

Acknowledgements

The authors would like to thank the following for allowing access:

Douglas and Angus Estates (Happendon Wood)

W. Mitchell, Hazel Side Farm (Happendon Wood)

J. McInnes, Cairnlodge Services (Happendon Wood)

Natural Power Systems (Bowbeat Hill)

Penicuik Estates (Auchencorth Moss)

William Sinclair Horticulture Ltd (Whim Moss)

Mr G.A. Pitt-Rivers (Piddles Wood)

Thanks to Melanie Heath, (English Nature) for organising access to Piddles Wood and to Helen Pengelly (Consultant) for maintaining the standardised grass transplants at Piddles Wood.

The authors are also grateful to the following for their participation in the UK extensive sites study:

Ray Woods: CCW

Alex Turner: CCW

Bob Haycock: CCW

Chris Miles: SNH

Sandy Payne: SNH

John Clayton: SEPA

Ed Turner: SEPA

Jan Breckenridge: SNH

Brian Eardley: SNH

Janie Steele: FC

Tommy Donnelly: SNH

Richard Pollitt: English Nature

Bart Donato: English Nature

Joan Daniels: English Nature

Peter Lambley: English Nature

Alison Collins: English Nature

Chris Hogarth: English Nature

Ron Porley: English Nature

Malcolm Emery: English Nature

Melina McMullan: EHS

Andrew Excell: Suffolk Wildlife Trust

Dr R. Mitchell (CEH Banchory) for supplying epiphytic moss and lichen diversity data for Glen Nant.

Ms S. Tang for supplying NH₃ concentration and N deposition data.

The authors would also like to thank the Steering Group for their contribution throughout this project.

References

- ACHERMANN, B. and BOBBINK, R. 2003. *Empirical critical loads for nitrogen*. (UNECE Expert workshop, Berne, 11-13 November 2002. SAEFL, Berne, Switzerland.
- ASTA, J., ERHARDT, W., FERRETTI, M., FORNASIER, F., KIRSCHBAUM, U., NIMIS, P.L., PURVIS, O.W., PIRINTSOS, S., SCHEIDEGGEER, C. & WIRTH, V. 2000. Mapping lichen diversity as an indicator of environmental quality. In: Nimis, P.L., Scheidegger, C. & Wolseley, P.A. (eds), *Monitoring with lichens - Monitoring Lichens*. Kluwer, Dordrecht: 7-10.
- AVERIS, A., AVERIS, B., BIRKS, J., HORSFIELD, D., THOMPSON, D. & YEO, M. 2004. *An illustrated Guide to british Upland Vegetation*. JNCC, Peterborough.
- BIGNAL, K., ASHMORE, M. & POWER, S. 2004. The ecological effects of diffuse air pollution from road transport. *English Nature Research Report No. 580*, Peterborough.
- BURKHARDT, J., SUTTON M.A., MILFORD C., STORETON-WEST R.L. & FOWLER D. (1998) Ammonia concentrations at a site in S. Scotland from continuous measurements over 2 years. In: *International conference on Atmospheric Ammonia: Emission, Deposition and Environmental Impacts*. (Eds. Sutton M.A., Lee D.S., Dollard G.J. and Fowler D.) *Atmospheric Environment*, **32**, 325-331.
- COPPINS, A.M. & COPPINS, B.J. 2002: Indices of Ecological Continuity for Woodland Epiphytic Lichen Habitats in the British Isles. - *British Lichen Society*, Wimbledon. 36 pp.
- CROSSLEY, A., WILSON, D.B. & MILNE, R. 1992. Pollution in the upland environment. *Environmental Pollution*, **75** (1), 81-87.
- DfT, 2000. *Transport statistics bulletin. Road traffic statistics for Great Britain. Statistics Report SB (03) 26*. (Online) Available: http://www.dft.gov.uk/stellent/groups/dft_transstats/documents/downloadable/dft_transstats_023321.pdf (20.10.03)
- EHS, *Designated sites*, (online) Available from: <http://www.ehs.gov.uk/natural/designated/site>
- ELLENBERG, H. 1979. Indicator values of vascular plants in Central Europe. *Scripta Geobotanica*, **9**, 7-122.
- ELLENBERG, H. 1988. *Vegetation Ecology of Central Europe*. University Press. Cambridge.
- ELLENBERG, H., WEBER, H.E., DULL, R., WIRTH, V., WERNER, W. & PAULIEN, D. 1992. Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica*, **18**, 1-248.
- ENGLISH NATURE 2004. www.englishnature.org.uk/special/ssi/sitedocuments.cfm
- EUROBIONET. 2003. www.uni-hohenheim.de/eurobionet
- FALKENGREN-GRERUP, U. 1995. Long term changes in flora and vegetation in deciduous forests of southern of southern Sweden. *Ecological Bulletins*, **44**, 215-226.
- FARMER, A.M., BATES, J.W. & BELL, J.N.B. 1990. A comparison of methods for the measurement of bark pH. *Lichenologist*, **22**, 191-194.

