Natural Environment Research Council

Institute of Terrestrial Ecology

1976

Natural Environment Research Council

Institute of Terrestrial Ecology

Annual report 1976

London: Her Majesty's Stationery Office

First published 1977
ISBN 0 11 886600 1

The cover shows clockwise from the top:
Female hen harrier. Photograph N. Picozzi;
Large blue butterfly. Photograph J. Thomas;
Freshwater alga Pediastrum boryanum. Photograph E. Swale & H. Belcher;
Sitka spruce wood, stained section. Photograph E. D. Ford;
Badger. Photograph H. Kruuk;
Sea rocket. Photograph S. S. Anderson.

The Institute of Terrestrial Ecology (ITE) was established in 1973, from the former Nature Conservancy's research stations and staff, joined later by the Institute of Tree Biology and the Culture Centre of Algae and Protozoa. ITE contributes to and draws upon the collective knowledge of the fourteen sister institutes which make up the *Natural Environment Research Council*, spanning all the environmental sciences.

The Institute studies the factors determining the structure, composition and processes of land and freshwater systems, and of individual plant and animal species. It is developing a sounder scientific basis for predicting and modelling environmental trends arising from natural or man-made change. The results of this research are available to those responsible for the protection, management and wise use of our natural resources.

Nearly half of ITE's work is research commissioned by customers, such as the Nature Conservancy Council who require information for wildlife conservation, the Forestry Commission and the Department of the Environment. The remainder is fundamental research supported by NERC.

ITE's expertise is widely used by international organisations in overseas projects and programmes of research.

Contents

The development of ecological research

Introduction

In the Annual Reports of the previous two years, we have discussed the role of ecology in policy-making and some of the principles and constraints that influence the planning and management of environmental resources. Specifically, we have argued that, because ecology is a multidisciplinary science, it has an important part to play in governing the choices we make about the management of land. The overall objective of ITE is to respond to the changing demands on the ecologist by studying ecological problems relevant to the reduction of economic margins in our national land management. We therefore seek to respond to these problems by surveys which describe existing situations, practices and trends, by experiments which probe into the interactions of components of the relevant ecosystems and their responses to environmental practice, and by interpretation and assessment of 'environmental impact' in advance of a development so as to predict the likely changes that will occur and, consequently, to guide development to the most suitable site or constrain it to the optimal degree.

Development of ecology

It would be foolish, however, not to recognise that the science of ecology is itself also developing. In part, this development is a result of the greatly increased research effort in the whole field of ecology. In part, it is a response to the many problems currently being created by changes in land use, by pollution and the attempts to control or minimise pollutants, by changes in the intensity and techniques of harvesting of agricultural and forest crops, by increasing pressures on the stocks of useful plants and animals, and by the growing population of the world. Our knowledge of the ways in which ecological systems are modified by external pressures is therefore increasing at an unprecedented rate. Similarly, new research techniques are constantly being developed, sometimes by borrowing from other fields of science, and even from such unlikely sources as research initiated primarily for reasons of national defence and the exploration of space. Thus, the electronic computer, the electron microscope, lasers, cryobiology, remote sensing, and many other technical developments are all providing tools of potential value to the ecologist in his search for solutions to pressing and important problems.

As a result, an interesting paradox has revealed itself. While politicians, planners, and other decision-makers may be expected to identify the problems which they regard as being important for solution by the world's scientists, these same decision-makers are usually unaware of the research techniques which are capable of being exploited in the solution of practical problems. They are thus frequently willing to invest large sums of money in areas of research which, while capable of absorbing very considerable amounts of investment in capital and current expenditure, are unlikely to be productive, simply because they are not yet at a stage in which the techniques are ready for exploitation. Scientists, on the other hand, are concerned to see the exploitation of those technical developments which are capable of rapid development – and which are likely to lead to increased understanding and innovation in the control of our environment and its ecology. The need for a dialogue between decision-makers and scientists may be recognised, but the correct forum for such a dialogue has not yet been created in any country in the world. It may be helpful, therefore, to consider some of the new opportunities which are currently being developed within the broad field of ecology.

Survey of environmental patterns and resources

We have already suggested that surveys which involve some form of sampling and measurement, allowing us to make statistically valid statements about the frequency with which various types of plant and animal communities occur, and about the kinds of relationship these communities have with factors of the environment, are uniquely able to relate the observations of different people at different times, and to state quantitatively the degree of change taking place from one period to another, thereby enabling us to make extrapolations into the future. New developments in the methodology of ecological survey have increasingly focused on relatively rapid and inexpensive ways of undertaking surveys and investigating the complex interactions between the physical, chemical and biological components of our environment. Not only do such methods enable us to design surveys which achieve a predicted level of precision for the estimates we require to make, but they need take no longer than the more subjective and descriptive approaches which have hitherto been used by ecologists. They also have the advantage that they are more readily repeated and interpreted. In part, the improvement lies in our ability to make better use of existing information in designing any further collections of data. Each new survey, therefore, is firmly based on all those surveys which have already been undertaken, and exploits our ability to interpret and utilise information which we already have about the areas and the ecological systems which are being re-investigated.

Even where no previous surveys have been carried out, it is now possible to make effective use of information which can be derived from maps, from aerial photographs, and from satellite photography, so as to ensure the progressive characterisation of the ecology and

physical environment of the areas under investigation. In this way, we can maintain a continually updated picture not only of the averages of particular qualities and quantities, but also of their variability. By concentrating on those variables for which precise information is required, and contenting ourselves with less precision for other variables, our surveys can be made, at one and the same time, more penetrating and more economical. In this, we are, of course, helped by our ability to hold considerable quantities of data in readily usable form through the use of electronic computers.

The first three years of the implementation of the proposals contained in Lord Rothschild's report on government-supported research and development* have demonstrated the need for ecological information at local, regional, and national levels. In part, much of this information already exists, but is not in a form which can be conveniently summarised or presented. Most of the information has never been properly analysed, even as a basis for the collection of further data. Some information can only be gained by further ecological survey, especially in areas that have not previously been regarded as of conservation or ecological interest.

Experience with surveys, and the wider contact with customer departments which has resulted from the planning and execution of surveys, have emphasised the fact that much of the information required by customers could be obtained with only a limited amount of field work, if the data already available had been properly analysed and were held in more accessible forms. Furthermore, the urgency of planning decisions makes it desirable that the requirements of ecological information are anticipated rather than perceived only when the decisions have to be made.

The main value of ITE's contribution to planning decisions and the formulation of policy lies in the expertise of the staff of the Institute for the interpretation of ecological data. Recent advances in the techniques of mathematical and statistical analysis of complex, space-orientated data have added new dimensions of possibilities to the interpretation of ecological information. Such techniques make possible the screening of data for redundant information, reification and ordination of data to illuminate the most important dimensions of the inherent variation, detection of pattern and trend amongst apparently random variation, and discrimination between two or more pre-assigned categories.

* *Framework for Government-supported Research and Development,* Command 5046.

While much of the interpretation of ecological information at local, regional, and national levels will depend upon mathematical analysis and modelling of the complex inter-relationships between organisms and their environment, the expression of these activities will usually be in the form of maps and diagrams. Some of these maps will be prepared by conventional cartographic techniques, but, increasingly, the maps will be prepared by computers from a machine-readable data base on teletypes, line-printers, cathode-ray tube displays, and specialised plotters.

All of these considerations have emphasised the importance of anticipating the many demands of ecological survey and analysis of local, regional, and national trends and characteristics. ITE has therefore undertaken a carefully phased long-term assembly of ecological information as a data base from which will be met as many demands as possible from customers, and which will incorporate data from specific commissions as they are developed.

The data base for the preliminary phases of this scheme will be maintained on the ITE computers, and principally in the environmental data centre at the Bangor Research Station. The data base for the subsequent stages will be maintained on the larger computers in NERC. Presentation of the results of ecological analysis and interpretation will largely be through maps prepared on a variety of computer systems. Some of the simpler presentations will be through teletype and line-printer maps produced on ITE machines. More conventional cartographic presentations will be made through plotters and laser scan machines of the Experimental Cartography Unit, or on special-purpose machines hired commercially. Increasingly, it is hoped to make wider use of microfilm and microfiche techniques.

Experimental approaches

Substantial experimental programmes are a necessary adjunct to survey and interpretation of the broad trends which relate ecology to important issues of land use and resource conservation. Many of these experimental programmes will necessarily be concerned with the manipulation of ecological systems in order to explore alternative configurations of land-use patterns, and the dynamics of the response of ecological systems to management practices. Some experiments will also be required to determine the impact of various forms of environmental management on the ecology of different parts of Britain, ranging from the south coasts, through the lowlands and uplands of Britain, to the mountains of Wales and Scotland. Increased use will necessarily have to be made of existing areas of nature reserves,

and especially the UNESCO Man and Biosphere reserves. In some areas, ITE will need to lease land for experimental work or make suitable arrangements with landowners who can provide sufficient security of tenure to ensure that relatively long-term experiments can reach their completion. Above all, we must be sure that these experiments do not proceed beyond their useful life, as detailed experimentation on this scale can occupy a considerable amount of the resources of any research organisation. We also have to ensure that the areas upon which such experiments are carried out are representative of the wider populations about which we will wish to make inferences in guiding management practices in agriculture, forestry, recreation, and pollution control.

Experimental programmes will also need to be set up to investigate ways in which ecological systems adapt to changes in the environment, to the cycling and pathways of energy through the systems in transmission of separate elements, many of which may act synergistically, and to the population dynamics of the systems themselves. Much work still remains to be done in the United Kingdom, where ecological research has been continuing for many years, on the stability and resilience of our basic ecological systems. This work will need to be accelerated if we are to determine the rates at which our various ecological systems, both artificial and semi-natural, can be driven at faster rates of change in the search for higher productivity.

The species composition of all biological communities varies in time and space, the rate and character of change being a function of the external and internal factors which influence different populations in different ways, but also of the scale at which the community is examined. The organism/environment interaction that characterises a point in time and space becomes part of a mosaic when an array of microsites is combined into a biological community. It follows that communities and landscapes constitute a range of possibilities which include the extent of microsite differentiation and pattern diversity, the degree of biological influence on microsites and on population regulation, the behaviour and longevity of dominant populations, the relative stability of populations, the roles of disturbance and succession, and the kinds of succession and extent of species-replacement during succession.

Recent developments in experimental techniques, both in the laboratory and in the field, including the use of tracers, radiotelemetry, and other sophisticated electronic devices, have made it possible, for the first time, for many of the basic physiological processes to be investigated experimentally. Nowhere are these possibilities more exciting than in the complex interactions of physiological processes of animals which are relatively close to the ends of food chains with the kinds of foods they take in and utilise. Similar opportunities exist in the understanding of the basic physiology of plants which enable them to succeed in hostile environments through adaptation, and to compete successfully with plants that are already established in such environments.

Ecological processes

Experimental programmes of research lead inevitably to the wider consideration of basic ecological processes in the cycling and pathways of energy through ecological systems and in the efficiency with which energy is transferred from one part of the system to the other. Study of such processes is vital to the whole concept of ecological production, upon which much of our future may depend, once we have realised that we cannot allow ourselves to continue to be dependent upon exploitation of fossil fuels. Since our only continuing source of creative energy is through sunlight, and green plants are the only organisms capable of making direct use of the energy of sunlight, study of the efficiency of various plants and ecosystems necessarily forms an important part of the creation of future supplies of energy. So too does the study of the ecological effects of various strategies for the provision of energy in other ways, whether nuclear, tidal, wind-driven, or by the direct use of sunlight.

Similarly, study of ecological processes forms an essential part in determining the effects of pollution and the complex interactions between many different elements, possibly working synergistically. We still know far too little of the responses of plants and animals to pollutants acting in complex ways, and it is only recently that the necessary tools for such studies have become available to the ecologists, through the efforts of their colleagues in physical and chemical sciences. As the barriers between biology, physics, chemistry, and mathematics break down further, even greater opportunities will be created for the transfer of techniques from one science to another.

Simulation and modelling

In recent years, the application of several powerful simulation and modelling procedures to ecological processes has stimulated research into various aspects of ecology in general, including those of ecological succession, the development of adaptive strategies, and the manipulation of ecological systems towards desirable stages. Such techniques have opened up the possibilities of providing a sounder ecological basis for the development of management strategies for natural and near natural ecosystems. Before any technique of

simulation or modelling is applied to a set of data, or to any models developed, it is, of course, most important that the objectives of the study are clearly defined. Techniques suited to the simulation of natural succession, for example, may be quite inappropriate when applied to management or vice versa. In many cases, the technique will also need major modifications because of limitations in the data available.

In order to improve both the general level of understanding regarding dynamic changes in ecological systems, and the effective use of techniques to explore them, well-designed surveys and experiments are necessary to provide the data sets for model generation and testing. Efficient design involves the recognition that it is the change in ecosystem parameters that needs to be measured, with emphasis on rates of change in response to well-understood perturbations that are themselves realistic in biological or management terms. Effective contributions to management require interaction between ecologists on the one hand and managers on the other. In turn, however, it is essential that the ecologist interacts with a variety of other specialists, particularly in experimental design, data interpretation, model building and model validation, and that the manager interacts with those individuals and agencies that influence his selection of management goals and constrain his management strategies.

ITE is fortunate in having a sufficient range of disciplines within its own organisation for these requirements to be met. As the new opportunities of ecological research are exploited and developed, ITE will increasingly be in a position to fulfil its research objectives of improving the understanding of the factors determining the structure, composition and processes of terrestrial ecological systems and the abundance and performance of individual species and organisms. In this way, we hope to provide a sounder scientific basis than is presently available for predicting and modelling future environmental trends, especially those resulting from man's activities, hence permitting a more critical assessment of the need for, and likely benefits of, specific measures to protect and manage the environment.

Some of the ways in which these objectives are being achieved are summarised in Sections II and III of this Report. Section II contains some longer reports of research projects which have reached a stage at which they are either to be terminated or at which the strategy for future research is to be changed in some major way. Section III of the Report gives accounts of individual research projects grouped in such a way as to reflect the main spectrum of interest and response. The accounts in this Section of the Report are deliberately kept brief, as reporting progress in a wide range of research in the terrestrial environment. The full list of projects currently being undertaken within ITE is given in Section IV. Taken as a whole, the potential contribution of ITE to many of the important ecological issues in the United Kingdom will, it is hoped, be evident.

J.N.R. JEFFERS
Director

Longer research reports

Introduction

This Section of the Report contains descriptions of research which has been completed, or which has reached a stage justifying rather longer reports than those contained in Section III.

The Section begins with a report on the effects of the summer drought of 1976 on terrestrial ecology and some of the implications of those effects for current and future research. The report was originally prepared for NERC from observations contributed by many members of the staff of ITE, and was subsequently used in a submission by NERC to the Department of the Environment. The full report by ITE has not so far been published, and is therefore reproduced here.

There then follow reports on two desk studies carried out by ITE for the Countryside Commission. The first of these studies had the aim of defining the main land uses in the uplands, the factors which influence those uses, the changes which are occurring and which are likely to occur, and the ecological and landscape consequences of change. The study also provided ITE with an opportunity to determine the subject areas in which research effort should be concentrated. The second of these desk studies was on vegetation management in country parks. The main report on this research has been published by the Countryside Commission, but the main points that emerge from this report have been summarised here.

Research on the puffin, *Fratercula arctica*, has been going on since 1972, and the third of the reports in this Section describes some of the results that have so far been achieved. The report on dieldrin residues in carcases of kestrels and barn owls also summarises work which has been going on for some time, and marks a change in the way in which this important topic will be investigated in future. Similarly, studies of the large blue butterfly, *Maculinea arion*, commissioned by the Nature Conservancy Council, have reached a stage at which the results can be conveniently summarised. The Section ends with a description of a study of the mechanism of natural selection in *Puccinellia maritima*.

SUMMER DROUGHT – EFFECTS AND IMPLICATIONS FOR TERRESTRIAL ECOLOGY

Introduction

The low rainfall and high temperatures during the spring and summer of 1976 have given further emphasis to problems of water deficiency and increased solar radiation on national, regional and local scales. The extent and distribution of the drought in 1976 still need classification. The effects of the drought, together with those of the less severe conditions of 1975, seem likely to be considerable, whether these are short and long-term effects of a few abnormal years, or cumulative effects of a trend towards drier, warmer summers and increasing water deficit.

Documentation and analysis

One of the first tasks, undoubtedly, is to ensure an adequate documentation of the climatic conditions of the past two years, in comparison with a sufficiently long run of information for past years. Strangely, although the density of climatic stations in Britain is probably higher than anywhere else in the world, we still have relatively little knowledge of the patterns of variation of climate over Britain as a whole. In part, this lack of knowledge is due to preoccupation with meteorological forecasting, but a large part of the blame must also be attached to an obsession with maps and other forms of visual assessment and presentation which has inhibited the analysis and modelling of the information obtained from the recording stations. Support should, therefore, be given to the preparation of an effective analysis of the climatic trends of the past twenty to thirty years.

Observed effects: trees

The observed effects of the drought on vegetation were perhaps most striking on trees, and particularly those trees growing on relatively shallow soils. Birch, under these conditions, showed early signs of browning of the foliage, and, in the most severe conditions, died in considerable numbers. Some other species were similarly affected, although it was not immediately obvious whether trees with premature browning and/or withering of the foliage, as in beech, would succumb entirely, or were merely suffering from an earlier enforced period of dormancy. Drought crack of the bark of conifers, last reported during the dry years of the 1960s, has again been reported from several parts of the country, and the Forestry Commission has already issued a warning of the increased occurrence of the Sooty bark disease of sycamore.

Some of the most interesting effects on trees, however, were less obvious. Taken together, 1975 and 1976 will produce a characteristic growth-ring pattern in all woody plants, and this pattern will be useful in dendrochronology, both in comparing climate in this period with that of similar, earlier droughts, and in acting as a 'marker' zone for future growth. Following from this observation, the response of growth in a range of tree species to the unusual conditions, and, particularly, the effects of climate on provenances of exotic trees, will provide opportunities for interesting research. Do

provenances from low rainfall areas respond very differently to abnormally dry conditions than those from wetter regions, for example?

Similarly, the effect of sunshine and high temperatures on ripening wood and promoting increased flowering in some species of trees is well-known. In 1976 because of the lack of late frost in many areas following flowering, there were large seed crops in a wide range of species. It is likely that this heavy seeding will be repeated next year, unless the trees have a mechanism to avoid bearing large crops of seed two years running. It will certainly be interesting to study the effect of seeding on the vigour of the trees, and their growth, flowering and fruiting in subsequent years.

Even without this effect, a continuation of abnormally dry and hot summers could give greater importance to ITE's work on the selection of 'tolerant' trees for industrial spoil, and the response of the selected clones to drought will necessarily have to be included in our research programme.

Perhaps even more subtle are the effects of drought on the formation of buds. Most conifers have preformed buds and extension growth may be affected next year, because fewer stem units are formed in apices during periods of drought. Contrasting with this delayed effect, one might also see an immediate effect on the activities of lateral meristems affecting volume increments. Pines will be able to compensate for the deficiency in stem units by producing long needles next year if it is wet, but spruce will not. By mid-October, it was possible to say how many needles there would be on next year's conifers, and to compare this estimate with the numbers formed in last year's buds.

Observed effects: other plants

The effects on other plants have also been marked. For example, poor shoot growth and premature shrivelling of flowers have been observed on *Calluna* and *Erica* growing in dry sites, together with heavy July–August yellowing and browning of bracken foliage, and the complete drying out of standing water on many moorland bogs, with consequent decrease in the growth of bog plants. Direct effects include death (or apparent death) in some plant species, the most noticeable on heathland in the south being the browning of *Calluna*. Whether such plants are capable of regeneration from their roots remains to be seen, but plants browned last year now seem to be dead. A wetter year in 1977 may, however, allow some of the plants to recover. Earlier in the year, the dry conditions seemed mainly to affect *Erica*, with *Calluna* suffering later in the summer, and areas that were green in mid-summer were rapidly turning brown towards the end of the summer.

The effects of high summer temperatures, which are usually concomitant with drought, exacerbate the effects of lack of rain, but have consequences of their own on plant distributions. Relatively small increases in temperature, if coinciding with critical stages in the life cycle of a plant, can have apparently disproportionate effects. Plant geographical boundaries occurring within Britain will undoubtedly alter, presumably with a northern extension of more southerly or continental species, accompanied conversely by a withdrawal of oceanic or northerly plants, e.g. Atlantic bryophytes, Arctic alpines. No doubt the position will be considerably more complex than this, with many subtle and less obvious forecast changes. Thus, wheat-growing areas may extend northwards at the expense of grazing, and marginal land in the north and east may be more readily improved, following a reduction in leaching and acidification.

The effect of the prolonged dry spell upon wet heath and bog plants is difficult to predict. The water table was reduced to well below normal levels, with bog pools being almost non-existent. Many species survive by capillarity and the *Sphagna*, although very dry, are likely to recover. The danger to bog species is therefore more likely to be due to fire than to drought. Local species, such as *Gentiana pneumonanthe* and *Lycopodium inundatum* remained reasonably healthy, although flowering and growth in gentians was somewhat reduced. Bracken has shown signs of drought in many areas, but, on areas that have been burnt, has also shown surprising regrowth.

Point quadrat data on salting pasture at Bridgwater Bay, Somerset, showed peaks of annuals *Atriplex hastata* and *Suaeda maritima* one year after the 1959 summer drought, and a peak of the biennial *Aster tripolium* two years after. Short-term effects of this type are likely to recur and be widespread and no doubt have their repercussions on the cyclic relationships between plants and herbivores. It has been observed, for example, that coastal grass communities may persist for a decade or so at a level of maturity where transplants of species from the next stage of the succession can survive, and where natural establishment of these species cannot occur, or can only occur very slowly. Drought, or winter ice, opens the sward and encourages rapid establishment of succeeding species. ITE has continuous records of lichen succession and spider orchid populations, and it will be interesting to see if the drought has produced any major changes over long periods.

Observed effects: invertebrates

Animal populations have also been affected, either because of changes in the availability of food plants and habitat, or because of complex interactions between predators, competitors and parasites. Some of the changes in the invertebrates are quite marked, as in the large blue butterfly, which is particularly associated with close-cropped, south-facing, arid grassland, that experiences some degree of drought in a normal year. The droughts of 1975 and 1976 were exceptionally severe and were exacerbated by the very high temperatures. It has sometimes been difficult to distinguish between the effects of moisture deficit and temperature, but drought has adversely affected the large blue throughout its habitat.

The longevity of many adult insects is reduced by low humidities, and, as with the large blue, early mortalities were probably common in 1976. For example, among the butterflies, the meadow brown butterfly, the comma butterfly, and the silver-washed fritillaries are all likely to have suffered to some extent. Egg-laying was probably also reduced for those species whose adult stages coincided with the drought. This is perhaps especially true of the egg-laying of butterflies, which seems to be more susceptible to climatic conditions than in most other insects. Observations suggest that the numbers of eggs of the common blue butterfly and the holly blue were very low in the second generations of 1976, in respect of the larger number of adults seen flying, and compared with casual observations in previous years.

In contrast, the white admiral butterfly has been shown in the past to have benefited from a series of warm summers, increasing its numbers and expanding its range. The fine summers of 1975 and 1976 have resulted in a rapid build-up in numbers, with large numbers of eggs in 1976 – a 30-fold increase on 1974. However, the effect of drought has been to increase the mortality of young larvae due to predation by invertebrates such as spiders, to such an extent that next year's numbers will almost certainly be lower than this year's. The high predation has presumably been due to a shortage of other invertebrate food, because many food plants have died. The white admiral butterfly food plant, honeysuckle, is more resistant.

Study of a small isolated population of the Roman snail has suggested that there was no successful breeding in 1976, following a very poor year in 1975. The adults are long-lived, probably up to ten or fifteen years, and breeding success is rather erratic, depending on the availability of moist conditions. Also, for the first time since the study began in 1971, there has been substantial adult mortality due to predation by small mammals. This, too, would seem to be an effect of the drought, the predators turning to a food source which is not normally considered palatable, but which provides a substantial amount of moisture. The effects on the population have therefore been detrimental, but probably not catastrophic, as many adults do survive.

In north-east Scotland, increases in numbers of grasshoppers have been observed in their usual habitat, with a spread on to moorland grassy areas that are normally too wet for these invertebrates. There have also been increases of several species of butterfly at lower altitudes, and crane flies at low altitudes and on the arctic/alpine ground.

Observed effects: other animals

Observations of effects on birds have been less striking, but good breeding success has been reported by wheatear and snow bunting in the high Cairngorms.

Accumulation of animal faeces on the land during drought produced measurable nitrogen flushes in inshore coastal waters, immediately following the first heavy rainfall. This effect could have repercussions on the public health at bathing beaches, and might produce pollution thresholds affecting the survival of certain species.

Observed effects: freshwater systems

The national press, radio and television have drawn attention to the most obvious effects of the drought on freshwater ecosystems – reduced water levels and flow rates, high temperatures causing fish kills, increased concentrations of nutrients, effluents, etc. – but some effects escaped notice. For example, the exceptional summer conditions resulted in unusually rapid and luxurious growth of aquatic vegetation, particularly in smaller drainage channels and ponds. Indeed, the general consensus of opinion in the fens is that there has never been a better year for weeds nor a worse one for water levels.

The potential dangers of controlling aquatic weeds with herbicides applied in warm weather are well-established, and the incidence of severe de-oxygenisation and fish kills associated with decaying vegetation has decreased. However, there have been several instances where this has happened, following the application of a herbicide to small lakes used for amenity purposes, and although the herbicide was applied as recommended in late spring, the effects on plants were not seen for several weeks, by which time the hot spell was in progress.

Many freshwater ecosystems adversely affected by the drought recovered quickly after the heavy rains. Even

those water bodies which had dried out completely, for example the dykes and experimental ponds in Woodwalton Fen NNR, recovered completely with the sustained autumn rainfall. While it would be of interest to follow the pattern of recolonisation and subsequent recovery of such systems, there is an urgent case, if the trend towards drier, warmer summers continues, to reconsider the timing of herbicide treatments and their effects on freshwater ecosystems.

If summers with low rainfall are to become a feature of our climate, there is bound to be an effect on the spawning of migratory salmonids, and this may also affect otters and other animals that feed on the salmonids. We have no detailed knowledge of how dependent any carnivores are on these organisms, and it is possible that winter breeding in otters, for example, is timed to coincide with the abundance of dying kelts. Prolonged de-oxygenisation of the rivers may affect the spawning ability of fish which move up rivers in spring as well as the survival of fish in shallow lakes.

Drier conditions reduced the availability of surplus drainage water to form rivers, lakes, ponds and ditches, thus modifying aquatic and sub-aquatic vegetation and wildlife, and reducing the availability of wet habitat generally. The rate of drying out of raised bogs has increased, encouraging further colonisation by trees.

Observed effects: soils

The composition, both physical and chemical, of soils and many soil processes, particularly the nutrient and decomposition cycles, has also been affected. Similarly, losses of H_2S from a cultivated soil, due to mineralisation of organic sulphur, have been particularly large in the early stages of the change from aerobic to anaerobic conditions. In the absence of precipitation, atmospheric concentrations of SO_2, and perhaps its oxidation products, increased considerably so as to give very acid rain when the drought was finally broken. There is also some evidence of an increase in the amount of deposits on plant surfaces consequent to the long period without rain, and these may affect the level of activity of plant surface microflora and microfauna, particularly where these substances are toxic, e.g. sulphur and heavy metals.

Drought effects on agricultural land are worst on gravelly or sandy river bank fields, on similar material on glacial ridges and knolls, and on land subjected to extra artificial drainage in the past. These effects might possibly make farmers delay before contemplating further large drainage schemes. Wind erosion on dried-out soil, sand and gravel has been worse than usual in summer and autumn. Such dry, powdery material is more easily removed by rain than is a damp surface, and erosion by a rainstorm in the Cairngorms in July was locally the most severe since at least 1956, and, for the massif as a whole, was the worst since before 1940.

Effects of fire

In addition, there has been the direct effect of fire itself, causing the destruction of climax vegetation and breaks in the natural succession of vegetation. Frequently, fire modified existing ecosystems and also had important effects upon soils by the destruction of humus, etc. A considerable proportion of the heathland in southern England was burnt. How the dry heath recovers, and whether by rootstock regeneration or from seed, remains to be seen. We have no experience of the combination of two seasons' drought and such intensive fire. In general, the older heather is less likely to regenerate from rootstocks than the younger heather, and future growth must therefore depend, to a great extent, upon the level of rainfall in 1977.

The effects of the fires upon bog vegetation may have been more damaging than on the drier heath. When conditions are wet, fires will pass over the bog surface, but, in places, the recent fires burnt deep into the peat and killed much of the local vegetation. Where the bogs are grazed by ponies, cattle, etc., as in the New Forest, some peat areas showed physical damage by trampling by animals trying to reach food material.

