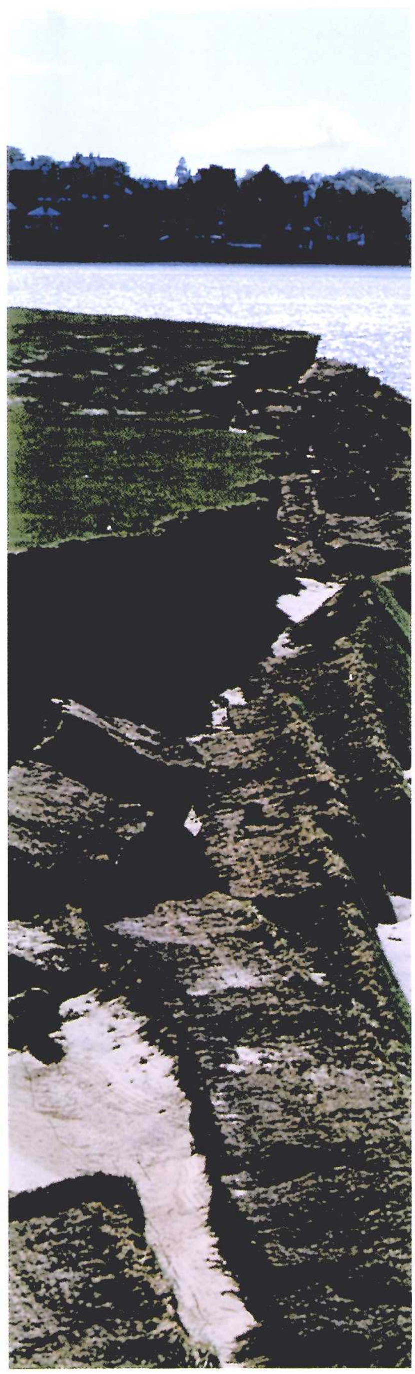
1990 — 1991
REPORT



Institute of Terrestrial Ecology

Natural Environment Research Council

Foreword

Environmental issues continue to grow in importance both nationally and internationally These issues, whether local, regional or global, must be addressed on the basis of sound and up to date scientific knowledge NERC's Terrestrial and Freshwater Sciences Directorate provides a focus for fundamental and applied research in land use and the development of natural resources, the maintenance of environmental quality and the principles which underline management and conservation

Much of this research is interdisciplinary and demands the wide range of expertise in NERC establishments and higher education institutions The Directorate's in-house capability comprises the Institute of Freshwater Ecology, the Institute of Hydrology, the Institute of Terrestrial Ecology, the Institute of Virology and Environmental Microbiology, the Unit of Comparative Plant Ecology (Sheffield University), the Interdisciplinary Research Centre for Population Biology (Imperial College, London), the Unit of Behavioural Ecology (Oxford University) and the Water Resource Systems Research Unit (Newcastle-upon-Tyne University)

The Institute of Terrestrial Ecology continues to provide the major national resource of expertise in ecology and related subjects Its research in areas as diverse as air pollution effects and vertebrate population biology has an international reputation This Report shows the wide range of skills of ITE staff and how essential the research is to the environmental quality and management of the land surface both in the UK and overseas

Dr P B Tinker
Director of Terrestrial and Freshwater Sciences
Natural Environment Research Council

Front Cover Illustration
Salt marsh erosion - photographer R Scott

Report of the Institute of Terrestrial Ecology 1990/91

Natural Environment Research Council

CONTENTS - Science reports 2

Reminder Printing Co Ltd , Ulverston (Cumbria) and Lancaster, England

Environmental pollution

The Institute's programme of research on environmental pollution includes work on radionuclides, acidic atmospheric pollutants and trace gases, pesticides and herbicides, and trace metals. It also encompasses deposition processes, the transfer of pollutants within terrestrial ecosystems, and impacts on terrestrial organisms and communities. An increasing proportion of the research is directly related to, and provides support for, the development of Government policy. Thus, the work on critical loads reported in one of the following papers is providing the basis for the UK input to the critical load map of soils for Europe, which will be used in negotiating future sulphur dioxide (SO_2) emission control protocols. The Institute is also involved in the Department of Environment programme of work to develop critical loads for UK vegetation communities. ITE Monks Wood acts as the co-ordination centre for producing critical load maps for soils, vegetation and surface waters, linking the UK work with the west European centre in Bilthoven.

Critical load maps for soils, vegetation or surface waters can be overlain with data on current inputs of atmospheric pollutants to identify those areas where present deposition exceeds the critical load. Clearly, such an exercise requires the best available data on current levels of deposition. The work on SO_2 deposition, described in a following paper, is part of a broad programme of work on deposition processes which is providing improved estimates of acidic pollutants being deposited across the UK.

The main thrust of ITE research on trace gases has changed recently, and increased emphasis is being given to nitrogen species and radiatively active gases. The emphasis on deposition has also been replaced by consideration of fluxes to and from terrestrial surfaces. Several approaches are available for the study of such fluxes, and the paper on trace nitrogen gases describes an ambitious multi-national study on one site, which aimed to compare the different methods. Improved information on the net fluxes to the atmosphere of the radiatively active gases is essential for the development of policy to control greenhouse gas emissions.

The research on radionuclides continues to be dominated by work on the Chernobyl fallout, with the main emphasis on the cycling of caesium in the acid, organic soils of the uplands and its transfer to grazing animals. However, the Chernobyl fallout contained other radionuclides which are of great scientific interest, and which could form an important part of fallout from accidents involving other reactor types. The paper on radiosilver reports work on one such radionuclide. Other radionuclides in the fallout close to the site of the Chernobyl reactors were also more important than caesium, staff of the Radioecology Group are currently developing a programme of work with Russian and CEC scientists which will involve some of these other radionuclides.

Critical loads for soils

(This work is funded by the Department of the Environment, and forms part of the activities of its Critical Loads Advisory Group)

A critical load can be defined as the maximum load of a pollutant, or pollutants, which will not cause long-term damage to an ecosystem, or to some specified element of that ecosystem.

The critical load concept was developed in Canada during the early 1980s, where it was used in negotiations with the United States concerning reduction of trans-national pollution. The concept has since been developed in a series of workshops sponsored by the Nordic Council of Ministers and the United Nations Economic Commission for Europe (UN-ECE) (Nilsson 1986). These workshops have considered the definition, calculation and mapping of critical loads (Bull 1991, Nilsson & Grennfelt 1988). The UN-ECE is currently sponsoring the production of critical load maps for Europe, and has produced a mapping handbook (Sverdrup, de Vries & Hendricksen 1990), ITE Monks Wood is acting as the co-ordinating centre for UK inputs to this exercise.

The concept provides a means of quantifying the sensitivity of ecosystems to pollutants. Critical load maps show the location of the sensitive systems. When these maps are overlain with pollutant deposition data, they allow areas to be identified where the critical load is exceeded. Further, given suitable models, they can be used to determine by how much emissions must be reduced to prevent damage, or to protect specified systems.

In determining a critical load, the first stage is to define the target receptor system, eg soils or surface waters. Ideally, a biological indicator should be identified as the critical load receptor, eg tree roots in forest soils or brown trout (*Salmo trutta*) in surface waters. A chemical limit may then be determined,

Table 4 Some chemical criteria suggested for use in setting critical loads (after Sverdrup et al *1990)*

Criteria	Critical chemical value for forest rooting zone
pH	E-layer >pH 4.0
	B-layer >pH 4.4
Alkalinity	>–300 µEq l^{-1}
Total aluminium	<4.0 mg l^{-1}
Labile aluminium	<2.0 mg l^{-1}
Ca/Al molar ratio	>1.0
NH_4/K molar ratio	<5

beyond which the biological indicator will suffer 'damage'. The critical load is calculated to ensure that this chemical limit is not transgressed. In practice, there is no general agreement on a satisfactory biological indicator for use in determining critical loads for soils, but a number of chemical limits have been suggested for forest soils (Table 4), and used in calculating critical loads; with some of these proposed chemical limits, a biological indicator is implicit.

Several methods of calculation have been proposed, and they can be divided into two broad groups – those using some type of mass balance calculation, and those using process, or mechanistically based, dynamic models, eg MAGIC, RAINS. In calculating critical loads for acidity, both approaches determine the balance between sources and sinks of acidity. The biogeochemical mass balance approach suggested in the UN-ECE mapping handbook uses the following equation:

$$CL\ (acidity) = BC_W - BC_U - ANC_L - 2.NH_{4D} + N_{TOTU}$$

where BC_W = base cation release by weathering; BC_U = acidity resulting from base cation uptake; ANC_L = ANC limit (alkalinity) x water flux; NH_{4D} = ammonium input by deposition; and N_{TOTU} = total N uptake by vegetation.

Table 5. Mineralogical classification of soil materials and critical loads for soils (0–50 cm) in each class (after Nilsson & Grennfelt 1988)

Class	Minerals controlling weathering	Critical load (kmol H$^+$ km^{-2} yr^{-1})
5	Quartz K-feldspar	<20
4	Muscovite Plagioclase Biotite (<5%)	20–50
3	Biotite Amphibole (<5%)	50–100
2	Pyroxene Epidote Olivine (<5%)	100–200
1	Carbonates	>200

Table 6. Factors causing a decrease or increase in loads of acidity for soils (after Nilsson & Grennfelt 1988)

Factor	Decrease	Increase
Precipitation	High	Deciduous forest
Vegetation	Coniferous forest	Deciduous forest
Elevation/slope	High	Low
Soil texture	Coarse–sandy	Fine
Soil drainage	Free	Impeded
Soil/Eill depth	Shallow	Thick
Soil sulphate adsorption capacity	Low	High
Base cation deposition	Low	High

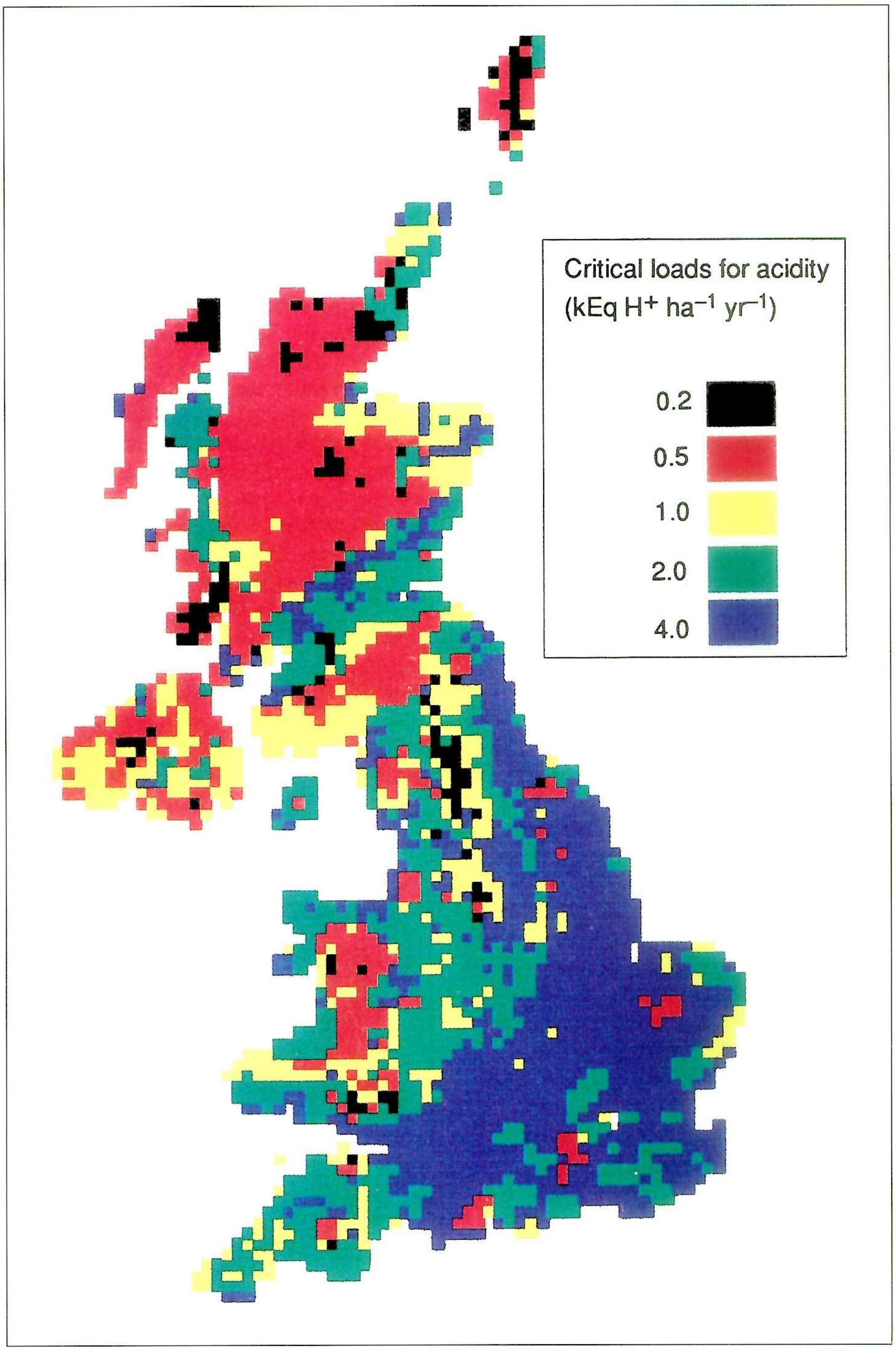


Figure 27. Critical loads for acidity of GB soils

The derivation of the equation is detailed in the mapping handbook (Sverdrup *et al.* 1990). Base cation release by weathering is the main sink for acidity as protons are consumed, exchanged for base cations during the weathering process. The net uptake of base cations and ammonium nitrogen by plants is, however, a potential source of acidity, as protons are released from plant roots into the soil solution to balance the uptake of the bases. The mass balance approach only provides the critical load under equilibrium conditions. More dynamic models facilitate the exploration of time-dependent processes which may influence critical loads.

Provisional critical load map for soils of GB

Critical loads are currently being calculated for several sites in GB, using both the mass balance and dynamic modelling approaches. Because only a few sites have all the required input data for the equations or models, a less rigorous approach has been adopted to produce a provisional critical load map for British soils, for use in the early phases of the UN-ECE European mapping exercise.

The provisional map is based upon principles and proposals developed at two workshops, held in 1986 and 1988. The first workshop suggested that critical loads for soils should be set to prevent chemical changes which would lead to long-term harmful effects to the soil/plant system (Nilsson 1986). It also suggested that such chemical changes could be prevented, if acid inputs did not exceed internal (within the soil) alkalinity production, essentially the production of base cations by mineral weathering. The main factor determining the rates of weathering in soils is soil mineralogy. The 1988 workshop, at Skokloster in Sweden, divided soil materials into five classes, defined on the basis of their dominant weatherable minerals (Nilsson & Grennfelt 1988). Critical loads were then assigned to these classes, according to the amount of acidity which would be neutralised by base cation production, by weathering from the relevant minerals (Table 5). The critical load for a given soil could also be adjusted, within the range of values suggested for each class of soil material, by applying modifying factors (Table 6). Thus, if one of the 'decrease' factors applies, eg high precipitation, the value of critical load is used which is at the lower limit of the values suggested for the given soil material class; if an 'increase' factor applies, then the upper value is used.

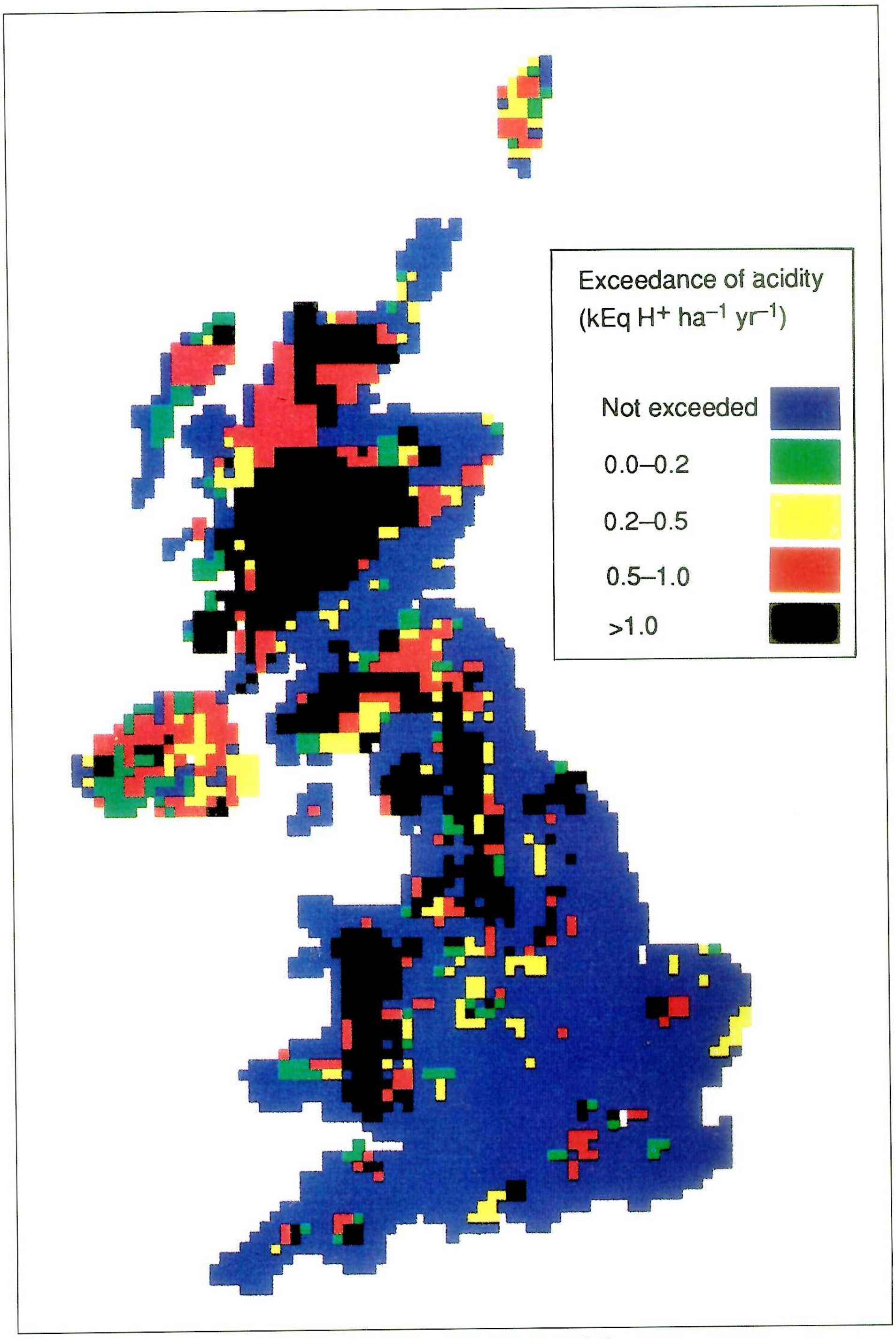


Figure 28. Areas where critical loads for acidity of soils are exceeded

Given the excellent soil maps and accompanying data bases available for GB, it was felt that sufficient information might be available for map units on existing, published, maps to be allocated to one of the soil material classes defined at the Skokloster workshop; the map units could then be assigned a critical load. If this allocation were possible, it would provide a relatively rapid method for producing a critical load map for British soils. The approach was first tested in two exploratory studies, one in north-west Wales and one in northern England. In both cases, the relevant 1:250 000 soil map produced by the Soil Survey and Land Research Centre (SSLRC) was used as the base map. The map units are soil associations, which comprise a mosaic of different soil series. The associations were allocated to one of the soil material classes on the basis of the mineralogy of the dominant, most widespread, soil series.

The results from these trial studies were encouraging, but indicated that the definitions of the soil material classes proposed at Skokloster would need modifying for GB conditions. The classes were originally defined using primary minerals commonly found in relatively young soils, developed on material derived from igneous and metamorphic rocks, whereas many soils in GB are derived from sedimentary rocks and are rich in micas and secondary clay minerals. Such factors had to be taken into account when allocating the soil associations on the GB maps to a soil material class.

The trial study in northern England also showed the important influence of land management on the ability of soils to neutralise acidic deposition (Langan & Hornung 1991). In particular, it demonstrated that the allocation of soils to a soil material class, and hence the assignment of a critical load, should be modified to allow for the effect of liming: the addition of lime effectively increases the critical load.

The approach used in these exploratory studies has now been extended, with modifications based on the results of the above studies, to the whole of Great Britain, in a co-operative exercise with the SSLRC, the Macaulay Land Use Research Institute, and the University of Aberdeen (Figure 27). In practice, the national critical load map uses a 1 km grid; each grid cell was first categorised according to the dominant soil association in the 1 km square. The associations were then allocated to a soil material class, using the properties of the dominant soil series in the association, chiefly mineralogy and texture. Where the dominant land use in any 1 km square was arable, or intensive grassland agriculture, the association was moved to the next lower soil material class, ie the critical load was increased to allow for possible impacts of liming. The Skokloster approach could not be applied to peat soils. Instead, associations dominated by peat soils were categorised and assigned a critical load using an approach developed at the University of Aberdeen, based upon the results of leaching experiments. The map shown in Figure 28 has been derived by aggregating the 1 km squares into 10 km square cells, on the basis of the dominant critical load class in the 100 1 km squares with the 10 km unit.

The map shows that soils with small critical loads dominate in the uplands of western and northern Britain. These areas are underlain by rocks which often contain relatively few weatherable minerals; shallow soils are also common. Soils with large critical loads dominate in southern and eastern Britain. In these areas, the soils are often derived from sedimentary rocks, glacial debris or alluvium, and generally contain relatively abundant weatherable minerals.

The provisional critical load map has been combined with data on current pollutant deposition to produce an exceedance map. This map suggests that the critical loads are currently being exceeded in significant areas of Wales, northern England, and Scotland. Reductions in the deposition of sulphur of up to 80% would be needed to protect all the soils of GB.

M Hornung

References

Bull, K.R. 1991. The critical loads/levels approach to gaseous pollutant emission control. *Environmental Pollution*, **69**, 105–123.

Langan, S.J. & Hornung, M. 1991. An application, and review of the critical load concept to the soils of northern England. *Environmental Pollution*. In press.

Nilsson, J., ed. 1986. *Critical loads for sulphur and nitrogen*. Stockholm: Nordic Council of Ministers.

Nilsson, J. & Grennfelt, P., eds. 1988. *Critical loads for sulphur and nitrogen: report of a workshop held at Skokloster, Sweden 19–24 March 1988*. Copenhagen: Nordic Council of Ministers.

Sverdrup, H., de Vries, W. & Hendricksen, A. 1990. *Mapping critical loads*. Copenhagen: Nordic Council of Ministers.

Dry deposition of sulphur dioxide in the United Kingdom

The direct absorption of a pollutant gas by terrestrial surfaces is known as dry deposition, to distinguish this input from wet deposition where the gas dissolves in water in the atmosphere before reaching the surface. For atmospheric sulphur dioxide (SO_2), dry deposition represents the major input in the south and east of the country where ambient SO_2 concentrations are largest. Even in the high rainfall areas of the north and west where wet deposition dominates, the dry deposition inputs are still important and contribute between 10% and 40% of the total input.

