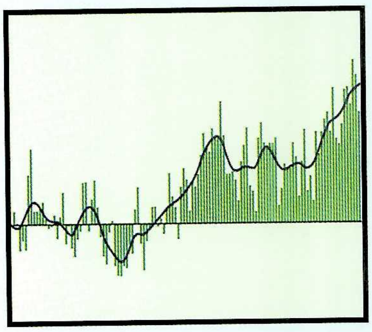
Contents

CEH core strategic programmes

Globally, 1996 was not as anomalously warm as 1995, but it was considerably warmer than the long-term average. It is still true that ten of the warmest years since global records began in 1860 have occurred since 1983. In the UK, there is a continuing trend towards warmer summers and an intriguing change in rainfall patterns; since the early 1980s there has been a consistent shift towards drier summers in England and Wales and wetter winters in north-west Scotland.



Global change

During the year, the NERC Terrestrial Initiative in Global Environmental Research (TIGER) programme on greenhouse gases ended, and an increasing fraction of ITE's research on global change is now closely tied to EC programmes and the requirements of the Global Atmosphere Division of the Department of Environment, Transport and the Regions (DETR). Core strategic funds have been carefully targeted toward key gaps left by the ending of TIGER, such as gas monitoring in Shetland and work on N_2O fluxes, and are being used to support eight ITE projects within the EC Environment and Climate programme. ITE also plays a major role in assisting DETR to meet national commitments, under the Framework Convention on Climate Change (FCCC), to monitor UK greenhouse gas sources and sinks, assess impacts in the UK, and improve the performance of the Hadley Centre model for climate prediction. Some of the current work will provide information for the Third Conference of Parties to the FCCC in Kyoto in November 1997, aimed at setting targets for national greenhouse gas emissions. The overall question is: what emission control is required to stabilise greenhouse gas concentrations at a level which will allow ecosystems to adapt naturally and not threaten food production and sustainable development?

Until now, the impacts of climate change on ecosystems were assessed by comparing predictions in current and $2xCO_2$ climates, where the ecosystems were in a stable, or equilibrium, state determined by the climate. The exciting development this year has been the prediction of changes in global ecosystems as they might actually occur during the next century, with all the lags and many of the climate interactions included. This work is summarised in the report by White and Friend. Their 'transient' predictions have been made possible by two developments. First, the Hadley Centre has completed major transient runs of the UK Meteorological Office General

Circulation Model in which aerosols were included the HadCM2 experiment The output from this experiment predicts climate conditions month by month across the globe until 2100 on the assumption that greenhouse gas concentrations follow a trajectory determined by 'business-as-usual' economic and population growth Second, the ITE model, Hybrid, has been developed, validated and published and is now ready for application This model couples ecosystem (ie soil–plant–atmosphere) processes involving carbon (energy), water and nitrogen, and is unusual in two major respects The type of vegetation and amount of soil that are predicted are solely determined by climate and not by any empirical relationships derived from current conditions Equally important, shifts from one type of vegetation to another are determined by competition between individual plants for light, water and nitrogen year-by-year, so that the model is truly dynamic and can predict non-equilibrium vegetation conditions

The report by White and Friend clearly suggests that the 'business-as-usual' scenario of climate change is not 'safe' That is, if we carry on as at present, ecosystems will change over a significant fraction of the globe, including the irreversible loss of areas of tropical forest (regardless of deforestation) The maps give 'potential' and not actual vegetation (ie they do not include the effects of land use change), but the fact that there are significant shifts in areas that can sustain forest indicates that there will probably be changes in potential land use which will have major implications for sustainable development More worrying is the prediction that, by 2100, the global land surface will not be such a large sink for atmospheric CO_2 as it is at present The land surface is currently taking up about 2 Gt C yr^{-1}, approximately predicted by White and Friend (as net ecosystem productivity), and thereby provides a brake on global warming The prediction is that this brake will be gradually released after about 2050, so that larger fractions of the CO_2 emitted by man will remain in the atmosphere

The report by Cape and McFadyen is an example of ITE's participation in major international global change projects Other examples include the tundra programme, aimed at predicting responses and feedbacks to climate involving CO_2, methane and changes in hydrology and energy balance, and our role in Amazon basin modelling The rationale for the international experiments on atmospheric chemistry reported by Cape and McFadyen is that aerosols and tropospheric ozone are important modifiers of the greenhouse effect, albeit in opposite directions Global atmospheric chemistry models need to be tested by observation and, with so many reactions going on simultaneously, the puzzle can best be unravelled by examining what happens in an atmosphere that is relatively unpolluted, hence the need to work in Tenerife It is too early yet to report the conclusions, but it is already clear that the models are unable to predict some of the events that have been observed, such as the spring maximum in tropospheric ozone and the extensive ozone layers that can occur at 5–8 km altitude over the remote ocean

Within the UK, there is continuing interest in anomalously mild winters and warm summers as events from which we might learn, should they be the precursors of climate warming – a foretaste of things to come The report by Cannell and McNally outlines the results of a study on the economic impacts of the unusually warm summer of 1995 This study, unlike previous ones, was part of a wider evaluation of impacts on all sectors of the UK economy and attempted to quantify financial costs and benefits The weakness of the study was that short-term responses may be poor indicators of long-term impacts, which have to take adaptation into account The strength of the study was that it identified some parameters which are climate sensitive and for which there are long time series These will be monitored more formally in future years in the same way that pollutant levels, sustainability indicators, and greenhouse gas emissions are monitored

More worrying is the prediction that, by 2100, the global land surface will not be such a large sink for atmospheric CO_2 as it is at present.

M G R Cannell

Global effects of climate change on terrestrial ecosystems

(This work was funded by the Department of Environment, Transport and the Regions)

The majority of the tropical regions in which C_4 grasses are currently dominant are predicted to be transformed into C_3 grassland or desert by the 2090s (a reduction from 10% to 1% in global land cover).

The potential response of natural vegetation to climate change was investigated by using output from the Hadley Centre General Circulation Model for a 'business-as-usual' scenario of greenhouse gas emissions (HadCM2 climate change experiment; Mitchell *et al.* 1995) as input data to a global ecosystem model (Hybrid v4.1; Friend *et al.* 1997). This model predicts the global distribution of plant and vegetation types. It represents the interaction of individual trees and a herbaceous layer with the environment and both intra- and interspecific competition between plants for light, water, and nitrogen. Six plant functional types are modelled:

- tropical broadleaf evergreen forest,
- cold deciduous forest,
- dry deciduous broadleaf forest,
- needleleaf forest,
- C_3 herbaceous, and
- C_4 grass.

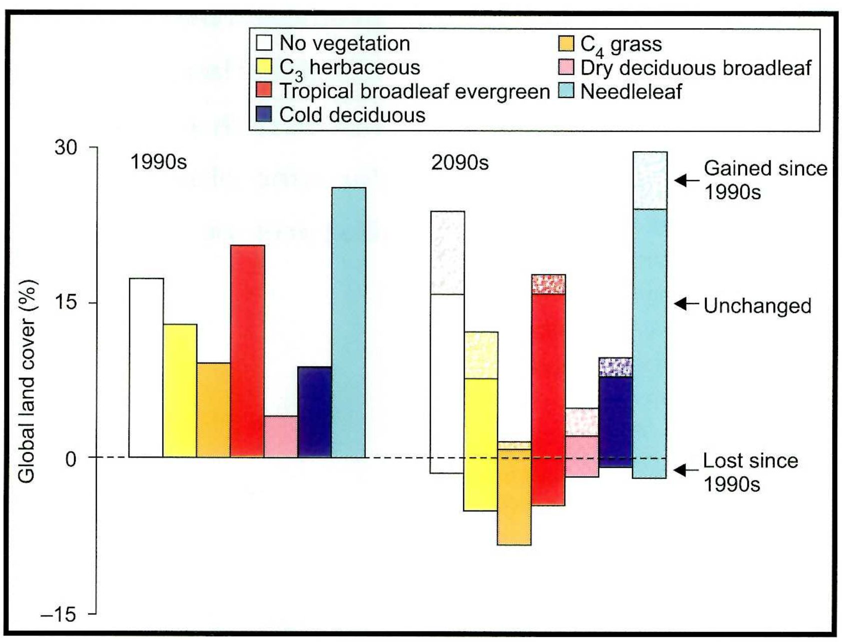


Figure 26. Predicted global vegetation in the 1990s and 2090s expressed as a percentage of global land area. Vegetation is divided into six categories and the areas gained, unchanged, and lost between the 1990s and 2090s are shown

The fluxes of carbon, nitrogen, and water between soil pools, vegetation and the atmosphere are simulated on a daily basis, resulting in dynamic predictions of productivity, biomass, vegetation type, and soil carbon and nitrogen contents. The processes of photosynthesis, respiration, transpiration, allocation, growth, regeneration, mortality, and soil carbon and nitrogen dynamics are all included.