GRIMSHAW, H.M., ALLEN, S.E. & PARKINSON, J.A. 1989. Nutrient elements. – In: ALLEN S.E. (Ed.), *Chemical analysis of ecological materials* (2nd ed.), 81–159. Blackwell Scientific Publications. Oxford.

HAINES-YOUNG, R.H., BARR, C.J., BLACK, H.I.J., BRIGGS, D.J., BUNCE, R.G.H., CLARKE, R.T., COOPER, A., DAWSON, F.H., FIRBANK, L.G., FULLER, R.M., FURSE, M.T., GILLESPIE, M.K., HILL, R., HORNUNG, M., HOWARD, D.C., McCANN, T., MORECROFT, M.D., PETIT, S., SIER, A.R.J., SMART, S.M., SMITH, G.M., STOTT, A.P., STUART, R.C., AND WATKINS, J.W. 2000. *Accounting for nature: assessing habitats in the UK countryside*. London: Department of the Environment, Transport and the Regions.

HARGREAVES K.J. 1989. The development and application of diffusion tubes for air pollution measurements. *Ph.D.thesis*. University of Nottingham.

HILL, M.O., MOUNTFORD, J.O., ROY, D.B. & BUNCE, R.G.H. 1999. *Ellenbergs' indicator values for British plants. ECOFACT Volume 2*, Technical Annex. ITE Monkswood, Huntingdon. London: Department of the Environment, Transport and the Regions.

JAMES, P.W., HAWKSWORTH, D.L. & ROSE, F. 1977. Lichen Communities of the British isles: A preliminary conspectus. In *Lichen Ecology*, ed. M.R.D. Seaward, Academic Press. pp. 295-413.

JNCC, *Commons Standards Monitoring guidance* (online), Available from: <http://www.jncc.gov.uk>

KERMIT, T. & GAUSLAA, Y. 2001. The vertical gradient of bark pH of twigs and macrolichens in a *Picea abies* canopy not affected by acid rain. *Lichenologist*, **33**, 353-359.

LARSEN, R.S., BELL, J.N.B., JAMES, P.W., CHIMONIDES, P.J., RUMSEY, F., TREMPER, A. & PURVIS, O.W. 2005. Lichen and bryophyte distribution on oaks in London in relation to air pollution and bark acidity. *Environmental Pollution* (In press).

LEITH, I.D., HICKS, W.K., FOWLER, D. & WOODIN, S.J. 1999. Differential responses of UK upland plants to nitrogen deposition. *New Phytologist*, **141**, 277-289.

LEITH, I.D., SHEPPARD, L.J., PITCAIRN, C.E.R., CAPE, J.N., HILL, P.W., KENNEDY, V.H., TANG, Y.S., SMITH, R.I. & FOWLER D. 2001. Comparison of the effects of wet N deposition (NH₄Cl) and dry N deposition (NH₃) on UK moorland species. *Water, Air and Soil Pollution*, **130**, 1043-1048.

