrier[1], A. Jenkins[2], R.F. Wright[3], W. Schöpp[4] and H. Barth[5]

[1] Macaulay Institute, Aberdeen, Scotland AB15 8QH, UK
[2] Centre for Ecology and Hydrology, Wallingford, Oxon OX10 8BB, UK
[3] Norwegian Institute for Water Research, PO Box 173, Kjelsås, N-0411Oslo, Norway
[4] International Institute for Applied Systems Analysis, A-2361 Laxenburg, Austria
[5] European Commission Research Directorate General, Environment and Sustainable Development Programme, Unit I-3, B-1049 Bruxelles, Belgium

Email for corresponding author: r.ferrier@macaulay.ac.uk

Introduction

Since the onset of the industrial revolution in the 18th century, emission of acidifying compounds to the atmosphere has increased steadily reflecting the general growth and expansion of industrialisation (Mylona, 1996). Major pollutants include sulphur (S) and nitrogen (N) compounds derived from the burning of fossil fuels, farming, smelting of metal ores and other industrial activities. These acidifying pollutants are carried by air and deposited as gases and aerosols and dissolved in rainwater, in areas far from their sources (Rodhe and Granat, 1984). In large areas of Europe, this chronic, long-term deposition of acidifying compounds has led to acidification of soils and surface waters (Mason, 1990) with extensive adverse effects on biota, on salmonid fish in particular (Hesthagen *et al*., 1999; Jeffries, 1997) and on dieback of forests.

In recent decades, there have been national and international efforts to achieve reductions in emissions of acidifying compounds to the atmosphere (Jenkins, 1999). The United Nations Economic Council for Europe (UN-ECE) has been the primary forum for negotiating international agreements in Europe under the Convention on Long Range Transboundary Air Pollution (CLRTAP). The initial result of these negotiations was the First S Protocol, signed in 1985, in which the signatory countries committed themselves to a 30% reduction in S emissions by the year 1993 relative to 1980 levels. This was followed in 1994 by the Second S Protocol, in which the signatory countries agreed to reduce S emissions further by about 80% by the year 2010 relative to 1980 levels. For N, there have also been negotiations with the First N Protocol signed in 1988, in which signatory countries agreed to stabilise emissions of oxidised N compounds (NO_x) by the year 1994 relative to 1987 levels.

The most recent agreement, signed in Gothenburg in 1999, aims to abate acidification, eutrophication and ground-level ozone and recognises the interactive effects of four key atmospheric pollutants, S, NO_x, volatile organic compounds and ammonia (NH_3), and sets emission ceilings for the year 2010 (UN-ECE, 1999a). The ceilings were negotiated on the basis of pollution effects, using critical loads assessment and integrated assessment modelling, to optimise and target the emission reductions across Europe. When fully implemented, S emissions in Europe will be reduced by at least 63%, NO_x by 41% and NH_3 by 17% compared to the levels in 1990 (Table 1) which are already substantially reduced from the 1980 baseline used in earlier agreements (UN-ECE, 1999b).

In addition to the agreements under the CLRTAP, the European Union has formulated two new policy initiatives, namely the Water Framework Directive (European Commission, 2000) and the Emissions Ceilings Directive, both of which relate directly to the surface water acidification issue. The deadline for achieving good water quality status, relative to reference conditions, was proposed originally by the European Commission as 2010 although this has since been extended to 2016. Under the Water Framework Directive, control measures must be introduced to allow acidified surface waters to move back towards their pre-acidification conditions. The Emissions Ceilings Directive is currently still under negotiation.

These recent negotiations for controlling air pollution are underpinned by the scientific understanding of the acidification and recovery process. In this respect,

Table 1. European SO_2 emissions (Kt) 1960–2010 assuming implementation of the Gothenburg Protocol and relevant EU Directives

	1960	*1970*	*1975*	*1980*	*1985*	*1990*	*1995*	*2000*	*2005*	*2010*
Austria	224	336	338	330	326	93	51	47	44	39
Belgium	563	966	766	821	510	336	305	225	210	107
Denmark	227	532	436	444	389	182	241	209	189	55
Finland	297	532	554	596	436	226	163	139	144	116
France	1904	3313	3319	3330	1773	1250	884	688	685	400
Germany	4952	7549	7275	7559	7607	5280	2099	744	697	518
Greece	77	226	410	518	601	504	600	490	515	508
Ireland	46	152	183	210	141	178	214	163	153	42
Italy	945	3247	3271	3840	2958	1679	962	624	541	381
Luxembourg	20	42	39	19	19	14	9	9	9	4
Netherlands	410	494	293	462	295	201	153	105	78	52
Portugal	55	112	192	263	264	343	399	219	204	170
Spain	546	1305	1807	2618	2418	2189	1951	1384	1222	773
Sweden	318	512	447	494	372	117	85	80	79	65
United-Kingdom	5742	6936	5656	4831	4072	3812	2301	1467	1241	625
EU-15	16324	26252	24986	26335	22181	16404	10417	6573	6011	3855
Non-EU	16580	21204	25779	27878	29222	22763	15667	12977	12432	10254
TOTAL	**32904**	**47456**	**50765**	**54213**	**51403**	**39167**	**26084**	**19550**	**18443**	**14109**