Raising the CO_2 concentration increases photosynthesis and reduces stomatal conductance, causing greater growth and reduced water use. Thus, because of its potential direct importance for vegetation, CO_2 was increased during the simulation at the same rate as in the General Circulation Model.

Vegetation change

Global vegetation change between the 1990s and 2090s, expressed as the percentage areal coverage of the dominant plant types for each model grid cell (3.75° longitude by 2.5° latitude), is portrayed in Figure 26. Looking at the 'areas lost since the 1990s', grassland and tropical broadleaved evergreen forests (rainforests) are affected detrimentally by climate change. The majority of the tropical regions in which C_4 grasses are currently dominant are predicted to be transformed into C_3 grassland or desert by the 2090s (a reduction from 10% to 1% in global land cover). Also, some regions which are presently tropical rainforests are transformed to savanna, grassland or even desert (Figure 27; Plate 13). These changes occur towards the end of the next century and are a result of decreases in rainfall and increases in temperature of up to 8°C in regions such as northern South America, the Sahel, and India. By contrast, more northerly regions appear to benefit from climatic change, with an expansion of the boreal needleleaf

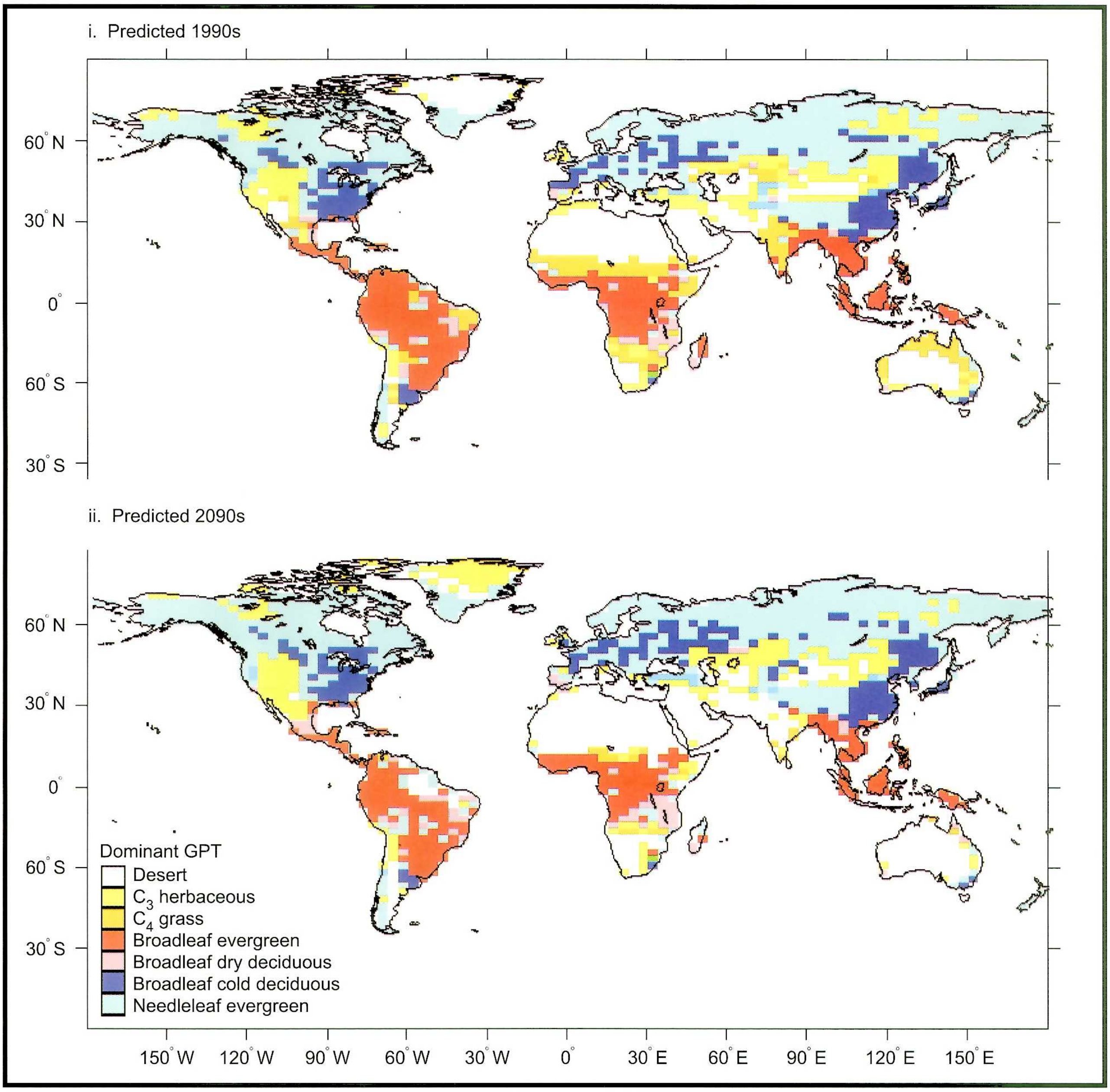


Figure 27. Distribution of dominant generalised plant types (GPT) predicted for the 1990s and the 2090s. Note the increase in broadleaf cold deciduous forest, the increase in forested regions in central Asia and North America, and the reduction in tropical C_4 grassland and forest

forests in North America and Asia (a 3% increase in the global land cover of needleleaf evergreen trees), and of the temperate forests over central and eastern Europe and southern China (a 1% increase in the global land cover of broadleaf cold deciduous trees).

Changes in terrestrial carbon storage

As well as influencing vegetation distribution, climate change and increasing CO_2 also affect the amount of carbon stored on the land surface. Because terrestrial vegetation and soils contain about three times as much carbon as the atmosphere, any changes in the amount of terrestrial carbon could have important consequences for levels of atmospheric CO_2, and hence for climate change itself.

A net accumulation of carbon by the land surface of about 500 Pg, where 1 Pg=10^{15} g (~30% of total terrestrial carbon in the 1860s), is predicted to