Unlike wet deposition, dry deposition is difficult to measure in the field and measurement procedures require expensive equipment which, in general, is not suitable for long-term monitoring. To estimate inputs to the country, it has therefore been necessary to understand the processes which control dry deposition, and to model the inputs on a regional scale.

The process of dry deposition may be divided into three stages:

i In the atmosphere, molecules of gas are transported down to the immediate vicinity of absorbing surfaces (leaves, stems, building materials, soil and water) by wind eddies (turbulent diffusion). The rate of turbulent diffusion is determined by the wind speed and by the roughness of the ground. Wind passing over an aerodynamically rough surface, such as a forest or an urban area, will induce a much larger rate of turbulent diffusion than wind passing over a smooth surface, like a grass field or open water.

ii Close to an absorbing surface, the physical properties of the gas become much more important. Transport through the layer of air closest to the surface (the viscous boundary layer) is by molecular diffusion, and therefore is dependent on molecular weight. Rates of molecular diffusion are several orders of magnitude smaller than rates of turbulent diffusion a few metres above the ground.

iii At the surface, the chemical properties of the gas become very important. For vegetation, the gas may react on the leaf

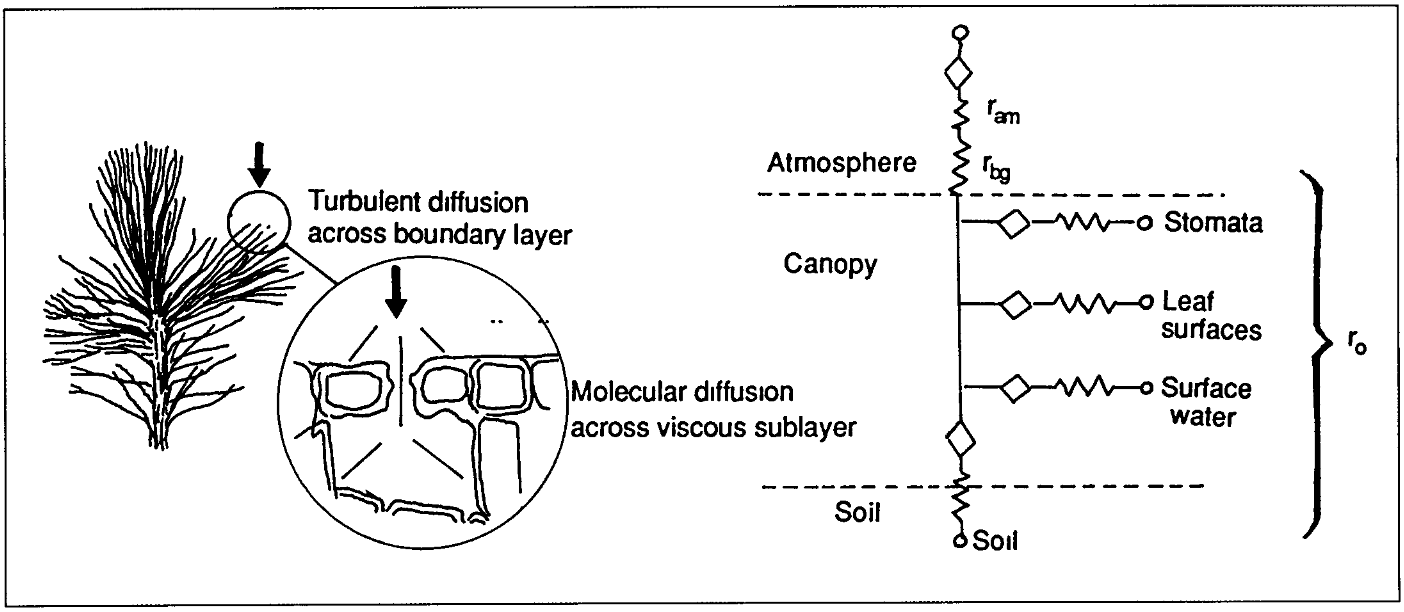


Figure 29. Deposition pathway of gases and small particles to vegetation and the resistance analogy used to describe the process

surface, or it may diffuse through open stomata and then either dissolve in water or react chemically with other internal leaf components Likewise, for soil, open water or building materials, the rate of reaction or sorption at these surfaces has a major influence on rates of deposition

These three stages in the deposition process are generally quantified using a resistance analogy, in which the flow of pollutant gases or particles is considered as analogous to the flow of electrical current through a network of resistances (Figure 29)

The two atmospheric resistances, for the free atmosphere (r_{am}) and for the viscous boundary layer (r_{bg}), may be estimated from the wind speed and the roughness length of the surface (Thom 1975) The surface resistance has so far been determined by measurement In practice, the total resistance to dry deposition is determined by measuring the flux to the ground, the atmospheric resistances (r_{am} and r_{bg}) are estimated directly from wind and temperature velocity profiles, and then a bulk surface resistance (r_c) can be calculated The stomatal component of r_c may be calculated from porometry measurements or from bulk canopy resistance to water loss using micro-meteorological methods (Monteith & Unsworth 1990)

Table 7 Land use categories used for the SO_2 dry deposition model

	Arable land	Grassland	Hill vegetation	Forest	Urban
Roughness length (m)	0 01–0 1*	0 1–0 2*	0 1–0 2*	1 0	1 0
Leaf area index (m^2 m^{-2})					
Maximum	4 5	4	3	6	2
Minimum	0 01	2	1 5	6	2

*Arable, grassland and hill vegetation all show a seasonal dependence on canopy height and leaf area index, monthly values are used, taken from the literature in the ranges shown

The uptake of SO_2 has been measured for a range of vegetation, including grass, wheat and pine (*Pinus* spp) forest, and over various soil types These measurements show that, in most cases, the stomatal resistance for water vapour loss can be used to deduce rates of SO_2 uptake by vegetation Because bulk canopy stomatal conductance

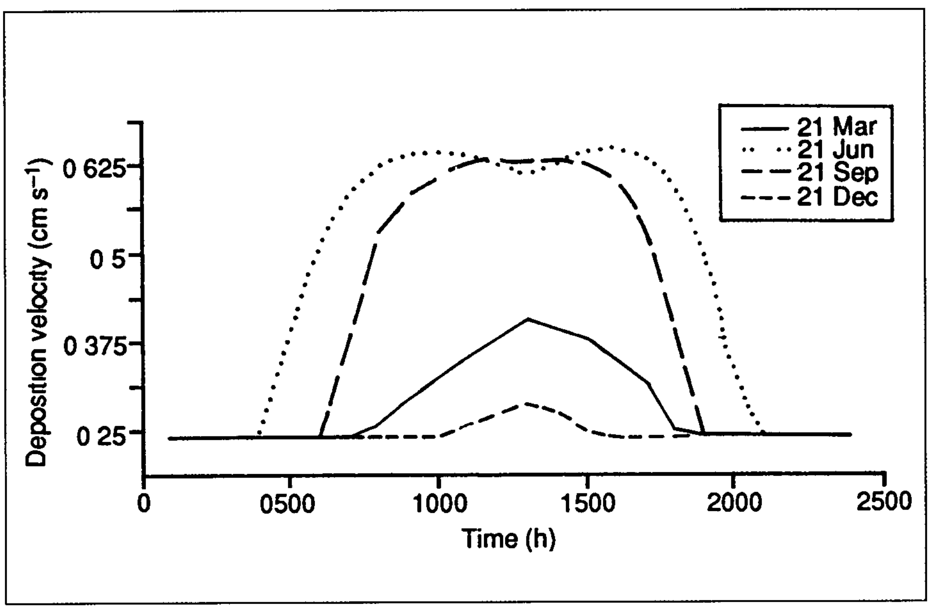


Figure 30 Daily cycle in deposition velocity of sulphur dioxide to forest

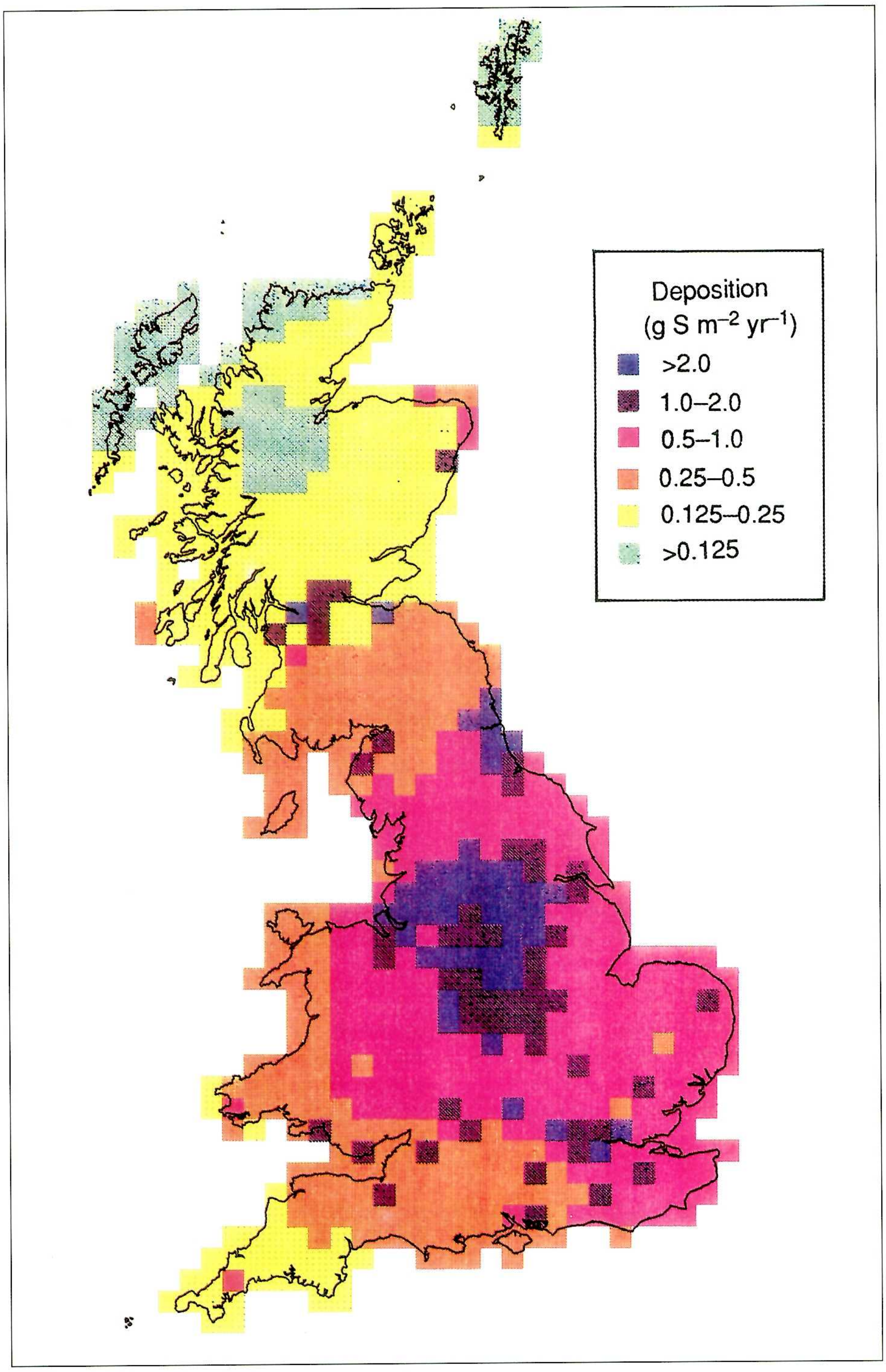


Figure 31. Dry deposition of sulphur in the UK

can be approximated for plant canopies from available radiation and temperature data, we can model SO_2 uptake over a wide variety of vegetated surfaces for extrapolation to the countryside of the United Kingdom (Fowler 1984).

The approach recently adopted for estimating regional dry deposition inputs of SO_2 in the UK uses a combination of land use and topographic data, averaged meteorological variables, and a model of plant surface resistance to estimate rates of deposition to five major land uses. The land within each 20 km x 20 km grid square is classified into arable, grassland, hill vegetation, forest or urban, using ITE land use data. Vegetation height and leaf area index were estimated for each day (Table 7) and used with the ambient SO_2 concentration, wind speed, air temperature, and solar radiation data.

The atmospheric resistances (r_{am} and r_{bg}) are calculated from the roughness of the vegetation and the average wind speed, assuming a logarithmic wind profile in the atmosphere close to the earth's surface. For each vegetation type, the physiological processes controlling gas uptake by stomata are modelled using modified 'big leaf' methods (Monteith & Unsworth 1990; Hicks *et al.* 1987), and the surface resistance is determined from the leaf area, air temperature and solar radiation. Stomatal opening characteristics and leaf (external) surface uptake are quantified from published data for a range of species. The computed deposition velocities for each vegetation type are then used to estimate the overall deposition rate, using an SO_2 concentration field in which interpolated rural values are replaced by the average of urban and suburban measurements in those 20 km squares where the latter data were available.

Figure 30 shows the hourly variation in deposition velocity for SO_2 on to one of the land uses (forest) computed for four days in the year. The pronounced effect of day length on stomatal opening is clear, but also the very small increase in deposition velocity in December is partly due to the temperatures being close to the threshold for stomatal opening and so causing stomatal closure. The small decline in deposition velocity at mid-day on 21 June is the result of water stress on plants, and is a commonly observed property of plant canopies.

The dry deposition of SO_2 to the UK computed using this model is shown in Figure 31. The largest values occur in the industrial Midlands of England with annual inputs of approximately 3 g S m^{-2}. The overall pattern in dry deposition closely follows that of ambient SO_2 concentration. These values for dry deposition of SO_2 are considerably smaller than those estimated earlier (RGAR 1987), because of smaller SO_2 concentrations and a reduction in deposition velocities. It appears that earlier dry deposition estimates were significantly overestimated.

An important area of uncertainty in the dry deposition of SO_2 is the influence of ammonia on rates of leaf surface

SO_2 uptake. There is growing evidence from recent field studies that large ambient ammonia concentrations increase the rate of SO_2 deposition. In practice, this would increase the amounts of sulphur deposited in the areas with large ammonia concentrations, but the magnitude of the effect is as yet unknown.

D Fowler and R I Smith

References

Fowler, D. 1984. Transfer to terrestrial surfaces. *Philosophical Transactions of the Royal Society of London, B*, **305**, 281–297.

Hicks, B.B., Baldocchi, D.D., Meyers, T.P., Hosker, R.P. & Matt, D.R. 1987. A preliminary multiple resistance routine for driving dry deposition velocities from measured quantitites. *Water, Air and Soil Pollution*, **36,** 311–330.

Monteith, J.L. & Unsworth, M.H. 1990. *Principles of environmental physics.* 2nd ed. London: Arnold.

United Kingdom Review Group on Acid Rain (RGAR). 1987. *Acid deposition in the United Kingdom 1981–1985.* Stevenage: Warren Spring Laboratory.

Thom, A.S. 1975. Momentum, mass and heat exchange of plant communities. In: *Vegetation and the atmosphere*, edited by J.L. Monteith, 57–110. London: Academic.

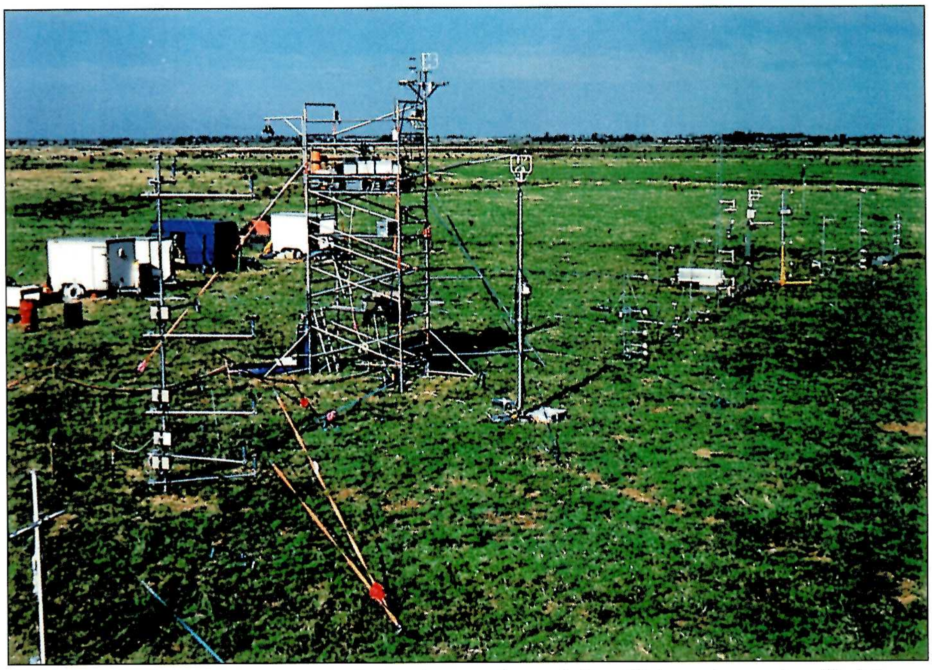


Plate 13. Some of the equipment installed at the experimental site at Halvergate marshes, Norfolk

The exchange of trace nitrogen gases between terrestrial ecosystems and the atmosphere

The nitrogen-containing trace atmospheric gases exhibit three contrasting types of exchange with vegetation and soil. Reactive pollutant gases such as nitric acid (HNO_3) and peroxyacetyl nitrate (PAN) are deposited on vegetation, water and soil, and, for unmanaged ecosystems (eg moorland), represent a source of nitrogen for plant nutrition. Nitric oxide (NO) and nitrous oxide (N_2O) are emitted by soil following microbial production. Gaseous ammonia (NH_3) and nitrogen dioxide (NO_2) have both been observed to be deposited on vegetation and emitted by vegetation, but in very different surface conditions.

Numerous measurements of the exchange of one or two of the above nitrogen-containing gases have been made in field conditions. However, a knowledge of the net exchange of reactive nitrogen species (ie all gases excepting N_2) is much more valuable. Such a set of measurements provides an insight to the effect of land use on the atmospheric composition for those sites leaking reactive nitrogen to the atmosphere. Where inputs of nitrogen exceed outputs – which is almost invariably true for semi-natural ecosystems in the UK as a consequence of pollution, the biological effects of the deposited nitrogen may be examined in terms of the net inputs.

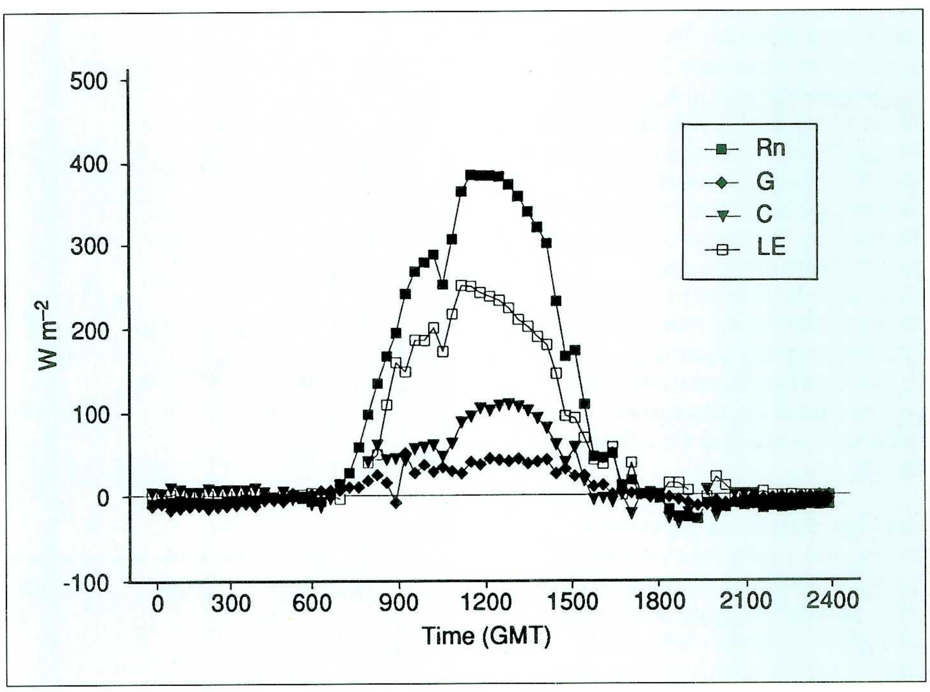


Figure 32. Halvergate radiation balance, 18 September 1989

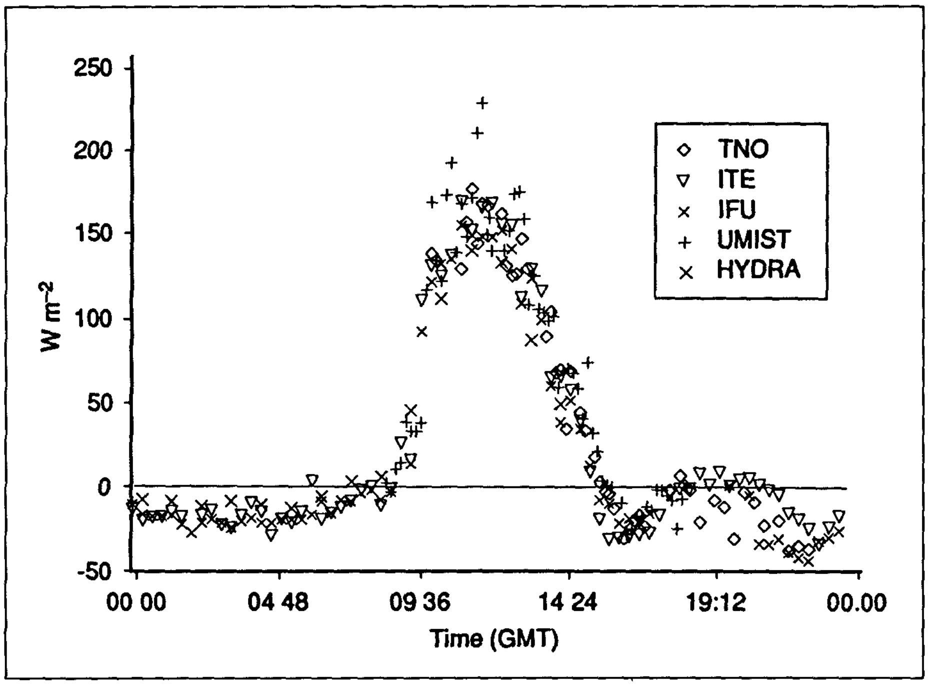


Figure 33 Halvergate sensible heat flux , 19 September 1989

At some sites, therefore, we need to study the full range of gases exchanged in order to quantify the contribution which each gas makes to the net exchange, and to investigate the processes controlling fluxes