investigations into the link between reduced deposition of S and N and recovery of surface waters from acidification have taken two approaches; (1) direct documentation from the field by careful long-term monitoring of acid deposition and acid sensitive lakes and streams; (2) whole ecosystem experiments with lakes or catchments entailing acid additions or exclusion (by roof). Of these, the second approach is well integrated within the scientific literature (e.g. Moldan *et al.*, 1995; Schindler *et al.*, 1991; Wright *et al.*, 1993). In the case of the first approach, the information is fragmented and measurement is ongoing. This is unfortunate in relation to determining what environmental legislation is required to improve the environment as the field measurements provide clear cut and direct evidence for change at the catchment and regional levels of concern. As part of the Commission of the European Communities RECOVER:2010 project (Appendix 1), surface water chemistry data from across Europe have been compiled to determine recovery trends, understand factors that confound the expected trends and take the steps required towards regional prediction of future recovery and response to the agreed emission reductions.

Trends in atmospheric deposition across Europe

The period 1960-2000 shows unprecedented historic levels in the emissions of SO_2 (Table 1) in Europe; yet at the same time, reductions achieved in the emissions of SO_2 are also significant since the mid-1980s. While much of the emission reduction is the result of targeted abatement policy through, e.g., the fitting of FGD-filters on large combustion plants, some of it is simply the result of structural changes in the economy, e.g. reducing the size of heavy industry or changes in energy consumption and fuel mix. There are differences between countries, both in the magnitudes of their emission reductions and in the share of emission reductions that are due to targeted abatement measures. Yet greater reductions are agreed under the Gothenburg Protocol by 2010 (Table 1).

The resulting deposition trends for SO_x (Appendix 2), as simulated from the RAINS model (Amann *et al.*, 1998; Alcamo *et al.*, 1990) for selected areas of Europe (Appendix 2) show a spatial variation in the peak deposition flux, being greatest in Scandinavia and smallest in the Southern Alps. The timing of peak deposition flux is consistent across

Europe, however, occurring in or around 1980. Thereafter, a major decline has occurred across Europe and this is predicted to continue to 2010 in response to the Protocol and EU Directives. For NO_x (Appendix 2), the trend of increasing deposition from 1960 to a peak in or around 1980 is consistent in all areas although in the Southern Alps, the increase continues to 1990. Since 1980, NO_x deposition has declined and this is projected to continue to 2010. For NH_3 (Appendix 2), there are few clear or consistent trends from 1960 to present or beyond to 2010.

Structure of the volume

This volume comprises 19 papers ordered from European scale assessment through regional and site assessment, influence of other environmental driving variables and finally development and testing of process-based models. The identification of the impact of reduction in acidic deposition in influencing the spatial extent and magnitude of recovery is assessed at European scale by Evans *et al*. (2001) using consistent trend analysis techniques at sites with long data series. Assessments of recovery using data from large scale regional surveys of surface waters are described for Scandinavia by Skjelkvåle *et al*. (2001), for Germany by Alewell *et al*. (2001) and for SW Scotland by Ferrier *et al*. (2001). Finally, trends in chemistry over time at several sites within individual regions are analysed in the UK by Evans and Monteith (2001), Harriman *et al*. (2001), Helliwell *et al*. (2001) and Soulsby *et al*. (2001), in Northern Italy by Rogora *et al*. (2001), in Scandinavia by Moldan *et al*. (2001) and in the Bohemian Forest and Tatra Mountains by Kopácek *et al*. (2001).

Changes in other environmental drivers that confound the long-term trend in response to decreased acid deposition are also important and must be considered in the assessment of recovery in response to reductions in acidic deposition. In this volume, meteorological influences, and in particular the North Atlantic Oscillation, are considered in detail by Evans and Monteith (2001) and Wright and Jenkins (2001); deposition of sea-salt and dust is assessed by Helliwell *et al*. (2001), Neal *et al*. (2001), Wright and Jenkins (2001) and Rogora *et al*. (2001) and interactions with land use change is assessed by Helliwell *et al*. (2001) and Neal *et al*. (2001).