It may be that, in the long run, the burnt areas of dry heath produce the least problems. When heather is cut and bailed as a commercial operation, any strips of cut material not removed prevent regeneration of the remaining rootstocks and one can only speculate about the large areas of standing heather that may be produced.

Following the severe fires, in the south of England in particular, that have resulted in the loss of property and the evacuation of a hospital, it may be that the public image of heathland and 'wasteland' suffers. It is likely that conservation bodies will have a further problem in the acquisition, maintenance and management of such areas, especially where they are small and near residential developments.

When the first appreciable rainfall occurred, the burnt areas suffered from soil erosion and considerable loss of topsoil and nutrients. The very dry, almost unwettable, soil makes erosion a significant factor, although it may also represent redisposition within a particular site. The NCC, and county councils which control large areas affected by both drought and fire, will undoubtedly require advice upon the future management of these areas.

Implications for ecological research

The above summary represents little more than a patchwork of observations suggesting that considerable changes have taken place as a result of the unusual conditions over the last two years. Some modification of the experimental programme in terrestrial ecology will almost certainly be essential during the next few years. It will, for example, be necessary to repeat experiments or measurements on existing experimental plots to compensate for the loss of information during these years. Similarly, it may be desirable to extend series of experiments to detect interaction with climatic effects over a period of some five or six years, and this extension will certainly affect those projects which are intended to select resistant strains of plants for recolonisation of difficult sites. In addition, new experiments to measure the effects of abnormal years, or the process of a trend towards drier, warmer summers, will need to be established.

In addition to the modifications of existing research, new research will be necessary to establish base-lines against which the changes in climate can be measured. Although there is a considerable body of recorded information on phenology, this information needs more critical analysis than it has received to date, and there is a lack of phenological observation on species of importance as primary producers in ecosystems. Similarly, there is a need for the monitoring of change in ecological systems and in populations of important plants and animals as a result of climatic effects, with increased emphasis on the interactions between climate and response.

Perhaps even more important, however, is the need for increased research associated with the management of ecological systems. In part, this research needs to be directed towards the prevention and control of outbreaks of fire in natural and semi-natural ecosystems, and especially in those ecosystems which are commonly regarded as 'waste land'. In part, this research needs to be directed towards the problems of the storage and conservation of water in natural and artificial ecosystems, but a considerable investment also needs to be made in the forms of management of such systems which prevent the build-up of dry material leading to an 'intense' burn. There are strong similarities between the position in various parts of this country, especially in the south, and the conditions in parts of the USA and Australia, where campaigns against the starting of fires in forest and open country have been so successful that increasingly hazardous conditions have been created, leading to the outbreak of extraordinarily damaging 'hot fires'.

Research on the effects of climatic change, however, needs to be undertaken in association with analysis of the degree and distribution of changes in agricultural and forestry production, and other land uses. Research on this topic in terrestrial ecology will, therefore, only be effective if it is carried out in collaboration with research on the hydrology of lakes, rivers, and ground water, and on agriculture, forestry and wildlife conservation.

One major area of concern which has already emerged is in East Anglia, which is one of the most important agricultural and forestry areas of the country, and in which both industries are dependent upon the maintenance of a relatively high water table and adequate supplies of water. Bearing in mind the problems of the Norfolk Broads, and the proposals to extract considerable quantities of water from the Broads, and/or from the Wash, it seems likely that a major study is needed in this area. Such a study should certainly include various aspects of geology, hydrology, and terrestrial and freshwater ecology. Proposals for this major project are currently being formulated.

Finally, many of the effects noted in this paper have direct implications for the major projects being undertaken within ITE. In the study of upland land use, for example, any significant change in the pattern and variability of climate would inevitably have a major effect on the factors influencing land use, particularly in the uplands. For example, decisions concerning upland cropping are based upon an expectation of the profitability of cultivation. These might rest upon a number of considerations, but of special importance is the farmer's intuitive appreciation of the relative probability of good and poor years, i.e. the balance between adequate reward and crippling loss. The chance of outright failure, which may decrease with elevation owing to the increasing availability of summer warmth, may thus be as important to the upland farmer as reduced average returns to seed. For this reason, research is already going on in ITE to provide basic models of climate and of climatic change which can be used in the ecological characterisation of considerable areas of Britain. Fortunately, a good foundation has already been laid in past research which, although not given high priority, has provided the base for a developing research programme.

J.N.R. Jeffers

UPLAND LAND USE

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

The uplands of England and Wales constitute a land resource in which management options are largely determined by ecological relationships dominated by climatic, physiographic and soil conditions. Over much of the area, management is of low intensity or is non-existent, although the land is used for a wide range of activities – livestock rearing, forestry, recreation, water catchment, mineral extraction and nature conservation. A consequence of the low intensity of use and management is that multiple use of the land is a normal practice, many areas combining, for example, rough grazing, water catchment and recreation. Because of the dominance of ecology in upland management, and because the research of ITE is not aimed towards the support of a particular land use, we have the opportunity in the uplands to analyse and integrate information on a range of uses, and to examine the ecological possibilities and consequences of management. Our interests thus coincide with those of planning authorities and with the Countryside Commission and the National Parks who are concerned with landscape conservation over much of the uplands.

Under contract (483/10) to the Department of the Environment, with the Countryside Commission as lead agency, a desk study has been completed with the aim of defining the distribution of main land uses in the uplands*, the factors which influence them, the changes which are occurring and which are likely to occur and the ecological and landscape consequences of change. Although there is a vast literature concerning the uplands, the study was required because a number of new factors are coming into consideration: the effect of the Government policy on agriculture defined in 'Food from our own resources'; the consequences of commitment to the European Economic Community; the changes in national and international economy linked with availability of non-renewable resources; and the preparation of policy plans for Counties and National Parks. The study also provided an opportunity for ITE to determine the subject areas in which research effort should be concentrated. A full report of the study is to be published as a Countryside Commission Paper and only some aspects are summarised here.

The future?

Interpretation of the official statements on land use policies which are likely to affect the uplands indicates that major changes in the distribution and intensity of land use are unlikely to occur over the next decade or so. Many of the recent trends in agriculture are likely to continue, with maintenance of livestock rearing increasingly concentrated on a reduced number of holdings but with increasing average size. As a result of the trend in agriculture the well-managed upland farm landscape will be maintained, particularly in areas where there is a relatively high proportion of permanent or temporary pasture of good quality to support livestock in winter. Although the agriculture may remain economically viable, it is probable that, as there is gradual concentration on larger holdings, management will decline in intensity and grazing pressure will decrease in areas with a small proportion of good pasture and in the uplands which are a considerable distance from winter pasture. Thus, the same areas will show a deterioration in walls and buildings, a reversion of enclosed land to more natural vegetation and probably a gradual change in the vegetation on unenclosed land.

Forestry developments, with a projected planting of 38,000 ha yr^{-1} to give 2·6 million ha at the turn of the century, can probably be absorbed in the upland areas associated with the withdrawal of agriculture. The projected development will occur mainly in Scotland, but also in the Pennines and Wales. These projections may well be conservative and there are strong indications that a much greater demand for forestry, resulting in competition for land in the uplands, will occur through an increase in demand for wood on the world market; a need to increase in self sufficiency of forest products in UK (currently only 8%) and an increase in demand for forestry as a source of fuel and hydrocarbons. The competition for land may be exacerbated by continuing emphasis on agricultural self sufficiency (currently 60% for mutton and lamb) and the high proportion (possibly 50%) of the uplands designated for landscape conservation (National Parks and Areas of Outstanding Natural Beauty). Thus, the future may consist of a continuation of existing trends as indicated by published policies or it may show major changes in land requirements with associated ecological and landscape consequences.

Land classification

Two major constraints to upland planning were identified early in the desk-study:

(1) Information is usually available at either national, regional or local levels, but the levels are often considered in isolation from each other and there is a need for a formal method of linking the three levels.

(2) There is no classification which has been applied to the uplands of England and Wales which:

* Defined here as land above 240m.

(a) defines the basic environmental variation relatable to biological processes;

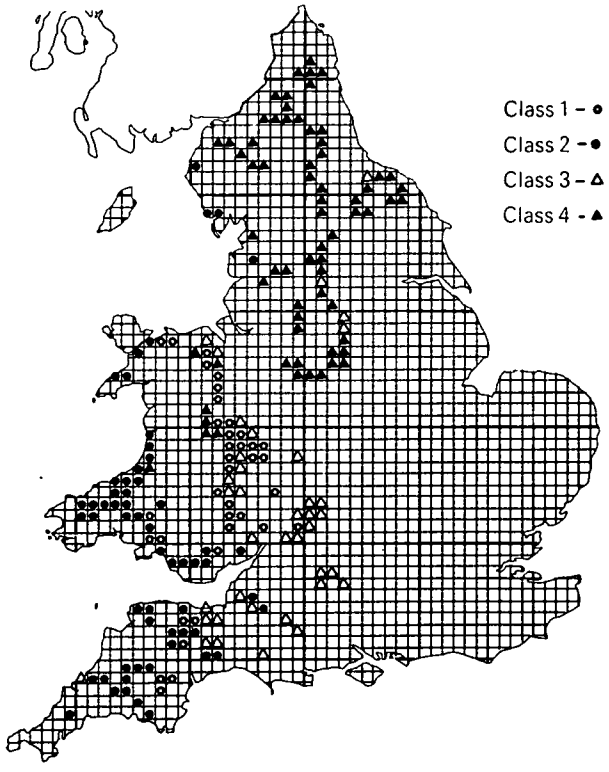
(b) can be interpreted in relation to a range of land uses; and

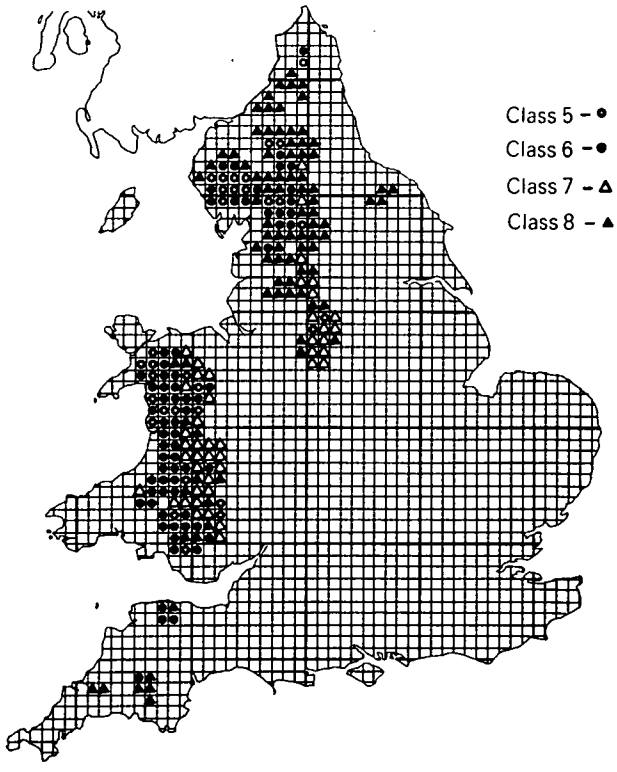
(c) is quick and flexible in use.

The Agricultural Land Classification of MAFF has been applied throughout England and Wales and fulfils some of these requirements but the uplands are contained in two Grades (4 and 5) thus providing little discrimination between different types of land. MAFF have initiated a more detailed survey of the uplands, but this will not be available for a few years and is geared to the definition of the agricultural potential of the land.

The approach to land classification described by Bunce, Morrell and Stel (1975) provides a means to overcome the two constraints. With this approach, a wide range of physiographic, climatic, geological, soil and land use characteristics can be defined for squares of the national grid, using existing maps. Computer analysis of the data determines the main patterns of variation and, using Indicator Species Analysis (Hill, Bunce and Shaw, 1975), the sample squares are assigned to a hierarchical dichotomous series of classes. Indicator features are identified which allow other squares in the population to be classified. Ordnance Survey maps provide a main comparable source of data for all the areas; detailed soil and climatic maps are not available for most of the country, but these features are mapped in generalised form for England and Wales. Thus, from existing maps, the land characteristics can be determined objectively and the land classes so determined are directly related to the distribution of many biological and land use features, thus providing a means of comparison within and between areas, as well as providing a framework for sampling and for assessment of land capability for particular uses.

In the desk study, a survey and classification of the uplands of England and Wales was made, on a broad scale of 10 × 10km grid, using Ordnance Survey, climate and soil maps from which 51 attributes were determined. This was linked to an existing regional land classification of Cumbria on a 1 km² grid based on data from Ordnance Survey and Geology maps with 152 attributes. Management is practised, landscape perceived, and biological systems analysed at a local level and the land classification was examined for local application by a comparison of valleys and parishes within Cumbria. At the local level, analysis of





Figures 1(a)–(b) The distribution of national upland land classes (1–8) in England and Wales based on 10 × 10km grid (map prepared by the Experimental Cartography Unit of NERC).

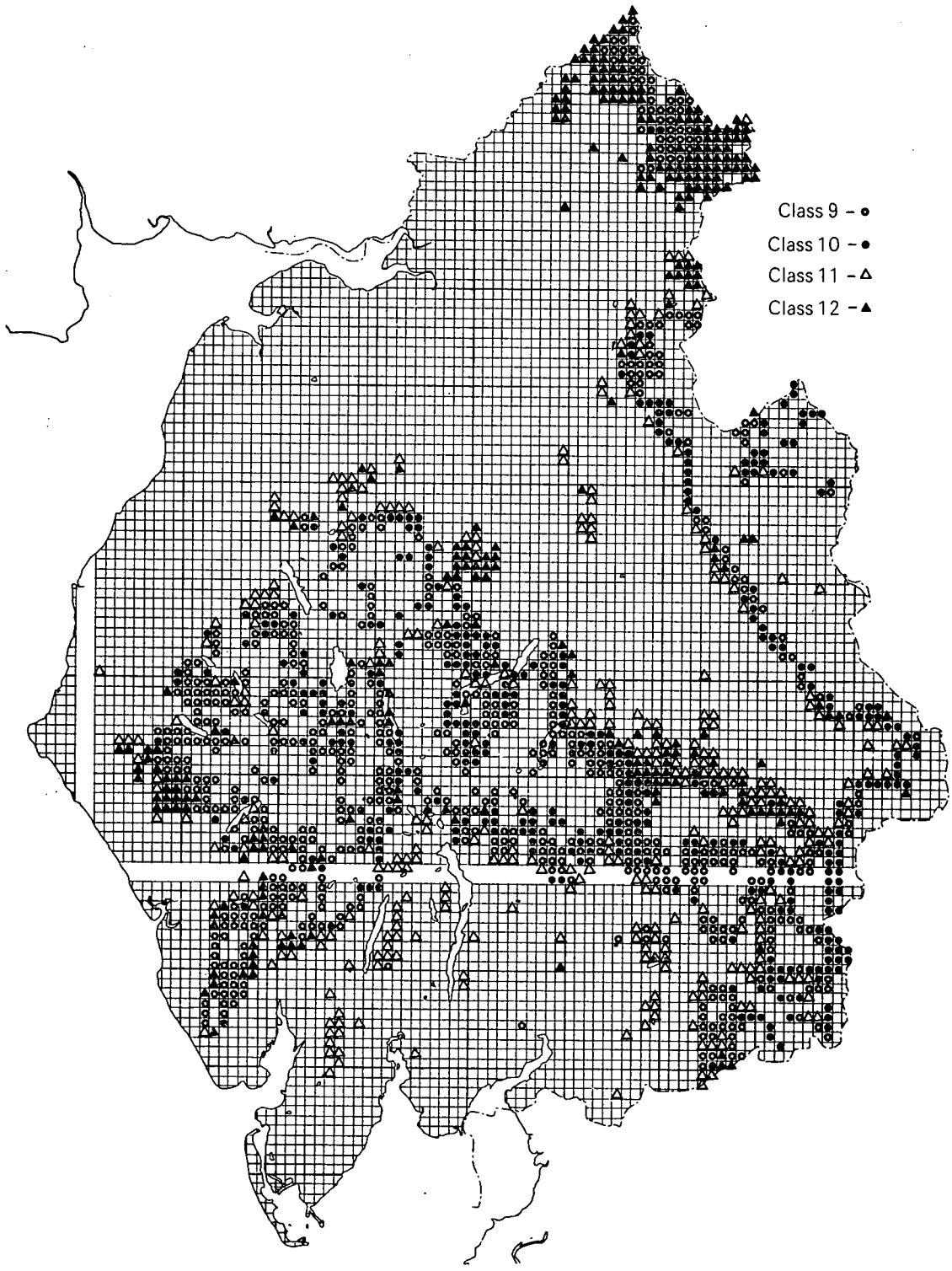


Figure 1(c) The distribution of upland land classes (9–12) of Cumbria on 1 km² grid (map prepared by the Experimental Cartography Unit of NERC).

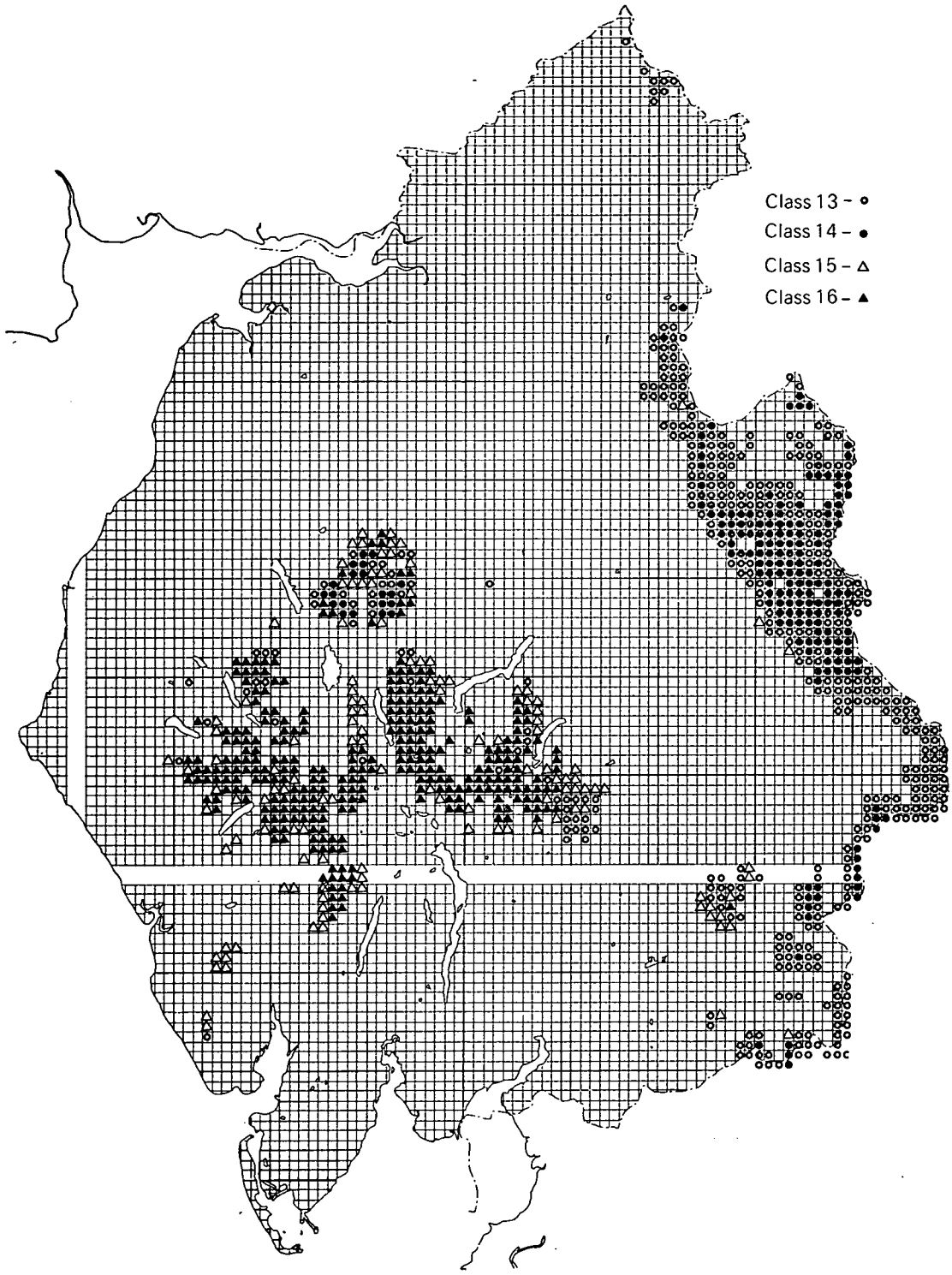


Figure 1(d) The distribution of upland land classes (13–16) of Cumbria on 1 km² grid (map prepared by the Experimental Cartography Unit of NERC).

soil conditions and vegetation is usually considered to be necessary in determining the land potential, so the extent to which such detailed information increased the sensitivity of interpretation from the readily available OS map information was examined in a study of part of Snowdonia for which detailed maps were available.

In the national analysis the primary distinguishing features were of altitude and climate, with slope as a secondary and soil as a tertiary level. The characteristics of the eight land classes are summarised in Table 1 which also shows the agricultural use and density of human settlement in each class. The class numbers show the hierarchical pairing of the classes, but should not be mistaken as representing a gradient in intensity of features. Classes 1–4 comprise the marginal uplands with the squares containing less than 30% of land above 800ft. Classes 5–8 are the central uplands, of which Classes 5 and 6 are mountainous. There is some geographical distinction between the land classes (Figure 1(a)–(b)), but the central upland classes show that similar environmental conditions occur in widely separated regions. Interpretation of the characteristics of each class indicates that agricultural potential is greatest in Classes 3 and 4, slightly lower in 1 and 2, severely restricted in 7 and 8 and negligible in 5 and 6, but it must be emphasised that this is an assessment for the 10 × 10km square as a whole and not for particular sites within each square.

Many of the attributes used in the classification are a reflection of landform on to which land use is superimposed to produce landscape. As land use is, to a considerable extent, determined by the land characteristics, the land classes can be considered to represent main variations in upland landscape. The class composition of the National Parks indicates the extent to which the upland landscapes are represented in those areas designated for landscape conservation and also shows the main similarities and differences between the Parks. Thus, the extreme upland classes (5 and 6) are well represented in the Snowdonia and Lake District Parks; Brecon Beacons and the Yorkshire Dales have similar landforms; the Peak District is the only Park which contains a high proportion of class 7; Northumberland and North York Moors Parks are alike with a predominance of Classes 4 and 8; Dartmoor and Exmoor differ markedly from the other Parks with high proportions of the marginal classes 1 and 2 associated with relatively good agricultural land; Only Class 3 is poorly represented in the National Parks; it has the most developed agricultural use and contains the highest proportion (65%) of Grades 2 and 3 agricultural land. Although comprising less than 1% of the National Park area, Class 3 is well represented in Areas of Outstanding National Beauty.

The land classes at the national level provide a means of broad comparison between major blocks of upland

Table 1 General characteristics of eight national upland land classes, defined from analysis of physiographic, climatic and soil attributes for 10 × 10km grid squares

Class	Altitude	Dominant range in characteristic				Land use characteristics		
		Relief	Slopes	Rainfall	Soil	Land Use	Agricultural Land Grades	Settlement Density
1	low	moderate	moderate	low	Brown Earth	improved grass and tillage	3 and 4	relatively high
2	low	low	gentle	moderate	Brown Earth	improved grass	3 and 4	relatively high
3	very low	low	gentle	low	Brown Earth and Calcareous Soils	improved grass and tillage	2 and 3	relatively high
4	low	low	gentle	low	Gley, Brown Earth and Peaty Gley	improved grass and rough grazing	3 and 4	relatively high
5	very high	very strong	very steep	very high	Podzol, Brown Earth and Peaty Gley	rough grazing and improved grass	5	low
6	high	strong	steep	high	Brown Earth, Podzol, Peaty Gley and Peat	improved grass and rough grazing	5	low
7	moderately high	moderate	steep	moderate	Brown Earth, Gley and Peaty Gley	improved grass and rough grazing	4 and 5	moderate
8	moderately high	moderate	gentle	moderate	Peaty Gley, Gley, Brown Earth and Podzol	rough grazing and improved grass	4 and 5	moderate

(a) Adult female

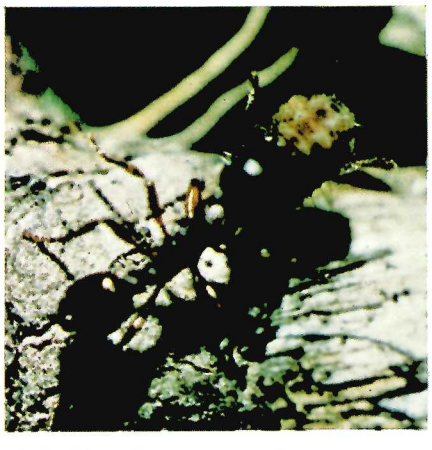
(b) Egg on thyme flower bud

(c) Young larva on thyme

(d) Young larva being milked by Myrmica *ant*

(e) Young larva signalling to ant that it is ready for adoption

(f) Myrmica *ant picking up larva*

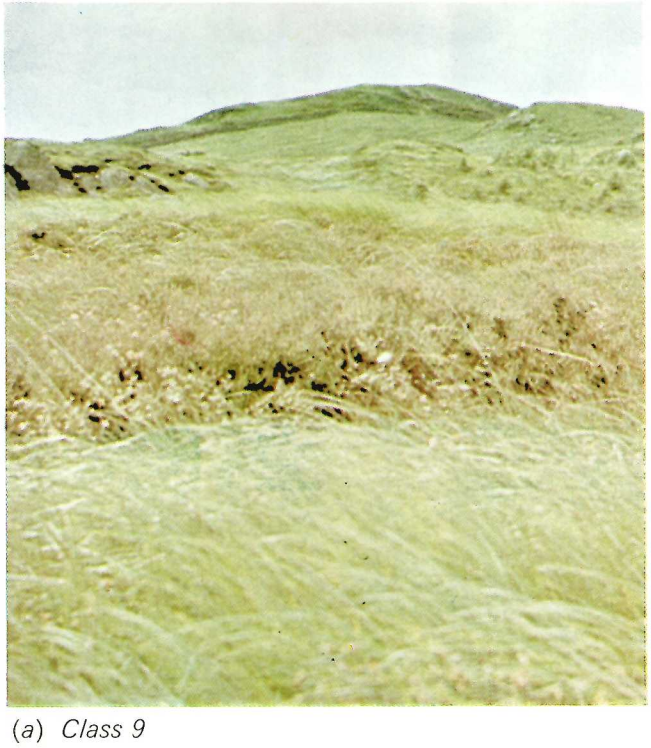


(g) Myrmica *ant carrying larva to its nest.*

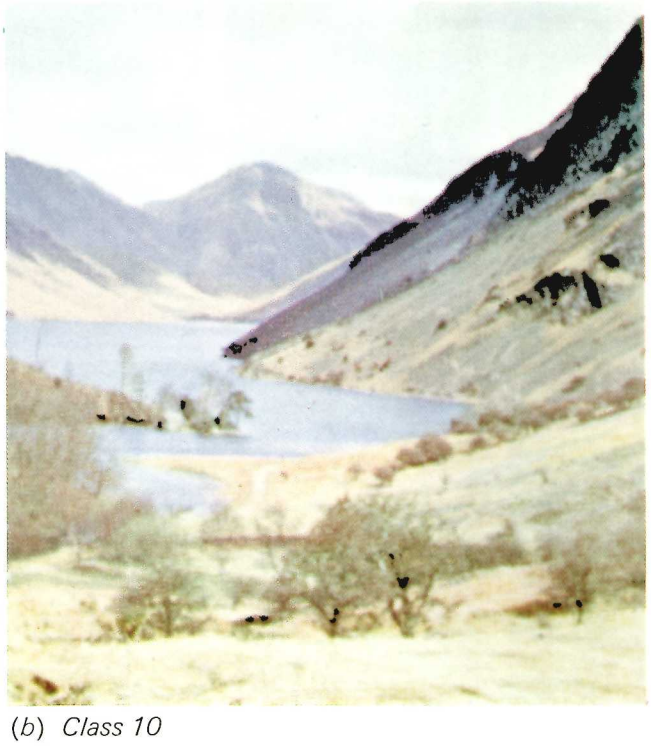
(h) Adult inflating wings after emerging from ants' nest

(i) Female laying egg (ovipositing) on thyme flower head.