Measurements of the exchange of trace gas species between natural surfaces and the atmosphere have been conducted at ITE for several years, and recently the work has been expanded to include collaborative experiments with other European research groups The most recent joint experimental campaign occurred in September 1989 at the Halvergate marshes in east Norfolk Groups from the UK (ITE Edinburgh, Atomic Energy Authority Environment and Technology, University of Manchester Institute of Science and Technology, University of Essex), and the Continent (Netherlands Organisation for Applied Scientific Research, Institut für Atmospharische Umweltforschung, Germany, University of Stockholm, Sweden) participated in the three-week campaign, which was co-ordinated by ITE

The objectives of the experiment were to determine the exchange of trace gas species, such as nitric oxide (NO), nitrogen dioxide (NO_2), nitric acid (HNO_3), nitrous oxide (N_2O), ammonia (NH_3), peroxyacetyl nitrate (PAN), ozone (O_3) and sulphur dioxide (SO_2), between the atmosphere and the land surface

The site consisted of unfertilised pasture (drained marshland) 2 m above sea level, from which cattle had been removed a short time before the beginning of the experiment A large array of equipment was set up by the various groups in order to measure gas concentrations and various micro-meteorological parameters Plate 13 shows some of the equipment installed at the site, including eddy correlation sensors for determining atmospheric turbulence, fast-response gas analysers placed on the tower, profile anemometers and temperature sensors on the smaller masts, and the mobile laboratories belonging to each group

A radiant energy budget for a typical day during the campaign, 18 September, is shown in Figure 33 From this sort of information, it is possible to determine not only the partitioning of energy and the value of various exchange coefficients, but also the bulk stomatal resistance of the canopy The provision of basic plant physiological information is invaluable for studies of trace gases which are frequently emitted or absorbed by plants via the stomata

One of the most important features of the Halvergate experiment was the extensive measurement of micrometeorological variables by a range of methods, which provided valuable opportunities to intercompare fluxes of basic quantities (sensible and latent heat, and momentum) Such an exercise enables a detailed analysis of energy budgets and of the behaviour of the crop

One of the intercomparisons possible was that of sensible (or convective) heat flux An example from 19

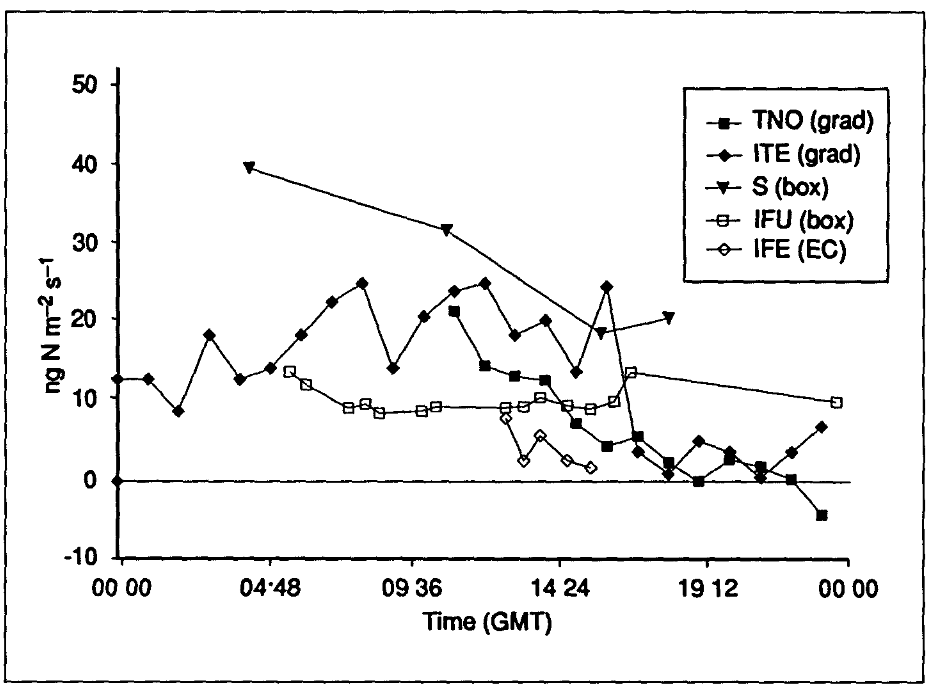


Figure 34 Halvergate NO fluxes, 19 September 1989

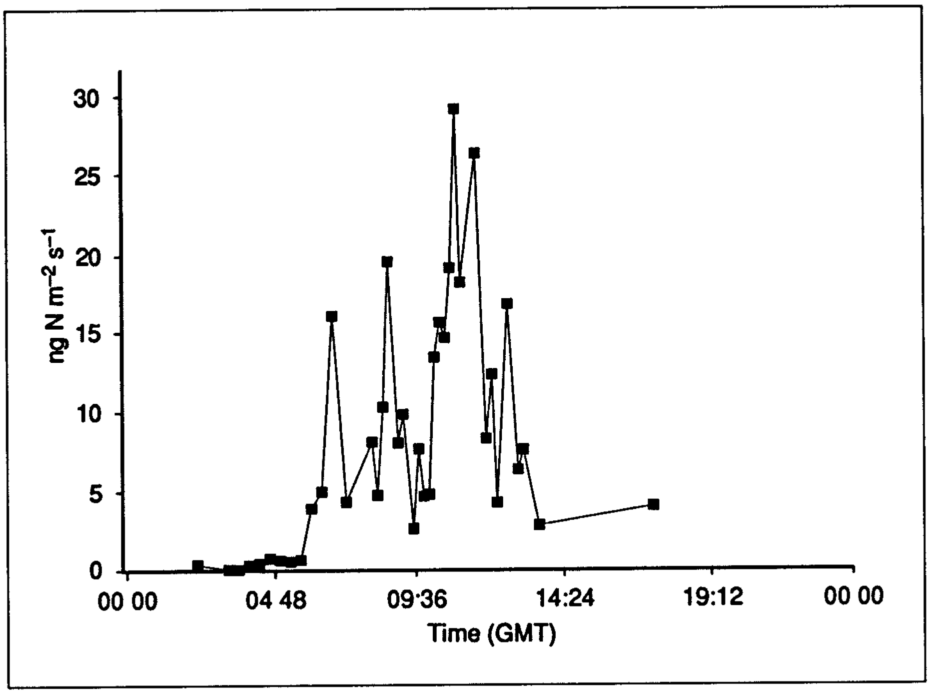


Figure 35 Halvergate NO flux, 15 September 1989

September is shown in Figure 33. Despite the use of three different techniques by five different groups, the agreement between the different systems is excellent when the physical separation of equipment along a 150 m cross-wind transect is considered.

Similar intercomparisons were possible when considering the trace gas fluxes, and Figure 34 illustrates nitric oxide fluxes determined by four groups using three techniques. Some of the measurement systems measured the fluxes over areas as small as 1 m^2, whilst others made integrated measurements extending to a scale of kilometres. Despite this variation in scale, the fluxes agree rather well: with the exception of one data point, all groups detected emission of NO at rates up to 40 ng m^{-2} s^{-1}. (Note that the convention for trace gas exchange is that emission of a gas has a positive sign convention and deposition a negative one.)

Results obtained by ITE on one other day (15 September) are included in Figures 35 and 36. Again, these results indicate an upward NO flux of 10–15 ng m^{-2} s^{-1}. The source of the gas is microbial nitrification. Although soil temperature plays an important role in the rate at which nitrification occurs, the variation in soil temperature on this day was insufficient to produce any detectable variation in emission rate. Ozone and nitrogen dioxide were both shown to deposit to the canopy at maximum rates in the middle of the day. These deposition processes were shown to be controlled by stomata, indicating that the pathway for the exchange of these two gas species is via the stomatal cavity. During the night when stomata were closed, the fluxes were small, and increased as the stomata opened during the day; as the stomata closed again during the afternoon and evening, the fluxes declined. Minimum canopy resistances in the order of 100 s m^{-1} were calculated, a value typical of an unstressed grass canopy.

Interpretation of the results is complicated by rapid chemical reactions which affect these three gas species. NO and O_3 react rapidly to produce NO_2, whilst NO_2 in the presence of ultraviolet light (contained in daylight) is rapidly photolysed to NO. Analysis is in progress, but, for most of the experimental period, the corrections to fluxes of O_3 for the effects of chemical conversion in the lowest 3 m above the surface (where measurements were made) were a small fraction of the flux (Hargreaves *et al* 1991). This is a consequence of the relatively small ambient NO concentrations at this site.

Ammonia was emitted from the site with net fluxes in the order of 100 ng m^{-2} s^{-1}. These large emissions were caused by the recent presence of cattle on the field, and the magnitude of the emissions declined during the experimental period as soil ammonium status declined. Sulphur dioxide is normally deposited to

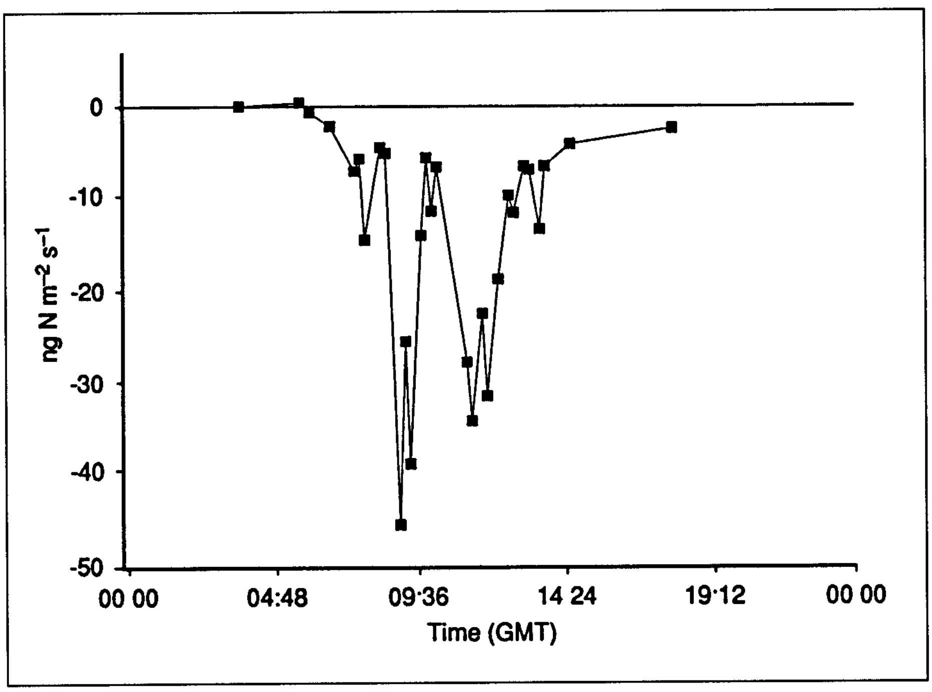


Figure 36 Halvergate NO_2 flux, 15 September 1989

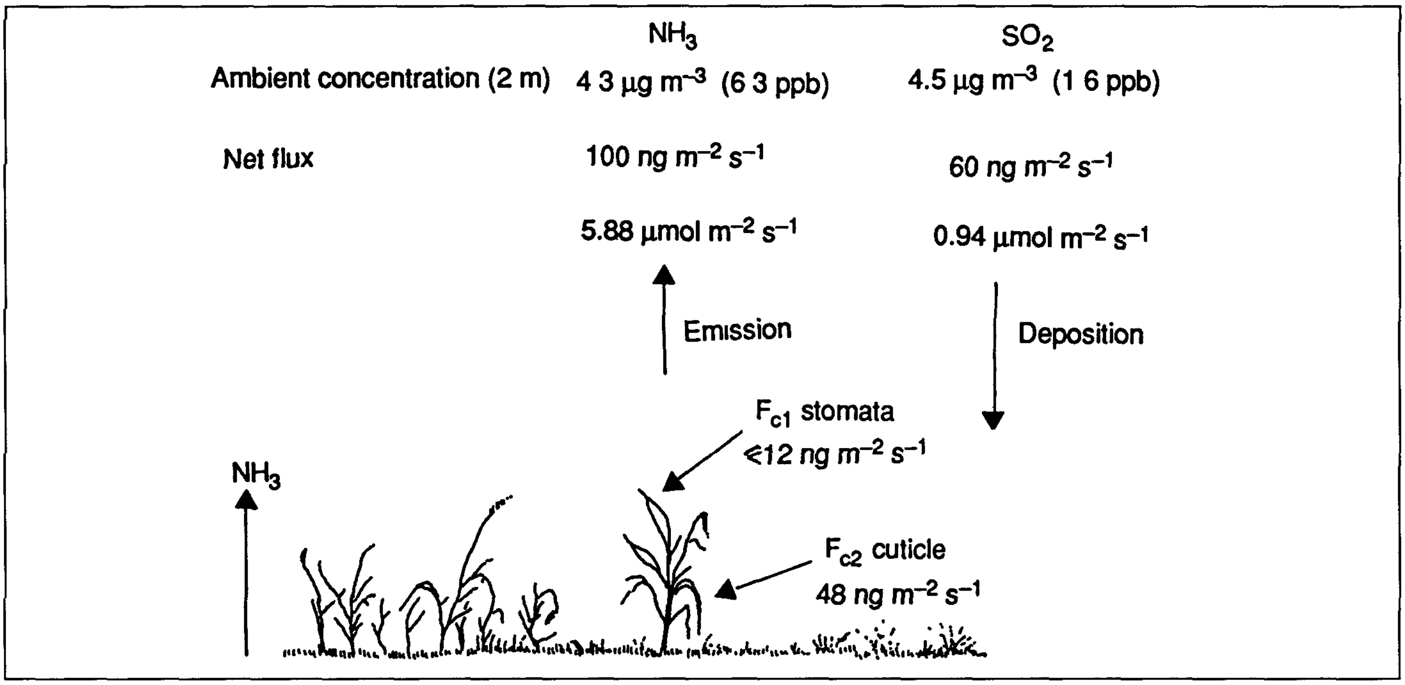


Figure 37 Interactions of NH_3 and SO_2 surface/atmosphere exchange, measured over grassland at Halvergate, Norfolk

vegetation via the stomata, but, in the presence of large quantities of ammonia, a significant proportion is deposited to leaf surfaces (Fowler, Duyzer & Baldocchi 1991) There was clear evidence of this 'co-deposition' of NH_3 and SO_2 at the site, as summarised in Figure 37 Nitrous oxide was also emitted, at rates of around 50 ng m^{-2} s^{-1}, probably as a result of nitrification or denitrification

Vegetation has been shown to be a perfect sink for nitric acid (Dollard, Jones & Davies 1991), and this was confirmed at the Halvergate site Deposition fluxes of PAN were generally very small, and made no significant contribution to the total nitrogen budget of the site

Although these measurements were concentrated on a four-week intensive study, the data may be used to gauge the magnitude and direction of average summer fluxes for the whole range of trace nitrogen-containing gases The estimated budget (Figure 38) shows a significant net loss of nitrogen (40 kg ha^{-1}), mainly as NH_3 and N_2O but including NO The inputs of nitrogen as PAN, NO_2 and HNO_3 are small by comparison Scaling up to the growing season is, of course, a speculative process, and more

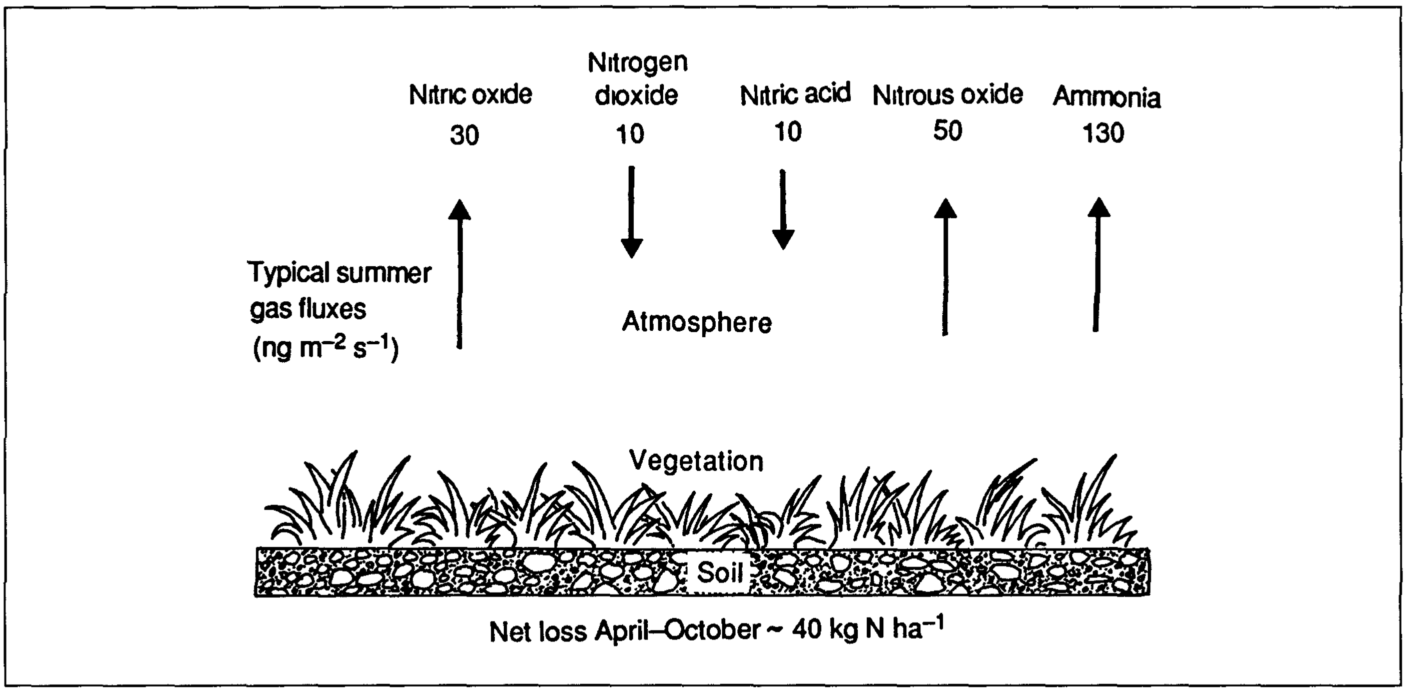


Figure 38 Halvergate nitrogen budget

precise estimates of individual fluxes using process-based models are necessary to reduce the uncertainties. However, for this site, the scaling up process provides a valuable guide to the gases which determine both the net direction and magnitude of the nitrogen exchange.

K J Hargreaves and D Fowler

References

Dollard, G.J., Jones, B.M.R. & Davies, T.D. 1991. Measurements of gaseous hydrogen peroxide and PAN in rural southern England. *Atmospheric Environment.* In press.

Fowler, D., Duyzer, J.H. & Baldocchi, D. 1991. Inputs of trace gases, particles and cloud droplets to terrestrial surfaces. *Philosophical Transactions of the Royal Society of Edinburgh.* In press.

Hargreaves, K.J., Fowler, D., Storeton-West, R.L. & Duyzer, J.H. 1991. The exchange of nitric oxide, nitrogen dioxide and ozone between pasture and the atmosphere. *Environmental Pollution.* In press.

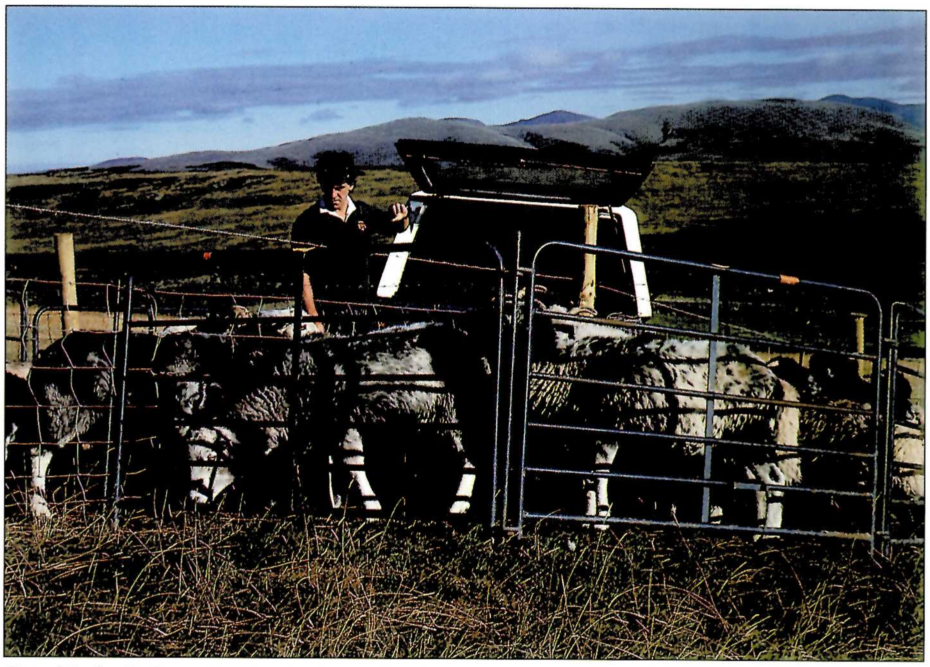


Plate 14. Study sheep in uplands of west Cumbria

Overview of the transfer of radiosilver within the environment

(This work was partly funded by the Ministry of Agriculture, Fisheries and Food and Nuclear Electric, and conducted in collaboration with the Macaulay Land Use Research Institute)

Fallout from the Chernobyl accident

The accident on the 26 April 1986 at the Chernobyl nuclear power complex in the Soviet Ukraine released large amounts of radioactivity into the atmosphere. High levels of fallout were deposited throughout Europe, and enhanced levels of activity were detected in the northern hemisphere.

The prime cause of concern following the accident was the need to identify potential pathways to man of the most radiologically significant nuclides present – the radiocaesium isotopes ^{134}Cs and ^{137}Cs and iodine as ^{131}I. Radiostrontium and actinides (eg plutonium and americium) were not deposited in any significant amount in western Europe. However, during the analyses of sheep tissues (Plate 14), we found that, apart from radiocaesium and ^{131}I, radiosilver (^{110m}Ag) (physical half-life = 250 days) was routinely detected in the liver. Although only a minor constituent of the fallout (Table 8), the activity concentration of ^{110m}Ag in the liver of sheep was sometimes as high as that of ^{134}Cs (Beresford 1989a).

Silver in biological systems

Data on the behaviour of silver in the environment are sparse. Although the factors influencing the behaviour of silver in soils are fairly well understood, results for its uptake and translocation by vegetation can show a 400-fold variation in the plant/soil concentration ratio in a single plant species. Data on the metabolism of silver by animals mostly relate to the study of argyria (the deposition of silver in the skin and various body organs resulting in a blue/grey pigmentation) in humans following industrial exposure, and more commonly to the medical use of silver. These results are of limited value in understanding the behaviour of radiosilver released into the environment. No studies had been conducted on silver uptake and metabolism by food-producing animals. Recommended values for the transfer of ^{110m}Ag to ruminants for use in predictive models were based on limited and diverse data. It was even unclear which organs would concentrate ^{110m}Ag. A small research programme was, therefore, initiated at ITE Merlewood to study the transfer of radiosilver within the environment.