The key internal catchment characteristics that influence chemical recovery include sulphate (SO_4) adsorption characteristics, which are assessed in detail by Prechtel *et al*. (2001) and future N dynamics which are assessed using the patterns of change in N leaching across Europe by Wright *et al*. (2001). Organic matter interactions, cation exchange and weathering, all of which may be determined by soil type and other physio-chemical attributes, are also important factors influencing recovery and are addressed in the site and region specific papers.

Enhanced process based understanding of biogeochemical cycling within catchments is essential for the development of robust models for scenario analysis and further developments of MAGIC and SMART are described by Cosby *et al*. (2001) and Mol-Dijkstra and Kros (2001), respectively. These models also require assessment and testing at individual sites/catchments with detailed physico-chemical long time series data before being applied to whole regions via up-scaling methods; this is attempted at a site in Scotland by Jenkins *et al*. (2001) and more widely at sites across the UK by Jenkins and Cullen (2001).

Acknowledgements

The RECOVER:2010 project is funded in part by the European Commission's Environment and Sustainable Development Programme (Key Action on Sustainable Management and Quality of Water under Contract No. EVK1-CT-1999-00018), the NERC Centre for Ecology and Hydrology (UK), The Macaulay Institute (UK), the Scottish Executive Environment and Rural Affairs Department (SEERAD) and the Norwegian Institute for Water Research (NIVA), Oslo. Thanks are due to all those people across Europe who have participated in the data collection exercise which makes this assessment possible. Thanks are especially due to Susie Beresford (CEH, Wallingford) who not only edited and corrected this paper, but each and every paper in this volume. All the authors are indebted to her enthusiasm, efficiency and fastidiousness.

References

Alcamo, J., Shaw, R. and Hordijk, L. (Eds.), 1990. *The RAINS Model of Acidification*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Alewell, C., Armbruster, M., Bittersohl, J., Evans, C.D., Meesenburg, H., Moritz, K. and Prechtel, A., 2001. Are there signs of acidification reversal in freshwaters of the low mountain ranges in Germany? *Hydrol. Earth Syst. Sci*., **5**, 367–378.

Amann, M., Bertok, I., Cofala, J., Cyarfas, F., Heyes, C., Klimont, Z., Makowski, M., Schöpp, W. and Shibayev, S., 1998. *Cost-effective control of acidification and ground-level ozone*. ISBN 92-828-4346-7, European Communities, Brussels.

Cofala, J., Heyes, C., Klimont, Z. and Amann, M., 2000. *Integrated assessment of acidification, eutrophication and tropospheric ozone impacts in Europe*. Shared analysis scenario of DG Energy until 2020. Draft IIASA report.

Cosby, B.J., Ferrier, R.C., Jenkins, A. and Wright, R.F., 2001. Modelling the effects of acid deposition – fifteen years of MAGIC: refinements, adjustments and inclusion of nitrogen dynamics. *Hydrol. Earth Syst. Sci*., **5**, 499–517.

European Commission, 2000. *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000* *establishing a framework for community action in the field of water policy*. Official Journal L327 of 22.12.2000, p. 1.

Evans, C.D. and Monteith, D.T., 2001. Chemical trends at lakes and streams in the UK Acid Waters Monitoring Network, 1988-2000: Evidence for recent recovery at a national scale. *Hydrol. Earth Syst. Sci.*, **5**, 351–366.

Evans, C.D., Cullen, J.M., Alewell, C., Kopácek, J., Marchetto, A., Moldan, F., Prechtel, A., Rogora, M., Veselý, J. and Wright, R.F., 2001. Recovery from acidification in European surface waters. *Hydrol. Earth Syst. Sci.*, **5**, 383–397.

Ferrier, R.C., Helliwell, R.C., Cosby, B.J., Jenkins, A. and Wright, R.F., 2001. Recovery from acidification of lochs in Galloway, south-west Scotland, UK: 1979-1998. *Hydrol. Earth Syst. Sci.*, **5**, 421–431.

Harriman, R., Watt, A.W., Christie, A.E.G., Collen, P., Moore, D.W., McCartney, A.G., Taylor, E.M. and Watson, J., 2001. Interpretation of trends in acidic deposition and surface water chemistry in Scotland during the past three decades. *Hydrol. Earth Syst. Sci.*, **5**, 407–420.

Hesthagen, T., Sevaldrud, I.H. and Berger, H.M., 1999. Assessment of damage to fish population in Norwegian lakes due to acidification. *Ambio*, **28**, 112–117.

Helliwell, R.C., Ferrier, R.C., Johnston, L., Goodwin, J. and Doughty, R., 2001. Land use influences on acidification and recovery of freshwaters in Galloway, south-west Scotland. *Hydrol. Earth Syst. Sci.*, **5**, 451–458.