LEITH, I.D., VAN DIJK, N., PITCAIRN, C.E.R., SHEPPARD, L.J., TANG, Y.S., WOLSELEY, P. & SUTTON, M.A. 2003. Refinement and testing of bio-monitoring methods, & development of protocols, for assessing impacts of atmospheric nitrogen deposition or concentrations on statutory nature conservation sites. *Interim report JNCC*. Contract F90-01-635.

LEITH, I.D., SHEPPARD, L.J., FOWLER, D., CAPE, J.N., JONES, M., CROSSLEY, A., HARGREAVES, K.J., TANG, Y.S., THEOBALD, M. & SUTTON, M.A. 2004. Quantifying dry NH₃ release system to ombrotrophic bog from an automated NH₃ field release system. *Water, Air, and Soil Pollution: Focus*, **4**, 207-218.

LOUBET, B. & SUTTON, M.A. 1999. Edinburgh protocol for measuring bulk NH₄⁺ of grass leaves in GRAMINAE: Integrating measurements protocol edited by Mark Sutton and Celia Milford.

LOUBET, B., MILFORD, C., HILL, P.W., TANG, Y.S., CELLIER, P. & SUTTON, M. A. 2002. Seasonal variability of apoplastic NH₄⁺ and pH in an intensively managed grassland; *Plant and Soil*, **238**, 97-110.

NÄSHOLM, T., EDFAST, A-B., ERICSSON, A. & NORDÉN, L-G. 1994 Accumulation of amino acids in some boreal forest plants in response to increased nitrogen availability. *New Phytologist* **126**, 137-143.

MITCHELL R.J., SUTTON M.A., TRUSCOTT A.M., LEITH I.D., CAPE J.N., PITCAIRN C.E.R. & VAN DIJK, N. 2004. Growth and tissue N of epiphytic bryophytes following increased and decreased inputs of atmospheric N deposition. *Functional Ecology*, **18**, 322-329.

MITCHELL, R.J., TRUSCOTT, A. M., LEITH, I.D., CAPE, J.N., VAN DIJK, N., TANG, Y.S., FOWLER, D. & SUTTON, M.A. 2005. A study of the epiphytic communities of Atlantic oakwoods along an atmospheric nitrogen deposition gradient. *Journal of Ecology* **93**, 482-492.

NEG-TAP, 2001. National Expert Group on Transboundary Air Pollution, Department of Environment, Food and Rural Affairs, London.

NILSSON, J. & GREENFELT, P. (Eds). 1988. Critical loads for sulphur and nitrogen (Report 1988:15). Nordic Council of ministers, Copenhagen, Denmark.

PITCAIRN, C.E.R., FOWLER, D. & GRACE, J. 1995. Deposition of fixed atmospheric nitrogen and foliar nitrogen content of bryophytes and *Calluna vulgaris* (L.) Hull. *Environmental Pollution*., **88**, 193-205.

PITCAIRN, C.E.R., FOWLER, D., LEITH, I.D., SHEPPARD, L.J., SUTTON, M.A., KENNEDY, V. & OKELLO, E. 2003. Bioindicators of enhanced nitrogen deposition. *Environmental Pollution*, **126**, 353-361.

PITCAIRN, C.E.R., LEITH, I.D., SHEPPARD, L.J., SUTTON, M.A., FOWLER, D., MUNRO, R.C., TANG, S. & WILSON, D. 1998. The relationship between nitrogen deposition, species composition and foliar nitrogen concentrations in woodland flora in the vicinity of livestock farms. *Environmental Pollution*., **102**(S1), 41-48.