Table 8. Gamma-analysis of a vegetation sample collected on 6 May 1986 from an upland site in west Cumbria

Radionuclide	Activity concentration (Bq kg^{-1} dry weight)
^{95}Nb	310
^{103}Ru	15 980
^{106}Ru	4 330
^{110m}Ag	230
^{131}I	39 960
^{132}Te	5 880
^{134}Cs	9 300
^{136}Cs	2 670
^{137}Cs	16 980
^{140}Ba	9 400
^{141}Ce	280

The uptake of ^{110m}Ag by vegetation

Studies on the transfer of silver to vegetation agreed with previous suggestions that silver is more mobile in soils with a low pH. For organic soils with a low pH, as found in the uplands of west Cumbria, a plant/soil transfer ratio (expressed as a ratio of concentrations) of more than two is estimated. This figure is higher than some earlier results would have suggested Given the limited nature of the data available, further studies on factors affecting the transfer of deposited radiosilver to vegetation are required, especially in relation to semi-natural ecosystems because they are more likely to receive high levels of fallout in future nuclear incidents, often have low pH soils, and they provide a potentially important pathway for transfer of radioactivity to man via grazing ruminants Additional studies investigating the behaviour of silver in soil types typical of those close to nuclear installations would also be useful

The transfer of ^{110m}Ag to animals

The liver was found to be the most important organ when considering the transfer of ^{110m}Ag to grazing animals, both because of a high uptake from the blood and a long biological half-life Advised equilibrium transfer coefficients* derived from this work for ^{110m}Ag to the liver of sheep are in the order of 5–10 d kg^{-1} and 1–3 d kg^{-1} for lambs and ewes respectively However, this value may decrease if ^{110m}Ag is incorporated into plant tissues

Transfer parameters derived for muscle suggest that previously advised values given in the literature were overestimates In contrast to radiocaesium, muscle is unlikely to be important when considering the transfer of radiosilver to grazing animals, as it has a transfer coefficient about four orders of magnitude lower than that of the liver The only tissue other than the liver which was found to have detectable levels of ^{110m}Ag following the Chernobyl accident was the brain

To illustrate the potential importance of ^{110m}Ag in the liver soon after a radioactive deposition, we considered the situation in the upland areas of the UK following the Chernobyl accident Restrictions

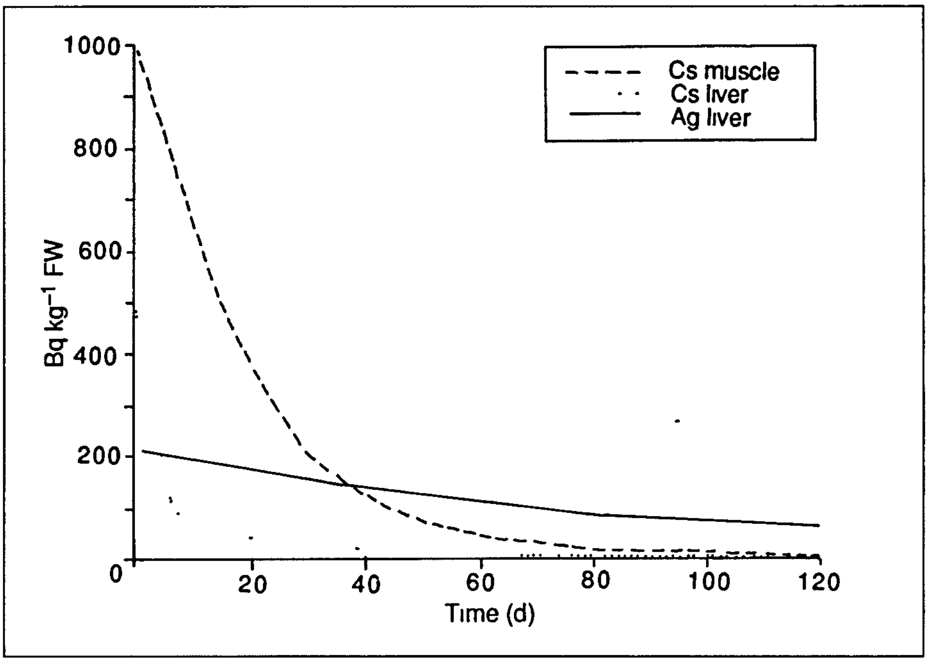


Figure 39 A comparison of the changes in radiocaesium ($^{134}Cs+^{137}Cs$) activity concentration in the liver and muscle of a '1000 Bq kg^{-1} sheep' with changes in the ^{110m}Ag activity concentration in the liver when the sheep is removed from contaminated to uncontaminated pasture (the curve for ^{110m}Ag takes account of physical decay of the isotope)

were placed on the movement and slaughter of sheep at 8914 farms in the UK in 1986, where $^{134}Cs+^{137}Cs$ levels in the muscle exceeded 1000 Bq kg^{-1} fresh weight (FW) Sheep from the restricted areas with over 1000 Bq kg^{-1} FW were allowed to leave the areas, but were grazed on less contaminated lowland pastures to allow their radiocaesium activity to decrease before entry into the foodchain

Using a model of the behaviour of radiocaesium in sheep developed jointly with the University of Nottingham (Galer *et al* 1990), the radiocaesium activity in the liver of a sheep with 1000 Bq kg^{-1} FW in its muscle can be calculated Using a $^{134}Cs/^{137}Cs$ ratio for radiocaesium in Chernobyl fallout in the UK of 0 53 (Beresford *et al* 1990) and a ratio of $^{110m}Ag/^{137}Cs$ in the liver of sheep soon after Chernobyl of 0 67, the ^{110m}Ag activity concentration in the liver can be estimated (Figure 39) A ratio for $^{10m}Ag/^{137}Cs$ of 0 67 was the highest value found during the work conducted, and, therefore, probably represents a 'worst case' example Applying a value of 87 5 days (measured in a metabolism cage study) for the biological half-life ($T_{1/2b}$) of ^{110m}Ag in the liver and rates of loss for radiocaesium from sheep calculated by the model, we can compare changes in the activity concentration of radiocaesium in muscle and liver with that of ^{110m}Ag in the liver for a '1000 Bq kg^{-1} sheep' after it has been transferred from contaminated to uncontaminated pastures (Figure 39) Because of its longer $T_{1/2b}$, the ^{110m}Ag activity in the liver exceeds that of radiocaesium after ten days After about 35 days, the activity concentration of ^{110m}Ag in the liver is greater than that of radiocaesium in muscle We can, therefore, predict that the ^{110m}Ag activity concentration in the liver for such an animal, at the time of slaughter, could be higher than that of other artificial radionuclides in any other tissue

An alternative and potentially important route for the transfer of ^{110m}Ag to man is through cattle

*The transfer coefficient (F_f) is commonly used to describe the transfer of radionuclides from feed to animal tissues or milk It is represented by the equation

$$F_f = \frac{\text{Activity concentration of } ^{110m}\text{Ag in a tissue (Bq kg}^{-1}\text{ fresh weight)}}{\text{Daily intake of } ^{110m}\text{Ag (Bq d}^{-1}\text{)}}$$

Table 9 Predicted activity concentrations of ^{110m}Ag in various environmental components around a Hungarian PWR nuclear power station (Kanyar et al *1990)*

Environmental component	Estimated activity concentration (mBq kg^{-1})
Soil rooting zone	2 1
Hay (dry)	34
Cow milk	12
Cow liver	115
Beef	0 37
Leafy vegetables	3 5
Root vegetables	1 5
Grain	4 3

Cows' milk is known to be an important source of some radionuclides to man, and perhaps the most serious gap in our current understanding of the environmental behaviour of radiosilver is the lack of data on its transfer from feed to cow milk The importance of this parameter is illustrated by recent results from Hungarian scientists

Increasing levels of ^{110m}Ag are being discharged from Hungarian nuclear reactors (Hoang *et al* 1990, Kanyar, Fulop & Kerekes 1990) In 1989, the airborne release of ^{110m}Ag from one Hungarian PWR was 2 GBq, compared with less than 50 MBq for cobalt (as ^{60}Co), ^{131}I and ^{137}Cs combined The increase in the discharges of ^{110m}Ag (0 74 GBq were discharged in 1988) may be due to the composition of the stainless steel reactor tank

Kanyar *et al* (1990) have attempted to model the behaviour of ^{110m}Ag in the terrestrial foodchain around the power plant in order to conduct a dose assessment, and the model parameters include ITE data for the transfer to the liver of grazing animals (Beresford 1989b) Table 9 shows the ^{110m}Ag activity concentrations estimated by the model for a number of environmental components

Cow liver is predicted to have the highest activity concentrations of ^{110m}Ag, as would be expected from our results for sheep However, milk is estimated to be the food product with the second highest ^{110m}Ag activity concentration Additionally, apart from the radiation dose from the soil surface, Kanyar *et al* (1990) state that milk will provide the largest contribution to the radiation dose caused by ^{110m}Ag Despite its apparent importance, there are no reliable estimates of the transfer of radiosilver to milk

N A Beresford

References

Beresford, N.A. 1989a Field observations of Ag-110m, originating from the Chernobyl accident, in west Cumbrian vegetation and soil samples *Journal of Radiological Protection*, **9**, 281–283

Beresford, N.A. 1989b The transfer of Ag-110m to sheep tissues *Science of the Total Environment*, **85**, 81–90

Beresford, N.A., Barnett, C.L., Howard, B.J., Poskitt, J. & Dighton, J. 1990 *Vegetation and soil survey in Cumbria to validate the aerial survey of 1988* (NERC contract report to Ministry of Agriculture, Fisheries and Food) Grange-over-Sands Institute of Terrestrial Ecology

Galer, A.M., Crout, N.M.J., Beresford, N.A & Howard, B.J. 1990 Modelling radio-caesium transfer in upland ecosystems In *1st International Conference on the Biological and Radioecological Aspects of the Consequences of the Accident at Chernobyl Atomic Station*, 264 Moscow Academy of Sciences of the USSR

Hoang, T.S., Szerbin, P., Stur, D. & Korosi, F. 1990 Uptake of Ag-110m by *Pisum sativum* In *Proceedings of Conference on Radioecology*, 124 Kosice IRANT

Kanyar, B., Fulop, N. & Kerekes, A. 1990 *Modelling of the ^{110m}Ag transport in the terrestrial foodchain and dose assessment around the nuclear power station in Hungary* Presented at Biomovs, Stockholm, Sweden, 7–11 October 1990

Population ecology

Research in this programme is concerned with understanding what determines the distribution and abundance of wild plants and animals. The distribution of any organism is constrained to a large extent by the distribution of its habitat, but within that habitat numbers may be influenced by the supply of food and other resources, or by the pressure from natural enemies, such as predators and parasites. Current research covers all these aspects on one species or another, with detailed studies on plant/herbivore, predator/prey and host/parasite interactions.

One research area of particular interest at the present time concerns the fragmentation of habitats arising from human activities, which leads to the increasing isolation of populations. New research is concerned with the genetic consequences of such isolation, and with the role of dispersal in ensuring the persistence of isolated populations. Another new area concerns the application of molecular genetics techniques to measure the degree of genetic differentiation between populations, and the rates of gene flow through populations. Knowledge of the latter is helpful in predicting the rates of spread of genetically engineered features. Such knowledge is likely to be increasingly required in future as genetically engineered organisms are released into natural environments. A third area of new activity concerns an assessment of the effects of climate change.

The projects described illustrate a cross-section of long-established work. The research on ducks forms part of an attempt to assess the impact of these birds on fish stocks in Scottish rivers, while the work on sparrowhawks (*Accipiter nisus*) describes the recovery in a population following reductions in the use of harmful pesticides to which these birds are unusually sensitive. The work on amphibia and reptiles is concerned mainly with dispersal, while the ant studies are designed to unravel some of the complexities of ant societies.

Predation of juvenile salmon by red-breasted mergansers

(This work is being funded by the Scottish Office Agriculture and Fisheries Department)

Red-breasted mergansers (*Mergus serrator*) are highly specialised ducks which feed mainly on small fish and crustaceans. In Britain, they spend the winter at the coast but move inland to breed, some to standing waters, but many to the lower reaches of rivers where they eat young salmon (*Salmo salar*). On the river North Esk in eastern Scotland, mergansers are abundant during May when juvenile salmon (smolts) are migrating downstream to the sea. Studies of these fish involve fitting them with external fin tags, many of which have been recovered from the stomachs of mergansers shot under licence. It has been suggested that these ducks could consume so many smolts as to significantly reduce the numbers of adult salmon returning to home waters and thus reduce the salmon harvest, but an attempt to model such impact (Shearer *et al* 1987) was disadvantaged by a lack of precise data. The present study (1987–90) was commissioned by the Scottish Office Agriculture and Fisheries Department to remedy this situation by quantifying the population of mergansers on the North Esk and estimating the numbers of salmon they eat.

Population

Mergansers came into freshwater in April, their numbers peaked at the end of April or in May, and fell thereafter (Figure 40). Many birds were in pairs when first recorded, but they did not breed until late spring, females laying eggs in May and beginning incubation in late May and in June. Most ducklings hatched in July and fledged in September, rapidly dispersing soon after.

Drakes abandoned incubating females, leaving the river in June and congregating to moult on the sea nearby in July and August. Few mergansers were seen on the river from late October through to mid-February.

The numbers of mergansers along the whole river (Table 10) varied

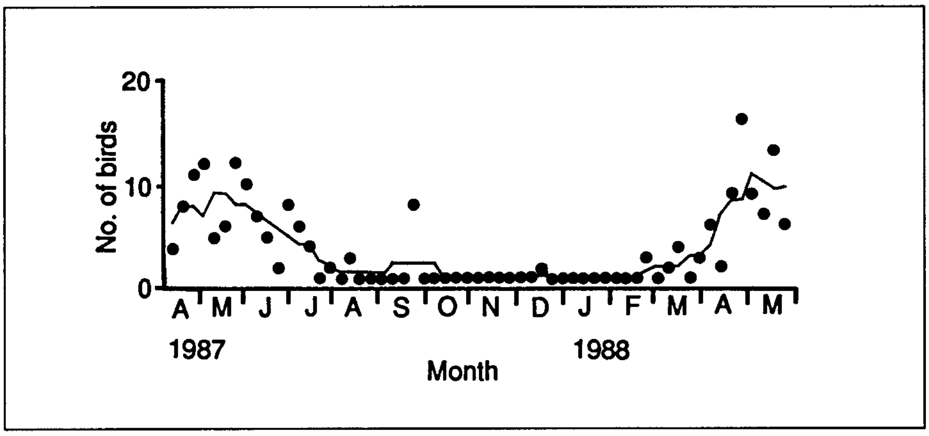


Figure 40 Seasonal trends in the number of red-breasted mergansers seen on a sample of freshwater sections of the river North Esk, eastern Scotland. The solid circles give weekly counts and the line connects five-week running means

Table 10 Annual estimates of the numbers of red-breasted mergansers on the river North Esk and moulting offshore, 1987–90

Month	Statistic	1987	1988	1989	1990
January	Total on whole river including estuary	–	7	0	3
April	Total	51	75	60	41
May	Total (number of pairs)	73(31)*	77(29)	78(32)	85(30)
August	Number of adults	19	19	10	10
	Number of broods	7	8	8	7
	Mean brood size+SE	3 1+1 2	3 9+1 6	7 4+1 8	5 5+0 8
	Total	41	50	69	49
August	Moulting flock offshore (mean+SE)	491+27	283+14	631+17	980+39

*57 mergansers were counted on 60 km of river in 1987 The numbers of birds on the remaining 25 km were estimated using the relationship between density and elevation (Figure 41)

enormously from year to year in April, but were reasonably constant in mid-May just prior to breeding Such stability in breeding numbers was unexpected, for between 12 and 31 ducks were shot in April each year as part of a licensed cull by fishery managers Either the shot birds were transients, passing through in April, or they were local breeders that were quickly replaced within the subsequent weeks If this were the case, the late spring population of about 75–80 mergansers (29–32 pairs) could have been the upper limit that the river could support in those years

The numbers of almost fully grown ducklings varied from year to year (Table 10) Most ducklings died within a week of hatching, and the numbers surviving to complete growth were greatest when river flow was very low for the main period of hatch (Table 11) High flows may physically disrupt broods so that ducklings become lost and die through lack of brooding Alternatively, low flows concentrate prey (large invertebrates and tiny fish) in shallow pools, enhancing the foraging of small ducklings, and so their survival

Diet

Merganser diet was estimated from the boney remains of fish in stomachs (Feltham & Marquiss 1989, Feltham 1990), of adults ducks shot in April, May and June, and of ducklings shot in August

At least six species of small fish were eaten by ducklings Salmon were only a minor part (<5% of mass) of the stomach contents, which were dominated by stickleback (*Gasterosteus aculeatus*) and gadoids in ducklings from near the river mouth, and by small trout (*Salmo trutta*) in ducklings from 20 km further upstream

In spring, adult mergansers also took a variety of fish species, including trout, eel (*Anguilla anguilla*), brook lamprey (*Lampetra planeri*), stickleback, minnow (*Phoxinus phoxinus*), sandeel (*Ammodytes* sp), goby (*Gobius* sp), flounder (*Platichthys flesus*) and stoneloach (*Noemacheilus barbatulus*), but generally 50–66% of the fish found in stomachs were juvenile salmon Judging from their size, most of these salmon were small 'resident' fish (parr), few of them were over 9 cm in length and therefore, potentially, smolts Such larger fish occurred mainly in ducks shot in April, almost none were present in ducks shot in June This seasonal decrease in the average size of salmon consumed resulted in a large decrease in the proportion by mass of salmon in the overall diet, from 60% in April, to 29% in May, and 15% in June

Predation of salmon in relation to their abundance

Mergansers did not take salmon smolts in direct proportion to their abundance in the river First, most smolts consumed

Table 11 The annual variation in the production of fledged young red-breasted mergansers on the North Esk, in relation to river flow, measured (in cumecs) at Logie Mill (data supplied by the Tay River Purification Board)

	1987	1988	1989	1990
Number of ducklings fledged	22	31	59	39
Daily discharge of water	11 3+1 1*	9 6+0 9	3 3+0 2	7 2+1 0

*Mean (+SE) daily discharge during the period of hatch (12 June–5th August)

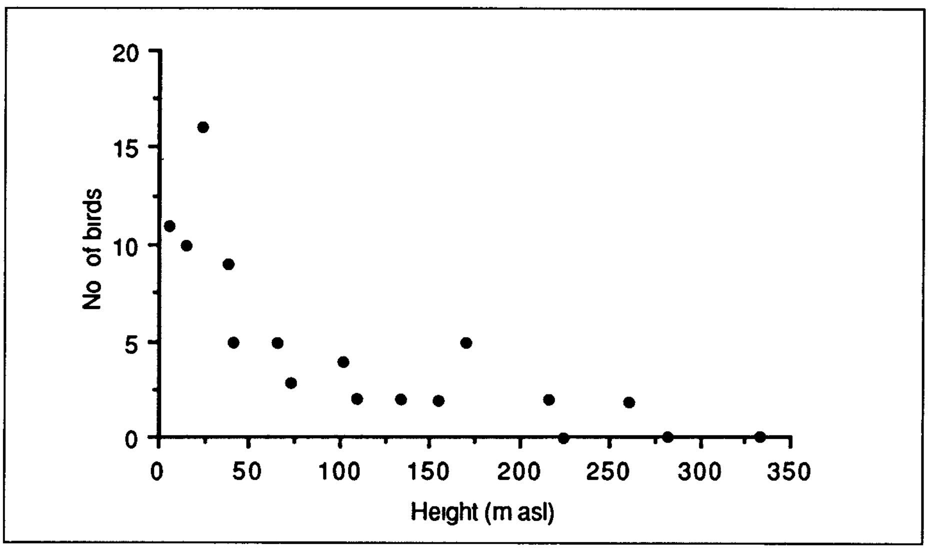


Figure 41 The distribution of red-breasted mergansers on the river North Esk, eastern Scotland, with respect to elevation Data are from a mid-May census of the whole river in 1988 Points denote counts of mergansers within 5 km sections of the river

by ducks were much smaller than average size, not because ducks could not consume large fish – occasionally they took quite large trout – but apparently because small smolts were easier to catch than larger ones which can swim faster. Second, most smolt-sized salmon were taken by ducks in April, at the start of the smolt migration; fewer were taken during the peak of the migration in May when thousands more were present. Third, fewer smolt-sized fish were taken in 1987 (12%) and 1990 (19%) than in 1988 (34%) and 1989 (39%), despite larger numbers of smolts migrating in those years (199 000 in 1987 and 175 000 in 1990, compared with 141 000 in 1989 – D A Dunkley, unpublished information).

A further apparent anomaly was that breeding mergansers in May were most abundant on the lower sections (Figure 41), where the river was wide and slow-flowing. Salmon parr were the major prey at this time of year, yet parr densities and biomass were greatest at higher elevations in narrower, fast-flowing river sections where ducks were scarce. One explanation could be that duck abundance was related to prey availability rather than to prey abundance. Salmon parr could have been easier to catch on the lower river sections where the bottom substrate was finer, less cobbled, with perhaps less 'cover' and fewer refuges for fish.

Modelling 'impact'

It is theoretically possible to model the impact of merganser predation on salmon harvest, but the process has become quite complicated. We now know that, at least on the North Esk, mergansers take far fewer smolts than was previously thought, but large numbers of parr. They selectively prey on fish of certain size classes and living in particular places, so an 'impact' model needs to incorporate intricate population dynamics, including the probability of survival of fish of different sizes living in different places. Moreover, we need to know whether the removal of fish results in the enhanced survival, or growth, of those that remain, and whether merganser predation on salmon is additive or compensatory to other sources of mortality. In other words, if we release fish from merganser predation, what proportion will be lost by a corresponding increase in other causes of mortality? These questions require intensive work on duck foraging ecology, including some small experiments removing ducks and/or removing fish in a controlled situation, whilst simultaneously measuring parr populations.

M Marquiss and M J Feltham*
(*University of Stirling)

References

Feltham, M.J. 1990. The diet of red-breasted mergansers (*Mergus serrator*) during the smolt run in northeast Scotland; the importance of salmon (*Salmo salar*) smolts and parr. *Journal of Zoology*, **222**, 285–292.

Feltham, M.J. & Marquiss, M. 1989. The use of first vertebrae in separating, and estimating the size of trout (*Salmo trutta*) and salmon (*Salmo salar*) in bone remains. *Journal of Zoology*, **219**, 113–122.

Shearer, W.M., Cook, R.M., Dunkley, D.A., Maclean, J.C. & Shelton, R.G.J. 1987. *A model to assess the effect of predation by sawbill ducks on the salmon stock of the river North Esk.* Scottish Fisheries research report no. 37.