Jeffries, D.S. (Ed.), 1997. *Canadian Acid Rain Assessment. Volume 3, Aquatic Effects*. National Water Research Institute, Burlington, Ontario.

Jenkins, A., 1999. End of the acid reign? *Nature*, **401**, 537–538.

Jenkins, A. and Cullen, J.M., 2001. An assessment of the potential impact of the Gothenburg Protocol on surface water chemistry using the dynamic MAGIC model at acid sensitive sites in the UK. *Hydrol. Earth Syst. Sci.*, **5**, 529–541.

Jenkins, A., Ferrier, R.C. and Helliwell, R.C., 2001. Modelling nitrogen dynamics at Lochnagar, N.E. Scotland. *Hydrol. Earth Syst. Sci.*, **5**, 519–527.

Kopácek, J., Veselý, J. and Stuchlik, E., 2001. Sulphur and nitrogen fluxes and budgets in the Bohemian Forest and Tatra Mountains during the Industrial Revolution (1850-2000). *Hydrol. Earth Syst. Sci.*, **5**, 391–405.

Mason, B.J. (Ed.), 1990. *The surface waters acidification programme*. Cambridge University Press, 522 pp.

Mol-Dijkstra, J.P. and Kros, H., 2001. Modelling effects of acid deposition and climate change on soil and run-off chemistry. *Hydrol. Earth Syst. Sci.*, **5**, 487–498.

Moldan, F., Hultberg, H. and Andersson, I., 1995. Covered catchment experiment at Gårdsjön: changes in run-off chemistry after four years of experimental reduced acid deposition. *Water Air Soil Pollut.*, **85**, 1599–1604.

Moldan, F., Wright, R.F., Löfgren, S., Forsius, M., Ruoho-Airola, T. and Skjelkvåle, B.L., 2001. Long-term changes in acidification and recovery at nine calibrated catchments in Norway, Sweden and Finland. *Hydrol. Earth Syst. Sci.*, **5**, 339–349.

Mylona, S., 1996. Sulphur dioxide emissions in Europe 1880-1991 and their effect on sulphur concentrations and depositions. *Tellus*, **48B**, 662-689, and corrigendum, *Tellus*, **49B**, 447–448.

Neal, C., Reynolds, B., Neal, M., Pugh, B., Hill, L. and Wickham, H., 2001. Long term changes in the water quality of rainfall, cloud water and stream water for moorland, forested and clear-felled catchments at Plynlimon, mid-Wales. *Hydrol. Earth Syst. Sci.*, **5**, 459–476.

Prechtel, A., Alewell, C., Armbruster, M., Bittersohl, J., Cullen, J.M., Evans, C.D., Helliwell, R.C., Kopáèek, J., Marchetto, A., Matzner, E., Meesenburg, H., Moldan, F., Moritz, K., Veselý, J. and Wright, R.F., 2001. Response of sulphur dynamics in European catchments to decreasing sulphate deposition. *Hydrol. Earth Syst. Sci.*, **5**, 311–325.

Rodhe, H. and Granat, L., 1984. An evaluation of sulfate in European precipitation 1955-1982. *Atmos. Environ.*, **18**, 2627–2639.

Rogora, M., Marchetto, A. and Mosello, R., 2001. Trends in the chemistry of atmospheric deposition and surface waters in the Lake Maggiore catchment. *Hydrol. Earth Syst. Sci.*, **5**, 379–390.

Schindler, D.W., Frost, T.M., Mills, K.H., Chang, K.H., Davies, I.J., Findlay, L., Malley, D.F., Shearer, J.A., Turner, M.A., Garrison, P.J., Watras, C.J., Webster, K., Gunn, J.M., Brezonik, P.L. and Swenson, W.A., 1991. Comparisons between experimentally- and atmospherically-acidified lakes during stress and recovery. *Proc. Roy. Soc., Edinburgh*, **97B**, 193–226.

Skjelkvåle, B.L., Mannio, J., Wilander, A. and Andersen, T., 2001. Recovery from acidification of lakes in Finland, Norway and Sweden 1990-1999. *Hydrol. Earth Syst. Sci.*, **5**, 327–337.

Soulsby, C., Malcolm, R., Gibbins, C. and Dilks, C., 2001. Seasonality, water quality trends and biological responses in four streams in the Cairngorm Mountains, Scotland. *Hydrol. Earth Syst. Sci.*, **5**, 433–450.

UN-ECE, 1999a. *Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-Level Ozone*, United Nations Economic Commission for Europe, Geneva, Switzerland.