PITCAIRN, C.E.R., SKIBA, U.M., SUTTON, M.A., FOWLER, D., MUNRO, R. & KENNEDY, V.K. 2002. Defining the spatial impacts of poultry farm ammonia emissions on species composition of adjacent woodland groundflora using Ellenberg indicators, nitrous oxide and nitric oxide and foliar nitrogen as marker variables. *Environmental Pollution*, **119**, 9-21.

RIEDO, M., MILFORD, C., SCHMID, M. & SUTTON, M.A. 2002. Coupling soil-plant-atmosphere exchange of ammonia with ecosystem functioning in grasslands. *Ecological Modelling* **158**, 83-110.

RODWELL, J.S. 1991. *British Plant Communities: Volume I Woodlands and scrub*. Cambridge University press, Cambridge.

ROSE, F. 1976: Lichenological indicators of age and environmental continuity in woodlands. - In: D. H. Brown, D. L. Hawksworth & R. H. Bailey (eds.): *Lichenology: Progress and Problems*. Academic Press, London, pp. 279-307.

SHEPPARD, L.J., CROSSLEY, A., LEITH, I.D., HARGREAVES, K.J., CARFRAE, J.A., VAN DIJK, N., CAPE, J.N., SLEEP, D., FOWLER, D. & RAVEN, J.A. 2004. An automated wet

Biomonitoring methods for assessing the impacts of nitrogen pollution: refinement and testing

deposition deposition system to compare the effects of reduced and oxidised N on ombrotrophic bog species: Practical considerations. *Water, Air, and Soil Pollution: Focus*, **4**, 197-205.

SIEBEL, H.N. 1993. Indicatiegetallen van blad-en levermossen. *IBN-rapport* 047, Wageningen.

SOMMER, S.G. & JENSON, E.S. 1991. Foliar absorption of atmospheric Ammonia by Ryegrass in the field. *Journal of Environmental Quality*, **20**, 153-156.

SUTTON, M.A., TANG, Y.S., MINERS, B. & FOWLER D. 2001. A new diffusion denuder system for long-term, regional monitoring of atmospheric ammonia and ammonium. *Water, Air and Soil Pollution. Focus*, **1**, 146-156.

SUTTON, M.A., CAPE J.N., RIHM B., SHEPPARD L.J., SMITH R.I., (SPRANGER T.) & FOWLER D. 2003. The importance of accurate background atmospheric deposition estimates in setting critical loads for nitrogen. In: *Empirical critical loads for Nitrogen* (UNECE Expert Workshop, Berne 11-13 November 2002) (Eds. B. Achermann and R. Bobbink), 231-257. SAEFL, Berne, Switzerland.

SUTTON, M.A., PITCAIRN, C.E.R., LEITH, I.D., VAN DIJK, N., TANG, Y.S., SKIBA, U., SMART, S., MITCHELL, R., WOLSELEY, P., JAMES, P., PURVIS, W. & FOWLER D. 2004a. Bioindicator and biomonitoring methods for assessing the effects of atmospheric nitrogen on statutory nature conservation sites. Edited by M.A. Sutton, C.E.R. Pitcairn & C.P. Whitfield. *JNCC Report No. 356*, Peterborough.

SMITH, R.I., FOWLER, D., SUTTON, M.A., FLECHARD, C. & COYLE, M. 2000. Regional estimation of pollutant gas dry deposition in the UK: model description, sensitivity analyses and outputs. *Atmospheric Environment*. **34** (22) 3757-3777.

SUTTON, M.A., LEITH, I.D., PITCAIRN, C.E.R., VAN DIJK, N., TANG, Y.S., SHEPPARD, L.J., DRAGOSITS, U., FOWLER, D., JAMES, P.W. & WOLSELEY, P.A. 2004b. Exposure of ecosystems to atmospheric ammonia in the UK and the development of practical bioindicator methods. In: *Lichens in a changing pollution environment*, English Nature workshop (Eds. Wolseley and Lambley) pp 51-62. *English Nature Research Report No. 525* [ISSN 0967-876X].