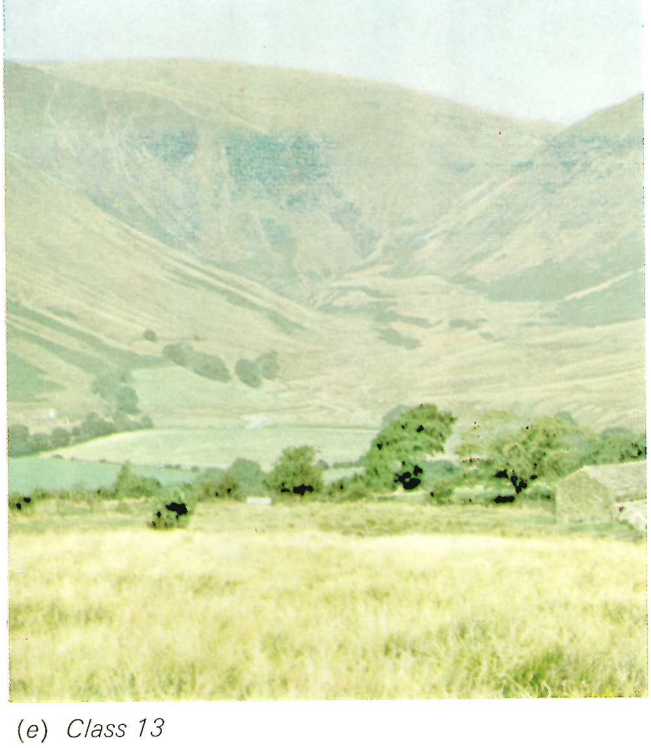
Plate 1 The life cycle of the large blue butterfly. Photographs J.A. Thomas.



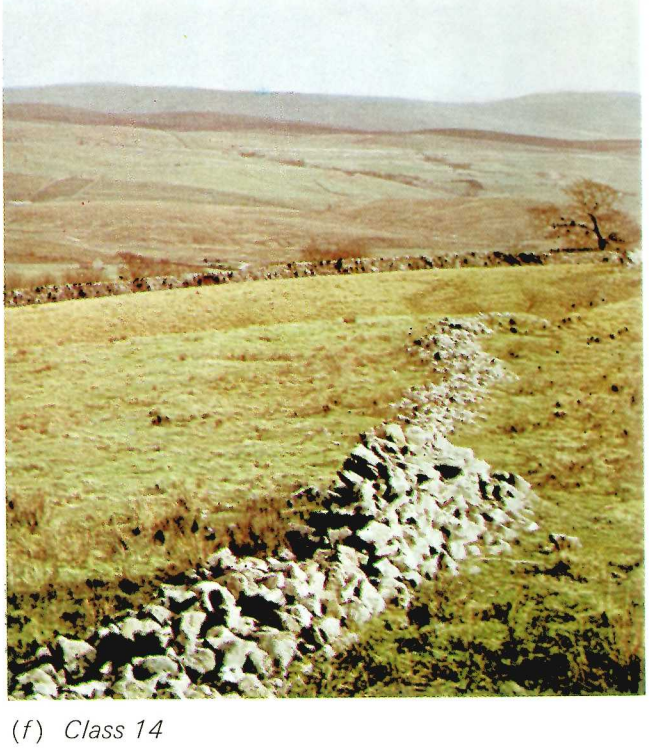
(a) *Class 9*



(b) *Class 10*



(e) *Class 13*

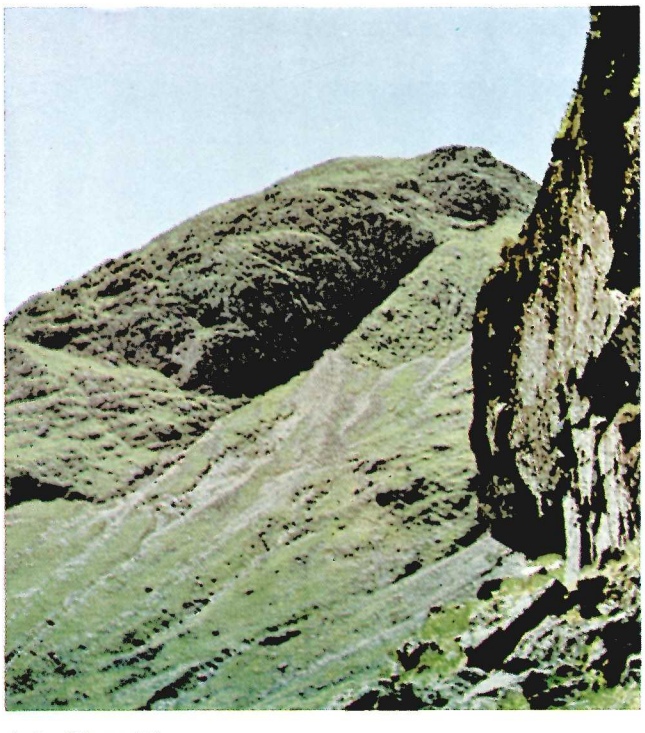


(f) *Class 14*

Plate 2 Examples of the eight upland classes in the Cumbria land classification.
(a)–(g) Photographs O.W. Heal; (h) Photograph J.K. Adamson.

(*c*) *Class 11*

(*d*) *Class 12*



(*g*) *Class 15*

(*h*) *Class 16*

Plate 3 (*a*) *Sparrowhawk* (Accipiter nisus)

(*b*) *Kestrel* (Falco tinnunculus)

Plate 4 (*a*) *Fulmar* (Fulmaris glacialis)

Photographs R.K. Murton.

(*b*) *Razorbill* (Alca torda)

in England and Wales and are relatable to land use. The 10 × 10km grid shows the basic land pattern within a region. Thus, in Cumbria (Figure 1(b)), there is a central core of class 5—the most extreme upland class—in the central Lake District, with outliers in the Dales National Park and in the Pennines. This core is bordered by Class 6 and by the more moderate Class 8. The marginal uplands bordering the morthern Lake District and Pennine ridge are of Class 4 and contrast with the Class 2 land on the coastal margin of Cumbria. However, the 10 × 10km grid is too coarse for any detailed analysis or planning within an area such as Cumbria and land characteristics of the 1 km² grid are more applicable. In a separate project, in conjunction with Cumbria County Council, the land in Cumbria was classified based on the analysis of 152 attributes derived from Ordnance Survey and Geology maps. Sixteen Classes were recognised (the numbers do not correspond to those of the national classes) of which Classes 9–12 are marginal and 13–16 main uplands. The distribution of the upland classes is given in Figure 1(c)–(d) and an example of each of these classes, showing the variation in landform and land use, in Plate 2. This framework has been used to stratify sampling for vegetation and other features, thus providing a ready means of estimating the total area and probable distribution of particular features, e.g. bracken, within the county. Land use is linked to these land classes, providing one way of indicating where future changes may occur, for example recent afforestation is associated with Class 12 land and, assuming continuation of this trend, the probable future distribution of forestry can be predicted.

Within Cumbria, it has been shown that the km squares can be aggregated to describe units relevant to land management, e.g. valleys, or to sources of data, e.g. parishes. Fifty valleys in Cumbria were ranked on their land class composition, showing a gradient in proportion of upland which was correlated with type and intensity of agriculture. This ranking provides a method for selecting local areas for more detailed analysis, the results of which can be generally applicable. Detailed soil, vegetation and climatic measurements are usually made within local areas such as valleys but, because there is no widespread coverage of such information, special studies are required. In Snowdonia, for which specialist maps were available, the land and its agricultural and forestry potential was characterised from OS map information alone and with the inclusion of specialist data. The main pattern of variation in land type and potential was reasonably well-described from the OS data, but more sensitive interpretation was provided by the inclusion of the specialist data. However, the limited increase in interpretation must be weighed against the increase in manpower required to collect the information. Thus, to survey, extract and analyse data on altitude alone, on OS maps and on specialist maps required an input of effort in the ratio of 1 : 5 : 300 respectively.

O.W. Heal

References

Bunce, R.G.H., Morrell, S.K. and Stel, H. (1975). The application of multivariate analysis to regional survey. *J. Environ. Mgmt.*, **3**, 151–165.

Hill, M.O., Bunce, R.G.H. and Shaw, M.W. (1975). Indicator species analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. *J. Ecol.*, **63**, 597–613.

THE MANAGEMENT OF GRASSLAND AND HEATHLAND IN COUNTRY PARKS

(This work was commissioned by the Countryside Commission)

Since the late 1950s, there has been a great increase in numbers of people visiting the countryside for leisure and recreation, stimulated by an increase in car ownership. Because this increase was bringing about rapid and significant changes in the value and use of the countryside, a Government White Paper *Leisure in the Countryside* was issued in 1966. One of the important results of this paper was the Countryside Act of 1968 which, among other things, established the Countryside Commission for England and Wales giving it powers to advise on all matters relating to (a) the provision and improvement of facilities for the enjoyment of the countryside, (b) the conservation and enhancement of the natural beauty and amenity of the countryside, and (c) the need to secure public access to the countryside for the purpose of open-air recreation.

One of the ways in which the Countryside Commission attempts to discharge its statutory function is by assisting, with advice and grants, the establishment of country parks. Since the first country park was officially opened in May 1970, there has been a rapid growth in this type of outdoor facility. Up to September 1976, 133 parks, covering 16,894ha (41,728 acres) had been approved, of which 129 received grant aid. As the number and variety of country parks increased, it soon became clear that guidance was required on the ways to manage vegetation to meet diverse demands from the public, and to sustain conservation interest, both set in a framework of economic necessity.

The Countryside Commission placed a one-year contract with the Institute of Terrestrial Ecology in 1976 to

prepare a report from a desk study of vegetation management in country parks and similar areas, the objectives of the study being:

(1) To review the available management knowledge and practices which have arisen from the use of different herbivores on the vegetation of lowland grasslands and lowland heaths.

(2) To assess the suitability of management techniques, particularly cutting and burning, as alternatives to grazing.

(3) To provide guidelines for the choice of management techniques which maintain or enhance conservation quality compatible with public use and enjoyment.

(4) To estimate the relative costs of different management techniques.

(5) To identify gaps in knowledge following the review of literature and discussion with country park managers.

(6) To design demonstration/experimental projects for 3–4 country parks to (a) demonstrate alternative management techniques and (b) explore gaps in knowledge identified above.

The report (CCP105), which has been published by the Countryside Commission, was compiled from two main sources (a) literature and (b) visits to 32 country parks and similar areas (five of which were used for detailed case studies), supported by discussions with authorities responsible for management. The main points to emerge from the report are as follows:

Characteristics of country parks

Country parks vary considerably not only in size, facilities and types of vegetation but also in the authority responsible for their administration. They range in size from 7 ha at Fell Cross, Cumbria, to 1,531 ha at Clumber Park, Nottinghamshire. Forty per cent of the 133 recognised country parks are below 50 ha, and 65% below 100 ha (Figure 2). Size is an important factor when considering different management options because extensive systems using grazing animals are unlikely to be suitable for parks below a minimum size.

About 50% of country park vegetation is grassland, heathland being a major habitat in only 12 parks, with woodland and open water making up the remainder.

Country parks are mostly situated within easy reach of large conurbations and many are sited within city boundaries. More than 80% of country parks are owned and/or managed by local authorities, but there are considerable differences in administration and management procedures which can have an important effect on the character of the park. Attitudes to countryside recreation vary from authority to authority, some devoting considerable resources to country parks within their areas, others giving countryside recreation a low priority. Inevitably, the attitude adopted towards visitors, vegetation management and wildlife conservation is strongly influenced not only by the available finance, but also by the composition of the committee responsible for these activities. In the preparation of management plans for vegetation in country parks, their principal function, to provide visitors with the opportunity of informal recreation in a countryside setting, should not be overlooked.

Vegetation management problems in country parks

Because country parks are 'designed' to attract people, it is not surprising that many of the problems encountered are essentially the same as those encountered wherever people congregate. For example, litter and vandalism are an everyday occurrence in towns, cities and country parks. Problems such as the worrying of livestock by dogs and the danger to cattle of eating polythene bags occur because land subject to agricultural practices is being used by the public for the pursuit of recreation and leisure. Damage to turf by excessive treading and trampling, eventually leading to soil erosion, and commonly seen around car parks and other access points, also occurs in country parks, and heathland areas are at risk from accidental fires.

Comparison and choice of vegetation management options

Grazing, cutting and burning are the most important means of managing grassland and heathland; other forms of management, such as spraying and the application of fertilisers, are used only in special circumstances.

Grazing

The presence of animals in a park, whether deer, cattle, sheep or horses, helps to create a 'countryside atmosphere' which is one of the primary objectives of country parks. Livestock not only add interest and perspective to the landscape, they also enable urban visitors to identify with the countryside and add to their enjoyment and mental well-being. Grazing is beneficial as it helps to maintain the diversity of plants and animals. From both the biological and economic points of view, grazing is likely to be preferred to other forms of management, except where the park is small and where staff and facilities for livestock maintenance are absent.

Cattle are likely to be the most successful livestock in country parks and they are able to utilise a wide range

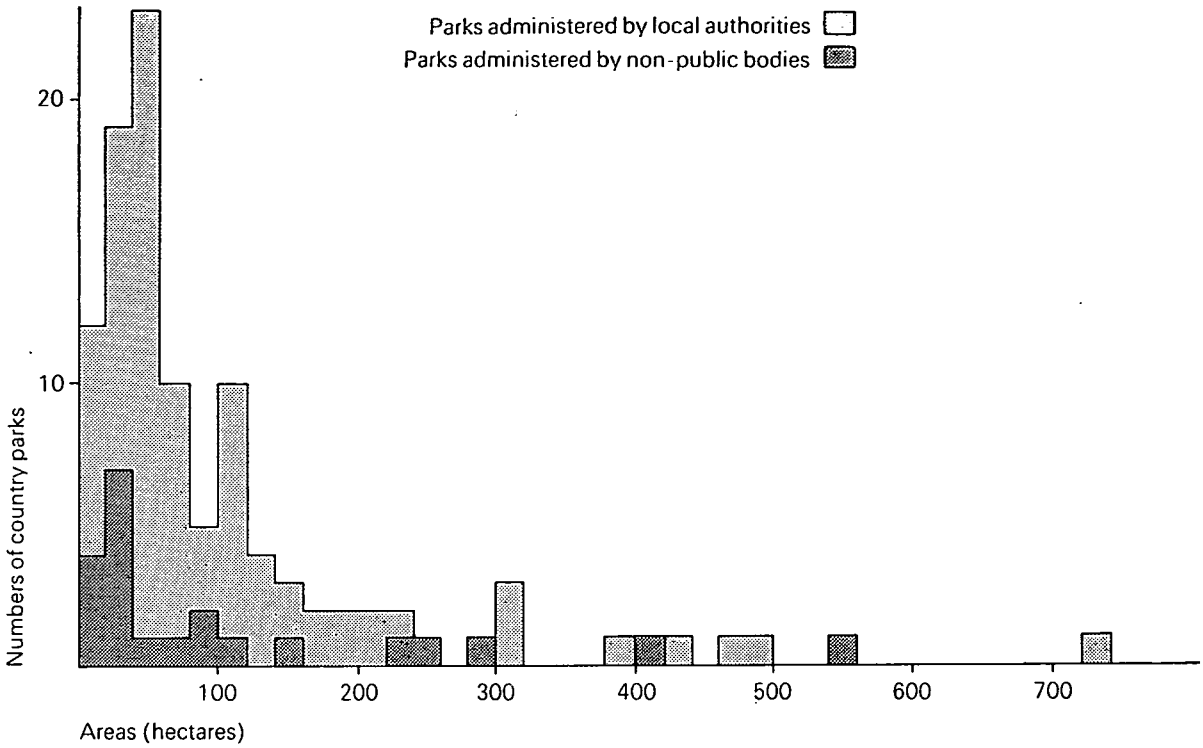


Figure 2 Frequency distribution, when arranged in 20 ha classes, of Country Parks in England and Wales, omitting the two largest at Cannock Chase (1,088 ha) and Clumber Park (1,531 ha).

of vegetation including both grassland and heathland; further, they are rarely physically injured by dogs. However, they are not recommended for (i) steep slopes where they can cause erosion, (ii) marshy ground or (iii) heavy clay. A wide variety of breeds may be used and the relevant characteristics of each breed are described on 'data sheets' in the report. The choice of animal will often depend on factors such as the availability of suitably aged bullocks, proximity to a market, or simply the livestock which a local farmer happens to be keeping.

Sheep have been the traditional grazing animals on certain grassland types, having been responsible, for example, for creating and maintaining the rich flora and fauna of chalk downland. Sheep are, however, apt to be worried by dogs and therefore are not suitable in some parks where wardens or experienced labour are not available. In general, breeding flocks are not recommended as their management requires skilled labour and they are particularly demanding during lambing, shearing and dipping.

Stocking rates will depend on types of vegetation and on systems of management. Chalk grassland can support about two sheep per hectare throughout the year, moorland about one sheep per hectare, while on a lush, lowland meadow the stocking rate may be as high as eight sheep per hectare. Continuous grazing with the same type of livestock brings with it disease problems, and both grassland and heathland are better managed by a rotational system of short periods of grazing. Stocking rates are best adjusted by the individual park manager to suit the available herbage and other local factors.

Red and fallow deer, often in mixed herds, have been an attractive feature of the English countryside since the Middle Ages, and, in at least six country parks, deer grazing is an important form of management (Plate 5). Except in the rutting season, deer are normally docile and allow visitors to approach close to them, a characteristic which enhances visitors' enjoyment. As grazing animals, deer are most effective in maintaining a short sward and require little attention except in winter, when supplementary feed is usually supplied in the form of concentrates and hay.

The major cost in keeping deer is associated with the maintenance of fences and walls which are essential if deer are to be kept within the confines of the park. All six country parks in which deer are kept are old deer

parks, with good perimeter fences—the cost of erecting a 7-ft-high deer fence is at least £3 per metre and this cost is likely to prohibit the establishment of herds in country parks without existing fences.

Horses and ponies are not commonly used for grassland management in country parks, partly because they need considerable care in the winter months and are expensive to feed, and partly because of their unpredictable temperament and potential danger to visitors.

The time of year in which grasslands and heathlands are grazed has an important effect on the structure and composition of the vegetation and also on insect life. These factors can have a marked effect on visitor enjoyment. Grazing throughout the year generally produces an even, short, sward, especially at high stocking rates, which has a relatively low wildlife conservation interest. Winter grazing has the advantage that it allows plants to flower and set seed the following year, and has been shown to be beneficial for a variety of insects. Most country parks have far fewer visitors in winter and autumn than at other times of the year, and these seasons may provide a period in which grazing is both effective and trouble-free. On the other hand, grazing in spring and early summer may be essential to control the growth of some coarse grasses, such as upright brome, *Zerna erecta*, and tor grass, *Brachypodium pinnatum*.

Rotational grazing, whereby parts of a country park are grazed while other areas are not, is a means of reconciling the often conflicting requirements of amenity, wildlife conservation and good agricultural practice.

Cutting

Cutting or mowing vegetation, whether grassland, heather or bracken, is widely practised in country parks. Effects of cutting are much more predictable than those of grazing, enabling park managers to control more closely the appearance and length of the grassland. However, cutting tends to produce a uniform appearance to a sward which is more in keeping with urban parks than country parks, and the factors which influence the choice of cutting rather than grazing need careful consideration.

Cutting is likely to be used in small parks of less than ten hectares in areas where dogs are a problem or where numbers of visitors are high throughout the year. Cutting is done with machines ranging from small, hand-operated mowers, to large tractor-powered flails, while, on a few country parks, large silage-making machines have been used. The frequency of cutting has a major impact on the structure and appearance of grassland which in turn affects (i) visitor enjoyment and (ii) wildlife interest.

Areas of grass cut once or twice a year are mostly peripheral and therefore little used by the public, or are wet and low-lying, near streams, and can only be cut during the summer months. Their variety and diversity of structure often makes them of high value for wildlife and, if these areas were interspersed with others cut more frequently, there would be more numerous opportunities for seeing wildlife. Tractor-mounted rotary or flail mowers are the most useful machines for managing these areas, with cutting in September or later probably best.

In areas where recreational use is moderate, a sward 7–15 cm high can be maintained by cutting with a flail or rotary mower at two-monthly intervals from April to October.

Grass cutting, whether once a year or more frequently, is a costly activity, rarely yielding an income. An alternative method, which deserves more attention, is the preparation of an agreement with contractors or farmers to harvest the grass for hay or silage. This type of agreement, which can produce an income, is still in its early stages, but results are already encouraging. Clearly, whether the grass is cut for hay or silage, harvesting is likely to recoup some of the cost of grass maintenance and, at the same time, produce useful forage.

Burning

Burning is unlikely to be widely practised in country parks as burnt areas are aesthetically displeasing for several weeks following a fire, and are also unsuitable for walking or picnicking. Traditionally, heathlands and moorlands in upland and lowland England and Wales have been burnt in rotation in February or March, principally to provide new shoots on which livestock and birds can feed. Until alternative methods of managing heather have been investigated, particularly cutting, burning may still be the best means of management in country parks. Regrettably, the frequency of accidental fires on amenity heathland often prevents rotational burning becoming a feasible objective. There is also some evidence that too frequent burning may favour the spread of bracken at the expense of heather, but this is an effect which needs research, particularly in lowland sites.

Relative costs of some management options

Of the fifty country parks and similar areas visited during the preparation of the report, very few were able to provide data of relative costs of different

management options. The running costs of individual parks were either included in a budget with other recreational areas such as picnic sites, urban parks, etc., or, at best, the annual expenditure on a site was broken down into categories such as labour, machines and management, without attempting to cost particular management practices. This unsatisfactory state of affairs highlights (i) the difficulties encountered in obtaining accurate information on costs and (ii) the need for 'research'.

Identification of gaps in knowledge

Management of vegetation in country parks, where amenity and visitor enjoyment are primary objectives, is a new concept in Britain and it comes as no surprise to find that there are many 'areas' needing research. As a result of discussions with land agents, country park managers, local authority staff and other scientists, some 21 topics for future research were identified, which for convenience can be divided into three groups – problems concerned with (a) the management of people, (b) costs of management options and (c) directly related to vegetation management. Among the eleven research topics identified under the general term 'vegetation management', four were concerned with the management of lowland heath. Various aspects of heathland management, including a study of suitable management techniques aimed at maintaining a balance between grassland, heather and bracken, will form the substance of a new contract currently being negotiated with the Countryside Commission.

T.C.E. Wells and J.E. Lowday

PUFFIN RESEARCH

(This work was commissioned by the Nature Conservancy Council)

The problem

The puffin, *Fratercula arctica,* is restricted to the colder parts of the North Atlantic. It also occurs in the Arctic but these populations are small. Britain is at the southern edge of the range of the species in the eastern Atlantic, and the sea temperatures here are much higher than those it encounters off eastern North America where the range extends 5° further south. Although some half a million pairs now nest in the British Isles (Table 2), the species was once even commoner. The historical record is poor, but there may have been two or even five times as many puffins at the end of the last century. Some of the southern colonies declined at this time, but it was assumed that the more northern colonies were unaffected. However, in 1969, it was realised that even these large, northern colonies had fewer birds than previous accounts suggested were present.

Concern at this decline in puffin numbers resulted in a research programme being started in 1972. This research had two aims: first, to document changes in the numbers of puffins breeding around Scotland; second, to determine the causes of these population changes. The main study areas, St Kilda, Outer Hebrides and the Isle of May, Firth of Forth, were chosen because the populations were apparently behaving differently. St Kilda once had one of the world's largest puffin colonies, but, by the time of the first survey in 1969, the size of the colony had greatly diminished, and it was thought that the decline was still continuing in 1971 (Flegg, 1972). The Isle of May was one of the few colonies where the population was known to be expanding, there having been only a few pairs in 1960, but 2,000 pairs in 1970. It was hoped that a comparison of the biology of the species in these two areas would indicate the 'weak link' in the life cycle of the St Kilda puffins and that the cause of the decline would be determined.

Table 2 Estimates of the orders of size of various populations of puffins Fratercula arctica

Species	Place	Probable population size
F. a. grabae	Scotland	*ca.* ½ million pairs
	Ireland	20,000–25,000 pairs
	England	*ca.* 15,000 pairs
	Wales	8,000–10,000 pairs
	Isle of Man	*ca.* 200 birds
	Channel Isles	*ca.* 1,200 birds
	Brittany	400–450 pairs
	Southern Norway	*ca.* 200 pairs
	Faeroe Islands	40,000–1,000,000 pairs
F. a. arctica	Western Greenland	Few thousand pairs
	Iceland	8–10 million birds
	Canada and United States	*ca.* ⅓ million pairs
	North Norway	1¼ million pairs
	Bear Island	Few hundred birds
	Jan Meyen	Few hundred birds
	Russia	? 20,000 pairs
F. a. naumanni	North-west Greenland (Thule area)	Six small colonies
	Eastern Greenland	Very few
	Spitzbergen	5,000–10,000 birds
	Novaya Zemlya (? this race)	Few

Are puffins still declining?

The numbers of puffins present at a colony in a single day can vary by a factor of a thousand. The only accurate method of determining trends in population size is to count regularly the number of nesting burrows in areas where this is feasible. Permanently marked belt transects have been set up in seven large Scottish colonies and the occupied (indicated by hatched egg shells, droppings or excavations) and unoccupied burrows are counted annually. All the transects run from one side of a colony to the other, and, as they include central and peripheral parts of the colony where there are no burrows, the transects are capable of detecting changes in colony size, as well as puffin numbers and burrow density in the already occupied areas. There are now more occupied burrows in all the transects than when the transects were first demarcated. On St Kilda, the increase is about 6–7% per year. From an examination of the published and unpublished literature, we conclude that the main population decline on St Kilda occurred between 1947 and 1958, and that there has been relatively little change since.

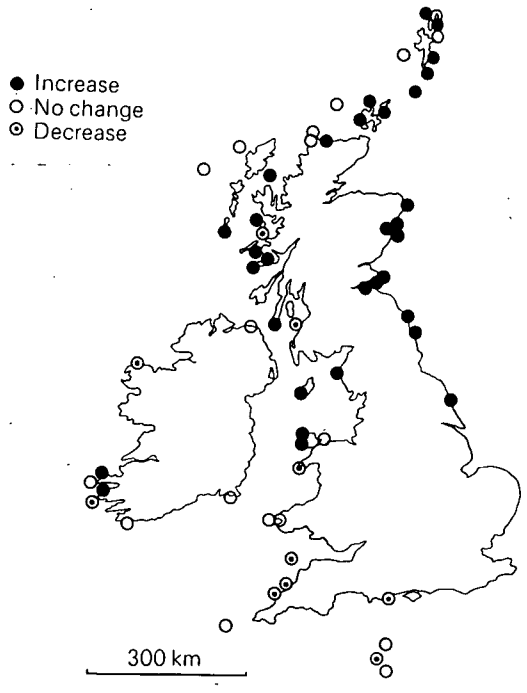


*Figure 3(a) Changes in numbers of puffins (*Fratercula arctica*) at colonies which have been counted or estimated since 1969–70. The No Change class indicates a colony which has been visited and where there was no obvious change.*

In case the recent increases in these colonies were atypical, many British and Irish colonies were visited in 1975, and the numbers of puffins seen were compared with the counts made in 1969–70 during 'Operation Seafarer'. Although care must be taken in the use of scattered counts of puffins at colonies, far more colonies appeared to have increased in the period 1969–75 than had declined (see Figure 3(a)). Also, many of the increases had been so large and/or in well-studied colonies that the upward trend in puffin numbers is probably genuine and widespread. The few recent apparent declines have been mostly in the small colonies at the southern edge of the range of the species, for example in the Channel Islands, Brittany, southern England, and many of these colonies may now be too small to be self-supporting. All the more northerly British populations, including those in Scotland, are flourishing. However, the total British population is still far below what it once was. The few available data suggest that the very large populations in the Faeroe Islands and Norway are not declining and the largest population of all, in Iceland, may even be expanding.

Possible causes for the population fluctuations

Many factors have been implicated in specific declines–increases in numbers of predatory great black-backed gulls, *Larus marinus,* on North Rona and Annet, of predatory great skuas, *Stercorarius skua,* on Foula, of kleptoparasitic herring gulls, *L. argentatus,* on Puffin Island, Anglesey, of gannets, *Sula bassana,* which compete for habitat on Sula Sgeir, of rats, *Rattus norvegicus,* on Lundy, Ailsa Craig and Shiants, and soil erosion caused by the birds themselves on Grassholm and parts of the Farne Islands. However, in some cases, all such causes can be discounted. For instance, there is no obvious reason for the decline which occurred on St Kilda after the large-scale killing of puffins for food ceased with the evacuation of the human population in 1930, where there are few skuas and gulls and no rats. There was probably some primary common factor responsible for all these declines whose effect was accentuated by the local secondary influences mentioned above.