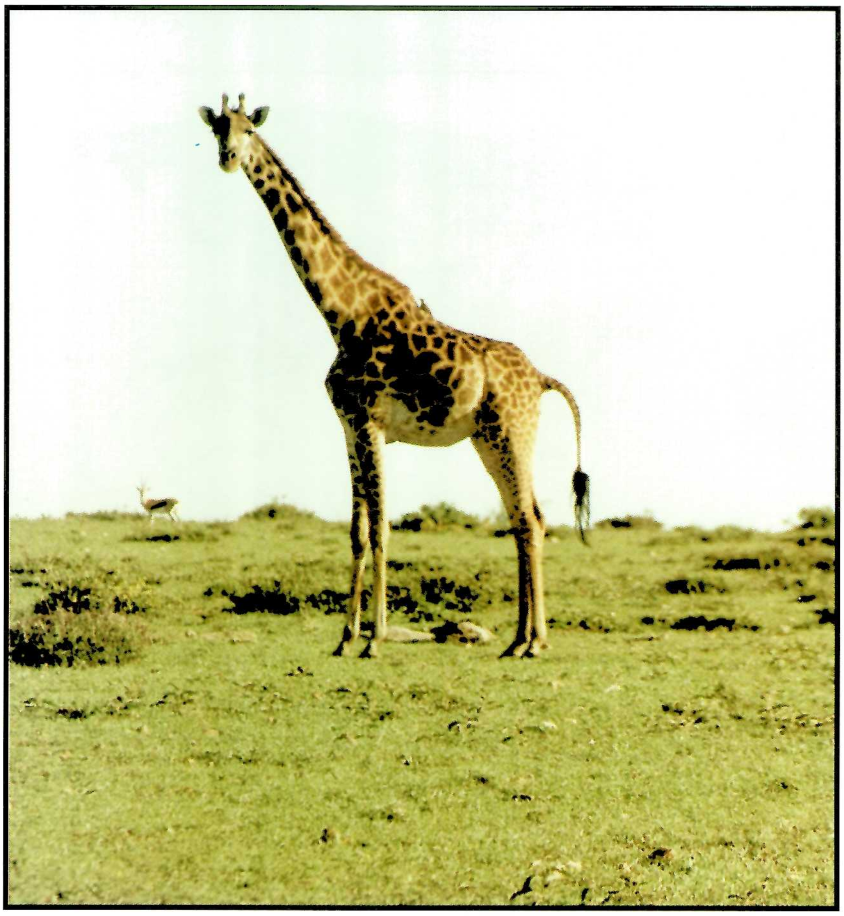


Plate 13. A region of C_4 grassland in Africa. Future climate changes may transform regions like this into deserts

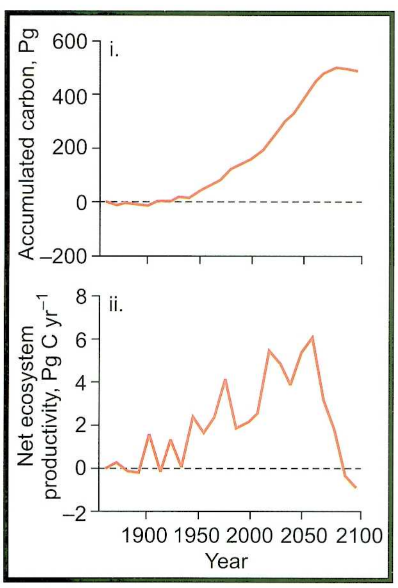


Figure 28. Predicted effects of transient climate and atmospheric CO_2 on:
i. accumulated carbon, and
ii. net ecosystem productivity (ie the net increase in terrestrial carbon storage)

occur between pre-industrial times (1860) and the year 2100 (Figure 28i). From the 2050s onwards, the model predicts a reduced rate of carbon sequestration, with a net loss of carbon from the land surface during the last two decades. This pattern is reflected in the net ecosystem productivity (NEP): the rate of change of stored carbon, or, equivalently, the net exchange of carbon between the atmosphere and the terrestrial biosphere. NEP is positive and increasing for much of the period between pre-industrial times and the 2050s (Figure 28ii), indicating that the terrestrial biosphere is acting as a carbon sink (with increasing magnitude). Most uptake is predicted to take place in the mid-latitudes of the northern hemisphere in response to increased rates of vegetation growth as a result of CO_2 fertilization and the expansion of temperate and boreal forests. These regions will still be sinks for carbon at the end of the next century. However, some tropical ecosystems may be vulnerable to extreme climate change, causing losses of tropical forest and grasslands, the net release of carbon into the atmosphere and a positive feedback to climate. The significance of these losses is displayed in the NEP signal (Figure 28ii), which after the 2050s decreases dramatically and is negative by the 2080s, indicating that the land surface is then a source of carbon. It may be concluded that the 'business-as-usual' scenario of climate change will have major effects on potential ecosystem distribution in the next century and that the terrestrial carbon sink will weaken after the 2050s.

A White and A D Friend

References

Friend, A.D., Stevens, A.K., Knox, R.G. & Cannell, M.G.R. 1997. A process-based, terrestrial biosphere model of ecosystem dynamics (Hybrid v3.0). *Ecological Modelling*, **95**, 249–287.

Mitchell, J.F.B., Johns, T.C., Gregory, J.M. & Tett, S.F.B. 1995. Climate response to increasing levels of greenhouse gases and sulphate aerosols. *Nature*, **376**, 501–504.

Aerosol chemistry, clouds and radiation

(This work was funded jointly by NERC's 'Atmospheric Chemistry Studies in an Oceanic Environment' (ACSOE) Community Research Programme and the Fourth Framework Programme of the European Commission)

Models of global warming due to greenhouse gases alone predict higher temperatures in the northern hemisphere than have been observed. This over-prediction of warming is because man's activities have also changed the amounts and nature of atmospheric aerosols, which increase the earth's albedo (reflectance) and lead to localised cooling. It now appears that the observed temperature changes in the northern hemisphere can be accounted for by a balance between greenhouse gas warming and aerosol cooling (Intergovernmental Panel on Climate Change 1995), but the mechanisms involved are poorly understood.

Atmospheric aerosol particles affect the radiation balance of the atmosphere directly, by absorbing and scattering light, and indirectly by acting as nuclei on which cloud droplets form. Besides the natural aerosol, man has added soot, dust, sulphates and nitrates, and a range of organic particles to the atmosphere. Although the importance of particles has been recognised, quantitative information useful to climate modellers is not available. The objective of the Aerosol Characterisation Experiments (ACE) is to provide, through measurement, a better understanding of the physical and chemical processes involving aerosols and clouds. Such large-scale field experiments and measurement campaigns require international collaboration, and this has been co-ordinated by the International Global Atmospheric Chemistry project. The first campaign (ACE-1) in 1995 was based in Tasmania, and looked at the properties of cloud and aerosol in the clean southern atmosphere. The ACE-2 campaign is based between Portugal and the Canary Islands, and includes clean marine air, polluted air masses from Europe, and continental dust from the Sahara. The campaign is subdivided into six projects, involving research ships, several aircraft, and ground-based measurements in Portugal and Teneriffe (European Commission 1995).

In collaboration with research groups from Europe and the United States, ITE is studying the transformation of aerosols as air passes through a stationary cloud in the marine boundary layer. The north-east trade winds, which are prevalent in June and July, bring moist air over the ocean that is forced upwards on reaching the northern end of Teneriffe, and a hill cap cloud forms on the Anaga mountain ridge. The ridge is often in cloud; in stark contrast to the east coast, with cacti and desert vegetation, the Anaga ridge is home to a luxuriant temperate cloud forest. In principle, the cloud that forms on the ridge is similar to clouds in the marine boundary layer, because there are few anthropogenic sources of dust or pollution between the sparsely populated north coast of Teneriffe and the ridge. The European and American scientists measured the physical and chemical properties of aerosols and gases below the cloud upwind, the chemical composition and sizes of cloud droplets in the cap cloud, and the residual gases and aerosols produced as the cloud evaporated downwind (Plate 14). The following questions were addressed.

- How do the numbers and sizes of aerosol particles change on passing through a cloud?