UN-ECE, 1999b. *Strategies and Policies for Air Pollution Abatement*. Economic Commission for Europe (ECE.EB.AIR/65), Convention on Long-Range Transboundary Air Pollution, United Nations, New York and Geneva.

Wright, R.F. and Jenkins, A., 2001. Climate change as a confounding factor in reversibility of acidification: RAIN and CLIMEX projects. *Hydrol. Earth Syst. Sci.*, **5**, 477–498.

Wright, R.F., Lotse, E. and Semb, A., 1993. RAIN project: results after eight years of experimentally reduced acid deposition to a whole catchment. *Can. J. Fisheries Aquat. Sci.*, **50**, 258–268.

Wright, R.F., Alewell, C., Cullen, J.M., Evans, C.D., Marchetto, A., Moldan, F., Prechtel, A. and Rogora, M., 2001. Trends in nitrogen deposition and leaching in acid-sensitive streams in Europe. *Hydrol. Earth Syst. Sci.*, **5**, 299–310.

Appendix 1. The RECOVER:2010 Project

The RECOVER:2010 project is designed to assess the impact of current and future anthropogenic pressures on sensitive European freshwater ecosystems. During recent decades there have been both national and international efforts to obtain reductions in the emission of acidifying compounds to the atmosphere and, hence, redress the historical impact of freshwater acidification. Potential delays in recovery through hysteresis in chemical and biological reversibility, however, may jeopardise the desired objectives of two key EU policy initiatives, namely the Water Framework Directive and the Emissions Ceilings Directive. Defining optimal strategies to achieve their objectives, by linking biogeochemical reversibility to biological and ecosystem impacts throughout Europe, is central to the research effort of RECOVER:2010.

The EU Water Framework Directive (European Commission, 2000) will commit EU Member States to achieving the objective of restoring "polluted surface waters, in order to achieve good surface water status in all surface waters". This entails restoration of impacted waters to good ecological status, defined as "the biological community which would be expected in conditions of minimal anthropogenic impact". Further "a set of procedures for identifying that point for a given body of water, and establishing particular chemical or hydromorphological standards to achieve it, together with a system for ensuring that each Member State interprets the procedure in a consistent way to insure compatibility", is required throughout Europe. The RECOVER:2010 project aims to provide such a set of procedures for acidified surface waters.

The RECOVER:2010 project does not focus on every ecosystem type in Europe; rather it has identified key spatial locations where changes in acidification have been tracked in detail and focuses on those ecosystems that are most geographically extensive and numerous (Table A1.1). These include the UK, Norway, Sweden, southern Alps (Italy), Czech Republic and Germany. Substantial site specific data are available (Fig. A1.1) for these regions and an understanding of the mechanism of recovery in these systems allows for a Pan-European evaluation of recovery response. The degree of reversibility will be related to regional differences in catchment physico-chemical characteristics and deposition reductions, both relative and absolute.

The RECOVER:2010 project identifies the following main objectives:

- to evaluate the extent of recovery to date of acidified freshwaters in Europe in response to decreased deposition of acidifying compounds;
- to identify and quantify the dominant driving processes and catchment and lake characteristics governing the timing and magnitude of recovery;
- to improve the predictive capability of existing biogeochemical models through enhanced process representation and incorporation of linkages between hydrochemical changes and biological impacts;
- to apply and validate regional dynamic models to acidified freshwaters to determine the spatial patterns of recovery from acidification under current emission reduction plans;
- to predict the degree of recovery at European scale from present day to the year 2010 and beyond, given the presently agreed and proposed UN-ECE protocols;
- to evaluate the degree of compliance with respect to restoration of acidified waters by the year 2010 as specified under the Water Framework Directive;
- to evaluate the economic costs and benefits of presently agreed and proposed UN-ECE protocols with respect to recovery of freshwaters by the year 2010.

This volume represents the product of the first three main objectives of the RECOVER:2010 project.

Table A1.1. Regional ecotypes under study within the RECOVER:2010 project

Region		*Characteristics*		
	Acid deposition	*Climate*	*Soils*	*Vegetation*
Southern Norway	Low-moderate	Cool, wet	Young	Forest, heathlands
Upland UK	Low-high	Maritime, cool, wet	Young	Forest, heathlands
Central Europe	Moderate-high	Continental	Old	Forest
High Tatras	Moderate-high	Cool, wet	Young	Alpine
Southern Alps	Low-moderate	Cool, wet	Young	Alpine

Fig. A1.1. *Location of the regions of Europe included in the RECOVER:2010 project*

Appendix 2. Modelled trends in deposition across Europe

For this volume, an assessment of trends in SO_2 , NO_x and NH_3 deposition over a 50-year period, from 1960 to 2010, as simulated by the RAINS model (Amann *et al.,* 1998; Alcamo *et al*., 1990; http://www.iiasa.ac.at/~rains), provides a basis for understanding the observed changes in water chemistry. Modelled data from RAINS are used because of the requirement to extrapolate beyond the period of deposition measurement, both historically and into the future. In this case, pollutant emissions can be estimated (Table 1) and combined with an atmospheric transport model to simulate deposition across Europe (Figs. A2.1 – A2.3).