Contamination by toxic chemicals (PCBs, DDE, dieldrin) and heavy metals, once thought to be a possible cause, appears not to be important in mortality or breeding failure in puffins. Most puffins have low levels of these pollutants in their bodies and eggs. Some individuals, however, accumulate cadmium. This element may be associated with their pelagic existence outside the breeding season as other pelagic birds, e.g. Manx shearwater, *Puffinus puffinus,* and

Plate 5 Grassland management in Bradgate Country Park, Leicestershire, using fallow deer. Photograph J. Lowday.

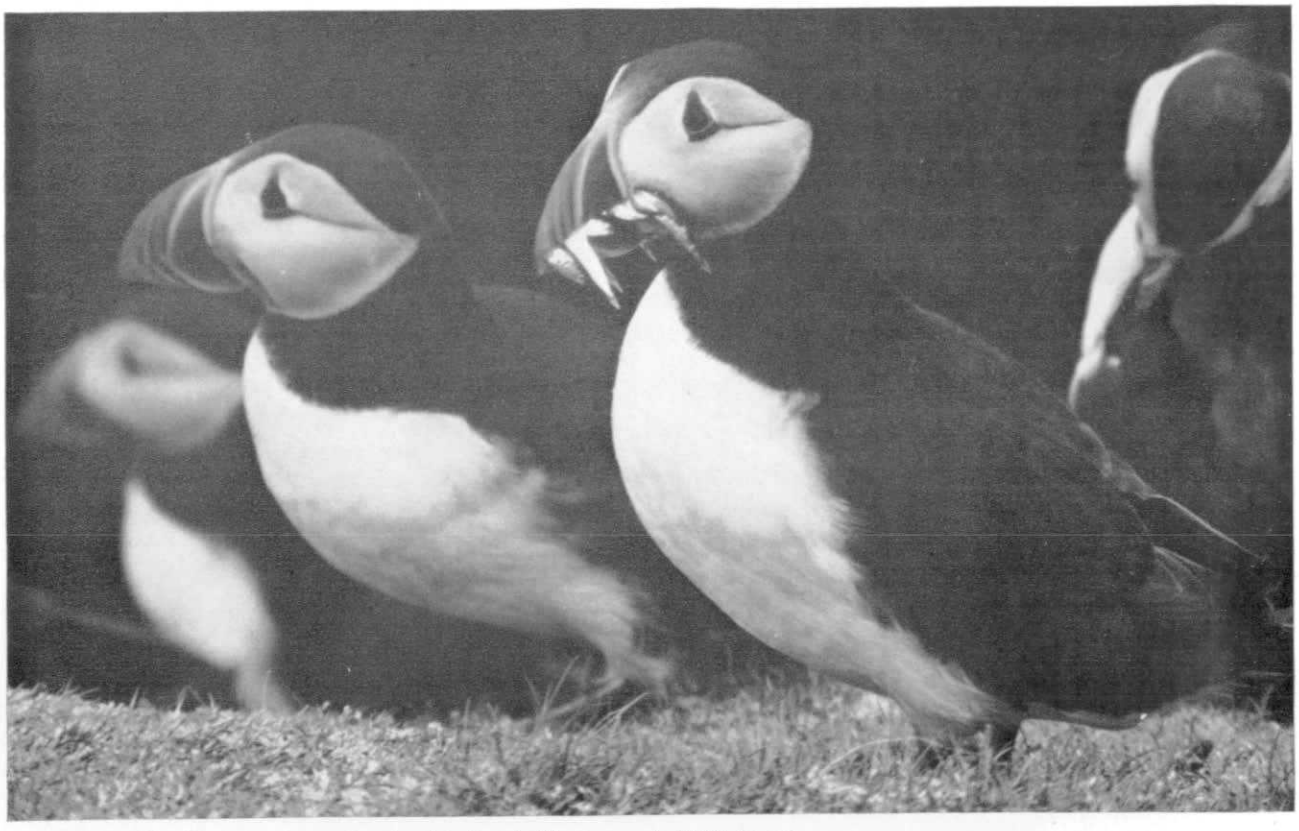


*Plate 6 Puffin (*Fratercula arctica*) with food. Photograph M.P. Harris.*

Plate 7(a) Adjacent grazed and ungrazed salt marshes near Grange-over-Sands in Morecambe Bay.

Plate 7 (b) Predominantly flowering and predominantly non-flowering clones of Puccinellia maritima *growing together on pioneer marsh at Holkham, north Norfolk. Photographs A.J. Gray.*

Leach's storm petrel, *Oceanodroma leucorhoa*, also have high levels of this metal. Adult puffins collected at colonies in north-west Scotland and which winter in the Atlantic had up to fourteen times as much cadmium in their kidneys and livers than adults collected from the Isle of May. These latter birds winter in the North Sea. The importance of cadmium in the physiology of birds is little understood (see pages 59–60), but many population declines occurred before pollutants became a serious threat to the environment. Elastic thread, once of common occurrence in the stomachs of dead puffins, is now rarely found. Puffins probably suffer less from contamination by oil than do most other seabirds, but the evidence for this observation is mainly negative in that puffins are rarely involved in oiling incidents. The most likely primary cause for fluctuations in puffin numbers is a change in the marine environment acting through the fish which form the bulk of the food of the puffin.

Food of puffins

In the late 1950s, large numbers of dead young were found on St Kilda, apparently killed by starvation. Even since 1973, by when the population decline had been reversed, puffins on St Kilda were having difficulty in raising their single young. Chicks were thin and continually begged for food, the loads of fish brought to them were smaller than is normal and the fish were often larval forms or white fish such as whiting, *Merlangius merlangus*, which have a lower calorific value (*ca.* 5 KJ/g wet weight) than the preferred sprats, *Sprattus sprattus*, and sandeels, *Ammodytes marinus* (up to 11 KJ/g). There has never been even a hint that puffins on the Isle of May were short of food and it is extremely rare to hear young begging for food. The growth rates of young on the two islands were not compared directly, but breeding adults on the Isle of May are significantly heavier (by 6·2%) and have longer wings (by 2·4%) than those from St Kilda. These differences are presumably of genetic origin as the wings of birds collected on St Kilda during the last century were also small. It, therefore, still remained to be shown that St Kilda young could grow better than they apparently did.

Supplementary feeding

Experiments to compare the effects of changes in food on the growth rates of young were undertaken on St Kilda in 1975. First, 50 g of high quality sprats were put daily into eleven burrows, each of which had a young puffin. The young ate all these fish in addition to what the adults brought. Second, five small young were taken into the laboratory and reared on sprats freely available. Third, one parent was removed from six burrows with a small young to find the effect of reduced food intakes. The growth of these young were compared with those of 39 control young.

The wild young given supplementary food grew better than the controls. The captive young consumed over twice as much food as did the control young, and attained much higher peak and fledging weights (see Figure 3(b)). Only three of the chicks with a single parent survived, compared to 37 chicks of the 39 controls, and these grew poorly and took five days longer than the controls to fledge. On the Isle of May, young given additional food also grew better, but the difference between them and the controls was far less marked. Only four of ten young with a single parent survived, and again they grew badly; even here a pair of puffins would not have been able to rear more than their normal single young.

There is, as yet, no evidence that heavy young puffins survive better after fledging than light young. However, this is the case in the Manx shearwater (Perrins *et al*, 1973), which, like the puffin, produces at the most a single young each year which is independent after fledging. It is reasonable to assume that young puffins need some food reserves at fledging to help them over the critical first days when they have to learn to fly, swim, dive, and find and catch their first meal. Fat

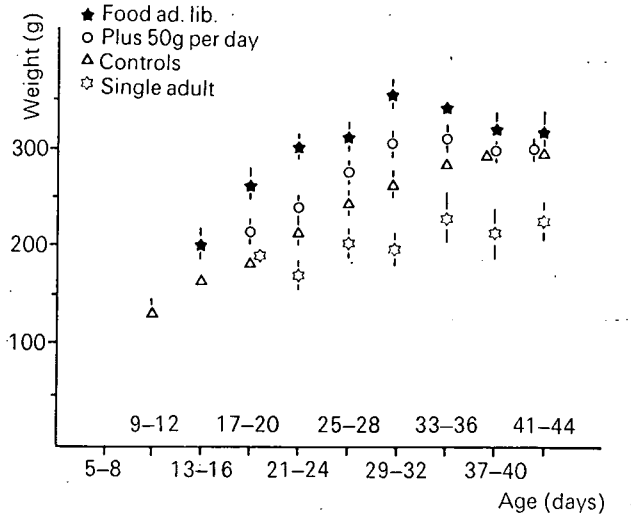


Figure 3(b) Growth curves of young puffins on St Kilda in 1975. Mean values are given for controls, captive young given food ad lib., wild young given an additional 50g. of food per day, and young reared by single adult. The lines indicate ± SE of each mean where this is greater than the range covered by the symbols.

reserves accumulated earlier probably act as a safeguard against food shortages, such as one which killed 10% of the young on St Kilda in a four-day period in 1976. Work in progress is designed to test the hypothesis that the post-fledging survival of young depends on their weight before fledging.

Conclusion

Britain is at the extreme edge of the puffin's range in the eastern Atlantic, and even minor changes in sea conditions would be expected to have a marked and noticeable impact on the populations breeding here. The declines in southern colonies earlier this century occurred when the sea surface temperatures in southern Britain were gradually rising and the St Kilda puffinry declined in the 1950s, when sea temperatures were at their highest. Sea temperatures have been falling since the 1960s (Southward *et al*, 1975), and this fall has resulted in increases of fish, including species eaten by puffins, more typical of cold water. The decline in numbers of puffins was reversed at more or less the same time. Some British populations of guillemots, *Uria aalge*, are now also increasing after a period of decline. It is probably not coincidence that the numbers of these two northern seabirds have started to increase just as sea temperatures are falling. This cooling is expected to continue until the end of the century and a selection of puffin colonies are being kept under surveillance to see if numbers will continue to increase as sea temperatures fall.

M.P. Harris

References

Flegg, J.J.M. (1972). The puffin on St. Kilda. *Bird Study*, **19**, 7–17.
Perrins, C.M., Harris, M.P. and Britton, C.K. (1973). Survival of Manx shearwaters, *Puffinus puffinus*. *Ibis*. **115**, 535–548.
Southward, A.J., Butler, E.K. and Pennycuick, L. (1975). Recent cyclic changes in climate and the abundance of marine life. *Nature, Lond.*, **253**, 714–717.

DIELDRIN RESIDUES IN CARCASES OF KESTRELS AND BARN OWLS

In the summer of 1961, a voluntary ban on the use of the cyclodiene group of organochlorine insecticides on spring-sown cereals was agreed between Government, farmers and industry. This ban followed a series of incidents each spring from 1956 to 1961 when large numbers of graminivorous birds, particularly partridges, pheasants, wood pigeons and various finch species were picked up dead; sometimes several hundred individuals were collected from one roost in the vicinity of one farm. It took time to identify and agree that these pesticides, used to combat wireworm and wheat bulb fly infestations, were the cause. Wireworm infestations did not pose serious problems, while protection from wheat bulb fly was and is not needed on spring sowings. Accordingly, the Advisory Committee on Poisonous Substances used in Agriculture and Food Storage (1964) recommended that dieldrin, aldrin and heptachlor should only be used on winter-sown wheat up to the end of December, where there was a real danger of attack from wheat bulb fly. Assessment of risk depends on egg counts made by field officers of the Ministry of Agriculture, Fisheries and Food. This assessment has not proved an ideal procedure since eggs are not laid until late August and so cannot be sampled until early September, whereas farmers must usually order their seed between July and early August for delivery in readiness for planting in October and November; many farmers buy treated grain as an insurance. Moreover, if the autumn is wet and sowing is delayed, treated grain already purchased is planted in December, January or even February.

Concurrent with these incidents, several species of predatory birds suffered marked population declines and exhibited varying degrees of egg shell thinning associated with a reduction in breeding success. Notable amongst these has been the peregrine, *Falco peregrinus*, and sparrowhawk, *Accipiter nisus* (Prestt and Ratcliffe, 1972). DDE, which is the main metabolite of DDT, is clearly established as causing egg shell thinning and a reduced breeding success in these two species (Ratcliffe, 1970) and American sparrowhawk, *Falco sparverius*, in the USA (Lincer, 1975). To what extent population declines resulted from a reduced reproductive rate following DDT ingestion, or the compounding effects of direct mortality caused by such seed dressings as dieldrin, is still being investigated. The use of dieldrin was banned altogether in December 1975 and we expect to record the disappearance of residues and hopefully a pronounced increase in numbers of sparrowhawks in arable regions.

When the spring ban of the use of dieldrin was introduced, the Nature Conservancy decided to monitor residue levels in any dead raptor and owl specimens sent to the laboratory at Monks Wood, and national appeals for specimens were advertised via the ornithological and conservation journals. Many hundred specimens of kestrel, *Falco tinnunculus*, sparrowhawk, barn owl, *Tyto alba*, and heron, *Ardea cinerea*, have been received and analysed, and currently the results of these analyses are being prepared for publication. By combining data collected in different years, it is possible to detect seasonal trends and Figure 4 shows how concentrations of dieldrin in the liver of kestrels

vary from month to month. In all months, there were many carcases which contained virtually no organochlorine compound, or at most only background amounts. But, in some seasons, a proportion was found with medium to very high residues in the liver; if liver residues exceed about 10ppm of dieldrin, it becomes increasingly probable that the chemical was the immediate cause of death.

It must be emphasised that we are discussing liver residues, and it is clear from Figure 4 that these reach a peak some three to four months after dieldrin is directly available in the environment. In fact, our evidence shows that the birds obtain most of their residues in the autumn when the grain is sown, for this is when the kestrel's prey of small rodents, notably long-tailed field mice, *Apodemus sylvaticus*, themselves ingest the chemical. At this season, kestrels naturally accumulate large fat reserves and, because dieldrin (and the other organochlorines) is extremely fat soluble, but virtually insoluble in water, the ingested chemical is rapidly accumulated in adipose tissues, where it causes no immediate damage. It is only when the birds use their fat reserves later in the year that any stored chemicals are themselves mobilised and metabolised, and harmful effects become apparent; the presence of a chemical in the liver is evidence that it is being metabolised, and it will be detoxified and excreted if the animal has the necessary enzyme capability, both qualitatively and quantitatively.

Juveniles and first-year birds should not be exposed to dieldrin-dressed seed before September, so any small residues they contain in July and August will have been passed on either from the parent via the egg or from the background residues in prey species. Young birds accumulate less fat than adults and mobilise it more quickly, so that liver residues begin to rise in this age group sooner than they do in adults. However, the highest absolute concentrations of dieldrin in the liver occur in adults, because, initially, they carry proportionally higher body reserves of lipid, and so more 'dissolved' dieldrin can be processed through the liver. There is a good correlation between body weight and residue levels, for the best individuals in a population have larger body reserves and, therefore, the potential to absorb more chemical. In many biological situations, it is the animals which are in poor condition or are at the bottom end of the social hierarchy which suffer the highest mortality rates. Predators are well known to select ailing or weak prey. Paradoxically, in the case of the predators themselves, it is the better birds which are at greater risk. Assuming that selection has been occurring towards pesticide resistance, it could conceivably have favoured individuals with otherwise disadvantageous traits.

One of the themes of ITE is that wildlife species can only be used as monitors of environmental pollution if their ecology and physiology are very well understood. The barn owl illustrates the principle. It takes almost the same prey as the kestrel, notably the long-tailed field mouse, but does so at night rather than by day. Its seasonal exposure to environmental dieldrin is exactly the same as it is for the kestrel. But, in late autumn and winter, the kestrel experiences a decrease in length of the hunting day and must accumulate fat reserves to last it through a long, cold winter night when it goes to roost. The opposite applies to the barn owl, and, in consequence, its seasonal cycles of physiological function are rather different. The seasonal pattern of dieldrin residues in the liver is noticeably different (Figure 4).

The lessons are simple. If an observer collected some kestrels and barn owls in January and February and analysed only the livers for residues, he might easily conclude that kestrels generally contain high residues and are endangered by organochlorines, whereas barn owls are not at risk or else have some kind of tolerance mechanism. The mistake would be in looking at one species and at one tissue. Suppose too, that no spring ban on the use of dieldrin existed. One could easily conclude that spring-dressed cereals were a more serious threat than those planted in autumn and this would obviously be a contentious argument. Fat cycles in birds are generally well-recognised and understood. Even greater potential pitfalls must exist when we consider the significance of pollutants whose mode of action is through more subtle seasonal and diurnal changes in physiological mechanism.

We must also consider the methods by which specimens are obtained. Biologists have long appreciated that found dead or captured samples of animals are biased in various respects and are not representative of the population as a whole. For example, it is obviously more likely that human observers will record birds which are killed as a result of car collisions than those which are taken and eaten by a predator. It is a plausible, yet fallacious, argument to suggest that this selection does not matter so far as toxic residues are concerned: it may seem safe to imagine that road casualty returns are unbiased with regard to residues, even if they are a biased indication of the cause of death. Table 3 provides an evaluation of this approach which has been recommended by some authors. The circumstances of recovery allowed bodies to be placed into two broad categories: (1) Those birds clearly dying as a result of a trauma, such as flying into telegraph wires or glass windows, being hit by a car, or being shot; in this category two sub-groups could be defined; (i) definite road casualties, (ii) all other

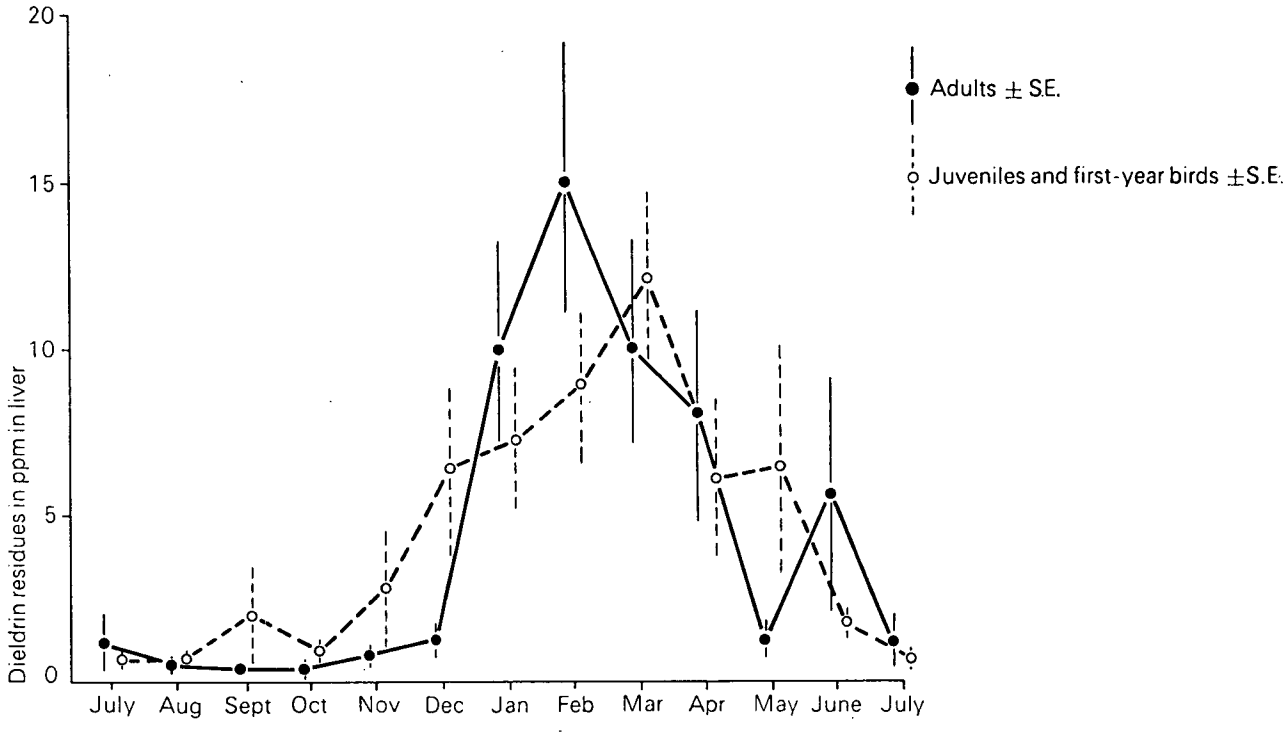


Figure 4(a) Seasonal variation of mean dieldrin residues in the livers of kestrels.

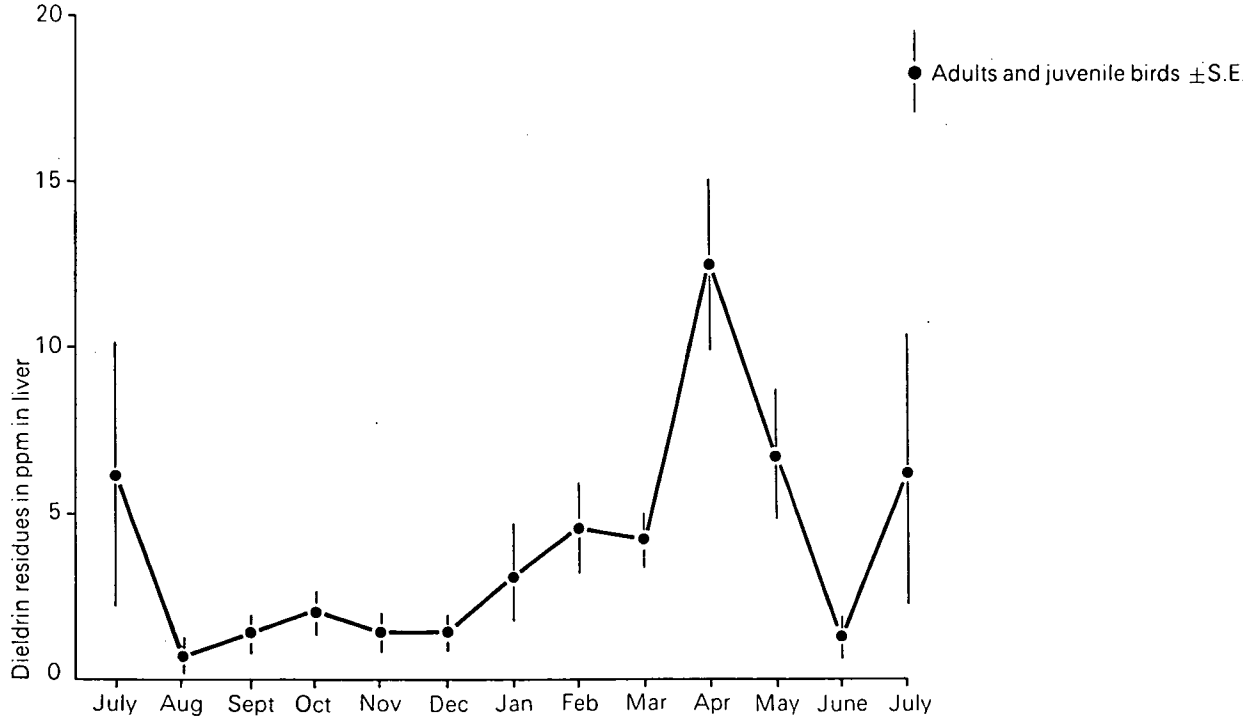


Figure 4(b) Seasonal variation of mean dieldrin residues in the livers of barn owls.

Table 3 Dieldrin residues in kestrels depending on cause of death and method of recovery

Cause of death or method of recovery	Amount of dieldrin ± S.E.M. in livers of adults or juveniles plus first-year birds (no. individuals in brackets)	
	Adults	Juveniles
(1) Trauma		
(i) Known road casualty	0·9 ± 0·3 (11)	4·9 ± 2·6 (19)
(ii) All other trauma	1·3 ± 0·5 (18)	2·2 ± 1·0 (29)
(2) Found dead		
(i) Diseased with overt signs of infection	2·6 ± 0·7 (18)	2·0 ± 0·4 (89)
(ii) Haemorrhaged	20·7 ± 3·8 (16)	13·5 ± 2·1 (27)
(iii) Negative	7·8 ± 1·6 (25)	8·6 ± 1·7 (48)

traumas. (2) The second category accommodated all other carcases, these being birds picked up dead from woods and fields. On autopsy, it was possible to divide this second category into three sub-groups; (i) diseased with overt signs of infection, (ii) haemorrhaged – and the organochlorines are known to cause internal bleeding, (iii) all others, called negative, for which no obvious explanation existed to account for them being found dead. If a bird was haemorrhaged or diseased at autopsy, but was known to be a road casualty it was counted as such.

It is clear from Table 3 that those kestrels which most likely died as a result of dieldrin poisoning and were picked up dead and found to be haemorrhaged were not represented among known road casualties. Hence, samples collected from roadsides under-represent the incidence of deaths resulting from dieldrin poisoning.

A.A. Bell and R.K. Murton

References

Lincer, J.L. (1975). DDE-induced eggshell-thinning in the American kestrel: a comparison of the field situation and laboratory results. *J. appl. Ecol.*, **12**, 781–793.

Prestt, I. and Ratcliffe, D.A. (1972). Effects of organochlorine insecticides on European birdlife. *Proc. Int. orn. Congr.*, 15th, 486–513.

Ratcliffe, D.A. (1970). Changes attributable to pesticides in egg breakage frequency and eggshell thickness in some British birds. *J. appl. Ecol.*, **7**, 67–115.

THE ECOLOGY OF THE LARGE BLUE BUTTERFLY

(This work was commissioned by the Nature Conservancy Council)

The large blue butterfly, *Maculinea arion* (Plate 1a), has always been a local species in Great Britain, and has been in decline for most of its recorded history. This decline has been particularly severe in the last twenty years, during which more than thirty colonies are known to have become extinct. It is now the rarest and most endangered of our resident butterflies, and had an estimated national population of fewer than forty adults in 1976.

There has been much speculation about possible causes for the decline of the large blue, and conservationists have tried many remedies over the last fifty years. Few of these remedies have been successful, and most colonies have declined as rapidly on protected sites as they have elsewhere. By 1972, it was clear that a greater understanding of the ecology of the butterfly was needed on which to base conservation measures. A research programme was, therefore, started, and has included studies of the distribution, local races, status, life cycle, and behaviour of the butterfly. However, the main emphasis has been placed on analysing the factors controlling the size of a colony each year, under various habitat conditions, in an attempt to understand the range of situations in which a colony can survive. Another field of research has been to determine how suitable conditions may be created and maintained by land management.

An unusual feature of the large blue butterfly is its possession of a specialised larval stage which depends on both thyme plants, *Thymus drucei*, and red ants, *Myrmica*, as a source of food. The main features of this dependence have been known for many years, but research has added to these early observations. Adults emerge in late June or July, and fly freely throughout their sites. Eggs are usually laid singly, and only on thyme flower buds (Plate 1b). They hatch after seven to ten days, and the young larvae feed on thyme flowers. They are also cannibalistic in the first instar, and there is usually only one survivor when more than one egg has been laid per flowerhead. Larvae continue to feed on developing seed for about three weeks (Plate 1c). They then make a final moult, desert their plants, and live the rest of their immature stages underground in ant nests, where they feed on grubs.

Ants of the genus *Myrmica* are the only known hosts of the large blue butterfly. Larvae are unable to search

for *Myrmica* nests themselves, but are taken underground by foraging worker ants. To achieve this transportation, larvae remain hidden in their thyme flowers until the early evening and then drop to the ground 1–3 cm below. This act places them in the main foraging stratum of *M. sabuleti* and *M. scabrinodis* at the time of peak foraging activity. A larva is soon found if it is within the territory of one of these ants, but, if not, it will die of starvation or be killed by a predator. When an ant has found a larva, it is attracted by a sweet secretion produced by a pair of posterior glands. The ant taps and bites the glands, feeding on the secretion for up to four hours (Plate 1d). Eventually, the larva rears up on its prolegs, contracts its body, and causes its thoracic segments to swell (Plate 1e). This posture acts as a signal to the ant which picks up the larva (Plate 1f). and carries it to its nest (Plate 1g). Once there, the larva feeds on ant grubs, hibernates when it is half-grown, and resumes feeding in spring. It pupates in the ant nest in late May and the adult emerges about three weeks later. It then crawls to the surface and inflates its wings (Plate 1h).

Changes in the size of a population of the large blue butterfly at several stages of its life cycle have been studied for four years on a site that contains a flourishing colony. These changes have been compared with those on another site in the year that its colony became extinct. It was found on the good site that the heaviest mortality occurred within ant nests, and that the mortality of young larvae on thyme, though severe, had only a small effect on the number of adults to emerge the following season. The number of eggs laid by females each year was also variable, but probably also has little effect on the size of the colony, except in occasional years when periods of exceptional cold or heat coincide with the adult stage. Either condition may result in such poor egg-laying that the adult population may be reduced in the following year. However, such extreme conditions probably occur only about once every fifteen years, and are unlikely to be an important factor in the national decline of the species.