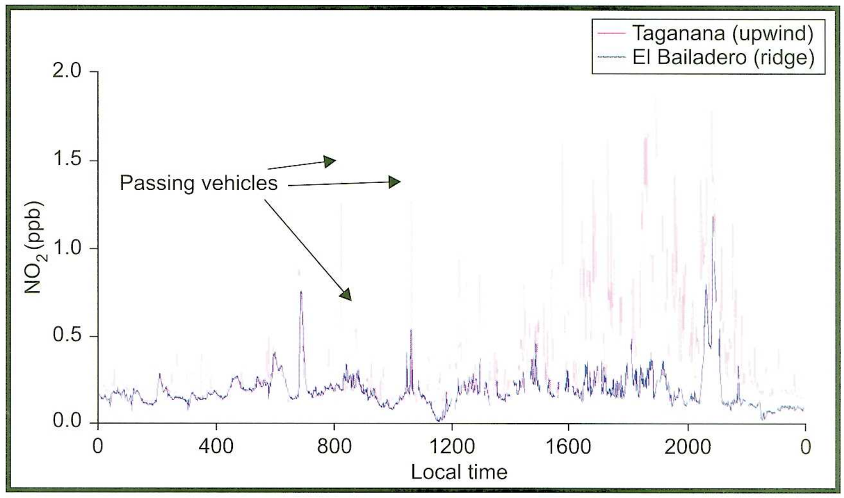


Figure 29. Concentrations of nitrogen dioxide (NO_2) in Taganana valley, north Teneriffe, upwind of the cloud, and at the ridge site (El Bailadero) during the pre-campaign in 1996. The spikes in the trace were caused by emissions from individual vehicles passing through the village several hundred metres upwind of the measurement site

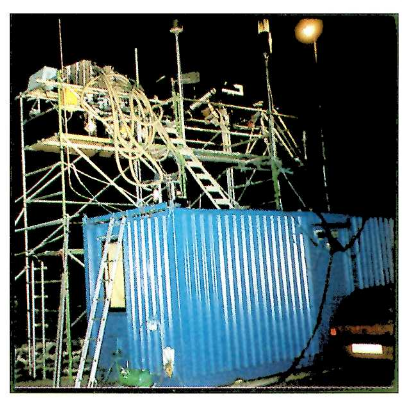


Plate 14. View of the ridge measurement site at El Bailadero, Teneriffe, showing the laboratory container and the scaffolding tower on which the cloud and aerosol samplers were mounted

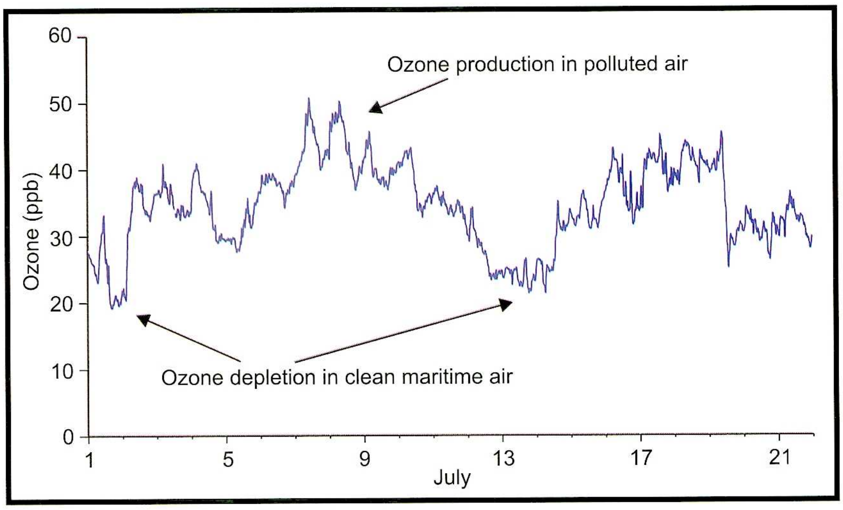


Figure 30. Ozone concentrations (ppb, parts in 10^9 by volume) in Taganana valley, north Teneriffe, upwind of the cloud during the first three weeks of July 1997. Low concentrations (<25 ppb) show ozone depletion and are characteristic of very clean marine air; concentrations greater than about 35 ppb are indicative of polluted air and photochemical ozone formation involving nitrogen oxides

- How is this affected by the presence of gases?
- Are new particles formed following oxidation of gases such as sulphur dioxide?
- Does the behaviour of the aerosols depend upon their chemical composition?
- How do observations compare with predictions of the best-available models?

Research groups from Europe and the United States have collaborated to measure the physical and chemical properties of clouds, aerosols and gases.

Most of the time, the air arriving at the north coast of Teneriffe is very clean, with trace gas concentrations typical of the remote marine troposphere and close to the limits of detection of commercially available gas analysers. Typical concentrations of nitrogen oxides, for example, are less than 50 parts per trillion (parts in 10^{12} by volume). Against such a low background, contributions from individual vehicles are easily detected, so that the main intensive field measurements were made during the night, to avoid contamination by local traffic. Measurements made in July 1996, as a preliminary to the main campaign in 1997, show the contribution of local sources of nitrogen dioxide (NO_2) upwind of the cloud (Figure 29). During the main experiment in 1997, ITE operated equipment at all three sites, measuring gas concentrations below cloud, and on-line cloud chemical composition at the ridge site. From early July, the weather permitted measurements to be made under a range of conditions, from very clean north Atlantic air to air containing European pollution. As many aerosol-forming reactions involve oxidation, the concentration of ozone is a good indicator of the variety of conditions observed (Figure 30). In very clean oceanic air, lacking nitrogen oxides, 'natural' ozone is slowly destroyed. In polluted air, however, even small concentrations of nitrogen oxides (50 ppt or more) result in a series of chain reactions, driven by sunlight, which produce 'pollutant' ozone.

The data from ACE-2 will be analysed and interpreted in 1997–98, and will be placed in a central database operated by the Joint Research Centre of the European Union at Ispra in Italy, who co-ordinated the campaign. Further details of ACE-2 may be found on the World Wide Web at http://www.ei.jrc.it/ap/projects/ACE-2.

J N Cape and G G McFadyen

References

European Commission. 1995. *North Atlantic Regional Aerosol Characterization Experiment (ACE-2): science and implementation plan.* (Report EUR 16229 EN.) Luxembourg: European Commission.

Intergovernmental Panel on Climate Change. 1995. *Climate change 1994.* Cambridge: Cambridge University Press.

Economic impacts of the 1995 summer in the UK

(This work was funded by the Department of Environment, Transport and the Regions)

Since the unusually mild winter of 1988–89, ITE has received several commissions from the Department of Environment, Transport and the Regions (DETR) to provide information about the impacts of anomalous seasonal weather on the natural environment in the UK (Cannell & Pitcairn 1993). In 1995 there was an unusually warm and dry summer, with mean temperatures in central England in July and August being 3°C above the long-term average and exceeding the previous record set in 1983. The average rainfall in England and Wales in July and August 1995 was the lowest on record, with only 47 mm, compared to the 1961–90 average of 139 mm. It was evident that such extreme conditions had widespread economic impacts on many sectors of the economy, and DETR commissioned a study, led by the University of East Anglia, on this aspect (Palutikof, Subak & Agnew 1997).

In the DETR study, ITE had special responsibility to examine impacts on the natural environment including forestry, water and air quality (Cannell & McNally 1997; McNally *et al.* 1997).

In general, the hot summer increased the abundance and activity of invertebrates (Plate 15) and birds. Data from four national bird surveys revealed that there were more positive than negative effects on bird species (eg greater numbers, activity and breeding success). Analyses of the ITE Butterfly Monitoring Scheme showed that most species had higher indices of abundance in 1995 than in previous years (Figure 31). Furthermore, unlike in the prolonged dry summer of 1976, adverse impacts were not evident, although a negative relationship was found between orchid populations and temperature (Plate 16). Overall, the economic implication was unlikely to have been significant. Longer-term changes in populations as a result of changing climate would be more important. One way of estimating benefits or costs of long-term changes is to examine the implications for species listed in the Biodiversity Action Plan and then to estimate the change in restoration costs necessary to achieve targets.

Spatial (site) variation in the productivity of upland coniferous plantations in northern Britain is closely and positively related to mean annual temperature. One anomalously warm year has a negligible impact on forest productivity, but a sustained increase in temperature of 1.6°C (as occurred in 1995) over a rotation would increase the yield class by 3–5 $m^3\ ha^{-1}\ yr^{-1}$. The Forestry Investment Appraisal Package (FIAP) software, developed by the Forestry Commission, was used to estimate the economic impact of such an increase in productivity using costs based on the Kielder Forest District. The main assumptions and results using FIAP are summarised in

Analyses of the ITE Butterfly Monitoring Scheme showed that most species had higher indices of abundance in 1995 than in previous years.