Version 7.5 (V7.5) of the RAINS model was developed for the 1999 Gothenburg Protocol (UN-ECE, 1999a) and uses 1990 as the base year to provide deposition scenarios in five-year intervals up to 2030. It covers emissions of SO_2, NO_x, ammonia (NH_3), and volatile organic compounds (VOCs) to analyse effects of acidification, eutrophication and ground-level ozone. Version 6.1 (V6.1) of RAINS was developed earlier for the negotiation of the 1994 Oslo Protocol and includes the years back to 1960. It calculates emissions of SO_2, NO_x and NH_3 to assess their acidifying effects. For this study, data for 1960, 1970, 1975, 1980 and 1985 are extracted from V6.1 of RAINS whilst data for 1990, 1995, 2000, 2005 and 2010 are from V7.5.

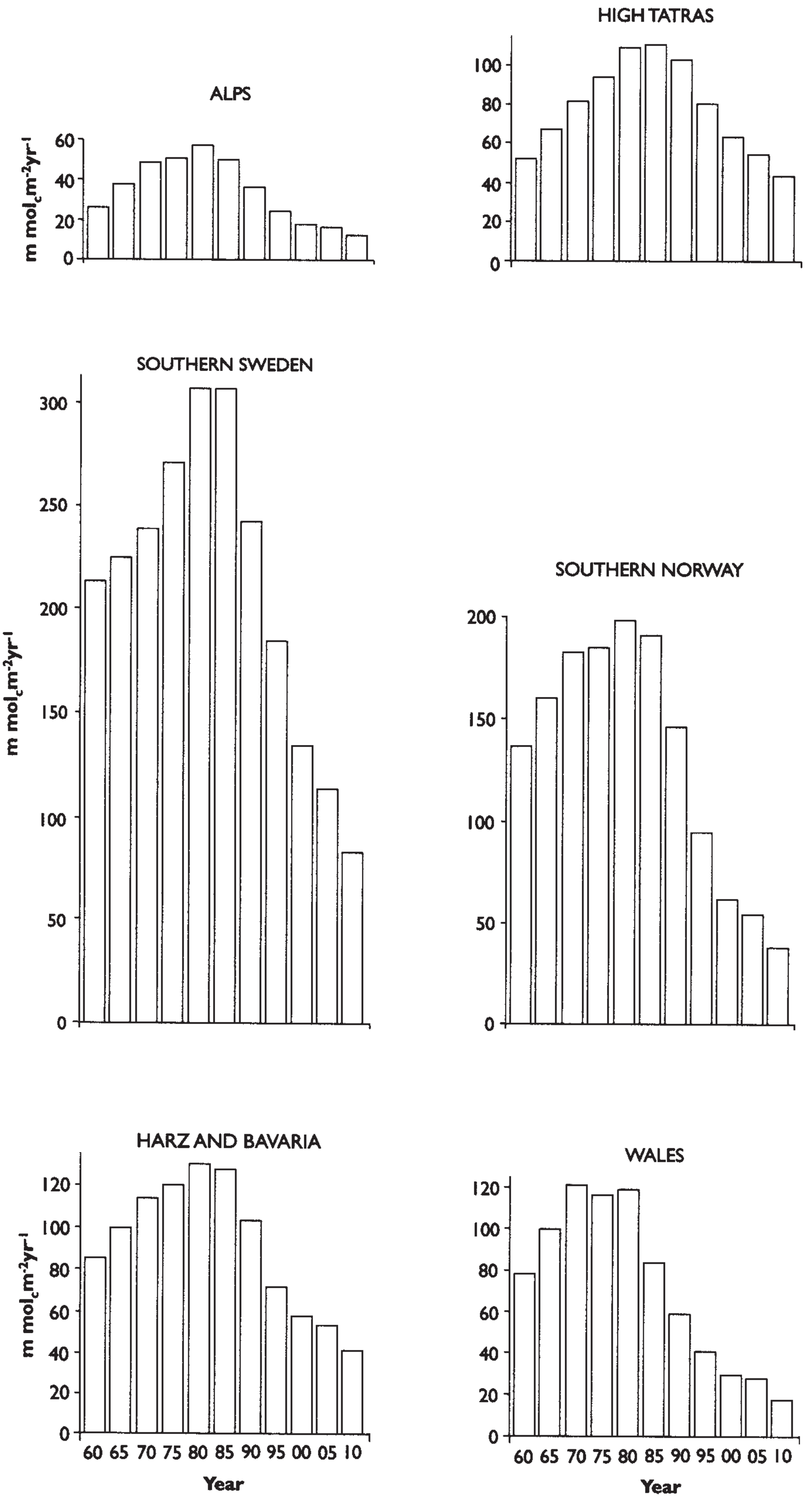