The most important factor causing annual fluctuations in the size of this colony was the extent of mortality in the ant nests. Mortality was always heavy, but its severity varied with the species of ant, the density of larvae entering nests, and probably with the biological condition of the nests. Four species of *Myrmica* occur commonly on this site, but only two are used with any frequency by the butterfly, as the territories of the others rarely extend into habitat in which thyme will grow. The two important species are *M. sabuleti* and *M. scabrinodis*, which are both abundant throughout the areas that contain thyme, and which may both act as host. However, the survival of the large blue is better in nests of *M. sabuleti*, and it is possible that *M. scabrinodis* may be unable to support a colony of this butterfly alone.

Survival in an ant nest also varies with the number of larvae entering a nest, and probably also on the size and vigour of the larva. The capacity of any *Myrmica* nest to support the large blue is generally small, and variable. Many nests seem unable to support a single butterfly and the emergence of more than one adult, from a nest of even *M. sabuleti*, is rare. When more larvae than can be supported are taken into a nest, they soon eat all the ant grubs and die. This over-predation can cause heavy mortalities in years when the population of the butterfly is high.

The survival of the large blue on this good colony appears to be sufficiently high in most years for the population to increase until it reaches a level where further growth is countered by heavy mortalities from overcrowding in *Myrmica* nests. The site is clearly being managed in a way that produces suitable, though not necessarily the best, conditions for the large blue.

An analysis of the habitat showed that the site was heavily grazed, and that most areas of turf were maintained at less than 1 cm tall all the year round. This vegetation results in the development of very high densities of *M. sabuleti* and *M. scabrinodis*. It was found that 98% of thyme plants occurred within the territory of one of these species and that the other 2% were within the territory of *M. ruginodis*. Experiments have shown that *M. sabuleti* is restricted to, and will eventually dominate, very short turf, but that *M. scabrinodis* can live under rather lighter grazing. All species of *Myrmica* were found to be highly mobile and were rapidly lost if grazing was reduced or stopped. In contrast, thyme is far more persistent and will continue to flower in turf that is too tall and dense for *Myrmica*. Thyme, too, is eventually killed by heavy shading, but, unlike *Myrmica*, is extremely slow to recolonise areas when conditions again become suitable. Studies on the good site, therefore, suggest that it is important to maintain a close-cropped turf in which high densities of *M. sabuleti* and thyme may co-exist.

Studies on a site with a declining population of large butterflies showed that the vegetation was being less heavily grazed than formerly, and that the average height of the turf was about 7 cm tall. Flowering thyme occurred at a higher density and over a greater area than on the good site, and, superficially, the site appeared to be highly suitable for the butterfly. However, *Myrmica* densities were low and only about 30% of thyme plants occurred within the territory of

any *Myrmica* species. It was also found that female large blues could not discriminate between suitable and unsuitable plants when egg-laying. Few eggs were found that year, but several of these were laid outside *Myrmica* territories and the larvae were therefore not adopted by ants. Five years previously, this colony had been the largest known colony in Britain, but it had declined to a small population by the time of the study and became extinct the following year. It seems likely that a failure of larvae to be adopted by ants was a major cause of this loss. *Myrmica* continued to decline on the site, although the thyme cover was maintained by light grazing, and only 7% of plants occurred within a *Myrmica* territory two years later.

A similar situation has been found on two other sites that had lost their colonies of large blues two and five years previously. These were even less well-grazed than the declining site and a very low proportion of their thyme plants occurred within a *Myrmica* territory. *Myrmica* densities were even lower when these sites were revisited two years later. More superficial studies were then made of 130 other sites, including all (80) sites with records of a large blue colony in the last hundred years. About 40% of these sites appeared superficially to be suitable, having sufficient thyme distributed over a large enough area for a colony. However, none was as heavily grazed as the good site and only six had more than 75% of their thyme plants within a *Myrmica* territory. Even the best sites that were found may be less suitable than at first appeared, for all but one were grazed only sufficiently to support high densities of *M. scabrinodis*, and the more suitable host, *M. sabuleti*, was rare.

Overall, it seems likely that most sites are too lightly grazed at present to support sufficient densities of the ant host of the large blue butterfly. Recent declines on many sites are probably attributable to reduced grazing following myxomatosis, and to changes in farming practices. As a result of this research, conservation measures have been started on a few sites with the aim of encouraging high densities of *M. sabuleti* nests. Suitable grazing regimes are being imposed and early results show a very rapid increase in ant densities. Thyme is still sufficiently well distributed on most sites for most ant nests to contain at least one plant within its territory. However, one site has insufficient thyme due to prolonged shading in the past, and the slow natural recolonisation of cleared areas is being accelerated by the introduction of plants throughout the site. Over 1,500 thyme plants have been established in new areas, thus increasing the number of *Myrmica* nests that are available to the large blue about four-fold. It is hoped that the butterfly population will eventually increase to parasitise all the new nests that are made available. It is too early to know whether these measures will succeed, but already a small increase in the butterfly population has occurred.

J.A. Thomas

THE GENECOLOGY OF *PUCCINELLIA MARITIMA* (Huds.) Parl. – A STUDY OF THE MECHANISM OF NATURAL SELECTION

Puccinellia maritima is a widespread and abundant grass in salt marshes throughout the British Isles and Europe. It is found from the pioneer zones on unconsolidated intertidal mudflats to the mature communities of the salt marsh only occasionally flooded by the highest spring tides. This wide ecological amplitude is of particular interest to students of flowering plant evolution because it suggests that, in order to occupy such a wide range of habitats, the species will have become differentiated into several types, varying in their morphology and physiology. The process of differentiation is brought about by the selection of individuals best adapted to survive in particular niches as on a salt marsh where the environment is highly heterogeneous (Gray, 1974; and in press).

The environment may be thought of as a sieve which sifts and sorts the raw materials of variation. By studying patterns of variation between individuals and within and between populations and environments, it is hoped to learn more about the environment and the sieving process itself. The research becomes a study of the processes of natural selection in action, the mechanism by which many species are evolved by gradual divergence and isolation, and in which genetic resources in plants are sorted, conserved and exploited in the wild. First, however, it is important to understand how the raw materials pass through the sieve, in other words how the genetic information flows from one generation to the next and how it is inherited and expressed in individuals. This understanding begins with a study of the breeding system of the species.

Chromosome number and the breeding system

Until recently, the chromosome number reported for *P. maritima* in Britain was $2n = 63$ which, because the base number in the genus is 7, implies that the species is non aploid. This unusual feature, together with the mistaken impression that flowering rarely occurs in the field, probably triggered the suggestion that the species was apomictic, or at least reproduced asexually. However, recent counts of somatic chromosomes of more than 40 British populations indicate that *P. maritima* is octoploid ($2n = 56$) (Scott and Gray,

1976). Some of the cells contained fewer chromosomes, 53–55, but, in a species containing many field populations which reproduce mainly vegetatively, some variants might be expected. In addition, careful observation has indicated that the species flowers freely in the field and in glasshouse conditions. Furthermore, evidence from cross-pollination experiments (Gray and Scott, 1977a, and unpublished) indicated that the species is usually both self- and cross-fertile, although some individuals are apparently totally self-incompatible.

These observations shed light on the evolution of the species at the population level. Because it is apparently uniformly octoploid and fully sexual, with both inbreeding and outbreeding, *P. maritima* is strongly buffered against the effects of a highly heterogeneous and unstable environment. The self-compatibility of this perennial species, combined with its ability to reproduce vegetatively, enables it to survive in isolated colonising populations, even when established from a single individual. At the same time, its high ploidy level minimises 'genetic fixation' and counteracts the effects of inbreeding depression which might otherwise occur. In populations which are not isolated, the possibility of outcrossing allows genetic re-combination to occur, so increasing the degree of heterozygosity, the latter ensuring the maintenance of a wide spectrum of genetic variability and paving the way for the evolution of populations adapted to local conditions.

The components of variation

A preliminary assessment of variation in *P. maritima* was made with a replicated clone trial of 56 plants selected at random from six sets of sites within the British Isles. Twenty characters, including rates of tillering, plant heights and widths, leaf lengths and widths, dates of ear emergence and anthesis, weights of individual seed and heights of flowering tillers, were measured on seven replicate single-tiller ramets of each clone grown in horticultural composts within a netted enclosure. Except for seed weights, there were significant differences between clones. In contrast, there were few significant 'between-ramet' differences. The between-clone variation was examined in detail, using a correlation matrix of clone mean scores for each character and extracting the principal components of variation from this matrix. The first three principal components defined variation trends in terms of vegetative biotype, yield (= dry weight gain), and reproductive strategy.

(a) The *first component* contrasted plants which produced many small short-leaved tillers with those producing few large long-leaved tillers (vegetative biotypes). Variation in growth habit at the vegetative stage was also associated with this component, the rapid tillering biotypes being more prostrate;

(b) The *second component* separated large (in terms of above-ground dry weight) from small plants (*yield*); and

(c) The *third component* defined a trend from plants allocating a relatively large proportion of resources to the production of flowering tillers to those with relatively few of the many tillers actually flowering (*reproductive strategy*). The predominantly vegetative clones usually flowered later than clones with many flowering tillers.

Estimates of genetic variation and heritability of many of the differing characteristics were made with the methods used by plant breeders to evaluate varieties of forage grasses. These estimates indicated that much of the variation was genetically controlled, giving provisional estimates of heritability (broad-sense) ranging from 43% for inflorescence height to 95% for date of ear emergence.

The general picture of within-species variation which emerged from this trial has been used as a basis for further work. First, individual characters within groups of significantly inter-correlated characters were selected for measurement. For example, assessments of tiller production made after 3–4 months were good indicators of tillering over a longer period, and of leaf and plant size. Second, the biological basis of variation in characters associated with major within-species differences were studied in controlled environments, e.g. the effects of day length (photoperiod) on rates of tillering, growth habit and flowering. Third, the relationships between trends along the major components of variation and habitat conditions have been examined in order to identify habitat-correlated variations.

Habitat-correlated variation

Visual inspection of the principal component analysis showed that the vegetative biotype component was related to the grazing management of the salt marsh from which the plants were collected. Plants from grazed marshes tended to be fast-tillering, small, short-leaved and prostrate and, although some individuals of this biotype were collected from ungrazed areas, no plants of the contrasting biotype were found in grazed areas.

Variation of the yield component was found to be related to soil nutrient status, which, in turn, was frequently related to position along the pedogenetic and successional gradient from pioneer to mature

marsh (Gray and Bunce, 1972). In general, the higher yielding types came from mature marshes.

Variation in the reproductive strategy component appeared to have a regional basis. Plants from the Scottish populations allocated proportionally more of their resources to the production of non-reproductive structures, whereas those from the south and east coasts of England favoured flowering.

Differentiation of local populations

The study of variation within and between populations was restricted to *P. maritima* growing in two geographically separated areas. Having taken note of the habitat-correlated variations, ten populations (six in Morecambe Bay, and four near Wells, in north Norfolk) were chosen from grazed and ungrazed areas, and from pioneer and mature areas of salt marsh. Although the analyses are not yet complete, they confirm that plants from grazed populations were generally smaller, shorter-leaved and more prostrate than those from ungrazed populations with, on all marshes, plants from the pioneer populations usually smaller than those in mature populations. Importantly, it seems that pioneer populations are more variable than mature populations. For example, the pioneer populations from two adjacent Morecambe Bay marshes, one grazed and the other ungrazed, had individuals with widely varying growth habit ranging from prostrate to erect. Grazed mature populations consisted almost entirely of prostrate individuals, whereas those on the ungrazed marsh consisted of erect individuals.

The contrasting variability of pioneer and mature populations suggests that non-adapted individuals are eliminated by selection as salt marsh successions proceed. It could be predicted, if the mature marsh individuals are survivors and represent only a part of the variation occurring in the original 'founder' populations, that, in some conditions, the range of variation in pioneer populations would gradually diminish. This reduction in the range of variation is likely to happen where the major sources of colonisers, for newly accreted mudflats, are mature marsh populations in which infrequent outbreeding prevents gene segregation and recombination. This being so, it is suggested that pioneer populations of *P. maritima* below isolated marshes with vegetatively reproducing mature populations will be unvarying.

In practice, it is difficult to establish if the wider range of variation in pioneer populations is attributable mainly to random events or 'disruptive' selection. The former implies that selective forces acting on characters such as vegetative biotype and reproductive strategy are unimportant, compared to chance events governing establishment and survival. On the other hand, if selection plays an important part, it is necessary to assume that a mosaic of micro-habitats exists in pioneer marshes, the micro-habitats possibly being created by the plants themselves. Different biotypes undoubtedly make different demands on, and exploit different parts of, the environment, a feature recognised in crop husbandry where some mixtures of species with, for example, different growth forms may outyield monocultures of the two species grown separately.

The genetic structure of natural populations

To focus more closely on the actual processes of natural selection, two further lines of research are being explored:

(i) a more detailed analysis of the genetic control of selected characters;

(ii) the genetic structure of populations from the different types of marshes.

The former involves progeny trials in which self- and cross-pollinations are used in which the inheritance of selected characters is assessed, taking note of additive effects, maternal effects, etc. From this breeding programme, as well as from studies of the effects of genotype/environment interactions on dates of flowering, it is hoped to obtain a more accurate picture of the genetic control of variation, and to assess the importance of phenotypic plasticity in enabling some measure of adaptation to the environment.

To strengthen our understanding of the genotypic structure of natural populations; attempts are being made using variation in isoenzyme complements of different individuals to analyse the structure of populations on adjacent grazed and ungrazed marshes in Morecambe Bay. To date, preliminary analyses do not support the notion that mature populations always consist of many representatives of relatively few individuals surviving from the pioneer phase. Although there are fewer isoenzyme phenotypes in mature grazed than in pioneer grazed marsh populations, plants on the mature ungrazed marsh have as many isoenzyme phenotypes, and greater heterozygosity than their pioneer counterparts. In contrast to plants from the mature grazed populations, those from mature ungrazed populations flower more freely, their greater diversity possibly reflecting greater gene flow between individuals.

The mechanics of natural selection

The second main line of research concerns the nature of the selection process. First, an attempt has been made, using transplants, to discover the nature and

strength of the selective forces which operate on heterozygous populations, and, second, the life history and survival of individuals has been followed on an accreting salt marsh. Because the principal component of variation (the vegetation biotype) highlights the contrast between rapidly tillering, small prostrate plants and slowly tillering, tall erect specimens – a difference associated with grazing – selection experiments have concentrated on simulated grazing. The effects of repeated clipping (defoliation) on survival and growth of contrasting biotypes have been investigated. It seems that tall genotypes of *P. maritima* are at a considerable selective disadvantage when repeatedly defoliated, and, although the potential yields of individual plants, whatever their genotypes, are always reduced by clipping, small, rapidly tillering biotypes are better able to maintain themselves and to survive.

Conclusion

The breeding system and major variations found within *Puccinellia maritima* in Britain have been investigated as parts of a comprehensive programme of salt marsh ecology (Gray, 1972; Gray and Bunce, 1972; Gray and Scott, 1977b). Increasingly, the study has focused on populations and on the ways in which selection and genetic variation maintain locally adapted populations. Like other fundamental research, it has produced results of immediate practical value, for example the possible production of salt- and drought-tolerant varieties of *P. maritima* and other grasses for planting coastal reclamation banks, walls of estuarine freshwater reservoirs, or salt-affected roadsides.

A.J. Gray and R. Scott

References

Gray, A.J. (In press). Genetic structure of plant populations in relation to development of coastal habitats. In: *Ecological processes in coastal environment,* ed. by A. Davy and R.L. Jefferies. 1st European Ecological Symp., September 1977. BES Symp. Vol.

Gray, A.J. (1974). The genecology of salt marsh plants. *Hydro. Bull.*, **8**, 152–165.

Gray, A.J. (1972). The ecology of Morecambe Bay. V. The salt marshes of Morecambe Bay. *J. appl. Ecol.*, **9**, 207–220.

Gray, A.J. and Bunce, R.G.H. (1972). The ecology of Morecambe Bay. VI. Soils and vegetation of the salt marshes: a multivariate approach. *J. appl. Ecol.*, **9**, 221–234.

Gray, A.J. and Scott, R. (1977a). Biological flora of the British Isles. *Puccinellia maritima* (Huds.) Parl. *J. Ecol.*, **65**, 699–716.

Gray, A.J. and Scott, R. (1977b). The ecology of Morecambe Bay. VII. The distribution of *Puccinellia maritima, Festuca rubra* and *Agrostis stolonifera* in the salt marshes. *J. appl. Ecol.*, **14**, 229–241.

Scott, R. and Gray, A.J. (1976). Chromosome number of *Puccinellia maritima* (Huds.) Parl. in the British Isles. *Watsonia,* **17**, 53–57.

The research of the Institute in 1976

Introduction

This, the main Section of the Report, gives relatively short accounts of research projects in ITE during 1976. The main emphasis of these accounts is on projects which have been completed, or in which significant progress has been made during the year. A full list of the ITE research projects will be found in Section IV of the Report.

No single classification of ITE research projects can be both exhaustive and mutually exclusive. The accounts of this Section have therefore been grouped so as to illustrate some main concentrations of the ITE research strategy. They begin with a group of projects concerned with trees and woodlands, which form an important component of the semi-natural vegetation of Britain, as well as of the planted broadleaved and coniferous forests. It is, therefore, no accident that a considerable proportion of ITE's research is concerned with the woodland habitat and with woody plants.

The second group deals with a more varied selection of habitats, embracing the coasts, the uplands and the mountains. This group also contains two accounts of research on polar organisms whose physiology has marked similarities to that of the same or equivalent plants in the more extreme British habitats.

The next three accounts deal with research in the freshwater habitat, and emphasise the fact that, although the name of the Institute emphasises our concern with terrestrial ecology, we also have a particular concern for freshwater organisms and habitats. While our main interest in freshwater is focused on the inter-relationships between freshwater and terrestrial organisms, an understanding of the dynamics of freshwater systems is essential for the success of research on terrestrial ecology.

Not all of ITE's research can be conveniently grouped by habitats, and the next two groups of accounts deal with research on vertebrate and invertebrate organisms, respectively. Many of these organisms are found in several habitats, and the emphasis of the research is on the population dynamics and distribution of the organisms rather than their relationships with any particular habitat.

The more direct effects of man's manipulation of his environment form the emphasis of the next two groups of reports. The first of these deals with the effects of chemical substances on organisms and ecosystems. ITE research in this important field has been reorganised during the last few years, and the results of the replanned research strategy on pollution are becoming evident. The six reports in this group show something of the range and the penetration of the research. The second group deals with the more direct effects of land management on the vegetation and fauna, and again shows evidence of the redirection of ITE's research towards problems of resource management and conservation.

The diversity of ITE's work is further demonstrated by two groups of accounts dealing with species distributions and taxonomy, and with the work of special subdivisions and centres. It is, perhaps, worth emphasising that one of the strengths of ITE is that it has, within the one Institute, a wide range of specialist expertise that can be brought to bear on any selected topic. The accounts of the last group, in particular, illustrate some of the skills not often found in an ecological research organisation.

Trees and woodlands

PREDICTING TREE GROWTH RATES IN BREEDING PROGRAMMES

Tree breeding is uneconomically slow unless genotypes which will produce superior fast-growing forest stands can be selected at an early age. To do this selection with confidence, more information is needed about inherent differences in growth characteristics of (a) seedling progenies, (b) young progenies planted in forest trials, and (c) progenies growing as forest crops after canopy closure. These aspects of tree growth are being examined to support Forestry Commission breeding programmes for *Picea sitchensis* and *Pinus contorta.*

Amounts of seedling height growth were characterised in terms of:

(i) rates at which needle primordia were produced;

(ii) lengths of stem elongated per needle;

(iii) the seasonal periodicities of these two growth processes.

Techniques were developed to measure the first process and show how initiation rates depend on the size and activity of apical meristems. Other work has shown that differing lengths of stem, elongated per needle, depend more on cell division during elongation than on cell extension, whereas analyses of diallel trials of *P. sitchensis* have shown how differing amounts of 'internode elongation' and rates of needle primordia production are independently inherited. Current work aims to define the range of environments in which these and other growth attributes need to be measured to construct an early selection index.

Further characters of value in constructing selection indices appear when progenies are several years old, e.g. the proportion of the leading shoot which does not

extend from an overwintered preformed bud, a proportion called 'free' growth (Plate 8). Studies of *P. sitchensis* showed that the proportion of free growth is not correlated with height, or with genotype-environment interactions, but instead is a reflection of latitudinal day-length responses. Progenies with a high proportion of free growth, a useful seedling criterion, were usually relatively fast-growing.

Having evaluated progenies as individual seedlings and young trees, it is still not possible to predict their performance in forests after canopy closure. For example, there can be unforeseen differences in canopy characteristics and in the utilisation of light, minerals and water. These aspects are being analysed by (a) assessing the performance of individual trees in two mini-forests, each having 2,500 trees, which were planted 14cm apart in 1969, and (b) comparing the performances of progenies in mini-forest conditions with their growth as widely-spaced individuals. These analyses are inevitably slow using spruce and pine, so, meanwhile, some hypotheses have been tested on stands of tea, *Camellia sinesis,* growing in East Africa, following a consultancy visit there in 1974. It has been shown that sizes of individual bushes growing in commercial stands are affected by inter-bush competition, whereas their efficiencies (yields per unit area) are more affected by local site differences. With this information, attempts are being made to select high-yielding clonal stands fitted for East Africa.

M.G.R. Cannell, S.M. Baxter and S.C. Willett

MAKING TREES FLOWER

After many years' study, it is now possible to control flowering experimentally in species of *Thuja* and *Betula.* Sufficient is known to stimulate heavy flowering and seeding whenever required by the nurseryman or tree breeder, and, sometimes, to enable controlled pollinations to be made on easily accessible branches in the field, or on potted plants in the glasshouse.

These simple and effective techniques were developed with *Thuja plicata* (western red cedar) by studying the effects of:

(a) the growth regulatory gibberellic acid (GA_3) which affects cypresses and redwood trees; and

(b) the use of bark-ringing and changes in temperature and day length, which appear to induce flowering in a wider variety of genera.

By combining growth regulators and environmental treatments in growth cabinet experiments, using potted cuttings of *Thuja,* abundant cones of both sexes were produced. When injected with ten microlitres of solution, cuttings given 1,000μg of hormone produced large numbers of male and female cones irrespective of the temperature and day length regimes being examined. When only 20μg were injected, however, numbers of cones produced were greatly decreased. At an air temperature of 16 °C, as against 22 °C, numbers of male cones were halved. Plants given the smaller dose of GA_3 produced fewer female cones, but grew noticeably faster than plants injected with the larger amount.

Injecting wood at the base of 50 large field-grown trees of *T. plicata* with GA_3 stimulated the production of 0·5 million female cones and several million males which yielded over 7·5 million seeds, equivalent to about one-third of the UK annual requirement. Heavy flowering, assessed by comparing with uninjected controls, has now been induced in two successive seasons, an uncommon occurrence in untreated trees. The treatment cost is minimal, about 8p per tree at the recommended dose of 50μg.

As a result of phase-change research, the Finnish Foundation for Tree Breeding is now regularly making crosses with birches grown very rapidly in large polythene greenhouses. Progress has been dramatic, with one tree producing 100,000 seeds within twelve months of being sown.

These advances with species of *Betula* and *Thuja* have been stimulated by an increased knowledge of developmental physiology, equally applicable to 'difficult' temperate conifers and to tropical hardwoods. Current projects include investigations of flowering in (i) *Pinus contorta* (lodgepole pine) (for the Forestry Commission) and (ii) various commercially important West African hardwoods, including obeche, *Triplochiton scleroxylon* (supported by the Ministry of Overseas Development).

K.A. Longman and M.L. Edwards

MYCORRHIZAS AND TREES

Using tube cultures with agar media, experiments with different (a) seedlots of birch, *Betula pendula* and *B. pubescens,* and (b) isolates of *Amanita muscaria* (fly agaric) indicated that variation within the host, and especially the fungus, may affect (i) sheathing mycorrhizal formation; (ii) the extent of mycorrhizal development; and (iii) patterns of mycorrhizal branching. Some isolates of *A. muscaria* formed mycorrhizas with some seedlots, but not with others. Where mycorrhiza developed, they were, according to the isolate, either few in number and highly branched or

numerous and sparsely branched. *A. muscaria* often stimulated root and shoot growth. Closer examination of the more rapidly produced and thicker stems showed that they had a more 'mature' structure than those of the thinner non-mycorrhizal controls. The former had an outer, well-developed bark which was completely absent from the controls, more uniform secondary thickening of the xylem, and larger and more rounded cortical cells with conspicuous intercellular spaces. These changes can be interpreted as increasing the fitness of seedlings to survive and grow on difficult sites, including peat bogs, coal spoils and other industrial wastelands which commonly occur in the United Kingdom. The spongier cortex of mycorrhizal seedlings might, by allowing greater gaseous interchange, moderate the damaging effects of waterlogged and anaerobic conditions, so improving survival.

Techniques have been developed for testing clones of birch for their response to isolates of *A. muscaria* when grown aseptically in mixtures of vermiculite and peat previously inoculated with appropriate fungal isolates. Early results confirm those from experiments with agar media showing that the fungus can stimulate root growth and that mycorrhizal development depends on genetical factors in birch and *A. muscaria.* During the year, the collection of *A. muscaria* cultures was augmented, with some isolates coming from pine forests in India.

Once again, during the autumn, qualitative and quantitative observations were made of fruiting bodies developing around trees at two sites. On a reclaimed coal tip in East Lothian, planted with six different tree species, sporophores of *Suillus luteus* were restricted to pine (*Pinus nigra* and *Pinus contorta*), whereas *Hebeloma* spp. and *Laccaria* spp. were only found around birch, *Betula pendula.* Some fungi, including *Paxillus involutus* and *Thelephora terrestris,* were not 'host specific'. In a second series of observations, restricted to 60 birch trees growing at the Bush Estate, the co-ordinates of over 8,000 fruiting bodies, representing ten different fungal species, were recorded. Some fungi, including *Hebeloma crustuliniforme, Thelephora terrestris* and *Laccaria laccata,* appeared for the fourth successive year, whereas fruiting bodies of *Inocybe lanquinella* and *Leccinum scabrum* (only one tree) occurred for the first time – possible evidence of a succession which perhaps should be exploited if controlled inoculations are linked with programmes of tree improvement. Hyphal isolates of fungi obtained from mycorrhizal roots seemed to relate to isolates obtained from fruiting bodies associated with the same trees.

J. Pelham and P.A. Mason

VIRUSES OF TREES

Experimental work is being focused on two viruses – cherry leaf roll and poplar mosaic.

Cherry leaf roll virus (CLRV) in birch

Because virus particles have been detected in seeds collected from wild populations of *Betula* species, which are open-pollinated, and because CLRV was found in pollen of naturally infected *Betula verrucosa,* controlled crosses were made between virus-free seedlings and 'wild', naturally infected trees to explore the nature of virus transmission. In a typical experiment, CLRV was detected in 180 (56%) of 320 seedlings produced when pollen from an infected birch was used to fertilise emasculated flowers on virus-free trees. The latter, unlike their progeny, remained, at least during the ensuing year, free of CLRV. In the reciprocal crosses, when naturally infected trees were fertilised with pollen from 'virus-free' trees, only eight of 73 seedlings were infected, i.e. 11% compared with 56%. This difference suggests large maternal and paternal influences on the efficiency of virus transmission (Figure 5). Although injected, none of the seedlings developed virus-like foliage symptoms during the first six months after germination when they were grown in a heated glasshouse. In a second experiment, birch seedlings from experimental crosses using virus-carrying pollen were divided into two groups. One hundred and seventy of 830 seedlings less than 1 cm tall after two months contained virus particles, whereas none of the 540 taller than 1 cm were infected. This apparent relation between differing growth rates and the presence or absence of virus is being studied in detail.

Leaf roll symptoms developed on ten of twelve cuttings of *Prunus avium* F12/1 after being mechanically inoculated with *Betula* isolate of CLRV. Additionally, infection delayed bud break and was associated with leaf bronzing.