Recovery of a sparrowhawk population in relation to a decline in pesticide contamination

This study describes the recovery in the numbers of sparrowhawk (*Accipiter nisus*) in eastern England, associated with a reduction in contamination from organochlorine pesticide residues, namely HEOD (derived from aldrin and dieldrin) and DDE (derived from DDT). These chemicals were known to have caused a decline in the population in the late 1950s, HEOD increasing the mortality of adults and DDE causing eggshell thinning and breakage, thereby reducing the breeding rate (Newton 1986). Sparrowhawks accumulated these pesticide residues from the bodies of small birds which formed their prey (Plate 15). Sparrowhawks found dead in eastern England over the period 1963–90 showed a significant reduction in HEOD levels in their livers from around 1975, and a reduction in DDE levels from around 1980 (Figure 42). The decline in HEOD contamination was especially marked, and followed a major reduction in the agricultural use of aldrin and dieldrin, both of which were withdrawn at that time from use on autumn-sown cereal grains. From then on, increasing numbers of sparrowhawks were seen in the region, and increasing numbers of carcases were received for study (Figure 42). The start of the population recovery was associated more closely with the reduction in HEOD contamination than with the reduction in DDE.

A more detailed study of the population recovery was made in a 200 km^2 area centred on Rockingham Forest in the north-east of Northamptonshire, where sparrowhawks were last known to have nested about 1960. In 1979 a search of most of the woodland in the Rockingham area revealed three new nests, but no old nests remaining from previous years. Hence, 1979 was probably the first

Plate 15. Sparrowhawk at nest. These hawks nest in woodland and hunt the small birds that occur in woods and farmland

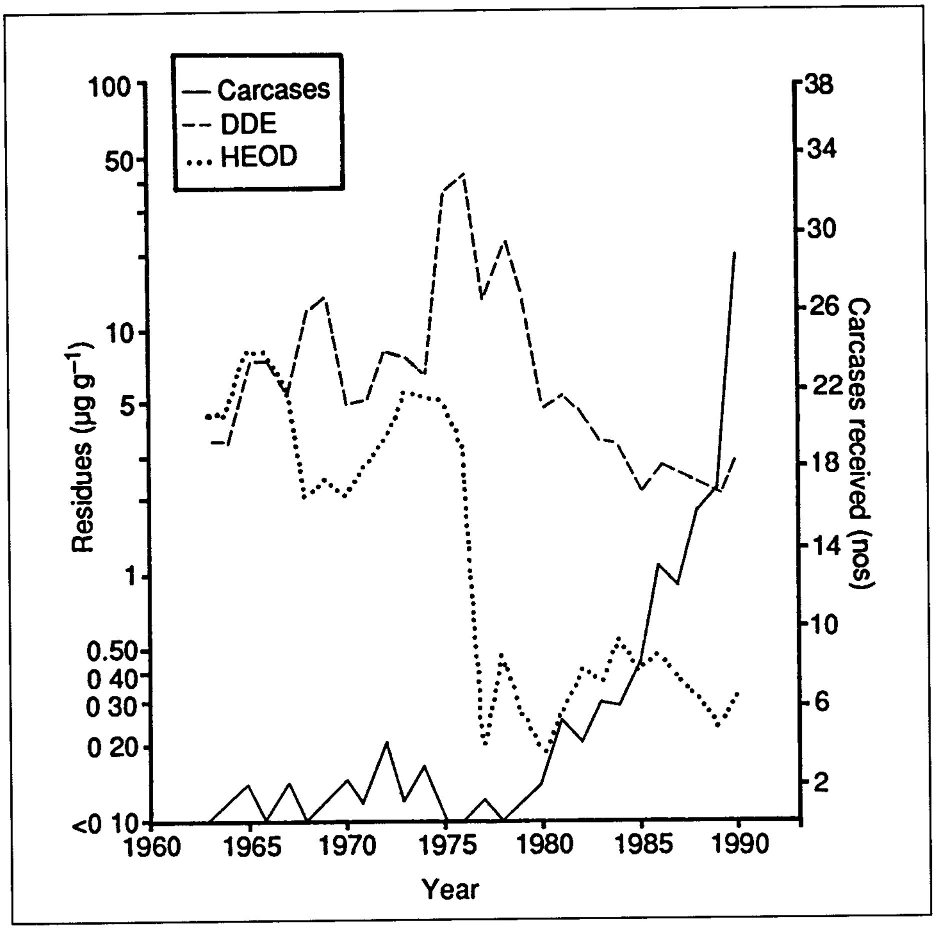


Figure 42 Numbers of sparrowhawk carcases received from eastern England, 1963–90, together with trends in the levels of DDE and HEOD found in their livers For both chemicals, lines show 5-year moving geometric means The increasing numbers of carcases received for study reflected the recovery of the sparrowhawk population in the region

year of renewed nesting in the area, following increased sightings in the region as a whole Over the next 11 years, when all the woodland was searched annually, nest numbers increased progressively from 17 in 1980 to 96 in 1990 (Figure 43), a mean growth rate of 20% per year By 1990, some areas of vacant habitat still remained, making further increase seem likely (Wyllie & Newton 1991)

Over the years 1980–88, based on a capture/recapture procedure, the annual survivorship of breeders was estimated at 76±SE 6% for males and 74±SE 4% for females (sex difference was not significant) This survivorship was high compared to that in two areas from which estimates had previously been obtained for females of 65±SE 3% and 62±SE 3% respectively (Wyllie & Newton 1991) These figures thus indicated that, during 1980–88, mortality in the Rockingham area was no longer greatly enhanced by pesticide contamination

Over the years of increase, breeding success in Rockingham gradually improved from an average of about 1 8 young per clutch in 1980 to an average of 2 9 in

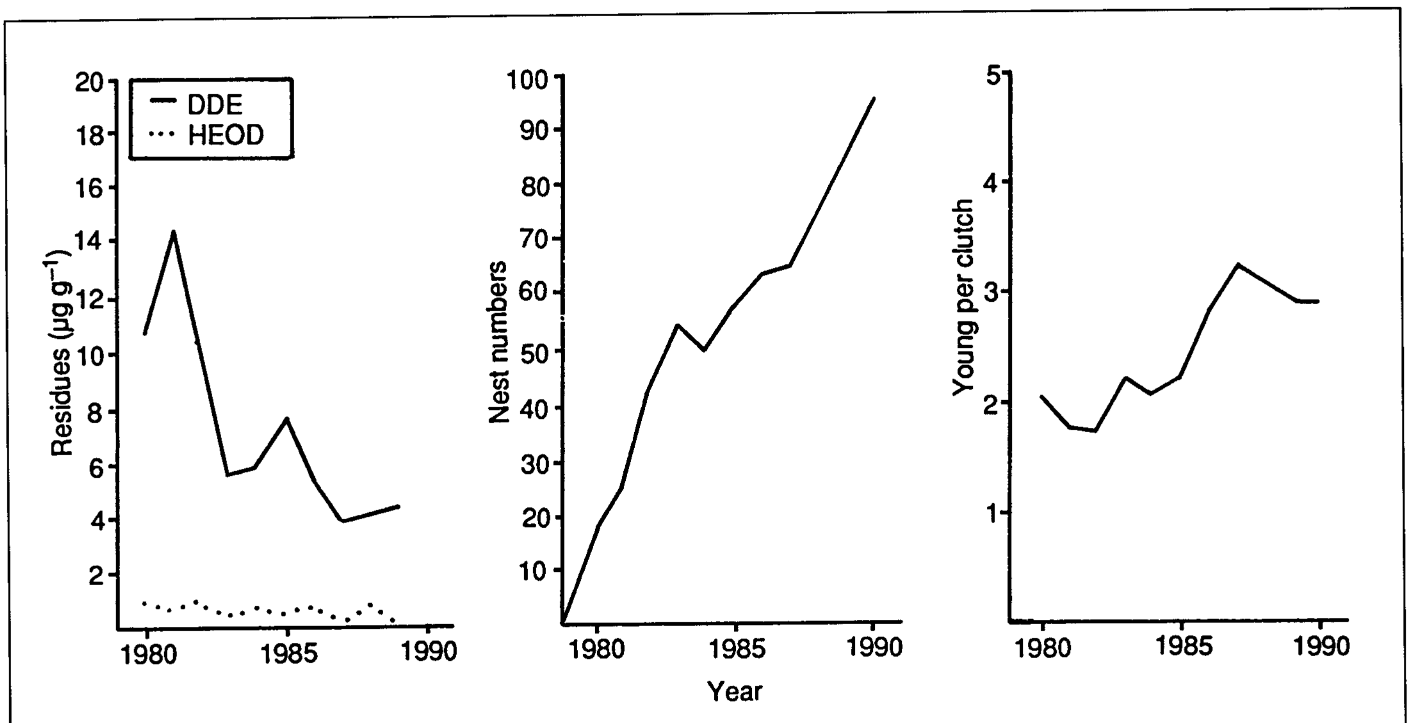


Figure 43 Trends in organochlorine levels, sparrowhawk nest numbers, and breeding success , Rockingham Forest,1979–90 Organochlorine levels (HEOD and DDE) were measured in addled eggs, and are expressed as µg g⁻¹ wet weight

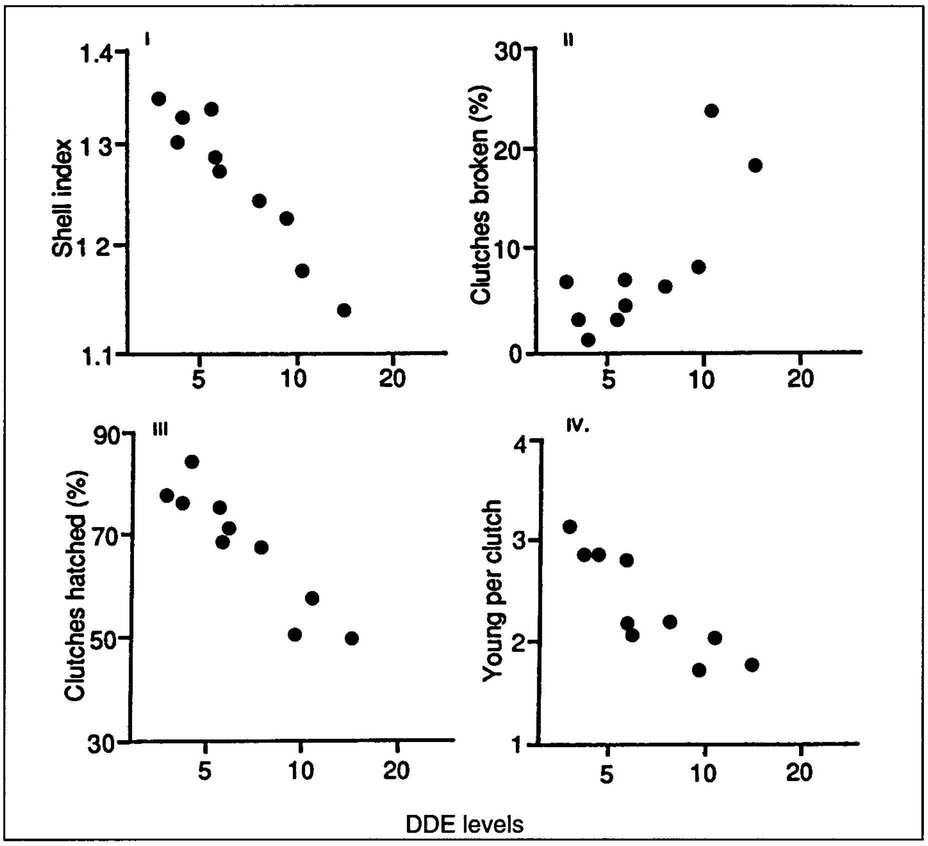


Figure 44 Relationships between annual mean DDE level (log scale) in addled eggs (μg g^{-1} wet weight) and (i) mean shell thickness index (measured as shell weight (mg shell $length^{-1}$ x breadth (mm)), (ii) % of clutches which failed through egg breakage, (iii) % of clutches which hatched, and (iv) mean number of young per clutch Significance of correlations (i), DDE vs shell index, r = –0 968, P<0 001, (ii) DDE vs % clutches broken, r = 0 906, P<0 001, (iv) DDE vs mean number young per clutch, r = –0 804, P<0 01

1990 (Figure 44) This improvement was due mainly to events at the egg stage to increases in the proportions of nests in which eggs hatched, and in the proportions of eggs per nest which hatched Throughout, some eggs were broken, while others failed to hatch after being incubated full term Most of the latter were light in weight, having lost excess moisture through a thinned shell Under a binocular microscope, faint hair-line cracks were often visible in the otherwise intact shells

Over the same period, DDE levels in unhatched eggs from the area continued to decline (as in carcases in the 1980s, Figure 42) Using the annual means, significant correlations emerged between the geometric mean DDE level and the mean shell index (negative), the percentage of clutches that were broken (positive), the percentage of clutches (or eggs) that hatched (negative), and the mean productivity (young per nest, negative) (Figure 44) These findings were consistent with the proposed causal chain of events, beginning with reduced DDT use, and leading to reduced DDE contamination of the birds, reduced shell thinning and egg breakage, improved hatching success, and increased productivity

During the study period, HEOD levels in unhatched eggs also declined slightly (Figure 43) The mean annual HEOD levels showed a negative relationship with hatching success and overall breeding success (young per clutch), but these relationships disappeared in a multiple regression analysis, after allowing for the effects of DDE Over the years, PCB levels showed no significant trend and no relationship with any aspect of breeding success Hence, DDE was the only chemical of those examined which was firmly implicated in breeding failure, a result consistent with earlier findings for this species elsewhere in Britain (Newton 1986)

The general conclusion was that the recovery of the sparrowhawk population was mainly dependent on declining HEOD contamination, with a resulting improvement in survival In the earlier years of increase, breeding success was still depressed by DDE, but it improved during the 1980s, as DDE contamination declined The study provided a good example of a recovery in a wild animal population after a decline in environmental pollution

I Newton and I Wyllie

References

Newton, I. 1986 *The sparrowhawk* Calton Poyser

Wyllie, I. & Newton, I. 1991 Demography of an increasing population of sparrowhawks *Accipiter nisus Journal of Animal Ecology* In press

Recolonisation of disturbed heathland by reptiles and amphibians

(This work was partly funded by British Petroleum)

The oil extracted from the Dorset oilfields is pumped to the oil refinery on Southampton Water along a pipeline that was laid in 1988 At certain locations in Dorset, the route of the pipeline (22 m wide) crossed areas of heathland that were the known habitat of all six species of endemic British reptiles, including the two rarest – the smooth snake (*Coronella austriaca*) (Plate 16) and sand lizard (*Lacerta agilis*) (Plate 17)

At one site in Wareham forest, the pipeline route effectively bisected an area of both wet and dry heath and, as a result, gave an opportunity for studying (i) how quickly the reptiles that inhabited the heathland either side of the pipeline route would recolonise the disturbed area, and (ii) whether the disturbed and exposed area of the pipeline would act as an effective barrier preventing reptiles crossing from one side to the other In order to answer these questions, we needed to know the distribution and relative abundance of the reptiles on the undisturbed heathland either side of the

Plate 16. Adult smooth snake on heathland in Wareham Forest

pipeline route. Also, the recolonisation of the disturbed area by heathland plants was monitored, as vegetation cover was considered an important factor in determining when the disturbed area would be suitable for reptiles.

To date, the distribution and relative abundance of reptiles found on the pipeline route and on equivalent widths of heathland adjacent and parallel to it have been estimated each year between May and September, using a grid of 150 corrugated steel tins (refuges) covering a total area of about 2.5 hectares. The vegetation cover, height and species composition of 42 quadrats from both the pipeline route and the adjacent heathland were determined each autumn, using a modified Braun-Blanquet scale, where 1 represents over 10% vegetation cover, 2 10–25%, 3 26–50%, 4 51–75%, and 5 over 75%.

Plate 17. Basking male sand lizard at the Arne G Well site

During the two years following the laying of the pipeline, neither the percentage vegetation cover nor the species composition of the undisturbed heath changed significantly (Table 12). On the pipeline route, however, the proportion of bare ground per quadrat decreased between 1989 and 1990, whilst the percentage cover of heathland plants, principally heather (*Calluna vulgaris*) and dwarf furze (*Ulex minor*), increased. This increased cover was also reflected in the height of the vegetation, which changed from 2–9 cm in 1989 to 5–30 cm in 1990. Excluding the trees, the vegetation height on the undisturbed heathland was 22–95 cm.

After compensating for the differences in the number of site visits each year, the number of sightings of all reptiles, except the sand lizard and common lizard (*Lacerta vivapara*), increased on the heathland adjacent to the pipeline route between 1989 and 1990. The most striking increases were seen in the numbers of smooth snakes, grass snakes (*Natrix natrix*) and slow worms (*Anguis fragilis*) (Table 13). No common toads (*Bufo bufo*) were found on the heathland in either year.

Table 12. Vegetation composition and cover. Mean values derived from a modified Braun-Blanquet scale (heathland N=28; pipeline N=14)

	Heathland 1989		1990		Pipeline 1989		1990	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bare soil	1.5	1.3	1.4	1.2	3.6	1.0	2.5	0.6
Moss	1.9	0.9	2.0	1.1	1.0	0.8	1.5	0.5
Purple moor-grass *(Molinia caerulea)*	1.1	1.0	0.9	0.7	0.4	0.5	0.3	0.5
Fiorin *(Agrostis stolonifera)*	–	–	–	–	2.7	0.7	3.4	0.7
Bristle agrostis *(Agrostis curtisii)*	0.2	0.6	0.2	0.4	0.1	0.3	0.1	0.4
Red fescue *(Festuca rubra)*	–	–	–	–	0.3	0.5	–	–
Heather *(Calluna vulgaris)*	3.6	1.5	3.9	1.3	0.4	0.5	1.0	0.6
Bell-heather *(Erica cinerea)*	0.9	0.6	1.0	0.3	0.1	0.3	0.1	0.3
Cross-leaved heath *(Erica tetralix)*	0.4	0.8	0.4	0.6	–	–	–	–
Dwarf furze *(Ulex minor)*	1.3	0.7	1.1	0.7	0.5	0.5	0.8	0.4
Sheep's sorrel *(Rumex acetosella)*	–	–	–	–	0.3	0.5	0.2	0.4
Pine *(Pinus* spp.)	2.2	1.5	2.2	1.3	–	–	0.1	0.3
Cladonia spp.	1.1	0.7	1.4	0.6	–	–	–	–
Bracken *(Pteridium aquilinum)*	0.7	0.9	0.7	0.9	–	–	–	–
Gorse *(Ulex europaeus)*	–	–	0.2	0.5	–	–	–	–

Table 13. Reptile and amphibian sightings. Mean number of sightings per site visit and total number of sightings (TN) per year (25 site visits made in 1989, four in 1990)

	Heathland 1989		Heathland 1990		Pipeline 1989		Pipeline 1990	
	Mean	TN	Mean	TN	Mean	TN	Mean	TN
Sand lizard (*Lacerta agilis*)	116	29	0.95	40	0.08	2	0.26	11
Common lizard (*Lacerta vivipara*)	0.48	12	0.36	15	–	–	–	–
Slow worm (*Anguis fragilis*)	0.20	5	0.71	30	–	–	–	–
Smooth snake (*Coronella austriaca*)	0.16	4	2.17	91	–	–	0.02	1
Grass snake (*Natrix natrix*)	0.04	1	0.14	6	–	–	0.05	2
Adder (*Vipera berus*)	0.04	1	0.05	2	–	–	–	–
Common toad (*Bufo bufo*)	–	–	–	–	0.68	17	1.05	44

On the pipeline route, there was a total of 19 sightings of just two herpetofauna species, the sand lizard and the common toad, during 1989. In 1990, the total increased to 58 sightings of four species – the sand lizard, smooth snake, grass snake, and common toad. In both years, the highest proportion of sightings was of common toads. Haapanen (1974) described site tenacity in the behaviour of the common toad, and the high figures recorded were almost certainly multiple observations of a few individuals.

All the sightings of hatchling sand lizards (five) during 1990 were on the pipeline route, as were five of the 28 adult female sightings, suggesting that the exposed sandy areas of the route may have been used as sites for egg laying.

The distribution of reptiles in the heathland adjacent to the pipeline route and sightings of some herpetofauna species on the route indicate that it did not form a barrier to the movements of sand lizards, smooth snakes, grass snakes, or common toads. It is also interesting to note that the increase in numbers of both species and total sightings coincided with the increase in vegetation height and cover between 1989 and 1990.

The monitoring of the recolonisation of the pipeline route in Wareham forest will continue during 1991.

C J Reading

Reference

Haapanen, A. 1974. Site tenacity of the common toad, *Bufo bufo* (L.). *Annales Zoologici Fennici*, **11**, 251–252.

Genetic determination of caste in the red ant

A major unresolved question in social biology is the occurrence of multi-queened (polygynous) ant colonies. Many ant species are organised into nests where several queens seemingly co-operate in the production of reproductives (queens and males) and the sterile female workers that care for them. One way in which a queen could increase her fitness is to behave parasitically by producing only reproductives and no workers. These queens would rely on the workers produced by other queens in the colony to tend their reproductives. If a gene arose that promoted this behaviour, it would spread rapidly and destabilise colony structure as the ratio of queens to workers increased. To explain the polygynous habit, therefore, we need to understand why parasitism does not appear to have evolved.

Hamilton (1972) suggested that parasitism may be suppressed because the members of a colony are very closely related. Queens would then not increase their fitness by becoming parasitic; it would be in their own interests to co-operate in maximising the output of their colony because they share many genes with other members. Several studies have shown, however, that levels of relatedness in polygynous ant colonies are no higher than relatedness between nests. As polygyny in ants is a widespread and apparently stable phenomenon, either genetic or behavioural counter-strategies to parasitism must have evolved.

Both queens and sterile workers are produced from fertilised diploid eggs and, therefore, the mechanisms which control the caste of ant (queen or worker) into which a diploid egg develops are the key to understanding the stability of polygynous colonies. Most studies of both monogynous and polygynous ants, and other social Hymenoptera, have favoured an environmental, rather than a genetic, control of caste (Brian 1979). Indeed, in a recent review of caste determination in the ants, Holldobler and Wilson (1990) state that '... allelic differences almost never separate the female castes of a colony, even to the extent of slightly biasing individuals to develop into one caste as opposed to another'. In the red ant (*Myrmica rubra*), however, we have evidence for a genetic determination of caste: heterozygosity at a queen-determining locus favours queen as opposed to worker production, and may act as a buffer against the evolution of parasitic behaviour, so stabilising the structure of polygynous colonies.