Fig. A2.1. *Trends in SO$_x$ deposition in six European areas as predicted by the RAINS model 1960–2010 assuming the implementation of the Gothenburg Protocol and relevant EU Directives*

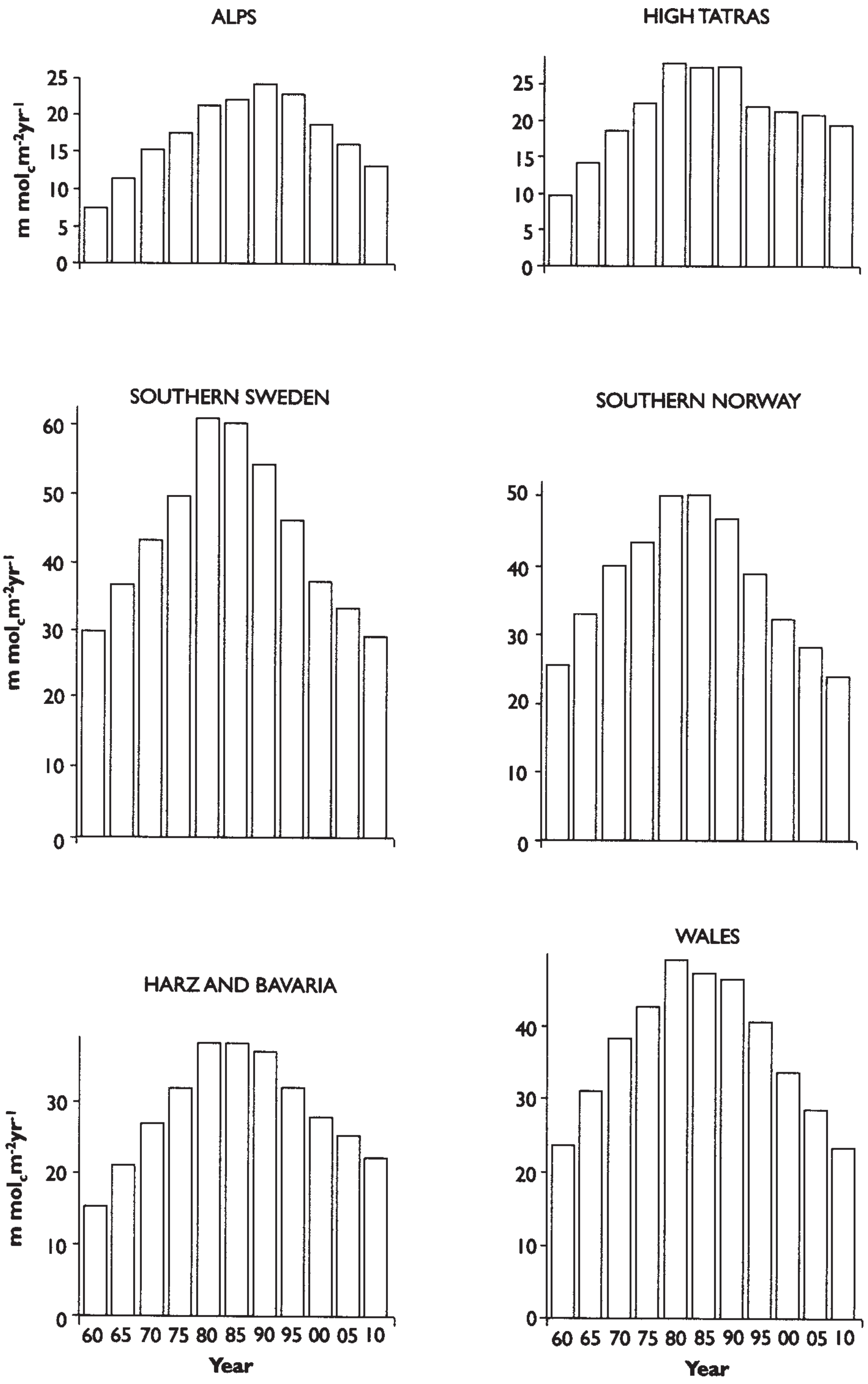

Fig. A2.2. *Trends in NO$_x$ deposition in six European areas as predicted by the RAINS model 1960–2010 assuming the implementation of the Gothenburg Protocol and relevant EU Directives.*

For prediction to 2010 under the Gothenburg Protocol, the model starts from a detailed inventory of present regulations on emission controls, taking into account the legislation in individual European countries, the relevant Directives of the European Union and the obligatory clauses regarding emission standards from the relevant Protocols under the Convention on Long-range Transboundary Air Pollution (Cofala *et al.*, 2000).