Poplar mosaic virus (PMV)

In poplar (*Populus* × *euramericana* cv. Robusta) infected with PMV, the distribution of virus-like particles and the general ultrastructural appearance of infected leaves closely resembled that in *Phaseolus vulgaris* infected with the carla-virus, potato virus M. (Tu and Hiruki, 1971). However, the transmission of PMV seems to differ from that of many carla-viruses; it does not seem to be aphid transmitted. Further studies of its spread in the field are hampered because the development of foliage symptoms in poplars is erratic. To overcome these difficulties, and to ensure the consistent production of local lesions on experimental

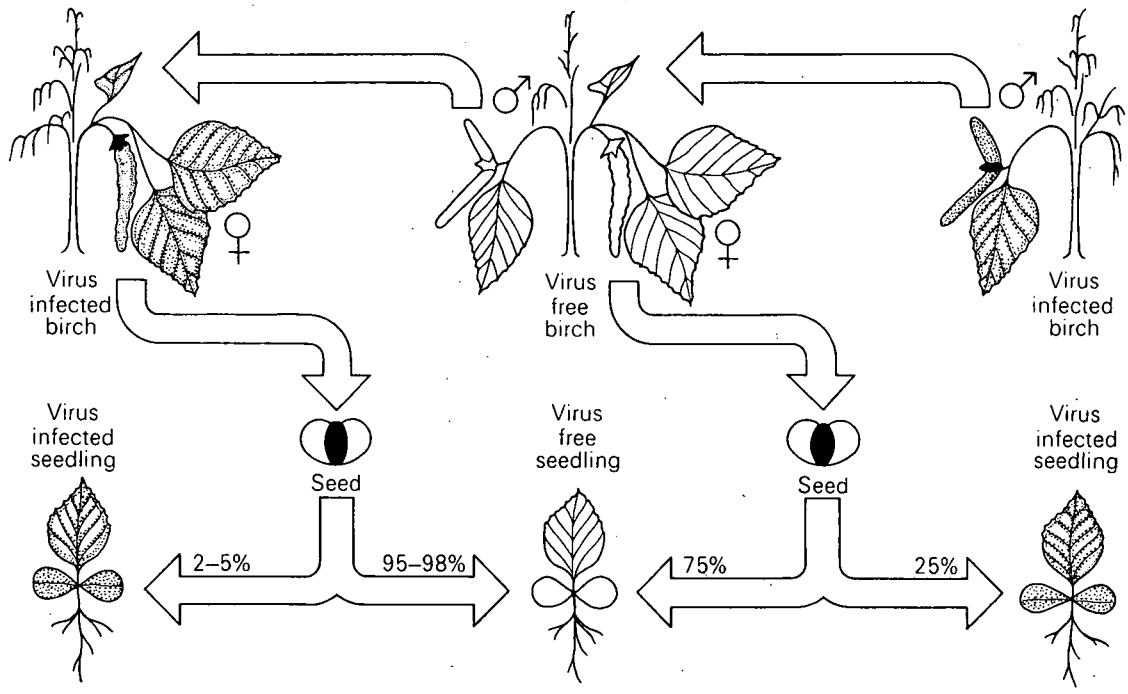


Figure 5 Maternal and paternal factors governing the transmission of cherry leaf roll virus (CLRV) to seeds of silver birch (25% of seeds were infected when female flowers on healthy trees were fertilised with infected pollen; in contrast, only 2–5% were infected when female flowers on infected trees were fertilised with healthy pollen).

plants, tests have been made using brief periods of thermal 'shock'. Whereas 40 seconds at 2° or 50°C induced local lesions when potato aucuba mosaic virus was inoculated to several hosts, the same shock did not induce lesions when a range of hosts, mainly solanaceous, were inoculated with PMV (Henderson and Cooper, 1977).

Other viruses

Arabis mosaic and strawberry latent ring spot viruses were detected in ivy, *Hedera helix,* with leaves having yellow chevrons, ring patterns or blotches. In contrast, similar patterns in *Vibrunum tinus* and *V. lantana* were associated with alfalfa mosaic virus; unexpectedly, the protein molecular weight of an isolate of this virus from *V. tinus* decreased during two to three weeks' storage in 0·01 M sodium azide – an unusual property.

J.I. Cooper and M.L. Edwards

References

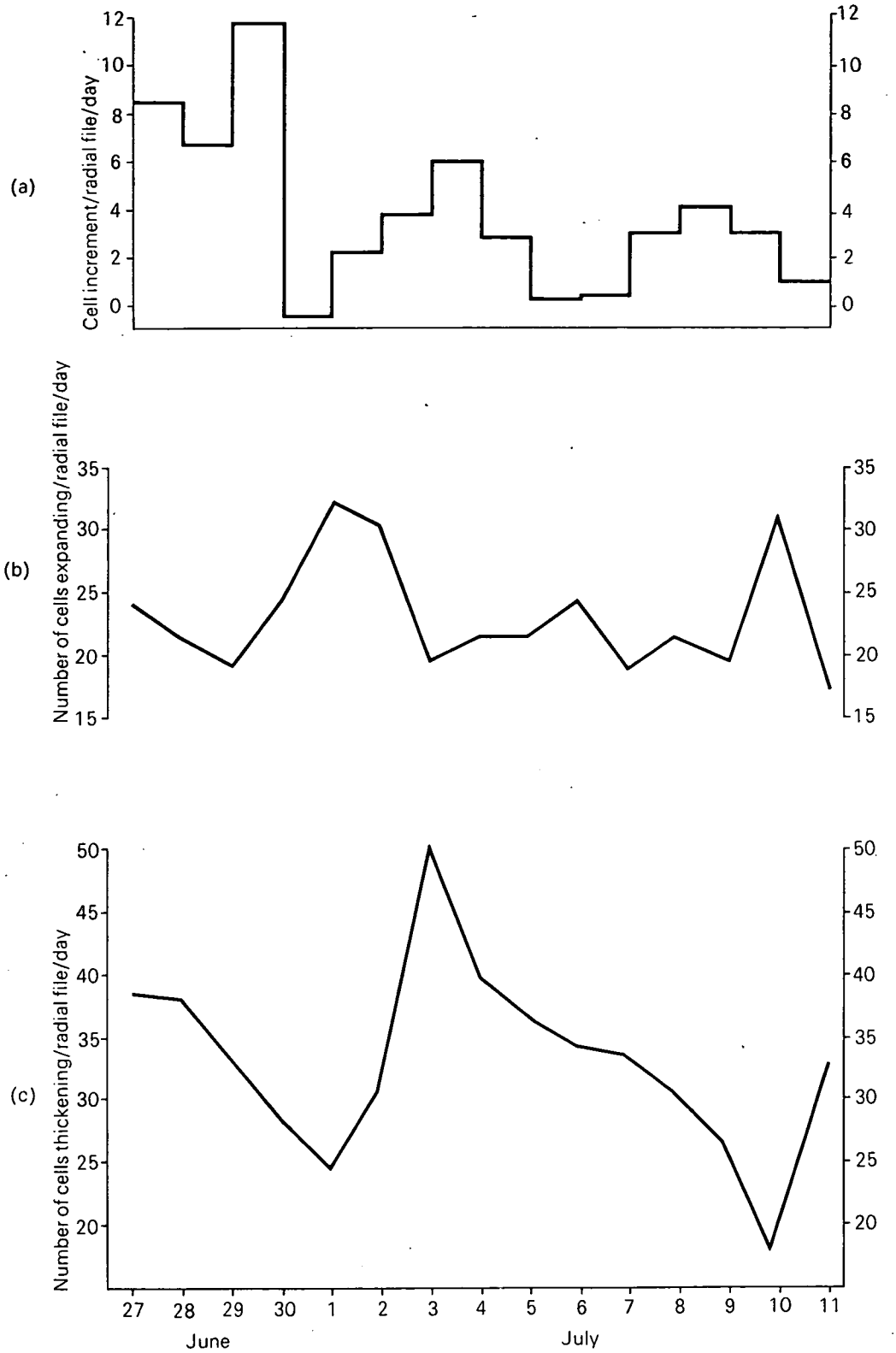
Henderson, H.M. and Cooper, J.I. (1977). Effects of thermal shock treatments on symptom expression in test plants inoculated with potato aucuba mosaic virus. *Ann. appl. Biol.,* (In press).

Tu, J.C. and Hiruki, C. (1971). Electron microscopy of cell wall thickening in local lesion of potato virus M infected red kidney beans. *Phytopathol.,* **61**, 862–868.

TREE RINGS AND CLIMATE

The use of annual rings of tree growth to date ancient timbers is well known. However, because specific sequences of climate produce unique patterns of growth, it is possible to go a stage further and compare seasonal and regional variation, e.g. the growth in the oceanic north and west of the country may be compared with that in the drier 'continental' south and east.

Tree rings are produced by a circumferential zone of small, thin-walled cells, the cambium, which divides to form (a) the xylem cells of the wood towards the centre of the tree, and (b) a comparatively small number of phloem cells towards the perimeter (Plate 9), and in so doing is itself gradually pushed outwards. In conifers, the xylem cells (tracheids) are produced in long, continuous radial files which first expand before their walls thicken. Whereas earlier studies, made on samples taken at fortnightly intervals, recognised that these processes are subject to broad seasonal differences, it was concluded that short-term weather changes were of little consequence. However, when examined at intervals of 12 h on Sitka spruce, *Picea sitchensis,* growing in Greskine Forest, Dumfriesshire, and using stem sections embedded in glycol methacrylate, it was found that xylem development was



(a) Number of new cells
(b) Number of cells expanding
(c) Number of cells thickening

Figure 6 Daily changes from three radial files of tracheids of P. sitchensis.

responsive to short-term weather changes. Starting at the inner edge of the cambium and moving inwards from cell to cell along adjacent radial files, groups of large thick-walled cells were found to be interspersed with groups of small thin-walled cells. How does the cambium change from producing large thick-walled, to small thin-walled, cells?

Estimates were made of the numbers of cells produced/radial file/day and of numbers of cell in (a) the expansion and (b) the wall thickening zones of the developing xylem (Figure 6). It was found that peaks of cell production were followed by peaks in the expansion and thickening zones, with a lag of about two days. It is suggested that the fluctuating cell sizes along radial files of tracheids are related to differing intervals of time spent by cells in the expansion and thickening phases which, in turn, are related to differing rates of cell production. Accelerated recruitment into one zone is not immediately followed by an accelerated rate of exit into the next. Consequently, some cells spend longer in a zone than others, and so, it is suggested, expand and thicken their walls to a greater extent. For this to happen, it seems that cambial activity can be stimulated by environmental changes, which in Dumfriesshire may be attributed, though not exclusively, to changes in solar radiation.

E.D. Ford and A.W. Robards (University of York)

SEASONAL PATTERNS OF SOIL PHOSPHATASE ACTIVITY

Seasonal variation in phosphatase activity, an important factor in the release of plant-available phosphorus from organically bound material, was studied during fourteen consecutive months in 1·6 m^2 plots, one in each of 48 different woodlands distributed throughout the Lake District. When phosphatase activity was expressed in terms of g^{-1} soil, only 5.8% of variation could be attributed to seasonal factors. However, when an allowance was made for differing soil organic matter contents by expressing phosphatase activity in terms of g^{-1} organic matter, 23·3% of variation was found to be seasonally related. Spatial differences in soil properties account for most of the remaining variation, and, because of the major effect of soil spatial differences, it was impossible to detect seasonal patterns of activity within individual plots.

By combining data from all 48 plots, summer and winter peaks in activity were evident (Figure 7). Whereas the summer peak is attributable to the greater phosphatase production by roots and microbes at relatively high soil temperatures, it seems that the high winter rates of phosphatase activity are due to enzyme release, by leaching, from newly fallen leaf litter.

A.F. Harrison

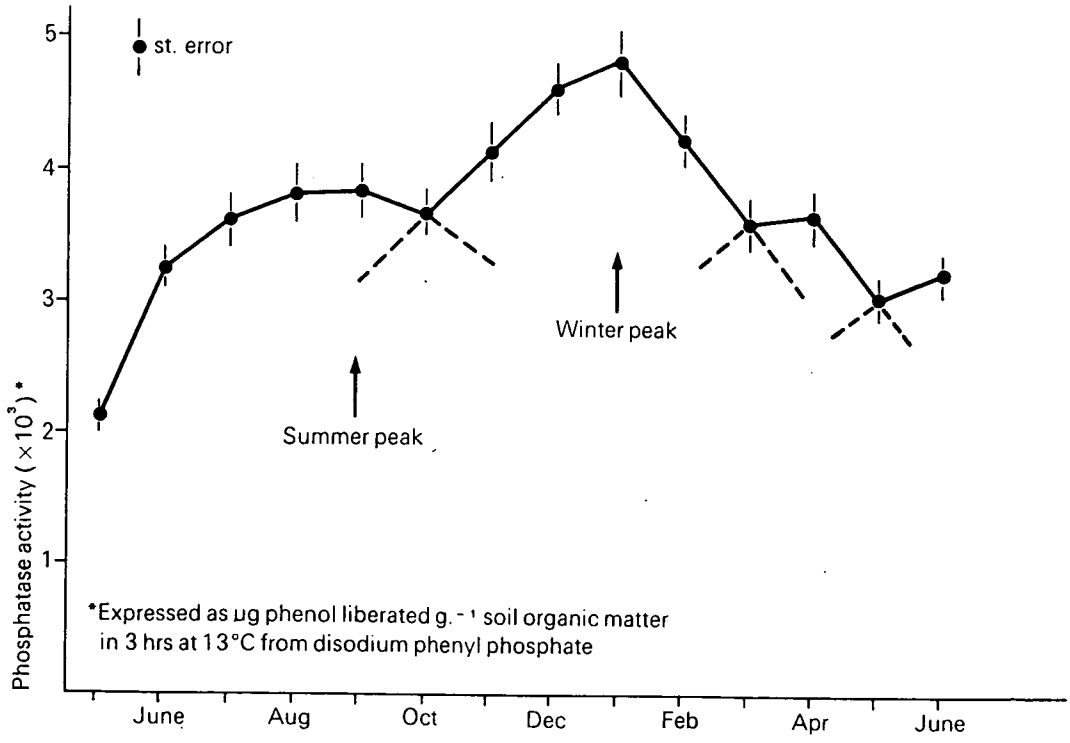


Figure 7 Seasonal pattern of phosphatase activity in Lake District woodland soils.

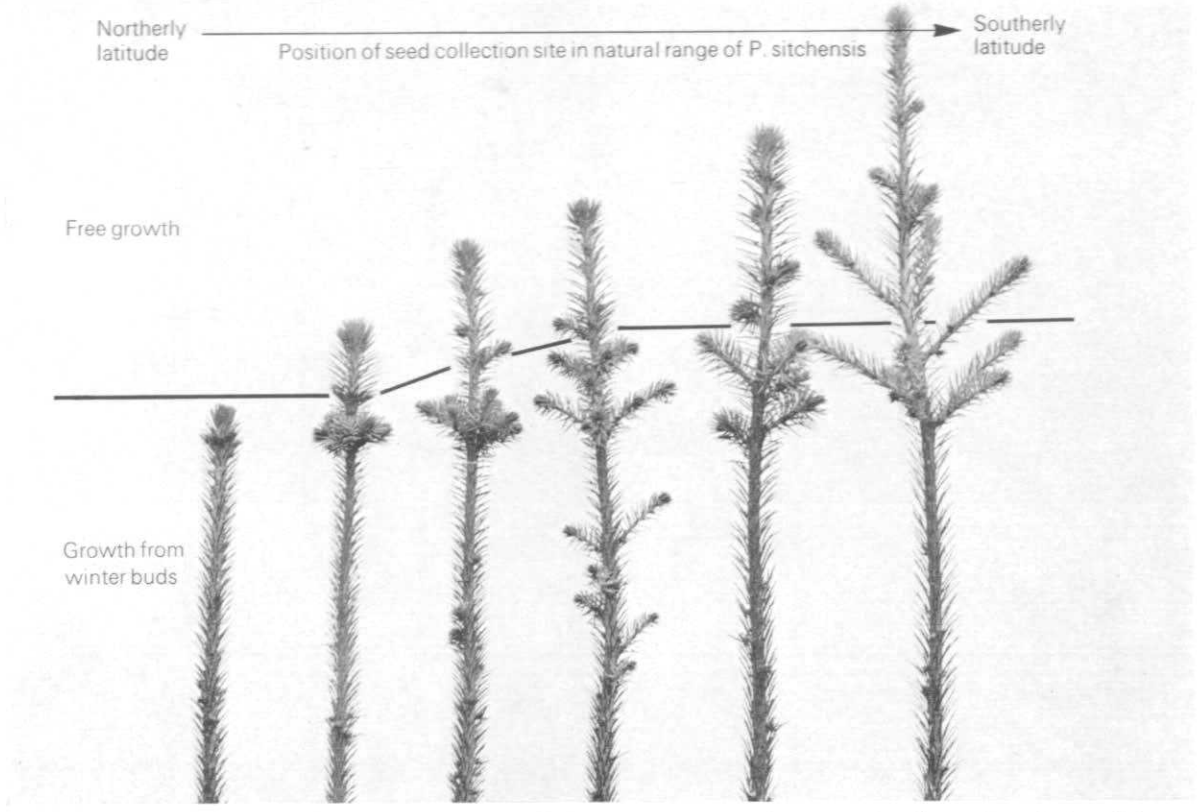


Plate 8 Growth patterns of leading shoots of Sitka spruce grown from seed collected at six localities spanning the N/S latitudinal range of this tree species. Stem growth below the horizontal line is attributable to the extension of initials formed 'last' year, whereas free growth, above the line, extended from initials formed in the current season. Photograph M.G.R. Cannell.

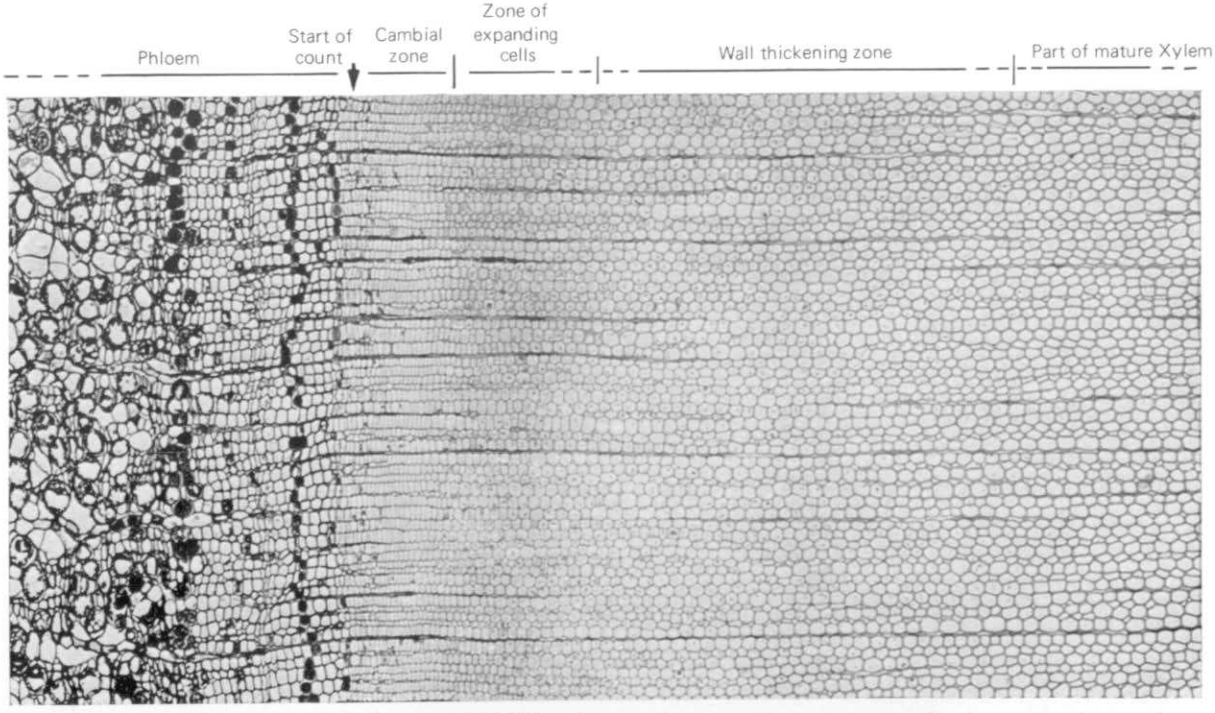


Plate 9 Transverse section of the stem of Sitka spruce showing the most recently formed xylem cells of the early wood. Photograph E.D. Ford and A.W. Robards.

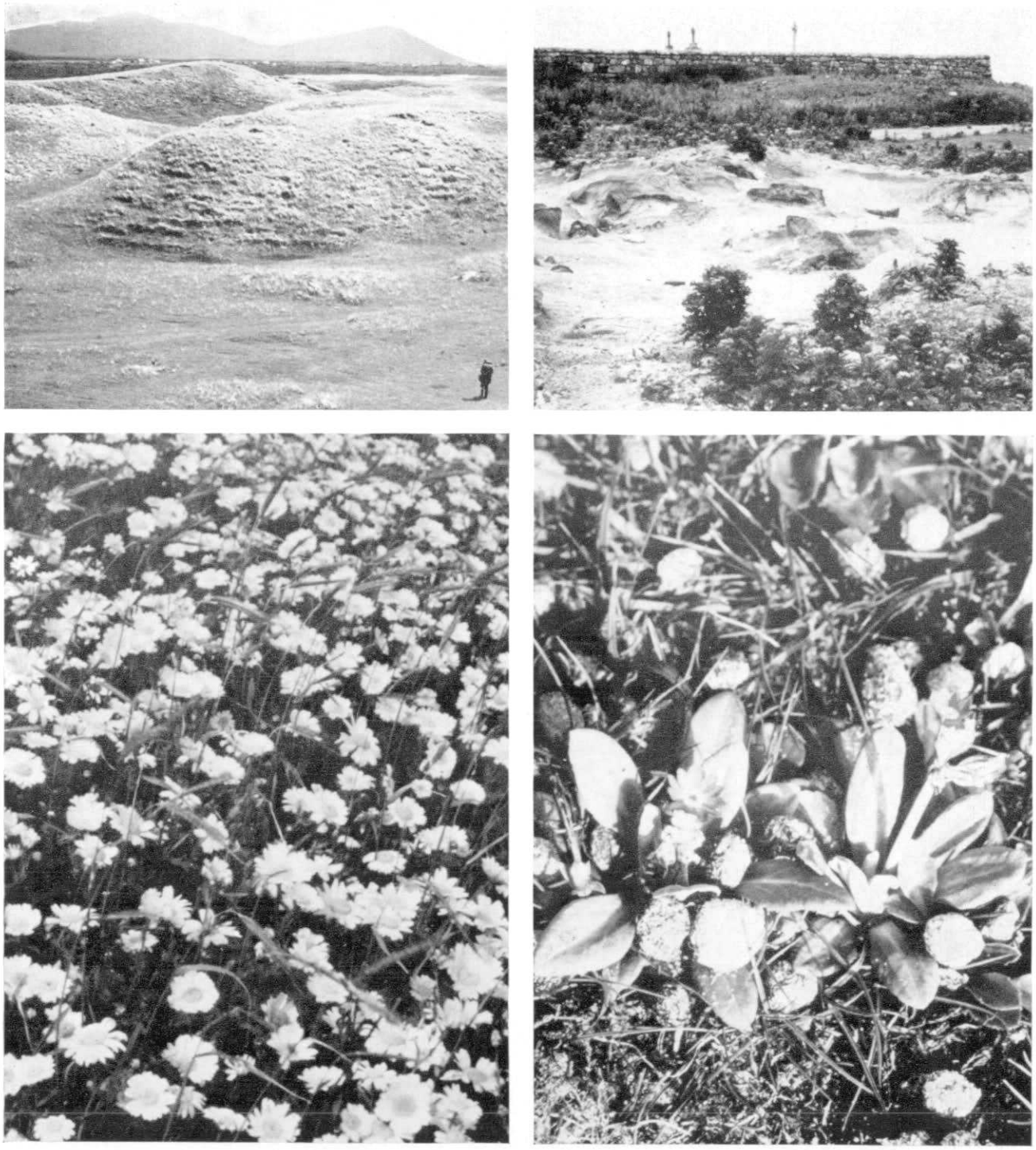


Plate 10 (a) Top left: Machair with stable dunes near Loch Hallan, South Uist. Machair is a type of dune pasture (often calcareous), subject to local cultivation and characteristically developed by wind deflation of sand dune in relatively humid conditions on the north and north-west coasts of Scotland.

(b) Top right: Rabbit damage to dune pasture (machair), South Uist.

(c) Bottom left: Chrysanthemum segetum *(corn marigold) on formerly cultivated dune pasture (machair). West Geirinish, South Uist.*

(d) Bottom right: Primula scotica *in a heavily rabbit-grazed damp-hollow (dune slack) amongst sand dunes. Sinclair's Bay, Caithness. Photographs D.L. Cheyne.*

EFFECTS OF BIRCH ON THE SOIL OF A YORKSHIRE HEATHER MOOR

The reputation of birch for soil improvement rests largely on comparisons of impoverished moorland soils under heather with neighbouring soils carrying naturally-regenerated birch woods. The assumption that the soils were initially alike is at best only partially verifiable and, to overcome this difficulty, G.W. Dimbleby, in 1948, set up a long-term experiment on Silpho Moor in the Cleveland Hills, where birch litter was applied at controlled rates to plots in a randomised block design.

Effects of the experimental treatments on earthworm populations, thought to be important in the postulated soil improvement, were studied. In the late 1950s, after about ten years, earthworm numbers were detectably larger in the 'birch' plots than in the control plots, but numbers of species had not increased above the two found sparsely elsewhere on the moor (*Bimastos eiseni* and *Dendrobaena octaedra*). In 1976, after 28 years, the population density was much as before, but now only one of the two species could be found.

Since the experiment began, the heather on the control plots has aged and the litter plots have developed as miniature birch woods, with a ground layer of bilberry, wavy hair grass and mosses. Heather burning having ceased, the surface horizons of the control plots have become even more acid than the original moorland. The 'birch' plots, which were initially 'screefed' to expose the mineral soil, have built up a new highly acidic (pH 3.4) surface layer of litter, raw humus and roots that has not favoured the large earthworms which might convert it to a forest brown earth.

On this evidence, birch colonisation seems unlikely to effect a radical change in soil type on Silpho Moor, but this result does not preclude the possibility that birch may improve more favourable sites where a substantial nutrient reserve still remains in the subsoil.

J.E. Satchell

TREE SELECTION STUDIES FOR REVEGETATION OF EXPOSED SITES AND AREAS OF DERELICTION

(This work was supported by the Department of Environment)

Slag heaps, and tips of industrial waste occupy many hectares of land. In 1974, there were 43,273ha of officially derelict land in England, derelict land being defined as 'land that has been so damaged by industrial development that it is incapable of beneficial use without treatment'.

Characteristically, tips of slag and other industrial wastes remain relatively free of plants because their physical and chemical properties adversely affect plant establishment. At present, many efforts are being made to reclaim derelict land where the major problem concerns the early phases of plant establishment. By analogy with agricultural practice, there are two possible approaches:

(a) site amelioration with the addition of lime and fertilisers before planting; and

(b) the use of genetically improved species.

The former has already been exploited, whereas the selection of grasses tolerant to toxic metals (Bradshaw, McNeilly and Gregory, 1965) suggests that it should be worth seeking tolerance among trees naturally colonising spoil-tips.

The present project was initiated to select, propagate and make available stocks of birch (*Betula pendula* Roth., *Betula pubescens* Ehrh.) and alder (*Alnus glutinosa* (L.) Gaertn., *Alnus incana* (L.) Meoch.) able to grow in exposed conditions and on unfavourable soils. At present, the research is concerned mainly with colliery spoil, where birch is the major natural recolonising species and alder one of the major planted species. Cuttings and seeds of these species have been collected from (a) naturally colonised and (b) planted tips in different parts of the country. The material obtained is being propagated and will shortly be tested for tolerance to industrial spoil. Trees will be selected on the basis of survival, growth rate, ease of propagation and amenity characters, but, earlier, they will have been inoculated with compatible root nodule endophytes (alder) and/or mycorrhizal fungi (alder and birch). These symbiotants are especially important when planting adverse colliery spoil (Schramm, 1966).

J.M. Clarke

References

Bradshaw, A.D., McNeilly, T.S. and Gregory, R.D.G. (1965). Industrialisation, evolution and heavy metal tolerance in plants. In: *Ecology and the industrial society*, ed. by G.T. Goodman, Blackwell.

Department of the Environment, Planning, Regional and Minerals Directorate (1975). Survey of derelict and despoiled land in England, 1974.

Schramm, J.R. (1966). Plant colonization studies on black wastes; from anthracite mining in Pennsylvania. *Trans. Am. Phil. Soc.*, **56**, 1–194.

Coasts, uplands and mountains

SURVEY OF SCOTTISH SAND DUNES AND MACHAIR

(This work was commissioned by the Nature Conservancy Council)

More than half of the sand dunes of Great Britain are found along the soft coasts of Scotland. Because dunes and machair are likely to be increasingly affected by a wide variety of new developments in areas previously unaffected by industrial and recreational pressures, the Nature Conservancy Council decided to seek information concerning the range of conditions in different sites throughout Scotland. In this way, NCC hoped to identify the most important sites and to be in a position to predict the impact of recreational and industrial developments particularly those associated with the oil industry. For these purposes, 94 sites covering an area of some 32,500 ha are being surveyed (Plate 10). In addition to recording plant assemblages and habitat factors, the occurrences of rare and localised species are being noted, as are some effects of human activities.