TANG, Y.S., VAN DIJK, N., CAPE, J.N. & SUTTON, M.A. 2002., Test and validation of passive diffusion sampling methods for long-term ambient monitoring of NO₂ and NH₃ concentrations, Biodiversity in roadside verges. *Interim Report to SEERAD*. Centre for Ecology and Hydrology, Edinburgh.

TANG, Y.S., VAN DIJK, N., LOVE, L., DRAGOSITS, U., VIENO, M., SMITH, R.I., RIPPEY, B. & SUTTON, M.A. 2004. Ammonia Monitoring in Northern Ireland. *Final report to SNIFFER*.

TANSLEY, A.G. 1911. *Types of British vegetation*. By members of the Central Committee for the Survey and Study of British Vegetation. Cambridge University press, Cambridge.

THEOBALD M.R. & SUTTON M.A. 2003. A critical assessment of the ADAS 'Ammonia Deposition and Concentration Study' for planned broiler houses, Bunns Lane, Frome, Somerset. Report AS 03/01. CEH Edinburgh, (October 2003).

TYLER, G. 1987. Probable effects of soil acidification and nitrogen deposition on the floristic composition of oak (*Quercus robur* L.) forest. *Flora*, **179**, 165-70.

UK NAMN: www.cara.ceh.ac.uk/networks

VAN DOBBEN, H. F. 1993. *Vegetation as a monitor for deposition of nitrogen and acid*. Ph.D. Thesis, Wageningen University.

VAN HERK, C.M. 1999. Mapping of ammonia pollution with epiphytic lichens in the Netherlands. *Lichenologist*, **31**, 9-20.

VAN HERK, C.M. 2001. Bark pH and susceptibility to toxic air pollutants as independent causes of changes in epiphytic lichen composition in space and time. *Lichenologist*, **33**, 419-441.

VAN HERK, C.M. 2002: Epiphytes on wayside trees as an indicator of eutrophication in the Netherlands. - In: Nimis, PL/Scheidegger, C/Wolseley, PA (eds.): *Monitoring with Lichens - Monitoring Lichens*. Nato Science Series. IV. Earth and Environmental Sciences, Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 285-289.

VAN HERK, CM 2003: Long distance nitrogen air pollution effects on lichens in Europe. - *Lichenologist* **35** (5-6): 413-415.

WIRTH, V. 1992. Zeigerwerte von Flechten. *Scripta Botanica*, **18**, 215-237.

WOLSELEY, P.A. & PRYOR, K.V. 1999. The potential of epiphytic twig communities on *Quercus petraea* in a Welsh woodland site (Tycanol) for evaluating environmental changes. *Lichenologist*, **31**, 41-61.

WOLSELEY, P.A. & JAMES P.W. 2000. Factors affecting changes in species of *Lobaria* in sites across Britain. *Forest Snow and Landscape Research*, **75**, 319-338.

WOLSELEY, P.A. & JAMES, P.W. 2002a. Assessing the role of biological monitoring using lichens to map excessive ammonia deposition in the UK. In: *Effects of NO_x and NH₃ on lichen communities and urban ecosystems-a pilot study*. Report to Defra by Imperial College and The Natural History Museum.

WOLSELEY, P.A. & JAMES P.W. 2002b. Using lichens as biomonitors of ammonia concentrations in Norfolk and Devon. *British Lichen Society Bulletin*, **91**, 1-5.

WOLSELEY PA & JAMES, PW. 2004 Using lichen communities to assess changes in sites of known ammonia concentrations. In: Lambley, P.W. & Wolseley, P.A. (eds.) *Lichens in a Changing Pollution Environment*. *English Nature Report* 525: 107-116

WOODIN, S., PRESS, M.C. & LEE, J.A. 1985. Nitrate reductase-activity in *Sphagnum fuscum* in relation to wet deposition of nitrate from the atmosphere. *New Phytologist*, **99**, 381-388