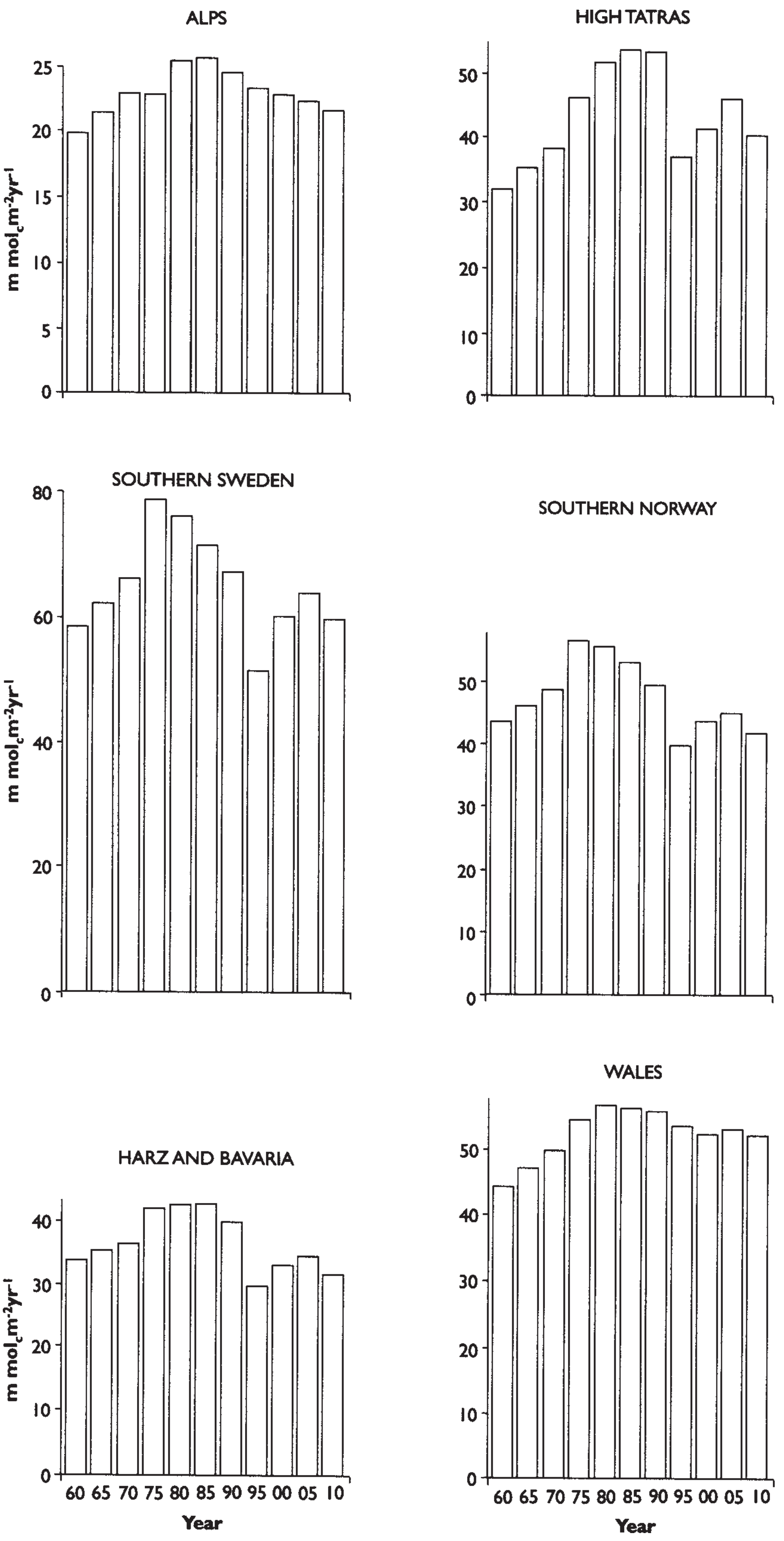

Fig. A2.3. *Trends in* NH_3 *deposition in six European areas as predicted by the RAINS model 1960–2010 assuming the implementation of the Gothenburg Protocol and relevant EU Directives*