Ants from three populations in Dorset were examined for a polymorphism in the enzyme malate dehydrogenase (MDH), detected by electrophoresis on iso-electric focusing gels, which separate proteins with different iso-electric points (pI). Three phenotypes were detected (Plate 18): 'fast' (F), 'slow' (S) and 'fast/slow' (FS). These are assumed to represent, respectively, two homozygotes for alleles coding for MDH polypeptide subunits with different electrophoretic mobilities, and the heterozygote containing both alleles. Table 14 shows the frequency of these

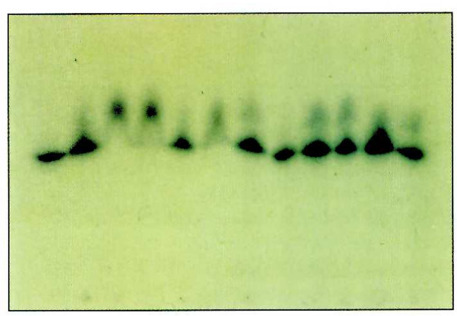


Plate 18. Malate dehydrogenase phenotypes in the red ant, from a nest at Kimmeridge, showing the association of heterozygosity with caste. Lanes 1–6 are workers and all are homozygotes, either for the fast allele (lanes 3, 4 and 6) or the slow allele (lanes 1, 2 and 5). Lanes 7–12 are queens and all are heterozygotes, except lane 8

Table 14 The distribution of malate dehydrogenase phenotypes in different castes of the red ant from populations in Dorset The number of heterozygous queens is that expected from the frequencies of the fast and slow alleles, whereas the workers show a significant deficiency of heterozygotes In the social insects, males are haploid and so no heterozygotes should be detected Occasionally, diploid males are produced, however, as revealed by the solitary male heterozygote found in the Encombe population (CP Chapman's Pool, EN Encombe, KM Kimmeridge m=males, w=workers, q=queens)

	Phenotype		
	SS	FS	FF
CPm	26	0	4
CPw	42	2	22
CPq	10	4	1
ENm	20	1	9
ENw	73	0	65
ENq	54	6	0
KMm	6	0	0
KMw	59	0	25
KMq	1	5	0
TOTAL m	52	1	13
TOTAL w	174	2	112
TOTAL q	65	16	1

phenotypes The striking aspect of the results is that there are almost no heterozygous workers (2 out of 288), but there are heterozygous queens (16 out of 82) The deficiency of heterozygotes in the workers can be explained if the MDH alleles are markers linked to a queen-determining locus If larvae are heterozygotes at this locus, then they can only develop into queens, whereas homozygotes at this locus can develop into queens or workers This effect appears to be associated with heterozygosity at a single locus, or group of loci, linked to MDH, rather than with heterozygosity in general, as previous studies of esterase variation in these red ant populations have revealed no association of caste with electrophoretic phenotype (eg Pearson & Child 1980)

Queen determination through heterozygosity can be seen as a mechanism that prevents parasitism in polygynous nests where the relatedness of queens is low The reason is that a queen-determining mechanism based on heterozygosity does not confer an advantage on the offspring of any of the three genotypes in a two-allele system (On average, given equal allele frequencies and random mating, SS, FS and FF genotypes all produce heterozygotes and homozygotes in equal proportions) The constant potential for the evolution of parasitism through genetic queen determination perhaps accounts for the apparent redundancy represented by the multiplicity of other caste control mechanisms, such as the manipulation of diet and the biting of larvae by adult workers, observed in *Myrmica* species

The fact that a ubiquitous unspecialised species such as the red ant exhibits a degree of genetic caste determination could mean that these mechanisms in the social Hymenoptera have been underestimated It would seem that environmental rather than genetic controls are better suited to the 'fine tuning' of colony output in response to environmental fluctuations This conclusion may, however, simply be a reflection of the lack of suitable genetic markers with which to detect genetic control of caste (enzyme polymorphisms being rather rare in the social insects), and further genetic controls may be revealed as the techniques for detecting genetic polymorphisms, such as DNA fingerprinting, become more sensitive

A F Raybould and B Pearson

References

Brian, M.V. 1979 Caste differentiation and division of labour In *Social insects*, edited by H R Herman, vol 1, 121–222 London Academic Press

Hamilton, W.D. 1972 Altruism and related phenomena, mainly in social insects *Annual Review of Ecology and Systematics*, **3,** 193–232

Holldobler, B. & Wilson, E.O. 1990 *The ants* Berlin Springer

Pearson, B. & Child, A.R. 1980 The distribution of an esterase polymorphism in macrogynes and microgynes of *Myrmica rubra* Latreille *Evolution*, **34,** 105–109

Community ecology

Research on community ecology in ITE, and other parts of NERC, aims to understand the complex factors and processes affecting interacting populations of plants and animals. The work combines long-term field studies of communities with manipulative experiments and mathematical modelling.

An area of increasing concern is the effect of changing land use on assemblages of organisms. In particular, the marked changes in agriculture in recent years have prompted investigations into modelling the environmental consequences of set-aside and farm woodlands, and the effects of grazing pressure on plant successions. Whereas previous emphasis has been given to the effects of increased grazing, there is now considerable interest in the effects of reduced pressures, particularly in the uplands where numbers of hill sheep are likely to decline. Coupled with these studies of impacts on plant successions are those concerned with herbivore ecology, especially the interactions between species. For example, in many Scottish hill areas, a reduction in sheep numbers is likely to be compensated for by increases in the distribution and abundance of red deer (*Cervus elaphus*). The ways in which herbivores such as sheep and deer select plant species and the different foraging strategies they adopt are two areas of current study under the Joint Agriculture and Environment Programme. The results of these and other projects will enable us to develop more reliable models for predicting the consequences of changes in grazing pressure on plant succession.

The projects described in this Report show the breadth of ITE's work on community ecology. The research on grazing reductions on upland vegetation illustrates the complex nature of plant succession and the difficulty involved in making reliable predictions from existing knowledge. The vegetation of Great Britain is currently being reclassified, and Tablefit is an elegant and useful model which enables us to classify vegetation types automatically and reliably. The work on nitrogen examines the effects of increasing fertiliser levels on the species richness of grasslands and the interaction between nitrogen and soil moisture, whilst the study on weevils is aiming to improve the methods of identification and to collate data on their distribution and ecology, with special reference to endangered or notable species.

Effects of ending livestock grazing on upland vegetation

(This work was funded by the Department of the Environment)

British uplands have long been used for free-range grazing by domestic livestock. At present sheep are the most numerous species, but in past years cattle, horses, goats and even geese were depastured on hill ground. These grazing pressures have modified the plant communities, making swards shorter and curtailing regeneration of shrubs and trees, so that vistas have remained open.

Large changes in the grazing of uplands are now likely. There is pressure to reduce the sizeable subsidies paid to farmers for sheep and cattle put to the hill, the aim is to lower agricultural surpluses and prevent unfavourable changes in vegetation from overstocking. However, there is also concern that reducing subsidies may cause livestock to be withdrawn completely from some upland tracts, and that the resulting 'wilderness' will be considered unsightly by most visitors.

Therefore, during 1990, ITE made a study of upland vegetation protected from domestic livestock in order to be able to forecast what plant communities would develop if stocking ceased over wide areas. Vegetation protected from grazing is at present scarce, but with help from bodies such as the Forestry Commission, the Nature Conservancy Council, the National Parks and the National Trusts we collected data from 74 sites.

The sites were broadly of two types, tracts and exclosures. Tracts were areas that had become inaccessible or unavailable to livestock because of such events as afforestation or reservoir construction, they mostly lacked 'control' areas, ie similar ground still being grazed. Exclosures were typically small areas (*c* 1000 m^2) within grazed uplands, 'controls' were more often available, although sometimes the whole of a feature of interest, such as a limestone outcrop, had been protected (Plate 19).

For each site, we determined how long there had been protection from large herbivores, and we recorded vegetation composition and height. We checked for any colonising shrubs or trees, for death of dominant plant species, and for evidence of former burning.

A most noticeable finding was the variation in compositional trends. In general, heather (*Calluna vulgaris*) increased in cover, as expected, but at some sites with control plots there was less heather in the protected than in the grazed vegetation (Figure 45). At 19 sites, heather had 1–25% cover in the grazed control so the initial cover was assumed to be low, only at 11 sites (class B sites) was there a substantial increase in cover in the protected area. For the other eight sites (class A), we

Plate 19. Spread of heather and tall grass inside a 31-year-old exclosure at a limestone outcrop at Inchnadamph NNR, Sutherland

believe the spread of heather was being prevented by the dense growth of grasses and by a failure of seedlings to become established. In one exclosure where trends had been closely monitored over 30 years, the few ericoid plants initially present had grown into full-sized bushes which then degenerated, heather taking 20 years to become extinct, and bell-heather (*Erica cinerea*) 12 years.

Other features of protected vegetation are listed in Table 15. Tracts of moorland from which domestic livestock had been withdrawn were often being utilised by red and roe deer (*Cervus elaphus* and *Capreolus capreolus*), especially in Scotland. Deer densities were usually much lower than the typical stockings of sheep and cattle, but, even so, the impact on preferred food species, especially shrubs and trees, could have important consequences.

Table 15. Characteristics of upland vegetation from which domestic livestock have been withdrawn

Increased utilisation by red and roe deer (*Cervus elaphus* and *Capreolus capreolus*)
Colonisation by trees and shrubs, eg birch (*Betula* spp.), Scots pine (*Pinus sylvestris*), rowan (*Sorbus aucuparia*)
Reduction in cover of grasses, sedges and rushes due to spread of heather and other ericoids
Increased height of vegetation
Greater proportions of dead herbage and dead plants visible in swards
Spread of lichens, eg *Cladonia impexa*, especially where plant growth is restricted by altitude or wet soils
Decline in number of vascular plants in areas of 1–10 m^2
Increased flowering of taller-growing herbs

Colonisation by trees and shrubs was found to have occurred at over 50% of the sites visited. However, often only a few scattered individual bushes were observed, and regeneration was considered prolific at less than 10% of the sites. Several factors were reducing or preventing colonisation, including (i) a lack of seed sources, (ii) lack of niches for establishment, (iii) grazing by deer or small mammals (hares, rabbits), and (iv) exposure and waterlogging which checked sapling growth. On some such sites, there were many dead or moribund small trees. Figure 45 gives an example of variable colonisation caused by the scattered positions of seed sources.

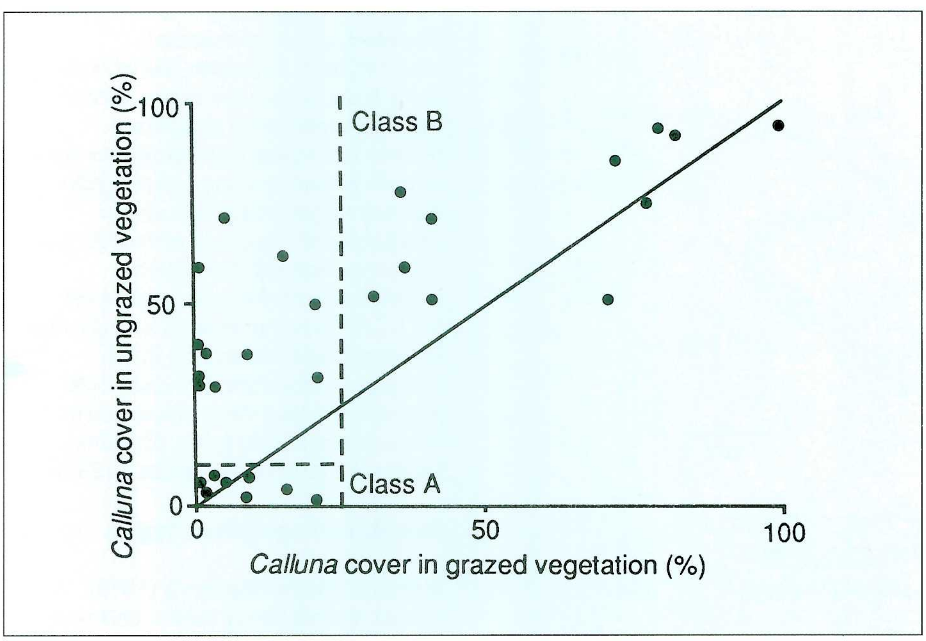


Figure 45. Response of heather to protection from grazing. The solid line links positions with equal cover in protected and control vegetations; classes of response discussed in the text are marked

The graminoids which thrived on protection from grazing were mainly taller-growing species, such as tufted hair-grass (*Deschampsia cespitosa*), wavy hair-grass (*D. flexuosa*) and red fescue (*Festuca rubra*). Species reduced in cover (Table 15) included common bent-grass (*Agrostis capillaris*), sheep's fescue (*Festuca ovina*) and heath rush (*Juncus squarrosus*). Some acidic grasslands were found to have been surprisingly resilient to change, eg swards dominated by cotton-grass (*Eriophorum vaginatum*) and mat-grass (*Nardus stricta*). Possible reasons could be the long lifespan of individual clones, and the relatively large above-ground standing crops which allow few niches for incoming species to establish Again, there was considerable variability in the observed trends, which we consider to be a result of the variable incidence of the many controlling factors, and, for small exclosures, of chance occurrences At the Moor House National Nature Reserve (NNR), for example, two exclosures at similar altitude on similar soil had cotton-grass dominant initially, one we categorised as a class A site in Figure 45, the other as class B, heather having spread markedly

The increases in height of vegetation, the flowering of taller-growing herbs, and the proportion of dead material present in the swards (Table 15) are all a *direct result of herbage no longer* being eaten in large amounts There is also an effect of changes in composition, more productive tall-growing species *replacing shorter species If herbage is* not eaten, it will inevitably decay sooner or later In a low-stature, long-lived woody plant like heather, the dead shoots and branches steadily accumulate *in situ*, and at several sites 10% of the total plant cover was estimated to be dead heather This accumulation has implications for management there is a greater fire risk, and, if moorlands are being managed for grouse shooting, more frequent *burning will be necessary to provide* young nutritious heather

There are several benefits from the cessation of livestock grazing, particularly for conservation Some attractive herbs which at present rarely flower because of grazing can produce fine displays of blooms, and the late-summer purple of lightly grazed heather-dominant vegetation is widely admired Plants such as lichens, dwarf birch (*Betula nana*) and many tall herbs will spread Also, diversity will increase in larger units of area, our finding of a decline in species richness applied to small quadrats (Table 15), but in larger tracts divergent trends can produce a more varied mosaic Thus, parts of an upland may be colonised by trees and scrub (Figure 46), most of the area will support dwarf-shrub heath, while patches of grassland will remain on rock outcrops, on shallow soils, and where herbivores concentrate

Our sites were widely spread from *south-west England to northern* Scotland, and covered a range of altitude and soil types It is apparent that many different successional pathways can occur and that there is considerable regional variation The study has highlighted the need for experiments with controlled levels of stocking and for long-term observations to provide information on the timescale of the successions This knowledge is necessary for the proper management of upland vegetation, and may be used for the setting of policy prescriptions for Environmentally Sensitive Areas, Heritage Areas, National Parks, and Nature Reserves

D Welch and R H Marrs

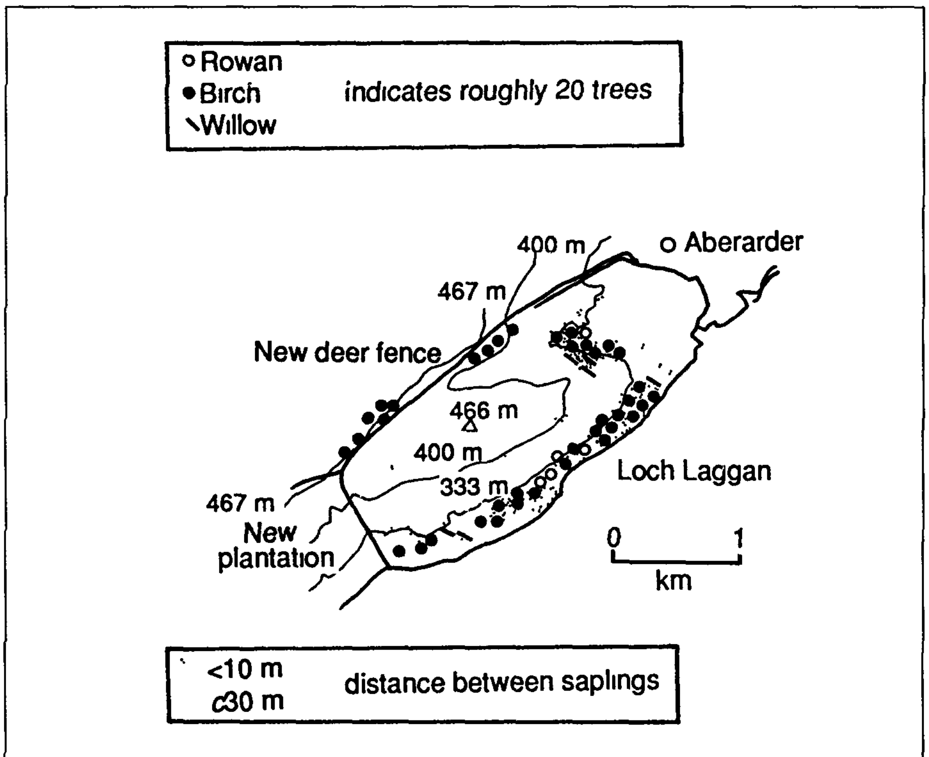


Figure 46 Zonation of tree colonisation at Creag Meagaidh NNR, Inverness-shire, in a block of moorland ungrazed by sheep or deer since 1986 Most saplings are birch

Tablefit and the identification of British vegetation types

(This work was partly funded by the Nature Conservancy Council)

Environmental consultants, nature conservation managers, field naturalists and many others require a common language to talk about habitats in the natural world At the broadest scale, ecologists and biogeographers assign ecosystems to biomes, such as tundra, tropical savanna, and cool/temperate broadleaved forest At a local scale, and particularly in a man-modified landscape such as that of Europe, a more precise terminology is required

Numerous attempts have been made to construct such a terminology for Britain and nearby parts of Europe, mostly based on the classification of vegetation In central Europe, a system of Latin names for vegetation types has been developed, comparable to the Linnaean system of binomial nomenclature However, vegetation and habitat are not the same similar vegetation can grow in different habitats, and historical differences such as past cultivation can produce quite different vegetation in a basically similar habitat Because of this fact and because some habitats have no vegetation, a recent enumeration for the CORINE programme (Co-ordinated Environmental Information in the European Community) is using both physical and vegetational features to characterise habitat types (Devillers, Devillers-Terschuren & Ledant 1991)

Standard vegetation types

In Britain, we use Tansley's (1939) classic description of natural and semi-natural vegetation His account is now out-of-date, and is being superseded by a series of volumes entitled *British plant communities*, which contain full descriptions and tables of vegetation types (Rodwell 1991). The vegetation types recognised by Rodwell have been used widely by the Nature Conservancy Council and are likely to become a national standard.

There are several problems in using a standard set of vegetation types, of which the most serious is the time taken to become familiar with the system. An ecologist or an environmental consultant will often want a quick and definite answer to the question 'What type of vegetation is this?', and will be deterred from using a system of classification if access is slow or the answer uncertain.

Tablefit – the basis of an expert system

Tablefit is a FORTRAN computer program designed to make an automatic diagnosis of vegetation types. It has been written with *British plant communities* in mind, but can equally be applied to vegetation anywhere in the world. The program measures goodness-of-fit between observed vegetation and descriptions of standard types in an association table. A prototype of Tablefit has already been published (Hill 1989). The program has now been enhanced to provide a fully operational diagnostic expert system for identifying British vegetation types. Not only does it identify the type according to the British system, but a cross-reference is provided, so that the CORINE (European Community) type is also identified.

Vegetation in Monks Wood NNR

As an example of the use of Tablefit, we consider the vegetation in the photograph of Monks Wood (Plate 20). In the foreground of this picture, five species can be seen (Table 16). This short list of species cannot be regarded as a complete enumeration for the site, but Tablefit can still give an indication of the likely vegetation type if the species are entered in descending order of abundance.

From the input data, Tablefit identifies the vegetation as belonging to the broad European (CORINE) type 'Non-alluvial ashwood'. Although no ash trees (*Fraxinus excelsior*) are visible in the picture, they are abundant in Monks Wood. Indeed, in the absence of recent felling, they would probably be the dominant tree species. Thus, the identification is not far-fetched. In the system of *British plant communities*, the stand falls clearly into the ash/maple/dog's mercury (*Fraxinus excelsior/Acer campestre/Mercurialis perennis*) woodland. According to Tablefit, it fits the generic description

Plate 20. Spring vegetation in Monks Wood NNR; Tablefit can be used to identify the vegetation type to which the woodland belongs, using little more information than a list of the species visible in the foreground

Table 16. Species, listed in descending order of abundance, visible in the foreground of the photograph of Monks Wood NNR; the canopy tree, field maple, is visible mainly as stems

English name	Scientific name
Field maple	*Acer campestre*
Bluebell	*Hyacinthoides non-scripta*
Hazel	*Corylus avellana*
Dog's mercury	*Mercurialis perennis*
Bramble	*Rubus fruticosus*

of the woodland type better than that of any subcommunity; the reason is the incomplete species list, taken merely from a photograph.

The two most likely subcommunities to fit the picture from the incomplete information available are the primrose/ground ivy (*Primula vulgaris/Glechoma hederacea*) subcommunity and the common ivy (*Hedera helix*) subcommunity. In fact, the first of these possibilities is correct; Monks Wood has abundant ground ivy (not, however, visible in the picture) and almost no common ivy. It formerly had abundant primroses, but these have now been eliminated by deer grazing.

Tablefit has been tested on a wide variety of vegetation and generally performs well. Where a complete species list is available, the program can be relied on to give the right answer, provided that the vegetation corresponds to a type included in *British plant communities*. The user requires no special training, only an ability to identify plants. Reliable, automatic identification of plant communities has become a reality.

M O Hill

References

Devillers, P., Devillers-Terschuren, J. & Ledant, J.P. 1991. *Habitats of the European Community.* (CORINE biotopes technical handbook 2.) Brussels: Commission of the European Communities.

Hill, M.O. 1989. Computerized matching of relevé s and association tables, with an application to the British National Vegetation Classification. *Vegetatio*, **83**, 187–194.

Rodwell, J.S., ed. 1991. *British plant communities. Vol. 1. Woodlands and scrub.* Cambridge: Cambridge University Press.

Tansley, A.G. 1939. *The British islands and their vegetation.* Cambridge: Cambridge University Press.

Nitrogen fertilisers on old peat grasslands

(This work was funded by the Department of the Environment, the Ministry of Agriculture, Fisheries and Food and the Nature Conservancy Council, and conducted in co-operation with the AFRC Institute for Grassland and Environmental Research (IGER))

The area of unimproved grassland in lowland Britain has greatly diminished since 1945 (Fuller 1987). Grassland has been improved through the use of herbicides and fertilisers, and by reseeding with productive varieties of grasses and legumes. Much alarm has been expressed about the impact of these activities on the flora of old grasslands. The designation of Environmentally Sensitive Areas (ESA) as zones for management sympathetic to conservation interests, and the scheduling of Sites of Special Scientific Interest (SSSI) under the Wildlife and Countryside Act (1981) placed restrictions upon farmers regarding the use of fertilisers and other means of intensification. There was concern among the farming community that the levels fixed for allowable use of fertiliser should be realistic and compatible with economically viable production.