Plate 15. The musk beetle (*Aromia moschata*) – the hot summer of 1995 increased the incidence of invertebrates

Many non-woodland, open-grown trees, especially those lacking deep roots and growing on poor sites, suffered wilting and defoliation in 1995, prompting a Tree Damage Alert Note from the Forestry Commission.

Cannell and McNally (1997). This analysis showed quite dramatic increases in the maximum discounted revenue associated with 10 ha of Sitka spruce (*Picea sitchensis*). It rose from £8,528, assuming no change in yield class, to £15,273 in the new scenario. Although this analysis was performed under restrictive assumptions, it illustrated the significant impact warmer weather could ultimately have on investment appraisals for commercial forestry in the UK.

Fire is not a major problem at present for British forestry: about 12 000 ha were recorded as lost by fire between 1975 and 1995, out of a total of 2 million ha. Over 1000 ha were burned in the drought years of 1980 and 1984, but also in the non-drought year of 1994. Only 426 ha of land owned by the Forestry Commission was lost by fire in 1995, valued at £350K. The risk of fire is greatly increased by the presence of young forests, because of the existence of ground vegetation, and by dry conditions in spring, but other physical and socioeconomic factors are also involved. Overall, the risk of forest loss by fire is obviously likely to increase in future because of climatic warming, and also if there were an expansion in the area of young plantations.

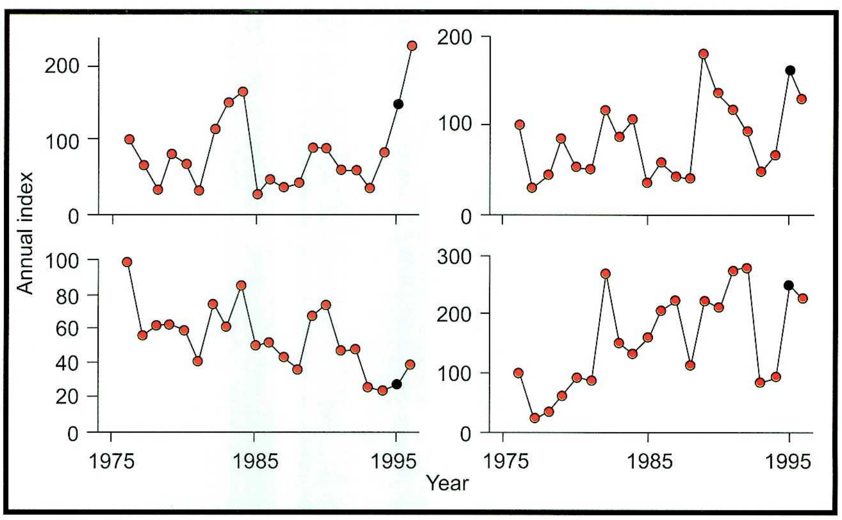


Figure 31. Indices of abundance of four butterfly species, taken from the ITE Butterfly Monitoring Scheme, showing the 1995 summer value relative to other years

Surveys of forest health (excluding non-woodland trees) have been conducted by the Forestry Commission since 1984, with consistent assessments of crown density since 1987. There is little evidence of a long-term trend, but beech (*Fagus sylvatica*) in southern Britain deteriorated following the summer droughts in 1984 and 1990, sometimes associated with heavy mast (seed) production. This deterioration was repeated in 1995. Many non-woodland, open-grown trees, especially those lacking deep roots and growing on poor sites, suffered wilting and defoliation in 1995, prompting a Tree Damage Alert Note from the Forestry Commission. A succession of dry years, allowing little time for recovery, is likely to cause enough deterioration in tree condition (including mortality) to lead to public concern. One way to assess the cost of this concern would be through the application of contingent valuation techniques.

Outbreaks of blue-green algae could have economic impacts resulting from the death of animals, dangers to human health, lost recreational benefits, and the cost of limiting bloom occurrence. However, blooms of blue-green algae were fewer and less extensive during the summer of 1995 than might have been expected, probably because:

- June temperatures were near normal and the frequency of anticyclonic days was not excessively high in either June or July,
- freshwater phosphate concentrations have dropped substantially in recent years, and
- management practices are now

in place to limit bloom occurrence.

Ozone, sulphur oxides and PM10 particles all display a distinct seasonal pattern in ambient concentrations, and 1995 was not an anomalous year in producing large concentration changes. This reflects the important influence of other factors; for example, in 1995, ozone concentrations were lower than expected from the temperature relationship due to the low number of air mass trajectories from central Europe compared to a year such as 1976.

The direct cost to the water supply industry in 1995 was about £100M, borne largely by Yorkshire and North West Water, and prompted investment to protect the industry from future shortages. During the 1995 summer, there was an added cost of £34M to domestic electricity consumers but a saving of £74M on domestic gas consumption. There were gains and losses in different parts of the agricultural industry, resulting in a net loss of about £180M. Clothing sales in the summer of 1995 dropped by £383M, but about £134M more was spent on beer and wine. Unusually high costs of about £326M were incurred by the insurance industry for subsidence-related claims. Transport costs were also increased by road surface rutting and fires. More people took domestic holidays, but apparently with little increase in income from tourism. Overall, the UK Gross Domestic Product was not affected, but the Retail Price Index seemed to increase as a result of the warm weather.

ITE is currently following up this and previous studies (Cannell & Pitcairn 1993), having been awarded a DETR contract to develop a set of climate change indicators which can be monitored annually.

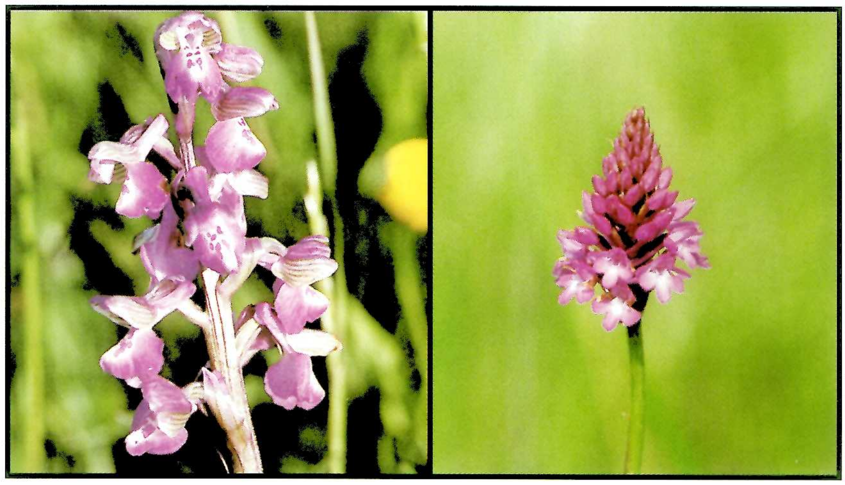


Plate 16. The green-winged orchid (*Orchis morio*) and pyramidal orchid (*Anacamptis pyramidalis*) – a negative relationship was found between orchid populations and temperature

M G R Cannell and S McNally

ITE is currently developing a set of climate change indicators which can be monitored annually.

References

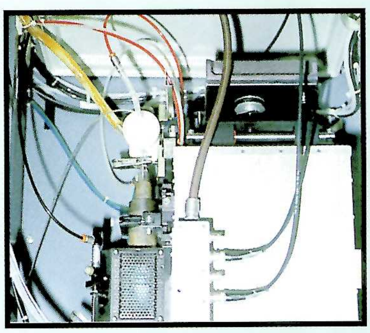
Cannell, M.G.R. & McNally, S. 1997. Forestry. In: *Economic impacts of the hot summer and unusually warm year of 1995*, edited by J. Palutikof, S. Subak & M.D. Agnew, 33–44. Norwich: University of East Anglia.

Cannell, M.G.R. & Pitcairn, C.E.R. 1993. *Impacts of the mild winters and hot summers in the United Kingdom in 1988–1990.* London: HMSO.