During 1976, its second year, the survey was concentrated on the Outer Hebrides, where massive accumulations of sand along the west coasts occur as low, flat, vegetated plains (machair). Forty-two sites were surveyed in 1976, leaving 24 of the 94 to be completed in 1977, the final year of the survey. Most of the data so far collected have been coded and punched for computer storage; cryptogams collected in 1975 have been identified. Preliminary analyses indicate that rather more than one-third of the British flora of vascular plants has been recorded. Some 25 basic vegetation groups, to which sample plots can be allocated, have been identified in the sites surveyed in 1975, their occurrence suggesting distinct geographical groupings. For example, Moray Firth sites are distinct from those on the north coast of Scotland. Vegetational groupings, not unexpectedly, seem to be associated to some extent with selected habitat factors (strata), some of which were recognisable from maps. The imprecise nature of this association reflects the heterogeneous nature of sand dune vegetation.

The plan survey was augmented by a survey of selected invertebrates as described in the following contributions.

D.S. Ranwell

INVERTEBRATE FAUNA OF SCOTTISH SAND DUNE AND MACHAIR SITES

(This work was commissioned by the Nature Conservancy Council)

Apart from a handful of sites which have been visited irregularly by entomologists, very little information exists regarding the invertebrate fauna of the sandy coasts of Scotland. Certainly, no attempt has previously been made to obtain comparative data from the large number of widely distributed sites. During 1976, such a survey was carried out to complement the more extensive botanical survey (described on this page and in *ITE Annual Report 1975*, pages 23–24).

During June and July, 47 sites were sampled simultaneously (Figure 8). These comprised thirteen east-coast sites, ranging from the Firth of Forth to Kinnaird's Head; sixteen north-coast sites, together with one at Enard Bay and two at Red Point on the west coast; and eighteen on the main islands of the Outer Hebrides, from South Uist to the Butt of Lewis.

At each site, a specially designed UV light trap, operated by a photoelectric cell and powered by a 12-volt car battery, was installed. These traps were left to operate for 7–8 nights. This sampling period was governed by the estimated life of the battery and the time taken to install traps at all sites in each of the three regions and to return to the first site. Two such trapping periods took place in the second half of the months of June and July in 1976. At the same time, eight pitfall traps were installed in a range of vegetation types in the vicinity of each light trap. These were left *in situ* for approximately three weeks between the main trapping periods.

Although England was experiencing its hottest summer for many years, Scotland, and the Outer Hebrides in particular, was subjected to many days of continuous rain and high winds, which drastically reduced the numbers of moths trapped during June.

Although a killing agent was placed in the light traps, a large percentage of the moths caught were so badly damaged that identification, now nearing completion, has only been possible by making genitalia preparations. Sorting of the pitfall trap material is continuing, and it is planned to complete identification of the Coleoptera, Myriapoda, Isopoda, Mollusca, Araneae and Opiliones during 1977.

In the months of June and July 1977, up to ten sites will be selected for further field survey, using identical trapping techniques, along the coasts of the Moray and Dornoch Firths. As a result, it will be possible to provide some data on the invertebrate fauna of approximately 60% of the sites covered by the botanical survey.

R.C. Welch

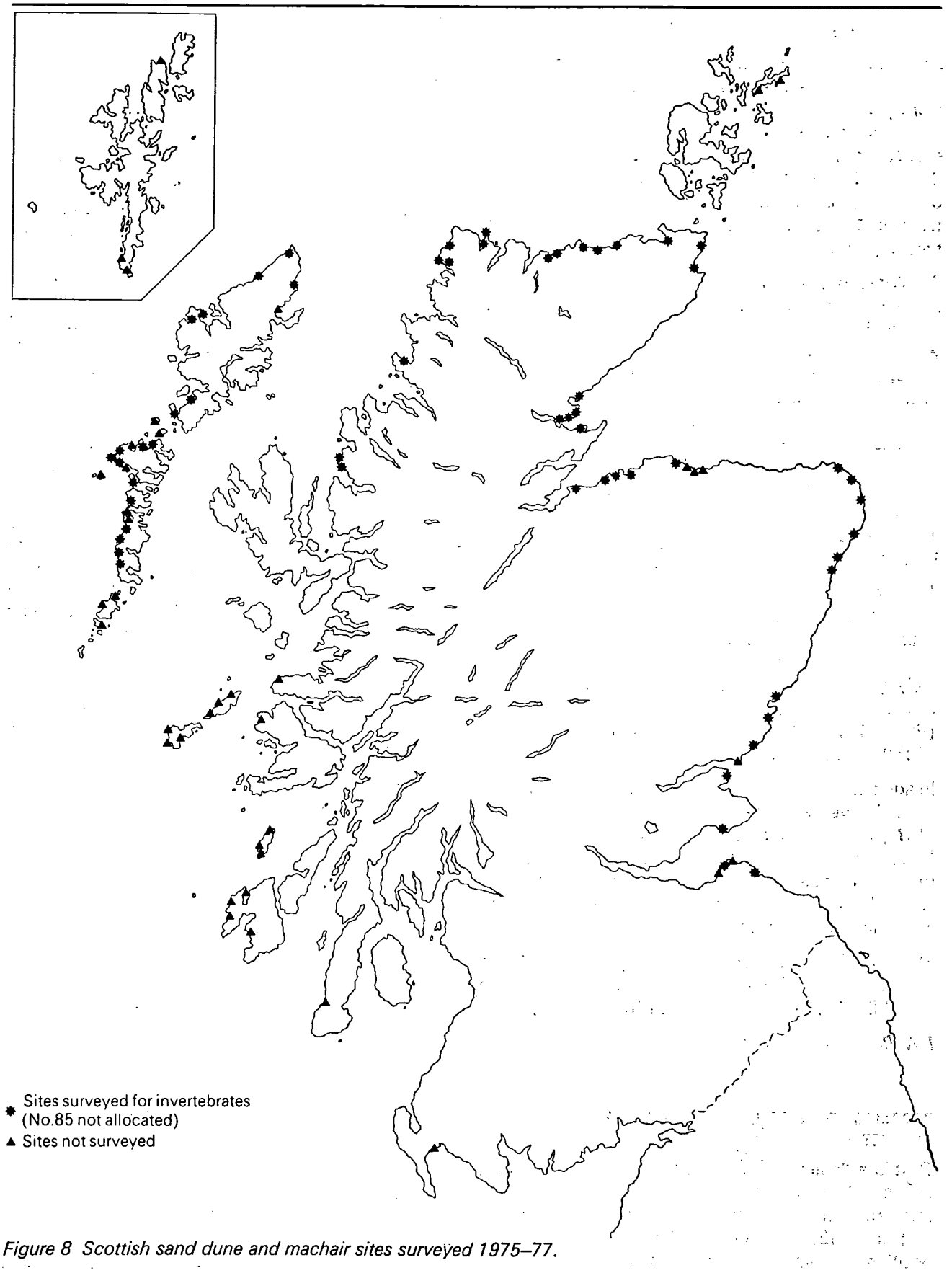


Figure 8 Scottish sand dune and machair sites surveyed 1975–77.

SPREAD OF RHODODENDRON ON SAND DUNES AT WINTERTON, NORFOLK

Rhododendron ponticum L., introduced from south-east Asia in the eighteenth century, is a forest weed in many parts of Great Britain, its dense foliage sometimes effectively smothering ground vegetation. At Winterton, east Norfolk, where *R. ponticum* occurs on acid sand dunes, its invasive tendencies, even when within 200 m of the sea, have been traced using aerial photographs taken in 1946, 1953 and 1973, and supported by a recent ground survey (Plate 11).

At Winterton, the *R. ponticum* population began invading in the 1930s, though very slowly at first. By 1953, it had spread to cover 0·6 ha, mainly in woodland and scrub areas, but with scattered individuals on open dunes, occupying, by 1973, a total area of 2·8 ha, including 1·8 ha on open dunes. The rapid encroachment between 1953 and 1973 is partly ascribed to the sudden decline in rabbit grazing following myxomatosis in 1954, the approximate number of *R. ponticum* bushes, 1 m or more in diameter, increasing on the open dunes from fifty bushes in 1953 to 16,000 bushes in 1973; there were 5–10 bushes in 1946.

Although open conditions, necessary for the establishment of *R. ponticum*, develop as a result of grazing, young seedlings which are poisonous when eaten in quantity are vulnerable to attack, particularly in their early years when height growth is slow, seedlings taking some five years to reach a height of 100 mm (Plate 11b). Older bushes can gain height at a rate of 150 mm per year.

In addition to being influenced by rabbits, the spread – 100 m in twenty years at Winterton – and establishment of *R. ponticum* by seed depends on the water table. Most specimens occur where the ground surface is 0·9 m to 1·4 m above the average summer water table; isolated individuals were recorded on sites up to 2·1 m above the average summer water table.

The annual spread of *R. ponticum* by seed equals the spread of *Hippophaë rhamnoides* by vegetative means at Saltfleetby, Lincolnshire, being 5 m per year.

L.A. Boorman and R.M. Fuller

DECOMPOSITION OF LITTER IN A CUMBRIAN BLANKET BOG

Peat is a dominant feature of much of upland Britain, accumulating as a result of an imbalance between rates of primary production and decomposition. As part of the IBP programme, a long-term litter decomposition experiment was established on a blanket bog at Moor House NNR in 1966–7 when tagged stems and shoots of heather, *Calluna vulgaris*, leaves of cotton grass, *Eriophorum vaginatum*, and cloudberry, *Rubus chamaemorus*, were set out (Heal, Latter, and Howson, in press).

After ten years the condition of replicate samples continues to differ appreciably, with coefficients of variation for weight losses for 'within sample sets' ranging from 6–40%. A few samples are now reduced almost to amorphous humus, whereas others, which have lost internal, but retained external, tissues, appear more or less unchanged (Plate 12). These differences can be related to differing moisture contents, to the ways in which different samples are being naturally incorporated into the evolving litter region, to patterns of colonisation by the fungus, *Marasmius androsaceus*, and to other factors.

Analyses of samples retrieved at different intervals indicate that rates of decomposition in peat soils decreased greatly after the first few years, confirming the mathematical estimates made by Jones and Gore (in press), for peat accumulation. Curves describing the progressive mean weight remaining have an asymptotic form, with losses usually being minimal after 4 years. Exceptionally, *Calluna* stems are continuing to lose weight, but very slowly (Figure 9). During

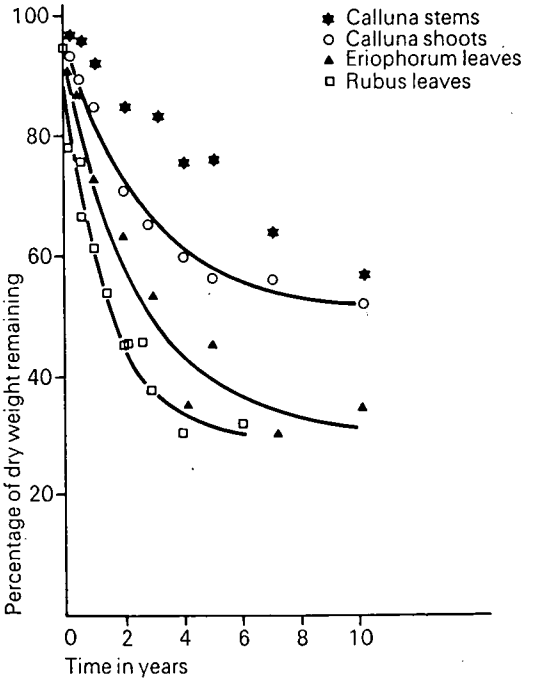


Figure 9 Weight of litter remaining, expressed as a percentage of original weight. (Asymptotic regression lines.)

the 10-year period, weights of *Calluna* stems and shoots decreased by 44 and 49%, *Eriophorum* leaves by 66%, and *Rubus*, during 6 years, by 73%.

In ten years, samples have 'moved down' to mean depths of 5–6 cm in the peat profiles, the depths varying from 0 to 15 cm. Amounts of movement depend on the accretion of new litter and/or the upgrowth and death of plants such as *Sphagnum*. Most samples had, in 10 years, passed through the litter layer to the F (dark-brown) horizon, some reaching the top of the green-brown horizon. These observations suggest that the transition from fresh litter to the F (dark-brown) horizon spans 5 years, and from the latter to the green-brown horizon more than 5 years.

Whereas populations of algae and fungi (fruiting bodies/superficial mycelium/bleaching/rhizomorphs) were maximal on tagged materials 3 months to 3 years after starting the experiment (Latter, in press), numbers of fauna were greatest from 2 to 5 years, with some animals, notably enchytraeid worms, still occurring after 10 years. Mites, collembola and fungi occurred more often on the drier samples (mean moisture contents 200–300% dry weight) and enchytraeid worms, diptera, and roots on the wetter samples (300–500% moisture contents). The ingrowth of roots, including mycorrhizal roots of *Calluna*, commenced after 2–3 years and continued until all litters are now permeated to some degree with rootlets.

P.M. Latter

References

Heal, O.W., Latter, P.M. and Howson, G. (In press). A study of the rates of decomposition of organic matter. In: *Production ecology of British moors and montane grasslands,* ed. by O. W. Heal and D.F. Perkins. Berlin: Springer Verlag.

Latter, P.M. (In press). Decomposition of moorland litter in relation to *Marasmius androsaceus* and soil fauna. *Pedobiologia.*

Jones, H.E. and Gore, A.J.P. (In press). A simulation of production and decay in blanket bog. In: *Production ecology of British moors and montane grasslands,* ed. by O.W. Heal and D.F. Perkins. Berlin: Springer Verlag.

DEEP ALTERATION OF THE WHIN SILL

Mineralogical and micromorphological investigations of soft, deeply-altered sections of normally hard and slow-weathering igneous Whin Sill dolerite were started on a site in Teesdale, County Durham. They showed a gradual breakdown of constituent rock minerals from the less to the more altered areas, with pyroxenes and feldspars being the most affected. Clay and silt-rich seams, which appear to delineate the original joint system in the dolerite, consist of an almost mono-mineralic, golden micaceous material with a range of crystal arrangements in thin section. This material proved to be a vermiculite/smectite when subjected to X-ray analysis. The nature of the clay suggests:

(a) that there may have been some early hydrotherma alteration when the Whin Sill cooled in the Carboniferous Period; and

(b) that weathering occurred much later, possibly in Mediterranean or Sub-tropical conditions.

The distinctive clay mineral was found in glacial drift mounds down the valley from the site, suggesting that weathering probably occurred at least before the last (Devensian) glaciation, and possibly during the later stages of the Tertiary Period, when a suitable climate prevailed.

More recently, the study of deeply-altered sections in the Whin Sill has been extended to other sites in the north of England; these are now being examined mineralogically/micromorphologically and by trace element analysis, to enable comparisons with the Teesdale site to be made. It is hoped that this investigation will indicate how the test rock breaks down to form a potential soil parent material.

A.A. Hatton

References

Hatton, A.A. and Hornung, M., 1977. Progress report on an investigation of deep alteration of the Whin Sill. *Proc. N. Engl. Soils Discuss. Group,* No. 12.

Hornung, M. and Hatton, A.A., 1974. Deep weathering in the Great Whin Sill, northern England. Proc. Yorks. Geol. Soc. **40,** Part 1, No 6, 105–114.

SOILS OF UPPER TEESDALE

Over the years, ITE has studied intensively the soils of the Upper Teesdale NNR, the soils of some 6,075 ha of the Reserve and its surrounding SSSIs having been mapped at a scale of 1:10,000, with a larger area covered in less detail. Within the mapped area, particular attention was paid to the soils of localities free of drift, especially those associated with the vegetational communities containing the arctic-alpine elements for which Upper Teesdale is famous. The drier of these communities usually occur on rendzinas or shallow brown earths, whereas mire and bog communities are found on gleys which are often calcareous and/or humic, or flushed peat. The rendzinas have developed in calcareous sand produced by the weathering of a granular marble, whereas the gleys usually occur adjacent to marble outcrops and are flushed by calcareous springs. The unusual chemical and physical characteristics of these soils have almost certainly been an important factor in the survival of the unique flora.

Interesting soils have also developed over sandstones in drift-free sites on the higher fells. Argillaceous, loosely cemented sandstones have been weathered physically to produce a layer of sandy material in which humus iron podzols have developed, these soils being associated with a species-poor *Festuca*-dominated community. The podzols have a variety of frost originated features, some of which date from past cold periods, whereas others are the result of present-day frost action. Harder, silica cemented sandstones have also been affected by previous cold periods, but, in this instance, they were shattered to produce angular blocks rather than sand. A characteristic *Calluna–Empetrum* community is usually associated with the rankers developed over the sandstone blocks.

The role of soils and physical site factors has been examined in relation to the development and survival of the species-rich hay meadows of the upper dale. It was found that these meadows commonly have many soil types and frequently have within them rock outcrops, very wet areas or steep slopes. Together, these factors have produced a range of habitats providing refuges for the many plant species that occur.

M. Hornung

References

Hornung, M. (1976). Frost originated features in soils derived from sandstones in the northern Pennines. *Proc. N. Engl. Soils Discuss. Group,* No. 11, 51–57.

Hornung, N. (In press). Some comments on the soils associated with the Upper Teesdale flora. *Proc. N. Engl. Soils Discuss. Group,* No. 12.

SOIL EROSION BY SEALS AND PUFFINS ON THE FARNE ISLANDS

Attempts to restore badly eroded areas have continued on the Wideopens—islands colonised by puffins and gulls where seals only occur on sandy beaches. Where ground has been covered with brash, erosion has decreased and amounts of plant cover have increased. At the same time, numbers of nesting puffins using the brashed areas have also increased, reaching densities comparable with those found on nearby non-eroded and well-vegetated sites. Trials with brashing materials will be extended during 1977.

On the main seal-breeding islands, the balance between soil erosion, vegetation changes, and the interplay between seals and puffins is being intensively investigated. In areas of severe 'seal pressure' on Staple Island, plant cover has been decreased to less than 10%, and over 90% of puffin burrows are filled in during the seal breeding season. Soil erosion is worst in and around seal wallows and along the main seal routes on, and off, the islands. Restoration of this 'seal damage' is a formidable problem unless the animals are excluded.

M. Hornung

PRODUCTION PHYSIOLOGY IN POLAR MOSSES

Growth occurs when gains from photosynthesis exceed losses from respiration. The duration and frequency of these periods of growth can be assessed directly, by measuring CO_2 exchange and also by 'simulation'. Growth of mosses can be assessed either per unit area or per unit shoot, the former having been used for *Calliergon sarmentosum*, which gives continuous ground cover, and the latter for *Polytrichum alpinum*, where cover is less complete.

The activity of *Calliergon sarmentosum*, a widespread bipolar species which also occurs in upland habitats in Britain, has been measured (Figure 10). At the latitude of Barrow, Alaska (71°21'N), the sun is above the horizon for 84 days, but, nevertheless, solar radiation and temperature show appreciable diurnal fluctuations. Fixation of CO_2 occurred throughout the whole day, but at a reduced rate for a 2-h period either side of midnight (12 July); the decreased net photosynthesis at mid-day is attributed to supra-optimal temperatures (Oechel and Collins, 1973; 1976). By 8 August, when the sun was below the horizon for considerable periods, temperatures were generally lower and net photosynthesis was negative for 6 to 7 h. However, rates at other times of the day were sufficiently high to give a net gain for the day of 0·77 g CO_2 m^{-2} versus 2·17 g CO_2 m^{-2} on 12 July.

An alternative method of assessing growth is to measure effects of light, temperature and water content on rates of net photosynthesis in controlled experiments and then, using field microclimate data, attempt to predict what happens in the field. For *Calliergon sarmentosum*, a moss species with a simple growth pattern, net production for a 120-day season at Barrow, Alaska, was predicted as 171 g m^{-2} (Oechel and Collins, 1976). Although dry matter production has not been measured directly at this site, this value falls on a gradient of net production for other similar species ranging from 60–350 g m^{-2} on Devon Island (continental Arctic), through 220–890 g m^{-2} on Signy Island (maritime Antarctic) to 350–1,400 g m^{-2} on South Georgia (sub-Antarctic) and Disko Island (oceanic Arctic) (Callaghan and Collins, in press). The predicted rates of net photosynthesis calculated per shoot for *Polytrichum alpinum, viz.* 38·5 g m^{-2}, compare favourably with those measured directly 43 g m^{-2}.

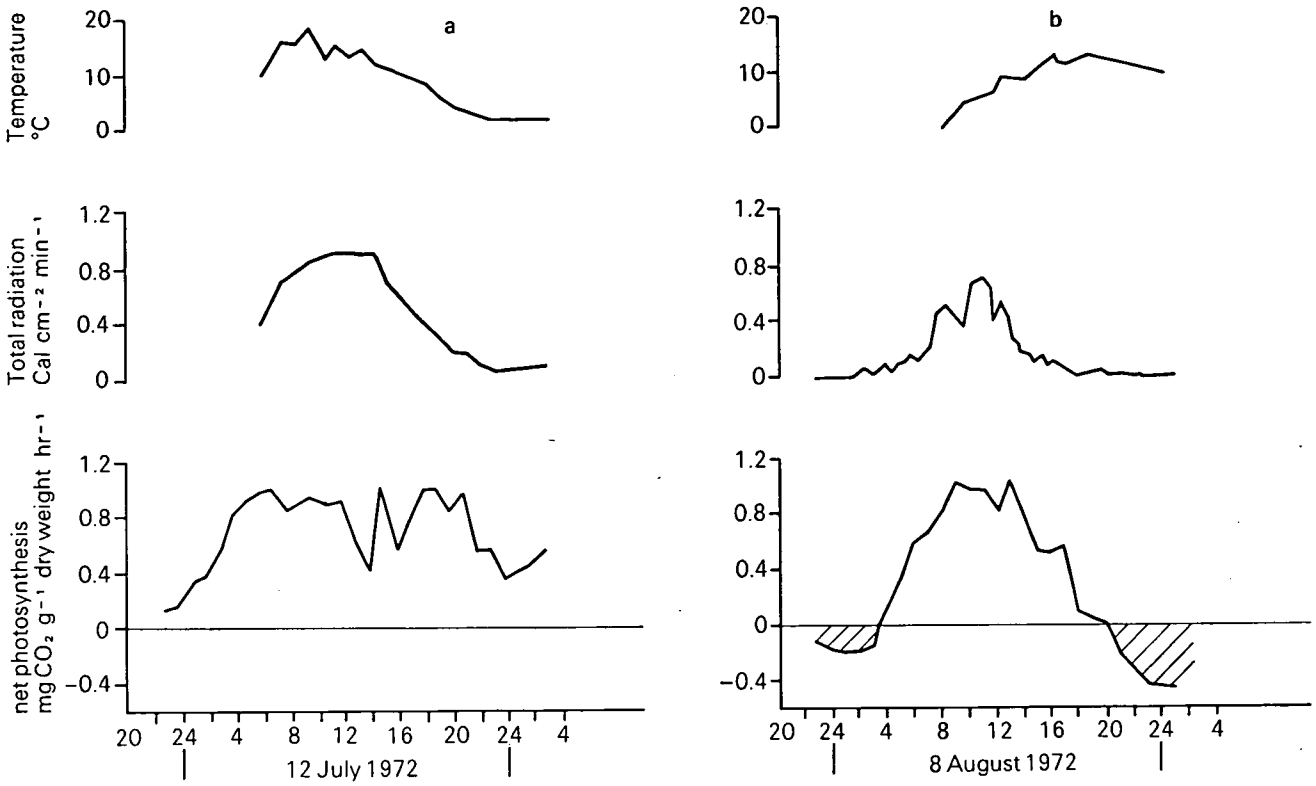


Figure 10 Patterns of photosynthetic activity in Calliergon sarmentosum *at Barrow, Alaska, on 12 July and 8 August 1972 (from Oechel and Collins, 1973).*

More detailed analyses of net production over short time periods are now being made for maritime Antarctic moss communities, using multiple regression models based on laboratory estimates of physiological activities linked with field microclimate data collected more or less continuously since 1969. Thus, if grown in a temperature regime corresponding to the mean summer regime on Signy Island, *Drepanocladus uncinatus*, another cosmopolitan polar/upland moss with a similar pattern of growth and habitat to *Calliergon sarmentosum*, would maintain high rates of net photosynthesis over widely ranging conditions of radiation and temperature. The rates of mid-day net photosynthesis on hot sunny days of *D. uncinatus* would be less depressed than those of *Polytrichum alpestre* which has a lower temperature optimum. However, when *Polytrichum alpestre* is grown at higher temperatures, corresponding to mid-summer microclimate conditions, the optimum temperature for net photosynthesis is much higher and consequently the mid-day depressions are minimised.

To date, most of the simulation work has concentrated on conditions where water is non-limiting. In collaboration with British Antarctic Survey biologists, it is now hoped to elaborate a predictive model of more general application.

N.J. Collins and T.V. Callaghan

References

Callaghan, T.V. and Collins, N.J. (In press). Life cycles, population dynamics and the growth of tundra plants. In: *Tundra: comparative analysis of ecosystems,* ed. by J.J. Moore. London: Cambridge University Press.

Collins, N.J. (In press). The growth of mosses in two contrasting communities in the maritime Antarctic; measurement and production of net annual production. In: *Adaptation within Antarctic ecosystems,* ed. by G.A. Llano. (Proc. 3rd Symp. on Antarct. Biol., Washington, 1974.)

Oechel, W.C. and Collins, N.J. (1973). Seasonal patterns of CO_2 exchange in bryophytes at Barrow, Alaska. In: *Primary production and production processes, tundra biome,* ed. by L.C. Bliss and F.E. Wielgolaski, 197–203, IBP Tundra Biome Steering Committee, Edmonton, Canada.

Oechel, W.C. and Collins, N.J. (1976). Comparative CO_2 exchange patterns in mosses from two tundra habitats at Barrow, Alaska. *Can. J. Bot.,* **54**, 1355–1369.

COMPARATIVE GROWTH STRATEGIES IN TWO MOSSES

The response of particular metabolic processes to changing environments can often be monitored directly, whereas much of the overall growth strategy can be analysed from the historical record of the plant's past development represented by its gross morphology (Callaghan and Collins, 1976). This historical record also provides information on reproductive strategies and life span. Differences between growth strategies could be expected to reflect adaptations to particular environments, and an understanding of the growth strategy of a particular species should allow an assessment of its ecological tolerances, distribution, and possible performance in new environments.

In polar and montane areas, the historical records of many species are particularly well-preserved and the seasonality of past growth can be identified easily. For this reason, field observations were made at Abisko, Swedish Lapland, during the summer of 1975 with the help of many facilities provided by the Abisko Scientific Station. These observations made it possible to compare the growth of *Hylocomium splendens* (Hedw.) B and S, and *Polytrichum commune* Hedw., important components of boreal birch forests, the former being usually restricted to damp, shaded, under-storey habitats, whereas the latter thrives in more exposed and disturbed sites.

A shoot of *H. splendens* consisting of a series of frond-like segments (Plate 13), each of which is produced laterally from a one-year-old segment, grows and develops side branches within its first year. There are no underground storage organs and labelling young segments with carbon-14 shows that translocation to older segments does not occur. This means that, as segments age and are shaded by younger generations, respiration exceeds photosynthesis and weight will be lost until the segment gradually dies and decays.

In contrast, shoots of *P. commune* possess underground systems which absorb nutrients and water, and are maintained by the translocation of photo-assimilates from the above-ground green segments (Plate 13). The presence of a well-developed conducting system and specialised leaves, which can control water loss, results in this species having an efficient control of its water balance. In hot, dry conditions, the leaves limit water loss while they receive water from the underground system. Photosynthesis can, therefore, be continued (Figure 11). In contrast, however, the soft fronds of *H. splendens*, which have a large surface area/volume ratio, lose water quickly and, in the absence of translocation and an underground system, the fronds become desiccated and photosynthesis ceases (Figure 11).