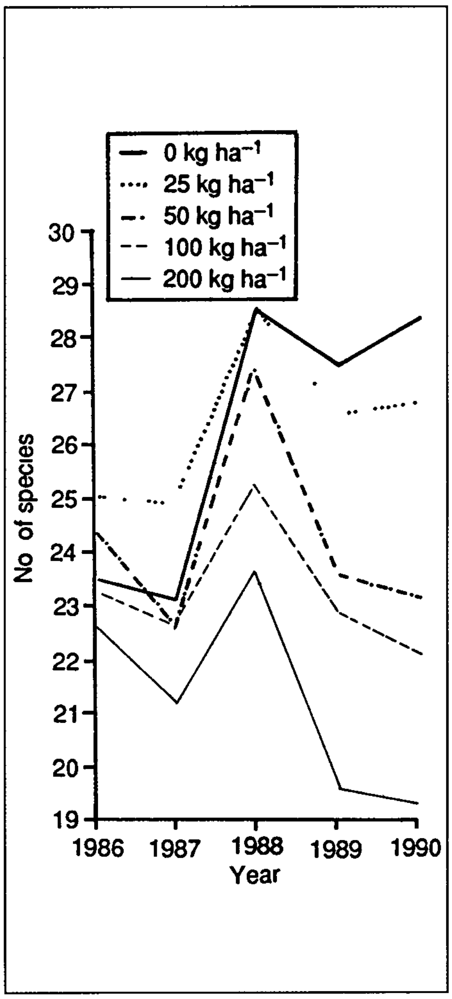


Figure 47 Mean number of species per quadrat for each treatment

Table 17 Simpson's index of plant diversity (I) for nitrogen fertiliser treatments at Tadham Moor, Somerset, in 1986, 1987, 1988, 1989 and 1990

Simpson's index $I = 1 - \sum_{i=1}^{k} p_i^2$

I	Nitrogen fertiliser applied (kg ha^{-1}) 0	25	50	100	200	F value and Significance
1986	0.930	0.918	0.934	0.929	0.924	0.855 NS
1987	0.941	0.931	0.935	0.918	0.918	3.405 P<10%
1988	0.928	0.915	0.911	0.908	0.868	9.144 P<0.5%
1989	0.939	0.930	0.912	0.901	0.868	32.447 P<<0.1%
1990	0.942	0.942	0.912	0.920	0.900	5.640 P<2.5%

The different interests of conservationists and agriculturalists found a focus on the Somerset Levels and Moors ESA, where a spirit of compromise led to a study being commissioned in 1986 at Tadham Moor, near Wedmore. ITE and IGER began an experiment into the effects of nitrogen fertilisers on the botanical composition and agricultural production of old grasslands on peat soils. Data were collected from 1986 to 1990, providing valuable comparison with the Park Grass Experiment at Rothamsted (Brenchley & Warington 1958, Thurston 1969). Five treatments of nitrogen fertiliser (0, 25, 50, 100 and 200 kg ha^{-1}) were applied annually, each replicated three times. The botanical composition in all plots was recorded in May each year, using 1 m^2 quadrats, and over 140 species were recorded in the five years in which the experiment has been running. The abundance of 35 species has been significantly affected by the fertiliser treatment in at least one year. After the quadrats had been recorded, the fields were cut for hay in early July, and bullocks were grazed until October. Phosphorus and potassium fertilisers were applied annually at levels calculated to replace the amount removed in the hay cut, but neither nutrient was applied to the control plots.

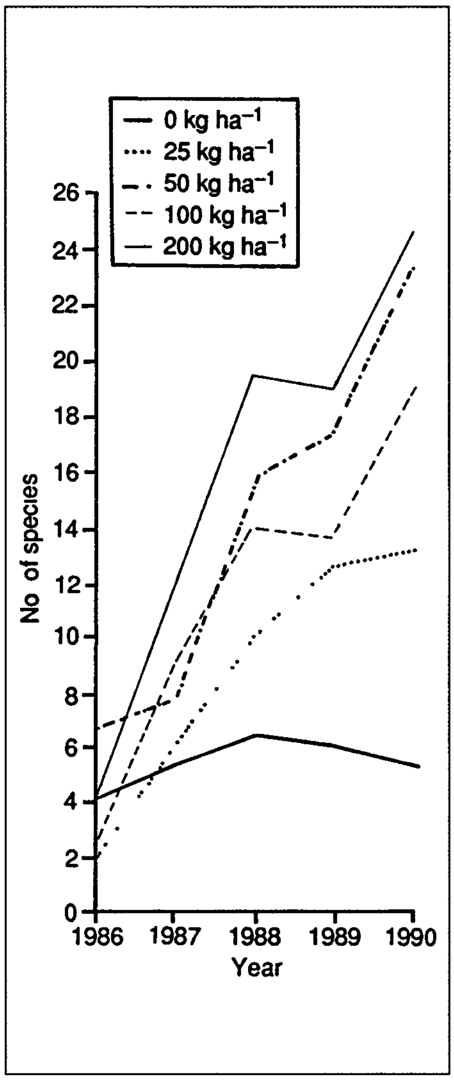


Figure 48 Mean percentage cover of perennial rye-grass in each treatment

The most marked effects of increasing fertiliser levels have been on the species richness of the grassland, expressed either in terms of the number of species per quadrat (Figure 47) or as Simpson's diversity index (Table 17). Both measures reflect a more species-poor sward in later years in those plots receiving the higher levels of nitrogen fertiliser (100 kg ha^{-1} and 200 kg ha^{-1}). This change reflects increased percentage cover of grasses, particularly perennial rye-grass (*Lolium perenne*) and Yorkshire fog (*Holcus lanatus*), in a much taller sward (Figure 48), where many low-growing herbs – buttercups (*Ranunculus* spp.), clovers (*Trifolium* spp.), self-heal (*Prunella vulgaris*) – and mosses have significantly declined. Not only does the composition of the grassland change, but also the production of flowers by many of the most attractive species of old wet meadows. Both marsh plume thistle (*Cirsium dissectum*) (Plate 21) and ragged robin (*Lychnis flos-cuculi*) have almost ceased to flower in plots receiving high levels of nitrogen fertiliser, where once they were abundant, and in 1990 only flowered frequently in the plots which received no fertiliser.

Fertiliser application is not the only factor affecting the distribution of plants in the plots at Tadham Moor. Although the land appears flat, there is considerable variation in microtopography. This variation and the proximity to drainage channels affect the water table in the plots. The analytical technique Canoco (ter Braak 1988) was used to ordinate species with respect to (i) the level of nitrogen fertiliser applied, and (ii) the position of the water table.

*Plate 22. Marsh marigold (*Caltha palustris*) – widespread in wet places, but increasingly rare in meadows. An example of the species of wetter sites*

An example of the ordination produced from the 1989 data demonstrates how soil moisture and nitrogen are inter-related (Figure 49). Species are distributed in response to water table, from upper left (those preferring drier sites) to lower right (those normally occurring in wetter sites, Plate 22). These species are also distributed along an axis of increasing fertiliser application, from upper right (species growing mainly in control plots) to lower left (species with high percentage cover in plots receiving 100 kg ha^{-1} or 200 kg ha^{-1} of nitrogen fertiliser). Those species most abundant in the fertilised plots (rye-grass, Yorkshire fog, common sorrel (*Rumex acetosa*), etc) are also absent or at low population levels in the wetter plots.

*Plate 23. Southern marsh orchid (*Dactylorhiza majalis* ssp. *praetermissa*) – widespread, but decreasing because of drainage. One of 14 species whose populations are being monitored in great detail at Tadham Moor*

Plate 21. Marsh plume thistle – typical of infertile, wet peaty meadows and local in Britain. It has ceased to flower in plots receiving high levels of fertiliser

By 1990, no species which had been common at Tadham in 1986 had been eliminated, although many had declined in cover and frequency in the quadrats (Plate 23). The long-term effect of fertiliser application, demonstrated on mineral soils at the Park Grass experiment, will be studied on the peat soils of Somerset. The rate at which intensively fertilised peat grassland reverts to its original composition, when nitrogen is no longer applied, is also being investigated by ITE and IGER in a second phase of the Tadham Moor experiment. This joint approach will provide both the farmer and conservationist with information about the

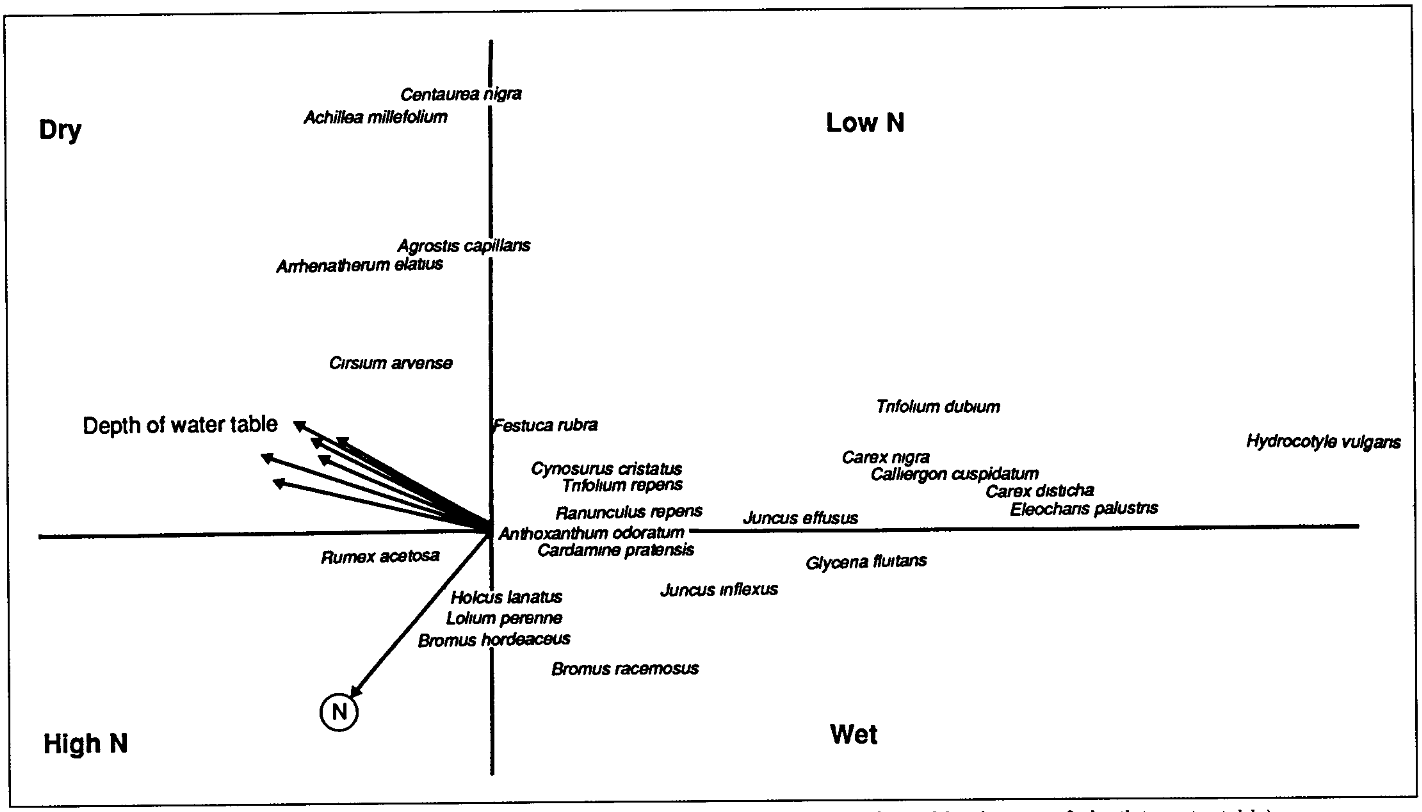


Figure 49 Results of a Canoco ordination where species are plotted in relation to environmental variables (nitrogen & depth to water table)

levels of nitrogen fertiliser which may be applied to species-rich grassland without any adverse effect It will also provide evidence on the rate at which previously fertilised grassland will gain species and revert to a community of conservation interest

J O Mountford

References

Braak, C.J.F. ter 1988 *CANOCO – a FORTRAN program for canonical community ordination by (partial) (detrended) (canonical) correspondence analysis (version 2 1)* (Technical report LWA-88-02) Wageningen Agricultural Mathematics Group

Brenchley, W.E. & Warrington, K 1958 *The park grass plots at Rothamsted 1856-1949* Harpenden Rothamsted Experimental Station

Fuller, R.M. 1987 The changing extent and conservation interest of lowland grasslands in England and Wales a review of grassland surveys 1930–84 *Biological Conservation*, **40**, 281–300

Thurston, J.M 1969 The effects of liming and fertilisers on the botanical composition of permanent grassland, and on the yield of hay In *Ecological aspects of the mineral nutrition of plants*, edited by I H Rorison Oxford Blackwell Scientific

British weevil fauna

In ecology generally, and more especially in community ecology, the accurate discrimination and naming of species are extremely important Failure to recognise the existence of several species in an investigation, or to determine them correctly, can lead to erroneous conclusions It is particularly important for commissioned research, eg in nature conservation and environmental impact assessments, that the identification of species is accurate Background information on the biology and distribution of species is also desirable for ecological studies, especially in the case of invertebrate animals Such information has been accumulated over many years in Britain and, although it can be of mixed quality, its existence has often proved useful as a basis for ecological studies

The term 'weevil' is applied to beetles of the superfamily Curculionoidea, though the Anthribidae and the Scolytidae (ambrosia and bark beetles) and Platypodidae are sometimes excluded The superfamily is the largest, in terms of species, in the animal kingdom With extremely few exceptions, all species are phytophagous and they include many well-known pests, such as the cotton boll weevil (*Anthonomus grandis*), on which a great deal of scientific work has been done Weevils are also important in the context of conservation, as the group contains many rare and interesting species Weevils contribute considerably to biological diversity in both the tropics and temperate regions

Over 600 species of Curculionoidea have been recorded from the British Isles The last monograph and major taxonomic treatise on the group is by Fowler (1891) Although the literature contains much scattered information, a modern treatment is urgently required Moreover, British work has tended to ignore, and has been overtaken by, major advances in this family in continental Europe

The work undertaken in ITE is not a major subproject, but one which is suitable for irregular, part-time work, and which attempts to capitalise on a long-standing interest of the subproject leader It has four main aims

i to establish a better basis for the identification of species by providing up-to-date dichotomous keys and accounts of additions to the British fauna,
ii to accumulate distribution records for later incorporation into designated Biological Records Centre schemes,

iii to improve knowledge of biology, particularly the range of foodplants utilised (thus linking into the Phytophagous Insects Data Bank),

iv to provide information on *Red Data Book* and National Notable species

The provision of identification keys has been a major activity Following the publication of illustrated keys to the 'orthocerous' groups (Figure 50) (Morris 1990), work is well advanced on the text for a handbook to the adelognathous (broad-nosed) species Some preparation for subsequent handbooks, three of which will be needed to complete the series, has also been done In the course of this work, species not previously recorded from the British Isles have been detected Preliminary accounts of the occurrence of *Rhynchaenus pseudostigma* and *Pelenomus zumpti* have been published, and more substantial papers are in preparation, as are checklists which incorporate the results of recent continental research In the past, erroneous records have been common, and several corrections have been made to the British list (eg Morris 1989)

The amateur contribution to studies of British weevils is substantial, and two semi-popular accounts of the group have been written for the guidance of new and inexperienced workers (Morris 1991a,b)

A formal distribution recording scheme covers only a small proportion of the British weevils Records are being accumulated in expectation of a comprehensive scheme or schemes being established soon Southern England is much richer in species than northern Scotland, and weevils have considerable potential for studying the impacts of global change The spread of *Ceutorhynchus picitarsis* is one example of a response to land use change, this was a scarce and uncommon species until recently, but its range and abundance have increased considerably as the result of widespread growing of oilseed rape The species is now a pest of the crop throughout eastern England

Some progress has been made in identifying foodplants and determining biological characteristics The discovery that *Apion waltoni* is a larval feeder in stems of its host, horse-shoe vetch (*Hippocrepis comosa*), has been published, but not followed up in any detail Comparative studies of *Dorytomus* species feeding on aspen (*Populus tremula*) showed that *D tortrix* (Plate 24) lays eggs predominantly in male catkin buds in autumn, whereas *D dejeani* (Plate 25) oviposits mainly in female catkins in very early spring *D affinis*, a rare species, also uses female catkins, but oviposits later than *D dejeani* Several other instances of phenology affecting the feeding of both adults and larvae are being explored

*Figure 50 A typical orthocerous (straight-antenna'ed) weevil (*Apion (Pirapion) atratulum*), male*

The phenomenon of 'skating' on the water surface, a locomotory feature of several semi-aquatic species, has been investigated in outline The behaviour seems to be an adaptation for avoiding adverse effects of wetting, and includes a series of 'righting' movements for appropriate orientation on the water surface

Plate 24. Dorytomus tortrix, *a weevil which feeds as a larva mainly in the male catkins of aspen*

In the *British Red Data Book* (Shirt 1987), 22 species of Curculionoidea are listed as endangered, 11 as vulnerable and 49 as rare (categories 1, 2 and 3 respectively), about 14% of the total British fauna. Of particular importance are the five British species of *Cathormiocerus*, because of their very limited European range, and a large proportion of our species of *Bagous*, a relict group also uncommon on the Continent. Most of the *Red Data Book* weevils occur in southern England, and Dorset is well situated for their investigation. These species, together with butterflies, Orthoptera, spiders and other species of conservation importance, will be considered by the Rare Invertebrates Research Group recently established at ITE Furzebrook. Some attention will also be given to National Notable species, information on which has been provided for the Nature Conservancy Council's review of Coleoptera.

Although ecological work based on a particular taxonomic group will always be ancillary to studies of processes and problem solving, there should be room for such work in a broadly based institute.

M G Morris

Plate 25. Dorytomus dejeani, *congener of* D. tortrix, *which feeds as a larva predominantly in female catkins of aspen*

References

Fowler, W.W. 1891. *Coleoptera of the British Island.* London: Reeve & Co.

Morris, M.G. 1989. The identity of four unique specimens of *Gymnetron* Schoenherr (Col., Curculionidae). *Entomologist's Monthly Magazine,* **125**, 25–30.

Morris, M.G. 1990. Orthocerous weevils. Coleoptera Curculionoidea (Nemonychidae, Anthribidae, Urodontidae, Attelabidae and Apionidae). *Handbooks for the Identification of British Insects,* **5** (16), 1–108.

Morris, M.G. 1991a. *Weevils.* (Naturalists' Handbooks series.) Richmond: Richmond Publishing.

Morris, M.G. 1991b. Weevils. In: *The coleopterist's handbook.* (Revised ed.) London: Amateur Entomologist's Society.

Shirt, D.B., ed. 1987. *British Red Data Books: 2. Insects.* Peterborough: Nature Conservancy Council.

Scientific services

The scientific services are a lynch-pin of all research programmes within the Terrestrial and Freshwater Sciences Directorate (TFSD) of the Natural Environment Research Council (NERC), and of ITE in particular The provision, on site, of these specialised services, staffed by personnel who have a positive interest in the ecological studies of the research scientists they support, is probably the main advantage that an institute scientist has over a university researcher Recognition of the importance of these services has increased considerably over the last few years, and the remodelling of the TFSD scientific services programme is another step, providing a direct link through to senior management so that the services receive their fair share of diminishing resources

The scientific services programme area represents the libraries, analytical chemistry laboratories, statistical support/biometrics, computing, data centres, electrical and mechanical instrument workshops, photography and graphics support, and special research facilities such as glasshouses Many of these services have a very high standing in their own right, the analytical laboratories within ITE being prime examples The new services programme is positively encouraging the development of links between service groups of the same discipline based at different TFSD sites Some of the early moves along this road have resulted in closer ties between widely dispersed sites, with exchanges of both knowledge and equipment, improving the utilisation of expensive hardware and making small units of specialist skills available for wider use

The following articles give examples of significant developments made in some of the ITE service sectors However, they represent only a very small part of the total output

Analytical chemistry group

The chemistry group at ITE Merlewood provides an analytical facility for ITE research and, increasingly, for other institutes and universities as contract demands increase After over 30 years' involvement in ecological research, it is clear that the analysts have been faced with contrasting challenges In the formative years, interest was concentrated on analytical methods applicable to a wide range of material This work formed the basis of the book *Chemical analysis in ecological materials,* edited by S E Allen, published by Blackwell Scientific, and recently updated (1989) Latterly, applied research effort has centred on evaluating mechanisms of nutrient and pollution movement This type of research generates high numbers of aqueous samples, and has required improvements in automation and strict standardisation of methodology

Automation

The recent injection of capital into analytical facilities, particularly automation and computing, has significantly increased the efficiency of the analytical service The inductively coupled plasma optical emission spectrometer (ICP-OES), continuous flow analysers, and ion chromatograph now operate routinely, unattended, on overnight runs This development has resulted in an increase in sample throughput of 60% over the last two years Nevertheless, although about 100 000 individual determinations are carried out annually, current demand still exceeds supply, and priority for contract research means that requests for analysis in connection with Science Budget projects remain largely unfulfilled

The high level of automation, combined with the overnight unattended operation, has also allowed more efficient use of staff time and resources for routine operations Normal working hours can be used to ensure optimum operating conditions for automated instruments, and to carry out essential data processing, without compromising sample throughput

Erratic mains electricity supplies initially caused some problems with the newer computer-controlled instruments, and small interruptions invariably proved 'fatal' The installation of an uninterruptable power supply with sufficient capacity to supply all the instruments has removed this problem, and 'down-time' is now minimal

The computing arrangements for data processing in the laboratory are being developed The essential hardware and most of the additional software are now operational Final interfacing of instrument output data with the report-generating package installed on the Station's mainframe is now being implemented The group is collaborating with NERC Computer Services local support to develop the necessary software, which should be available early in 1991–92

Analytical procedures

The routine procedures used in the laboratory are constantly being reviewed and monitored Investigations during the year have resulted in improvements to several methods

Matrix interferences in the determination of sodium and potassium at low levels by ICP-OES have been identified, particularly in low ionic strength samples such as environmental waters The conditions for maximum sensitivity when setting up the instrument with single-element standards have been shown to produce significant enhancements for these elements when applied to real samples Interference can be minimised by using multi-element standards, and by rigorous control of instrument operating parameters Those affecting the position in the plasma from which the emission spectrum is measured, such as excitation coil height and auxiliary argon flow, are most important The necessary procedural modifications to overcome the interference have been implemented This work is being written up, and will be submitted for publication in the near future

Only small amounts of phosphate are found in most British forest ecosystems, and research attention has been directed to the organic-bound phosphorus (P) The analytical approach has been to oxidise the organic material in solution and then determine the total phosphate, but initially we found that, at 20 ppb P or lower, the colorimetric method is subject to serious interferences because of matrix effects from acid digestion reagents and disturbances to the flow dynamics within the measurement cell Losses may also occur during the digestion stage Control of the acid concentration and care in the digestion proved necessary, but the addition of a modified flow cell was the critical factor in developing a reliable method

Lignin estimation by routine procedures is very time-consuming, it suffers from poor precision and has a limited range of application Two empirical methods based on the acid detergent fibre treatment have been evaluated using leaf litter residues from decomposition experiments From the literature, the oxidation procedure using permanganate to destroy the lignified residues appeared promising and straightforward However, we found incomplete and unreliable recovery was obtained from complex litter and woody plant material An alternative treatment of the fibre residue using sulphuric acid to destroy the cellulose yielded precise values for a wide range of material, and this is now being tested more extensively