McNally, S., Crowards, T., Cannell, M.G.R. & Sparks, T.H. 1997. The natural environment. In: *Economic impacts of the hot summer and unusually warm year of 1995*, edited by J. Palutikof, S. Subak & M.D. Agnew, 15–32. Norwich: University of East Anglia.

Palutikof, J., Subak, S. & Agnew, M.D., eds. *1997. Economic impacts of the hot summer and unusually warm year of 1995.* Norwich: University of East Anglia.

Any modern scientific research endeavour places increasing reliance upon a suite of technologies. The Institute of Terrestrial Ecology and its sister Institutes within the Centre for Ecology and Hydrology are no exceptions.



Integrating generic science

Among the plethora of scientific tools deployed across the Institute, some are of such central importance to the pursuit of its scientific research that they are considered legitimate subjects for research in their own right. Indeed, without such enabling research, the Institute would find it difficult to remain at the forefront of areas of environmental research such as ecotoxicology (analytical chemistry), landscape ecology (remote sensing and geographical information systems) and population ecology (biotechnology and genetics). This integrating, generic research programme addresses very real scientific challenges, although its immediate objectives are usually the development of improved methods and techniques, in support of the strategic scientific goals of the Institute.

The core strategic research programme of CEH recognises the importance of generic, underpinning research in a number of areas, including:

- the management and scientific exploitation of environmental databases and reference collections;
- the application of earth observation from airborne and space-borne platforms as a source of information on land and water and biophysical processes;
- the utilisation of analytical chemistry, particularly for investigating pollutant pathways and impacts and biogeochemical cycles;
- development and application of the statistical techniques that underpin so much of environmental science;
- technical developments in scientific instrumentation and biotechnology;
- the techniques of environmental assessment and the related themes of environmental economics and history, which are needed to provide insights into the evolution of present landscapes and land use systems.

Institute scientists are active in all these spheres, and the following sections detail representative examples in database management and in analytical chemistry.

Databases

One of the Institute's strengths is its capacity to build and to maintain large environmental databases, many of which are now rightly regarded as being a national resource. Effective database management is resource intensive and demands long-term commitment, to ensure that the data remain relevant to changing scientific and policy requirements and that they survive repeated changes in computer software and storage media Although the Institute recognises that its databases are a community resource, it has become increasingly difficult in recent years to justify the investment required from the core budget in maintaining them The strategy has been to levy charges, which vary depending on the nature of the application, to cover costs of servicing data requests and, in the case of non-academic users, a small proportion of the costs of acquisition and maintenance This strategy, though generally compliant with the NERC data policy (NERC 1996), has not achieved the goal of providing data free at the point of delivery to the academic user community

Recently, ITE was successful in winning funds from the NERC initiative 'Stewardship and Exploitation of Environmental Data via a CORe strategic NERC programme' (SEEDCORN), which will go a long way to rectifying this shortcoming while, at the same time, supporting the task of identifying and dealing with data that are currently outside the Institute's formal data management machinery The article by Moffat and Bull describes in more detail how funds from SEEDCORN are being deployed in order to improve the ITE data network and access to it

Chemical analysis

The Institute operates a number of specialist analytical chemistry facilities at several of its sites, and some have been described in previous annual reports ITE continues to upgrade these facilities in order to maintain the 'well-found laboratory' status The paper by Quarmby describes the recent upgrade of the Stable Isotope Facility (SIF) at ITE Merlewood, which provides a specialised service to both Institute and university scientists

Issues of consistency and techniques for intercalibration of methods and laboratories are far from new, however, recent developments have spotlighted the importance of formal methods of quality assurance in this area The first was the emergence of new community-wide thematic programmes, with the requirement for common use of analytical data from numerous collaborating laboratories for a variety of purposes The second was the requirement of commissioned research customers for traceability in relation to reported scientific results, and especially for chemical analyses

The Institute's network of analytical laboratories has invested heavily in meeting these requirements, with notable successes, many of the working practices that are now commonplace in our laboratories form the basis for quality assurance procedures that are being adopted in NERC thematic research, including notably the Environmental Diagnostics programme The accompanying article by Rowland details the strategy and the approaches that are being adopted

Reference

Natural Environment Research Council. 1996 *NERC data policy handbook Version 1 0* Swindon NERC

One of the Institute's strengths is its capacity to build and to maintain large environmental databases.

B K Wyatt

Plate 17. SEEDCORN enables better access to ITE's data resources, which underpin research into current ecological problems

ITE data network and SEEDCORN

The ITE data network is a distributed network that covers all scientific groups in ITE engaged in programmes of significant data acquisition and management. Because the scope of many of these programmes is geographically extensive and multidisciplinary, very large databases are often generated. For practical reasons, therefore, the databases are managed and maintained by dedicated data managers located throughout the Institute. Not only are these people specialists in data management, they are actively involved in the corresponding research. In this way, ITE data managers can provide expert advice on the acquisition and use of data to programme collaborators and to other external customers. At the hub of the data network is the Environmental Information Centre (EIC), located at ITE Monks Wood. As one of NERC's Designated Data Centres (DDCs), EIC has overall responsibility for the Institute's data holdings. It is also responsible for establishing Institute-wide guidelines to ensure that the network functions in a coherent and consistent manner.

Over the next three years the data network has two key objectives:

- to tackle the increasing problem of data archaeology in ITE, and
- to improve access to the Institute's data holdings.

To help meet these objectives, the data network is making use of NERC's new strategy for enhanced funding of data-related activities. The 'Stewardship and Exploitation of Environmental Data via a CORe strategic NERC programme' (SEEDCORN) initiative has been set up by NERC in appreciation of the value of its corporate datasets as assets of national importance. The programme provides financial support to safeguard existing datasets that would otherwise be at risk of being lost, thereby preserving them as a resource for future access and use by NERC and the environmental science community. It will also aid the dissemination of NERC datasets to scientists (Plate 17).

EIC is developing a prototype, World Wide Web-based, 'take-away' data service for the academic community.

The Environmental Information Centre is managing an ambitious SEEDCORN project called 'REsourcing the Archaeology and Provision of Environmental Data' (REAPED), which aims to identify and conserve the Institute's more dispersed data holdings and to incorporate important external datasets which merit more active stewardship. In the first year, the main data network activity is a scoping study on data at risk and worthy of preservation at each of ITE's research stations. This work will result in an updated and improved ITE data catalogue and a report identifying potential data rescues; it indicates actions required on each dataset for it to be preserved. The datasets identified as candidates for rescue will be prioritised to form the basis for establishing a work programme over the next two years.

The second main activity of the REAPED project is to improve the availability and access of the Institute's data holdings to the academic community. By virtue of being a DDC, EIC is already disseminating data to *bona fide* academic researchers in accordance with NERC's data policy (1996). Data are either wholly free of charge or are supplied for a nominal handling fee or at an appropriately discounted rate. EIC will use the SEEDCORN funding to improve this service by meeting requests for data free at the point of delivery.

EIC is developing a prototype, World Wide Web-based, 'take-away' data service for the academic community. The service will include a set of software tools that allow users to interrogate and download some of the Institute's summary datasets, such as the one km Land Cover Map of Great Britain. The ITE data catalogue will also be made available through this service.

T J Moffat and K R Bull

Reference

Natural Environment Research Council. 1996. *NERC data policy handbook. Version 1.0.* Swindon: NERC.

Stable isotopes in ecology

Early work using isotopes in ecology centred on the use of tracers, and the scope of such work was largely governed by the availability of suitable instrumentation. Measurement of radioisotopes was, and is, relatively simple and cheap, while that of stable isotopes is more complex and the instrumentation more expensive. This in part explains why the understanding of the carbon cycle is much more advanced than that for nitrogen; knowledge of the fundamental structure of the cycle was confirmed and extended using ^{14}C, a radioisotope, but there is no suitable radioisotope of nitrogen, and measurement of ^{15}N remained difficult. However, the use of ^{14}C in closed laboratory systems could not be extended to large-scale ecological use in the field for health and safety reasons. The subsequent substitution of ^{13}C for ^{14}C in fieldwork (Plate 18) added an impetus to the search for a more sensitive, cheaper magnetic sector mass spectrometer for the analysis of ^{15}N.