Quality assurance

Legislation, legal procedures and contract research are increasing the requirement for formal procedures of quality assurance Part of the assurance scheme is the traceability of analytical results to those of samples with certified values, and the CEC Bureau of Reference (BCR) has a range of available material There is a need to extend this range, and laboratories of international repute are invited to analyse material in collaboration, in order to obtain certified values During 1990–91, BCR required certification for trace elements of a sample of white clover (*Trifolium repens*) containing elevated levels of selenium Along with over 20 other laboratories throughout Europe, the analytical chemistry group at ITE Merlewood analysed the sample for selenium, arsenic and molybdenum ICP-OES proved successful for the measurement, in direct mode for molybdenum, and via hydride generation for arsenic and selenium Many laboratories experienced difficulty with selenium, even at elevated levels, because acid digestion in open vessels was subject to losses of volatile fractions The white clover standard will be made available by the BCR in due course, and work is now commencing on a standard for rainwater

There is increasing pressure within scientific research for international standardisation of methodology and comparability between studies and laboratories Agencies have been set up to monitor performance and to issue formal licences to laboratories by assigning accreditation For analytical laboratories, this accreditation is achieved by

i using validated methodology,
ii checking methods with certified reference materials (such as those mentioned above),
iii systematic quality control procedures (fully implemented),
iv well-documented laboratory management procedures

Work has begun to seek accreditation through the National Measurement Accreditation Service, and the necessary documentation is being compiled The laboratory plans to seek certification for common water analysis procedures, and for trace element procedures and soil and vegetation analysis

J A Parkinson and A P Rowland

Inductively coupled plasma mass spectrometer

The analytical section at ITE Monks Wood was set up in 1961 within the Toxic Chemicals and Wildlife Section of the Nature Conservancy to measure residues of organo-chlorine insecticides in birds and other animals The range of analytical equipment has gradually increased to meet the growing demands on the service to cover a wider variety of pesticides and pollutants and also to achieve ever greater sensitivity Thus, gas liquid chromatography and high-performance liquid chromatography are used routinely for detecting many pesticides and rodenticides, while atomic absorption spectrophotometry has been used to determine toxic elements such as lead, mercury and cadmium

It became clear from customer requests during the early 1980s that there was need for a technique to detect and measure a wide range of elements in very small samples Available techniques were reviewed by an Analysts Working Group in NERC, and it was decided that the inductively coupled plasma mass spectrometer (ICP-MS) could best meet the requirements ICP-MS can give simultaneous measurements of major, minor and trace elements important in animal and plant physiology down to sub-nanogram levels (10^{-9} g) It is also particularly useful in measuring elements that are important in ecological and toxicological studies

The development of the ICP-MS for environmental research was supported by NERC, and the commercially available VG plasma quad is based on an instrument built at the University of Surrey by Drs Gray and Date In late 1990, an ICP/MS facility was commissioned at Monks Wood, and three areas of work have already demonstrated its value

The first is in studies on animal metabolism It is well known that toxic elements, such as lead, cadmium and mercury, exert at least some of their harmful effects in farm animals and humans by disrupting normal biochemical pathways This knowledge needs to be extended to studies on wildlife A co-operative project has now started with Birkbeck College, University of London, and the University of Oxford to detect adverse environmental impacts on wildlife A range of analytical techniques is being used, in which ICP-MS is playing a major part These techniques are sufficiently sensitive and comprehensive that it should prove possible to work almost exclusively with samples of blood, urine or feather samples This non-destructive approach to ecotoxicology and wildlife health considerably extends the range of species and problems that can be studied It may also provide early warnings of significant impacts on wildlife, arising either from pollution or from natural processes, such as disease

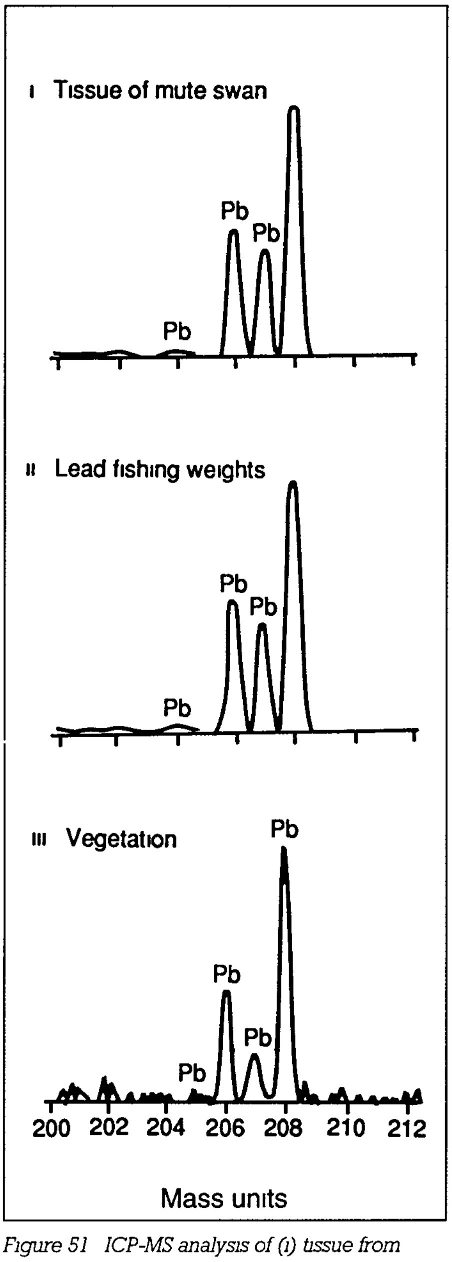


Figure 51 ICP-MS analysis of (i) tissue from a mute swan which died of lead poisoning, (ii) lead fishing weights removed from the gizzard, and (iii) vegetation sampled along the river bank The lead isotope ratio (^{207}Pb / ^{208}Pb) shows that death was caused by lead poisoning following the ingestion of the lead fishing weights, and not from the vegetation which most probably derived the lead contamination from motor vehicle exhausts

Another approach to studying pollution in birds and mammals makes use of naturally occurring stable isotopes Lead, for example, has four stable isotopes, three of which are radiogenic, ^{206}Pb, ^{207}Pb and ^{208}Pb The ratios of these lead isotopes to each other and to ^{204}Pb vary with geological age, and can readily be measured by ICP-MS The sources of lead can therefore have different lead isotope ratios, and this variation can provide a 'fingerprint' which enables us to distinguish different sources of lead pollution Figure 51 shows the results for lead fishing weights, vegetation and the liver tissue of a mute swan (*Cygnus olor*)

The third application of ICP-MS described is in an ecological study of insect dispersal with the University of Cambridge This project is tracking the movement of phytophagous insects under field conditions, using elements as markers Particular host plants are 'labelled' during their growth by irrigating them with solutions containing barium, strontium, rubidium, europium and dysprosium Preliminary tests have yielded positive responses from insects that are known to have fed on these plants, while negative results were obtained from other samples of insects ICP-MS provides a unique analytical tool for such research

There is a vast range of potential sample types and contamination levels, and a need for stringent quality control Reference materials include insects, hedgehog spines, liver, feathers and eggs Analyses of these materials will be validated independently by other laboratories

M C French

Future applications of radar remote sensing in terrestrial ecology

Considerable advances have been made in the mapping and measurement of terrestrial ecosystems using satellite remote sensing ITE's Environmental Information Centre (EIC) at Monks Wood has made important contributions (Fuller, Jones & Wyatt 1990) Most current applications use sensors that operate in the visible and infra-red regions of the electromagnetic spectrum One alternative means of remote sensing is radar, in which a pulse of microwave radiation (wavelengths of 1 mm to 1 m) is transmitted towards a target, and the 'echo' received by the sensor (Figure 52)

Spatial definition within the radar image is achieved by recording not only the strength of the return pulse but also the time period between transmission and reception Modern radar systems, known as synthetic aperture radar (SAR), use sophisticated doppler processing to attain spatial resolution comparable to that of visible and infra-red sensors, eg 20–30 m from an orbiting platform However, in marked contrast to visible and infra-red systems, radar imaging of the earth surface can operate largely irrespective of atmospheric conditions, through hazy and cloudy skies, and even light rain The time of day is no problem either, as the source of the radiation is the radar itself

The strength of the radar return, or 'backscattered' signal, depends on the dielectric and geometric properties of the target Hence, radar remote sensing can provide information relating to moisture conditions, surface roughness, and volumetric structure, therefore, radar is able to monitor directly terrestrial features, such as soil moisture content and snow depth, which visible and infra-red systems cannot

The 1990s are a very important period in the development of radar remote sensing applications, as there is to be a significant increase in the supply of SAR data from space Previous satellite radar missions have comprised the short-lived Seasat satellite of the late 1970s and short-duration space shuttle missions By contrast, this decade will see the launch of seven civil satellites carrying SAR sensors (Figure 53) These satellites will provide world-wide and long-term sets of SAR data, enabling thorough assessment of satellite SAR sensing and major advances in application However, considerable experimental and methodological research and development are required in the processing and interpretation of such data for terrestrial ecology before this technique attains the current operational status of some other remote sensing methods

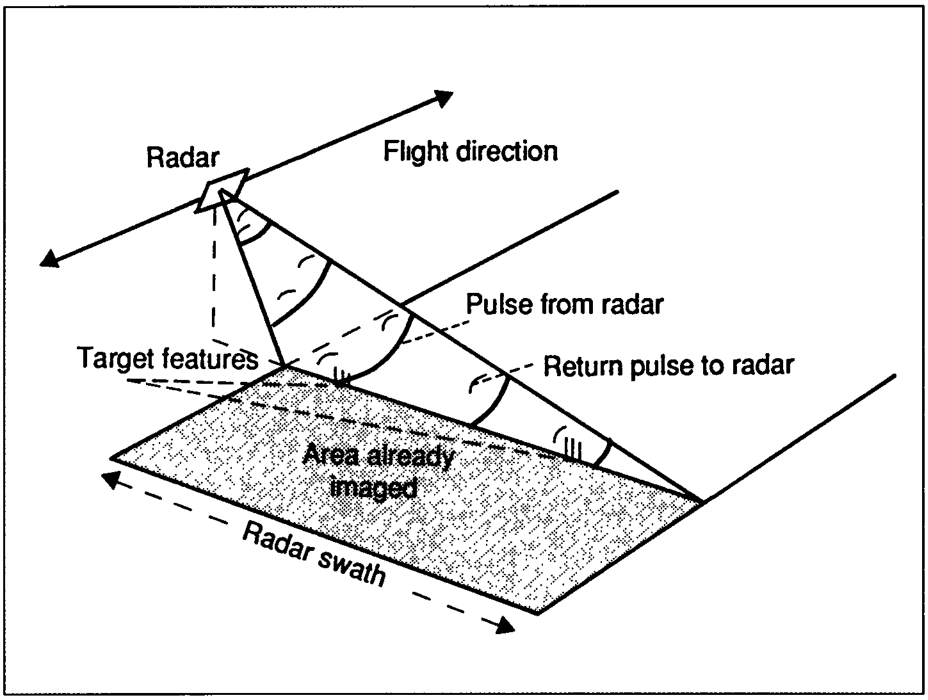


Figure 52 Principles of an imaging radar system

International research efforts into terrestrial applications of radar over the last two decades have used data from ground-based scatterometers and aircraft-borne SAR These efforts have concentrated upon radar's potential for estimating soil moisture content, and mapping agricultural crop types, and forest and snow characteristics The CEC Joint Research Centre (JRC) has co-ordinated numerous aircraft campaigns, with repeated use of several sites in East Anglia

European Space Agency and JRC joint developments include the European Radar Cross Section Database (EURACS), which brings together sources of SAR and ground reference data in order to improve the understanding of microwave backscatter from different surfaces (Churchill & Sieber 1988)

The radar wavelength influences the degree of radiation penetration into the target, and, therefore, for a multi-layer target, such as a forest or mature crop, the principal source of the backscattering Research suggests that backscatter from the ground received by the ERS-1 SAR, operating at a single wavelength of 5 6 cm, will be blocked by many vegetation types which have a high water content Conversely, the 23 cm wavelength radar of the JERS-1 SAR will be little impeded by such vegetation, providing greater potential for the monitoring of soil moisture and also the subcanopy structures of forested areas At the shortest wavelengths, ie less than approximately 3 cm, there is little sensitivity to soil moisture where vegetation is present, the backscatter is dominated by the scattering of the radiation within the uppermost portions of the cover At these wavelengths, many geometric properties of vegetation canopies, such as leaf and flower-head size, shape and position, influence the backscatter, and short wavelength microwave data therefore have high potential as a source of information on these characteristics Seasonal variations in the data, and the plant water content, have enabled demonstration of short wavelength SAR use for mapping crop types (Foody *et al* 1989)

Current research within the EIC, in collaboration with the British National Space Centre's Remote Sensing Application Development Unit (RSADU), is investigating the

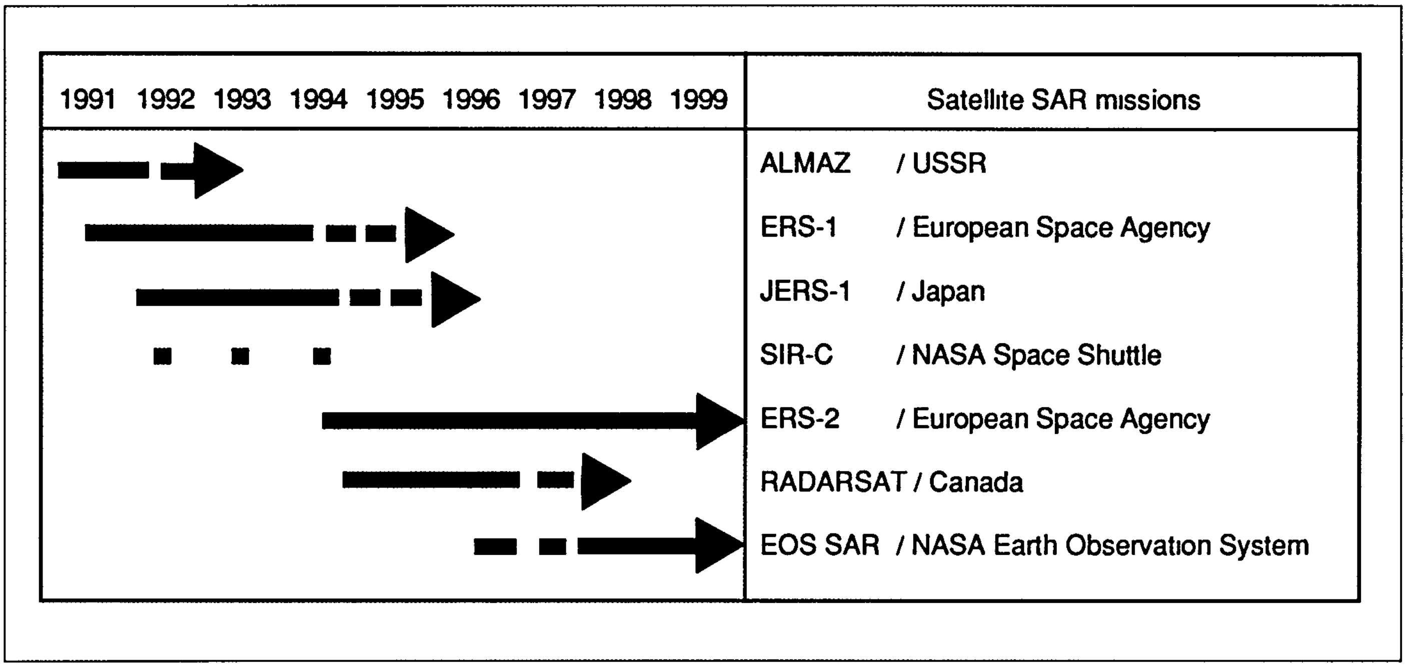


Figure 53 Satellite radar remote sensing for the 1990s

use of SAR for forest inventory through the monitoring of species composition, tree bole sizes and biomass (Baker & Mitchell 1991). This project (which will contribute to EURACS) is using data from the Thetford Forest in Norfolk that were sensed by the multi-wavelength NASA airborne SAR in August 1989. The greater global coverage of satellite SAR will enable extension of this work to other forest types. One such development, in conjunction with ITE Edinburgh and as part of the Terrestrial Initiative in Global Environmental Research (TIGER) programme, will monitor regenerative tropical forest in West Africa, using data from the JERS-1.

The wavelength-dependent response can be augmented by the polarimetric aspects of radar remote sensing. Through selective transmission and selective reception of either horizontally or vertically polarised radiation, the differential radiation scattering mechanisms of terrestrial targets provide an additional interpretive dimension.

Satellite polarimetric SAR will commence in the mid- to late-1990s with the Earth Observation System (EOS) programme. However, polarimetric data from the NASA airborne SAR, such as obtained from the 1989 and 1991 flights over East Anglia, enable polarisation signatures to be determined under experimental conditions. Initial polarimetric analysis of the 1989 Thetford data (Plate 26) has provided a strong basis for further developments in mapping and monitoring forests and other ecosystems.

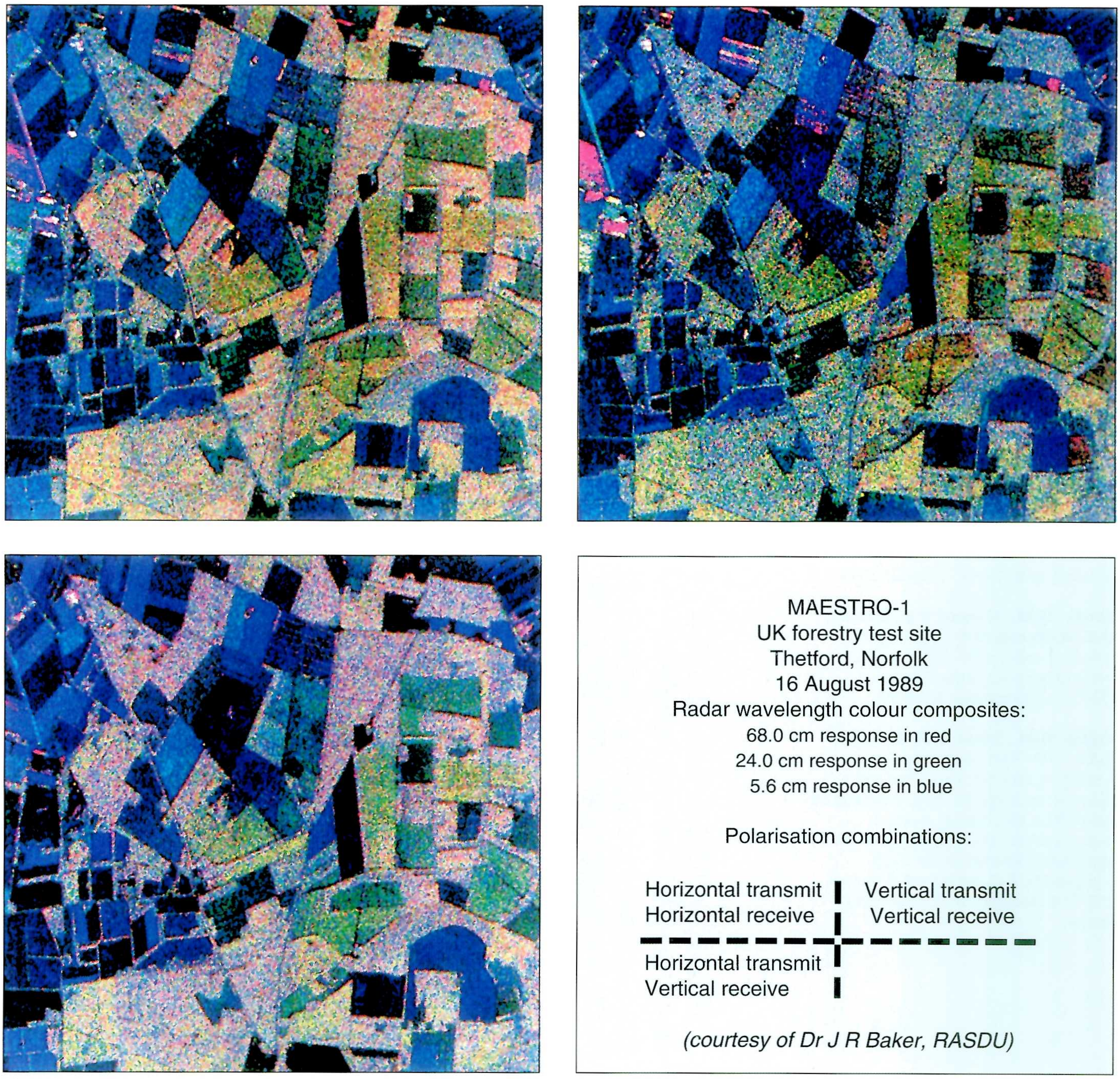


Plate 26. Analysis of multi-polarisation, multi-wavelength SAR image data

Much development of the use of radar data within the UK to date has concentrated upon areas of relatively level terrain Future research needs to include assessment of SAR within upland areas, in which more complex topography can introduce artefacts into the data geometry Land relief is particularly significant to SAR forestry applications in the UK, and also to the relatively under-developed potential of SAR within other semi-natural ecosystems, SAR airborne campaign flights this summer at Llyn Brianne in central Wales will go some way in redressing the balance More generally, the synergisms between radar and other remote sensing techniques require further research, so that applications make the greatest use of their relative strengths At the same time, opportunities for applying the unique feature responses and the systemic benefits of radar remote sensing continue to be pursued

G B Groom

References

Baker, J.R. & Mitchell, P.L. 1991 The UK element of the Maestro-1 SAR campaign *International Journal of Remote Sensing* In press

Churchill, P.N. & Sieber, A.J. 1988 EURACS a European Radar Cross Section Database In *Proceedings of IGARSS'88 Symposium, Edinburgh, Scotland, 1988,* 29–31 (ESA SP–284)

Foody, G M., Curran, P.J., Groom, G.B. & Munro, D.C. 1989 Multi-temporal airborne synthetic aperture radar data for crop classification *Geocarto International,* **3,** 19–30

Fuller, R.M., Jones, A.R & Wyatt, B.K. 1990 Remote sensing for ecological research problems and possible solutions In *Remote sensing for operational applications technical contents of the 15th Annual Conference of the Remote Sensing Society, 1989,* compiled by E C Barrett & K A Brown, 155–164 Reading Remote Sensing Society

ISBN: 1 85531 052 X

For further information please contact:

Institute of Terrestrial Ecology (North)
Bush Estate
Penicuik
Midlothian
EH26 0QB

Telephone: (031) 445 4343/6

Institute of Terrestrial Ecology (South)
Monks Wood
Experimental Station
Abbots Ripton
Huntingdon
PE17 2LS

Telephone: (04873) 381/8

Natural Environment Research Council

£8.00 net