By the time reliable machines became available, artificially enriched ^{13}C was little used in ecology, and, although enriched ^{15}N was initially used quite extensively, notably in the elucidation of nitrogen fixation, the use of ^{15}N as a tracer has also become much reduced of late. Not only was it very expensive to label an experimental plot of any size with ^{15}N, but it was also difficult to achieve even distribution of the label.

Recent advances have come from observing the variations in stable isotope ratios at naturally occurring abundance levels rather than relying on artificial enhancement (Figure 32). These variations result from small differences in reaction rates and equilibria when the elements taking part in a chemical reaction have isotopic components. Where such a reaction is rate limiting, the isotope ratio will change between substrate and product, and the element is said to fractionate. The significance of fractionation was established in geochemistry in the late 1940s, and early biological measurements used geological instruments. However, the two disciplines have different requirements. Geology generates few

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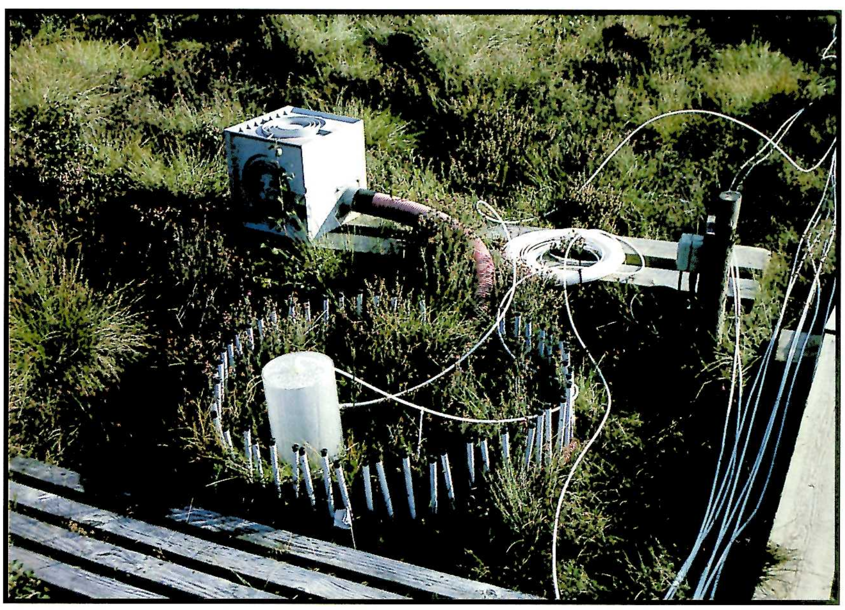

Plate 18. Equipment for maintaining a higher concentration of carbon dioxide in the air over a small plant community. The large difference in $\delta^{13}C$ signature between the added CO_2 (–44‰) and ambient (–8‰) allows measurement of incorporation of ^{13}C into the community

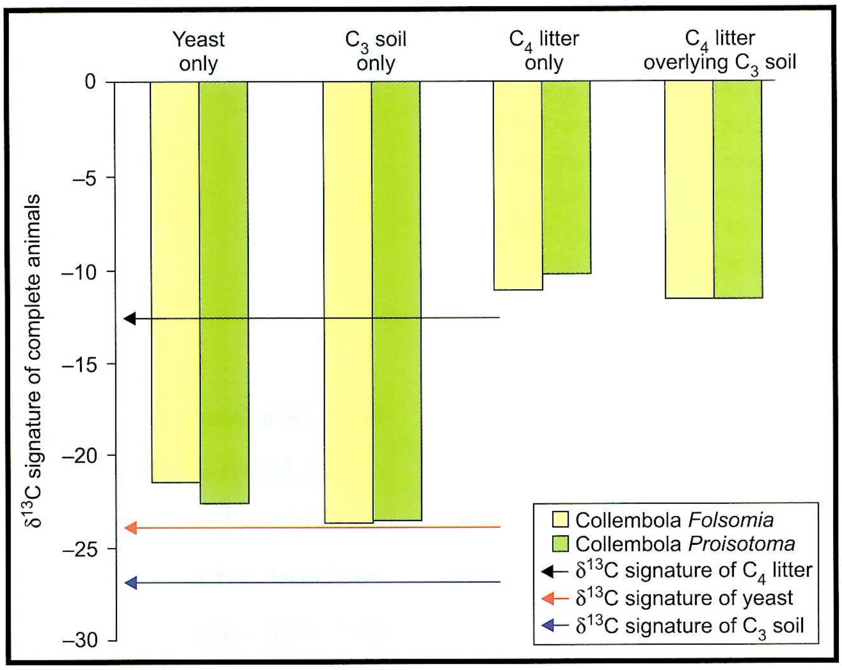

Figure 32. Identification of food sources: the whole-body $\delta^{13}C$ signature of two species of Collembola closely resembles that of their food source. Given a choice between litter and soil, these results suggest that the animals choose litter exclusively

samples, sample size is not usually limiting, and results are required to a very high precision. Most biological work, by contrast, produces a large number of samples, some of which may be very small, but the precision of the results can be an order of magnitude less than that needed in geology. In the 1980s this led to the interfacing of continuous-flow elemental analysers to single-inlet mass spectrometers specifically aimed at the determination of ^{13}C and ^{15}N in biological materials.

Improvements in instrument sensitivity mean that natural abundance determination of ^{15}N is now a routine operation. Such determinations remain 'totals', however: weighted averages of all the individual components where the significance of individual signatures is lost. Since the mid-1970s, techniques have been available for the measurement of ^{13}C in individual compounds by micro-combustion following their separation by Gas Chromatography (GC), but more recently the technique has been refined to measure ^{15}N in individual compounds. This is a more difficult problem because of the much lower concentration of nitrogen in the sample and its much higher concentration in the surrounding air. In a related development, concern over greenhouse gases and pollution generally has produced instruments capable of measuring ^{13}C in methane, carbon monoxide and carbon dioxide, and ^{15}N and ^{18}O in nitrous oxide, all at ambient concentrations. Samples of 100 ml of air and less are needed when only a few years ago 70 l would have been required.

The Stable Isotope Facility

The Stable Isotope Facility was established at ITE Merlewood in 1983 with the aim of providing a stable isotope analysis service for the terrestrial and freshwater sciences research community in Institutes and university departments supported by NERC funding. The Facility is equipped with two mass spectrometers:

- a dual-inlet SIRA 9 (VG) for high-precision work, and
- a Roboprep elemental analyser and single-inlet Tracermass (Europa Scientific) for total ^{13}C and ^{15}N measurement by combustion.

Some examples of research using stable isotopes include a ^{15}N bioassay technique for assessing the fertility of soils by measuring the actual rate of nitrogen uptake by plant roots grown in test soils. This technique avoids the use of chemical extractants on the soils or the use of foliar analysis as an indication of what may be happening in the roots. Early results which suggested that nitrogen uptake is not an independent function but linked to the availability of other nutrients, particularly phosphorus, have been corroborated.

Further modifications are being developed as a refinement of the technique. ^{15}N ammonium is being replaced by labelled organic compounds in measuring uptake rates of roots infected with mycorrhizae. The technique is limited by the availability of suitable labelled compounds, but tests with doubly labelled glycine have shown that uptake is measurable. For mycorrhizal-mediated uptake there is also a problem in excising the root without damaging the fungal association, and it may be that the present technique of washing the roots needs to be replaced with one in which the root ball remains intact. Other work with Sitka spruce (*Picea sitchensis*) has shown that the sensitivity of the method can be improved 20-fold by restricting the sampling to roots of 0.5 mm diameter or less.

Stable isotope analysis is also being used to distinguish autochthonous and allochthonous inputs to lakes and river systems. Traditional models of lake ecosystems have assumed that food webs are fuelled by autochthonous inputs of new organic matter from photosynthetic phytoplankton. Recent results from Loch Ness challenge this view by suggesting that about half the body carbon of zooplankton, and consequently of fish which prey on them, is derived from organic matter of terrestrial origin. This may also explain the observation that, in many lakes, plankton respiration exceeds primary production and leads to carbon dioxide supersaturation in surface waters.

At a very much smaller scale, ^{13}C and ^{15}N analyses have helped confirm a remarkable transformation. *Littorella uniflora* is a small amphibious macrophyte which grows rooted in sediments close to the margins of lakes and reservoirs. It is normally submersed, but, as water levels fall in spring and summer, it develops a new set of leaves, flowers, and sets seed. There are changes in the complement of stored nitrogen, chlorophyll and carbohydrates, but most striking is the loss of phospho-eno pyruvate (PEP) carboxylase as Rubisco activity increases eight-fold. In other words, a plant with CAM metabolism can change to one having C_3 metabolism.

The Facility is currently negotiating the purchase of a new instrument which will enable it to enter the field of compound-specific isotope analysis. It will then become one of very few laboratories in the UK able to analyse ^{15}N at natural abundance levels in individual organic compounds. The decision to make this move follows increasing recognition of the value of stable isotopes to elucidate the flow of N and C in terrestrial ecosystems, and in particular to improve our understanding of trace gas fluxes from soils.

C Quarmby

Quality assurance of chemical analysis

Environmental science is increasingly interdisciplinary in nature, and so analytical chemists are increasingly working in research teams. Analytical chemistry is a key element of almost every CEH core strategic programme, and research funding is now more geared to collaborative projects with other Institutes or universities within the UK, and across the European Union. Applications range from atmospheric chemistry and pollutant deposition flux, through ecosystems, to impacts on organisms.

The production of measurement data which are fit for their intended purpose depends critically on

Chemists provide input to research programmes at various levels and respond to demands with flexibility.

Plate 19. The ITE Merlewood mobile laboratory

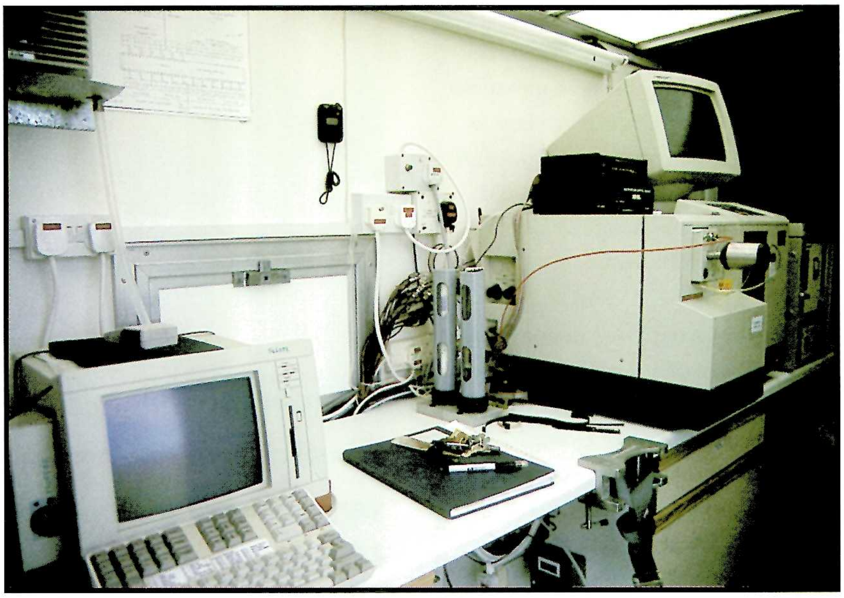

Plate 20. Gas chromatograph used for quantifying soil gases at field sites, housed in the ITE Merlewood mobile laboratory

ITE laboratories perform to standards well above the minimum criteria defined to meet environmental legislation and pollution control regulations.

analytical laboratories adopting a structured and coherent approach to both the scientific and quality aspects of the work. Quality assurance (QA) means the introduction of a planned system of activities designed to ensure that the quality control programme is effective, and in turn to provide a quality product.

The main analytical activities in ITE are concentrated at Merlewood (nutrient and pollution analysis), Monks Wood (toxic chemicals, trace metals, herbicides and pesticides) and Edinburgh (atmospheric pollutants). There are also a range of analyses carried out at Bangor, Banchory and Furzebrook. Chemists provide input to research programmes at various levels and respond to demands with flexibility. As well as leading the research in atmospheric chemistry, for example, or working in teams to provide analytical data, chemists function as specialists operating in permanent laboratories or in mobile field laboratories (Plates 19 & 20), as consultants offering advice on the design of research and monitoring projects, and as researchers developing methods.

In 1995, an ITE chemistry network was established to:

- ensure that analytical chemistry requirements were being met in the most cost-effective way;
- ensure consistent quality of data;
- identify and report progress on research and development priorities;
- provide a forum for chemists to discuss common interests;
- provide and disseminate information on facilities and expertise;
- provide a communication link for users.

It is the aim of the analytical laboratories within ITE to supply chemical data fit for the purpose of studies in environmental research. To provide quality assurance, operations in the laboratories involve:

- employment of professionally qualified analysts;
- a commitment to training in order to maintain skills;
- use of modern equipment;
- use of validated methods;
- reliable sample management systems;
- careful organisation of laboratory accommodation for efficient use and to minimise contamination;
- good liaison between analysts, the project leader and the customer; and
- application of rigorous quality control procedures.

QA procedures ensure that there is a traceable link from certified reference material and validation, through proficiency testing, to the results of analysis. This is achieved by documented management of stock solutions, the use of rigorous internal quality control procedures, and, where feasible, analysis of material with certified values, participation in inter-laboratory proficiency trials, and recovery tests.

Inter-laboratory studies carried out to compare the performance of laboratories sometimes produce disturbing results (Sherlock *et al* 1985) Inaccurate and unreliable analytical data rarely meet the customers' needs and therefore QA systems need to be established Proficiency testing provides laboratories with a regular, independent and objective means of assessing and demonstrating their performance These testing schemes are relatively expensive, in terms of both organisational costs and time spent by participating laboratories There are 25 listed proficiency testing schemes operating in the UK, with four of them specifically covering waters and environmental materials Where practical, our laboratories are committed to participation in recognised proficiency testing schemes, such as AQUACHECK (Water Research Centre) or the International Soil and Plant Exchange programmes (University of Wageningen), in order to test performance against the wider analytical community For the analysis of soluble or total fractions in water and total determinations in plant material, ITE laboratories perform to standards well above the minimum criteria defined to meet environmental legislation and pollution control regulations

In an ideal situation, inter-laboratory testing schemes provide an independent measure of the proficiency of the laboratory In the assessment of soil status, the vast array of extraction and analytical techniques that are available, coupled with the wide variety of soils and contaminants, have made the standardisation of methods very difficult Measurement parameters may be labile, presenting a challenge to produce a stable enough material for assessing proficiency Assessment of performance for labile fractions and soil extraction has proved difficult as there is usually a much greater spread of data from the participants Frontier science may involve the analysis of new species where validation is limited to internal calibration or recovery testing In this case, the quality of the analyses is determined by the proficiency of the analyst in developing new methods

Environmental monitoring is an increasing element of the ITE programme It places a particular responsibility on the analyst to produce accurate and reproducible results over longer timescales Within the UK Environmental Change Network, quality assurance is of prime importance to ensure that any changes in measurements are not artefacts of the analytical approach Protocols include strict guidelines of operation for analytical laboratories and a network quality control system designed to attach quality measures to the regular sampling programme

A P Rowland

ITE laboratories are committed to participation in recognised proficiency testing schemes.

Reference

Sherlock, J.C , Evans, W.H , Hislop, J., Kay, J J., Law, R , McWeeney, D.J , Smart, G.A., Topping, G & Wood, R 1985 Analysis – accuracy and precision. *Chemistry in Britain,* **11,** 1019–1021