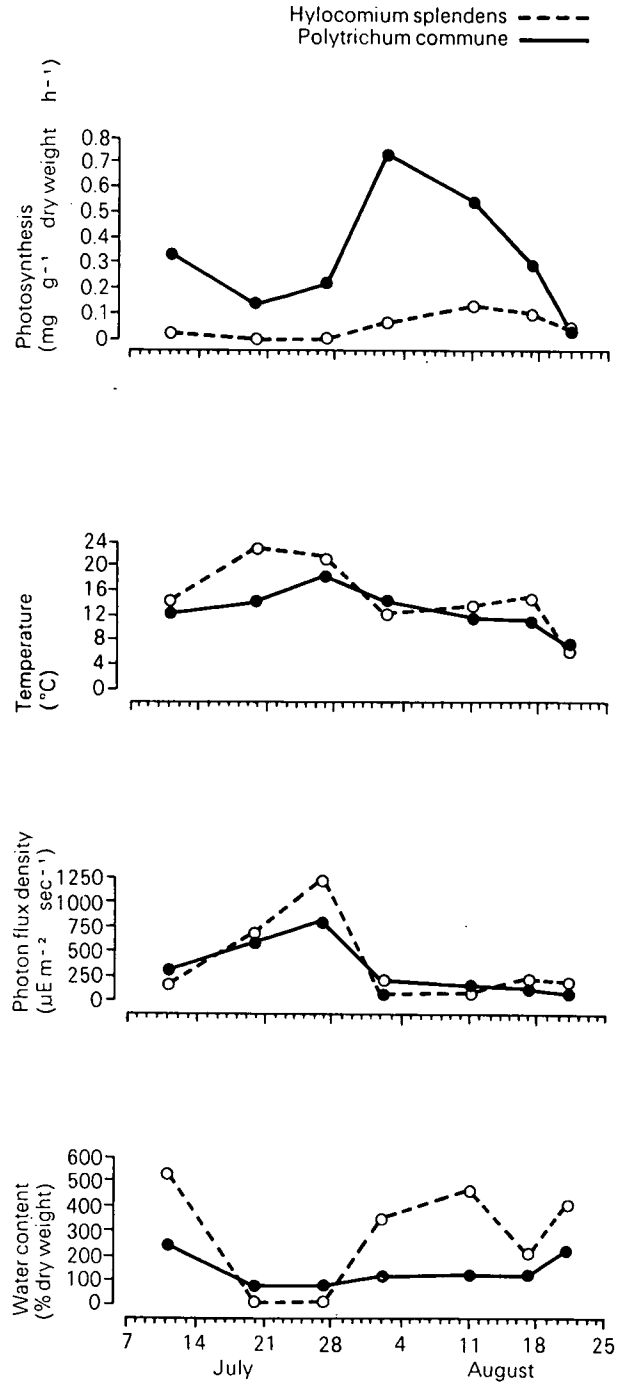


Figure 11 Seasonally changing rates of gross photosynthesis and water contents of Hylocomium splendens *and* Polytrichum commune, *related to temperature and light. Whereas moisture as per cent of dry weight remained more or less constant in* P. commune, *it varied greatly in* H. splendens. P. commune *photosynthesised more rapidly than* H. splendens *in all conditions.*

In *H. splendens*, old segments on each shoot are continuously drying at ground level, but the production of new segments at the surface of the moss carpet results in an indefinite life span for each whole shoot. However, as new segments are only produced from one-year-old segments, any damage to the youngest segments will result in the eventual death of the whole shoot. In addition, sexual reproduction is rare, with archegonia aborting during most seasons. *H. splendens* is, therefore, extremely sensitive to damage by trampling or grazing, and, once damaged, the regeneration of a carpet will be extremely slow.

By way of contrast, the above-ground shoots of *P. commune* show finite life expectancies (about six years maximum). In this species, damage to an above-ground shoot is not particularly serious because the underground system would not be greatly affected and would continue to reproduce vegetatively, giving rise to new above-ground shoots. Moreover, sexual reproduction in *P. commune* is regularly successful so that the species can invade newly or continuously disturbed areas where its growth strategy will enable it to survive.

In summary, *H. splendens* may be said to show a conservative growth strategy, whereas, in *P. commune*, the strategy is opportunistic. It is not surprising, therefore, that *H. splendens* occurs most commonly in habitats where disturbance is minimal and where shading and the production of a closed carpet can prevent desiccation. In these habitats, its continuous apical growth allows it to compete favourably with other species. On the other hand, *P. commune* is better able to withstand environmental fluctuations, but it is susceptible to competition from other species: another reason why it is often found on exposed and disturbed ground. The unreliable production of spores by *H. splendens* and the need for conservation of water between tightly packed shoots results in the production of extensive carpets of this moss, the extent of these carpets being rather paradoxical in view of the restricted vegetative reproductive capacity. In contrast, the branching underground system of *P. commune*, and its successful spore production, leads to numerous small colonies, often with widely scattered individual shoots.

T.V. Callaghan and N.J. Collins

References

Callaghan, T.V. and Collins, N.J. (1976). Strategies of growth and population dynamics in tundra plants. 1. Introduction. *Oikos*, **27**, 383–388.

Freshwater habitats

PRODUCTIVITY OF PHYTOPLANKTON IN LOCH LEVEN, KINROSS

One of the commonest methods of determining gross rates of phytoplankton productivity involves calculating rates of photosynthesis from changes in amounts of dissolved oxygen in water samples before and after being incubated in clear and blackened bottles held at different depths within a loch. Oxygen changes are attributable to both photosynthesis and respiration in clear bottles, whereas, in dark bottles, only respiration is operative. In practice, however, interpretation of the data is vitiated by an imprecise knowledge of how much photosynthate is respirated by the algae themselves, and how much remains as net production to appear as algal biomass.

In the past, estimates of net production have often been made assuming that (a) oxygen uptake in the dark bottle is primarily attributable to algal respiration, with a negligible contribution from bacteria and zooplankton, and (b) rates of dark respiration are independent of light history and hence are unaffected by diurnal changes in incident light or by the vertical gradient of irradiance in the water column. But, like that from elsewhere, evidence accumulated during the IBP study on Loch Leven suggests that these assumptions are not universally valid. To determine more precisely the nature of varying rates of respiration, influenced by depth and diurnal factors, attempts have been made to partition respiration related to the phyto- and zooplankton entities within Loch Leven. At the start, larger crustacean zooplankton were removed using a '60 mesh' (200μ aperture) nylon net. Attempts were then made to estimate bacterial O_2 uptake after removing algae by filtering loch water through GF/C glass fibre filters. Preliminary results suggest that a variable proportion (10–35%) of total O_2 uptake was attributable to non-algal oxidation of dissolved organic material, but more observations are required for an accurate seasonal assessment (Table 4).

Table 4 'Bacterial respiration' in water from Loch Leven after removing algae by filtration

Date	Water temperature (°C)	Respiratory Rates (O_2 uptake (μg l^{-1} h^{-1}))		B as % of A
		Unfiltered water (Bacteria and algae) (A)	Filtered water (Bacteria) (B)	
6.4.76	5	6·9	0·7	10
6.7.76	20	40·7	13·1	32
13.7.76	19	55·1	19·3	35
20.7.76	18	34·5	10·7	31
3.8.76	15	23·5	4·1	17

Weekly laboratory measurements are being made of rates of (a) O_2 uptake and (b) the carbohydrate content of water samples taken from different depths in Loch Leven, these data being related to chlorophyll *a* contents which are regarded as estimates of algal populations. Rates of O_2 uptake were greater in surface samples than in samples at a depth even though temperature and algal concentrations were virtually uniform throughout the whole water 'column', there usually being a difference of 10–30%, although the difference sometimes exceeded 80%. Differences in amounts of O_2 uptake were generally correlated with differences in carbohydrate content which may therefore be used as an index of respiratory rate. If this relation were substantiated, it would facilitate a more detailed description of spatial variation in respiratory rates.

M.E. Bindloss

ECOLOGICAL EFFECTS OF AQUATIC HERBICIDES ON FRESHWATER ECOSYSTEMS

Most freshwater ecosystems are subject to some form of periodic management, and the plant and animal communities present are a response to a particular management régime. Any modification of an established management practice can be expected to produce a corresponding change in the structure and function of these communities. For example, an increase in the frequency of dredging or the adoption of block weed clearance routines may affect the rate and pattern of recolonisation by macrophytes and their associated fauna.

The ecological effects of traditional methods of weed control are not fully understood, but are to some extent predictable; the short-term effects are severe, but recovery of the system is generally rapid, particularly if recolonisation from adjacent watercourses is possible. Aquatic herbicides cannot be assumed to produce only those sorts of effect that result from other forms of management. There may also be additional problems associated with persistence, selectivity and possible direct toxic and indirect effects of the chemical on non-target organisms, all of which may fundamentally alter the characteristics of the ecosystem. The current research programme funded by the Nature Conservancy Council was developed primarily to examine the long-term ecological effects of specific herbicides, with some attempt to relate these effects to those resulting from other forms of management.

Field experiments with cyanatryn were carried out on a local dyke system whose management history was known. One section was treated in March, but required a further application in May. A second section was divided by means of a polythene barrier and cyanatryn was applied to one-half early in May, the area upstream of the barrier being left untreated. Regular monitoring of a range of physical/chemical parameters, including dissolved oxygen and herbicide residues, was continued throughout the summer. The aquatic vegetation was mapped each month to follow changes in percentage cover following herbicide treatment and a range of aquatic organisms, including bacteria, phytoplankton, periphyton and invertebrates, were sampled at regular intervals. Preliminary observations indicate some unexpected results.

First, release of the herbicide was extremely slow, so that maximum concentrations in the water were not achieved until five or six months after treatment, instead of the two to three weeks predicted. All submerged weeds were completely eradicated but, because of the slow release, eradication was not attained until some twelve weeks after treatment.

Second, the polythene barrier did not prevent movement of the herbicide into the untreated area and almost all the submerged macrophytes were again eliminated, although some species present in the area furthest away from the barrier showed early signs of recovery. This effect may be of some relevance to the management of freshwater ecosystems where total eradication of vegetation is not desirable. It may be possible to adjust the dose so that such unwanted species as the filamentous algae are removed, while only temporarily suppressing the growth of other susceptible species.

Third, it is becoming clear that certain groups of organisms, particularly some of the Mollusca and the Hemiptera, have suffered drastic reductions in numbers following herbicide treatment and loss of aquatic macrophytes. Although the untreated section proved to be of limited value as a control because of the effects of herbicide seepage, a further section upstream of the untreated area remained totally unaffected and thus provided a useful measure of comparison. There is little doubt that some groups have suffered, but whether this is due simply to the loss of a favourable habitat or to some direct or indirect effect of the herbicide is not yet clear. Laboratory experiments may help to determine whether the prolonged exposure to sub-acute concentrations of the herbicide experienced during the experiment may have contributed to the observed declines.

Recovery of the experimental sites is already well-established, but, as yet, only in those areas which inadvertently received very low doses of the herbicide. The pattern of recolonisation by plants and animals in

the treated sections will be closely followed during the next year, when it is also hoped to investigate in more detail the effects of other forms of management in the neighbouring system of interconnected dykes.

H.R.A. Scorgie

SPATIAL ORGANISATION IN FRESHWATER ZOOPLANKTON

In the early days of research on freshwater plankton, it was widely believed that the planktonic crustacea were fairly homogeneously distributed across a lake. More intensive sampling, however, proved that the animals were usually very unevenly distributed in the horizontal plane. In planning an intensive study of zooplankton/phytoplankton population dynamics, such as that envisaged for Loch Leven, the extent of spatial variability is of interest in two respects:

(1) Some information on species patchiness must be obtained before designing sampling strategies to measure abundance.

(2) A study of spatial pattern may in itself provide information on the animals' response to physical, chemical and biological changes in the environment (Taylor, 1971).

In many terrestrial or benthic situations, the disposition of animals in space is readily apparent. Within the plankton, however, since it is not possible to observe the position of individual animals, patterns have to be investigated mathematically by measuring departures from a theoretical random distribution model (Elliott, 1971).

Despite the highly mobile nature of the open-water environment, the numbers of animals occurring at a given point in a lake are generally governed by a few dominant systematic factors. In most lakes, the general pattern of variability can be related to the directional influence of some physical factor such as wind or temperature, whilst the degree of patchiness generally reflects the behavioural characteristics of the animals concerned.

Figure 12 shows the horizontal distribution of the cladoceran *Daphnia hyalina* var. *lacustris* in Loch Leven, Kinross. The distribution pattern is believed to result from an interaction between the animals' swim-

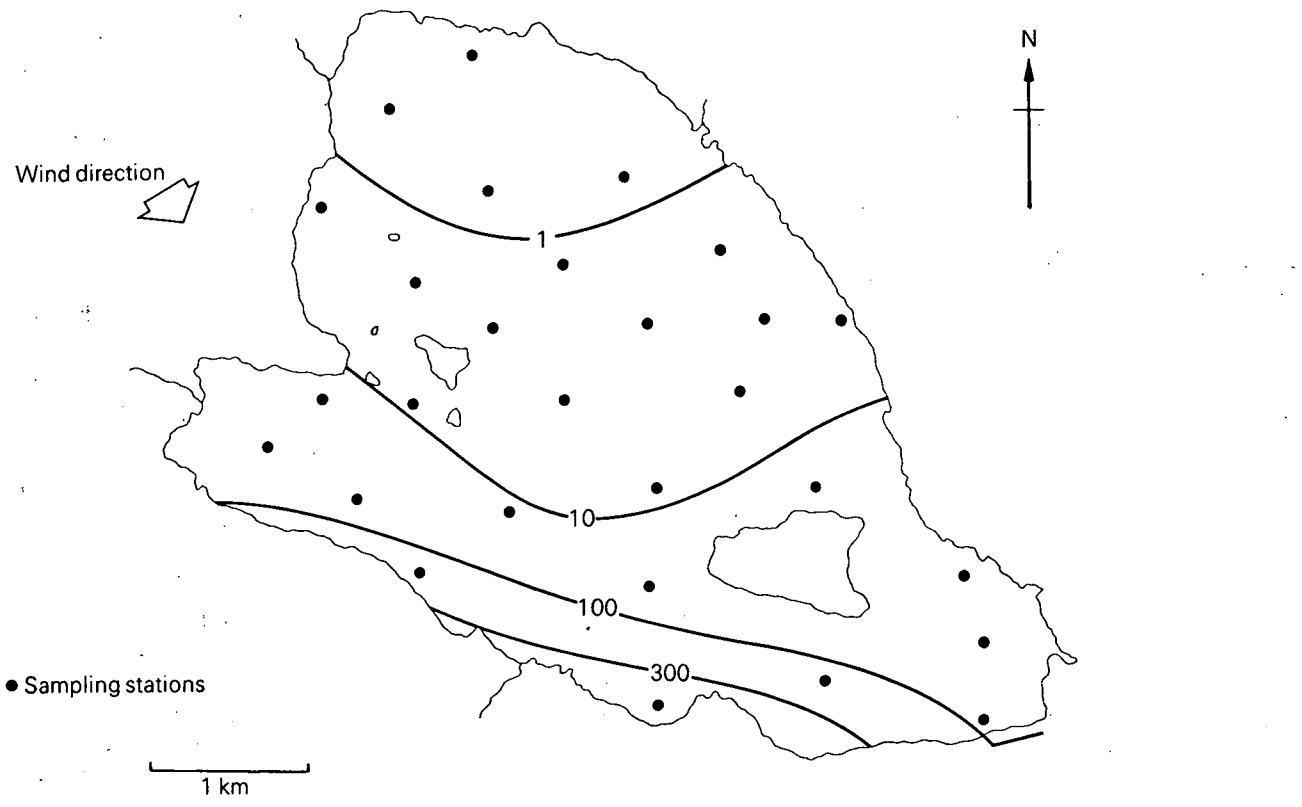
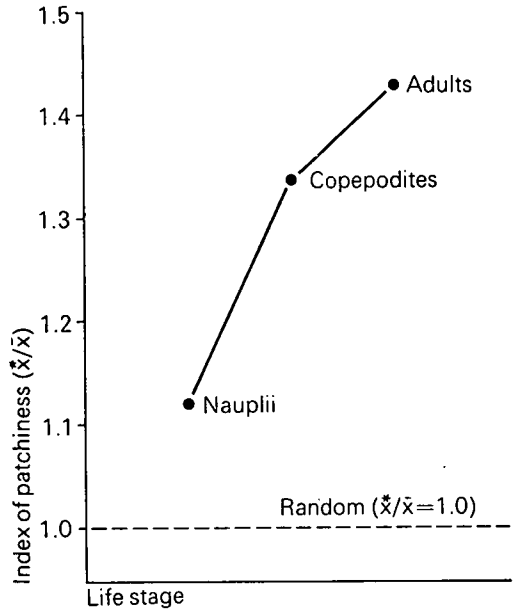


Figure 12 The horizontal distribution of Daphnia hyalina *var.* lacustris *in Loch Leven on 10 June 1976. Surface concentrations Nos/litre*



The estimates of patchiness ($\overset{*}{x}/\bar{x}$) are the mean of ten weekly observations (n=8)

Figure 13 The relationship between age (life-stage) and the development of horizontal aggregations in the copepod Cyclops strenuus abyssorum.

ming behaviour and wind-induced water movements (George and Edwards, 1976). In this example, animals tending to remain high in the water column were transported passively downwind and then became concentrated in areas of downwelling water as they attempted to correct their depth distributions with respect to vertical currents. Previous studies by George (1974) suggest that, in such situations, the degree of horizontal patchiness can be related to the animals' swimming capabilities. A preliminary analysis of Loch Leven data supports this hypothesis and shows that age and swimming ability are important factors influencing spatial patterns in the copepod, *Cyclops strenuus abyssorum*. Using the statistical measure of patchiness ($\overset{*}{x}/\bar{x}$) introduced by Lloyd (1967), the tendency for this species to form horizontal aggregations was found to increase from stage to stage in development (Figure 13). In this notation, $\overset{*}{x}$ (mean crowding) is the average number of other individuals per sample unit per individual and $\bar{x}$ is the mean number of individuals per sampling unit. In a random distribution $\overset{*}{x}/\bar{x}$ = 1·00. The earliest stages (nauplii) were almost homogeneously distributed ($\overset{*}{x}/\bar{x}$ approaching 1·00) whilst adult copepods formed the most intense aggregations both vertically and horizontally.

D.G. George

References

Elliott, J.M. (1971). Some methods for the statistical analysis of samples of benthic invertebrates. *Scient. Publs. Freshwat. biol. Ass.*, **25**, 143 pp.

George, D.G. (1974). Dispersion patterns in the zooplankton populations of a eutrophic reservoir. *J. Anim. Ecol.*, **43**, 537–551.

George, D.G. and Edwards, R.W. (1976). The effect of wind on the distribution of chlorophyll *a* and crustacean plankton in a shallow eutrophic reservoir. *J. appl. Ecol.*, **13**, 667–690.

Lloyd, M. (1967). 'Mean crowding.' *J. Anim. Ecol.*, **36**, 1–30.

Taylor, L.R. (1971). Aggregation as a species characteristic. In: *Statistical Ecology*, ed. by G.P. Patil *et al.* 357–377. Pennsylvania State University Press.

Vertebrate organisms

BREEDING OF OTTERS IN ABERDEENSHIRE

This study aims to obtain information on behaviour and breeding of otters in several places in Scotland. This information is required in order to give advice on the conservation of otters and their habitat. Otters are declining in much of their European range, but still occur widely in Scotland. Our study has started at two adjacent lakes near Aberdeen. Two years' work has been done by a team of one man and one day a week of another man. The plan was to catch otters and mark each animal with a radio transmitter. So far, only one otter has been caught and marked, but it has not yet been traced. Most conclusions come from sightings. Spraints (faeces) are also collected and analysed. These and the secretion of the anal glands (anal jelly) are thought to be used as signals.

The main previous study was in Sweden in 1958–66. Dr S. Erlinge concluded, from tracks, that otters of both sexes had individual territories in his study area, with the territories of one or two females with young within those of the dog, but with family territories separate from each other. Otters bred seasonally, with babies born in spring.

Our conclusions from observations and tracks are different. Since no animals were marked, they depend on a number of assumptions, e.g. that two or more otters seen together in the same place on several days were mother and young or young together, that adults carrying food ashore several times in a short space of time were feeding young, that groups in which one or more followed, or were apparently dependent on the other, were family parties, but that independent individuals in different parts of the lake were probably not a mother and her current family. In our case, baby otters were born in two main seasons, round about May and December. There was no evidence that mothers with young were territorial, as we saw or

suspected two or even three families at once, but the male may have been polygamous, with a group territory.

The story is summarised diagrammatically in Figure 14(a). There are obvious difficulties in interpretation as not all the young may be seen at once and some families may have been larger than we thought.

Small young (B, D, E, H, I, J) were seen or tracked in six periods between February 1975–December 1976. Supposed additional big young were seen in both years in spring and summer (C, F) and another family (G) may have also been present in May–June 1976. In 1975–6, the following families certainly or probably (in brackets) occurred together: B, D, (C); D, E; E, (F); E, (F), (G); E, (F), H; (G), (F), H; H, I; H, J. In addition, we recorded other otters, usually alone, 62 times in 1975 and 79 times in 1976. We identified a presumed dog otter on 28 occasions, including a characteristically white-cheeked animal 14 times. The important points are (a) several dependent and independent otters were sometimes seen at once; (b) there was a rapid succession of family parties; (c) more than one family was apparently often present at the same time. (Family E was born about early December 1975 and a baby, Benjie (Plate 14), was found apparently deserted on 10 January 1976 and brought to the laboratory, where we now have two otters.)

We derived indices of otter activity (Figure 14(b)) from the occurrence of spraints and anal jelly, and from observations. The first two are the numbers recorded on a standard monthly transect, and are not independent measures. The observation index is the proportion (per cent) of observation time in minutes in which otters were seen (discounting observation periods from the middle of the day when otters were unlikely to be seen) multiplied by the number of otters seen. These measures give two independent indices of otter activity, and suggest that otters were more active, and presumably more numerous, in spring than at other times of year at this study area. However, observations are obviously greatly influenced by day length, and we do not know enough about sprainting behaviour for any detailed conclusions.

We are continuing to try to catch otters in order to study their movements by radio-location, and hope to compare breeding and other behaviour in different habitats in Scotland.

D. Jenkins and D. McCowan

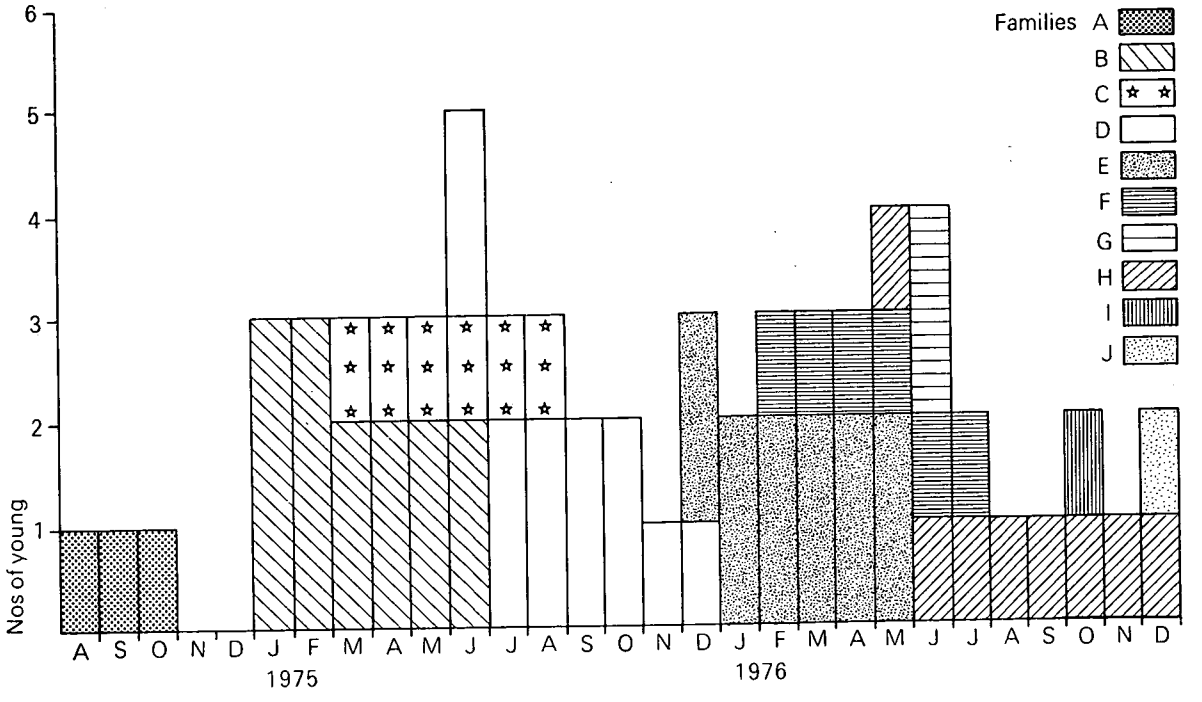


Figure 14(a) Numbers of otter families and numbers reared per family, 1974–76. Note: we do not know when family D decreased from two to one young nor how many young were present initially in most families. Families I and J were recorded only from footprints on 3 days and 2 days. The data for G are speculative and it is shown only in one month, though it may have been present for longer.

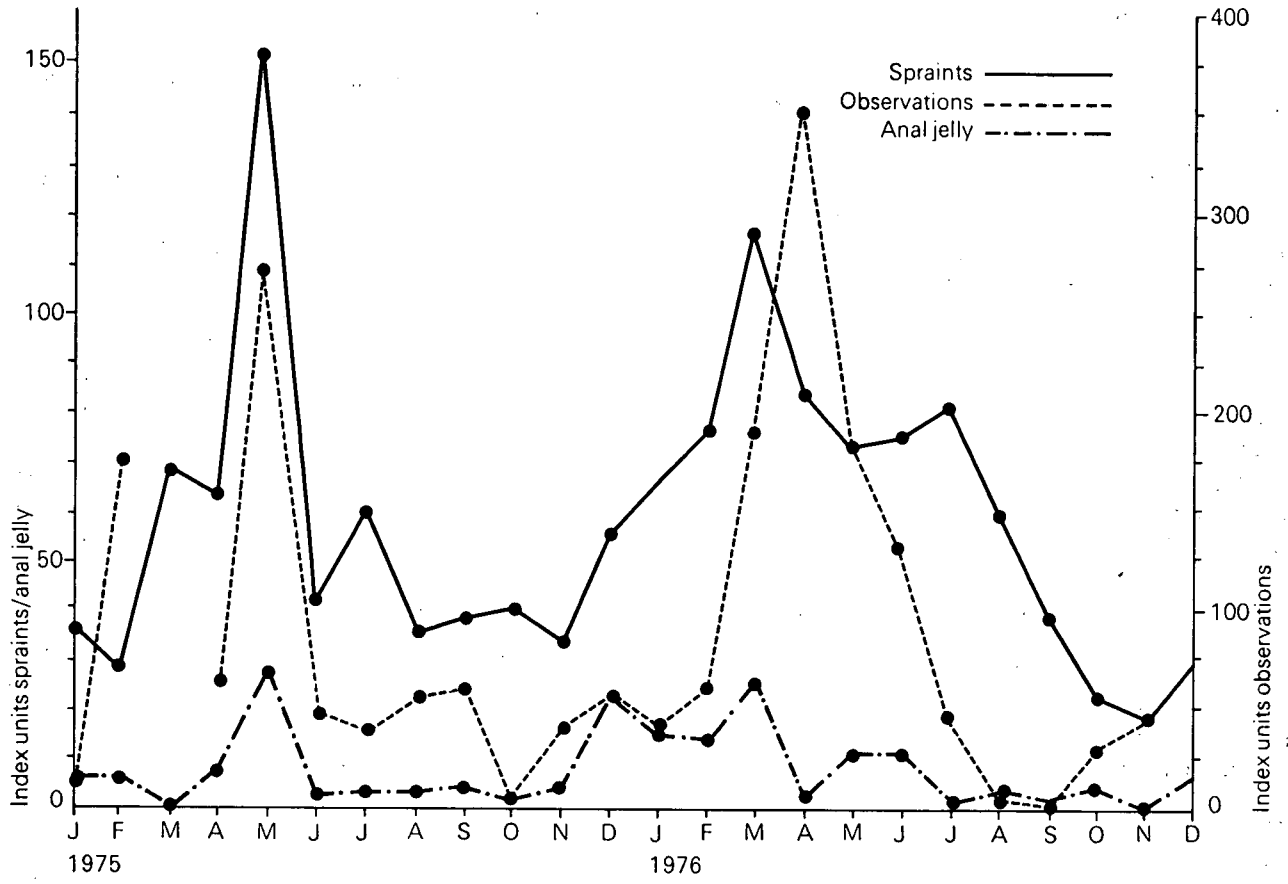


Figure 14(b) Indices of otter activity in 1975 and 1976.

BADGER ECOLOGY IN SCOTLAND

An attempt is being made to understand factors which limit populations of badgers by investigating the badger's food supply in five study areas, and the badger's response to these factors in terms of ranging behaviour, group-size and structure, and other parameters. Factors determining group structure are also being studied in captivity.

The five study areas are situated in north-east, central and north-west Scotland, covering habitats as diverse as heather moorland, conifer plantations and broadleaf woodlands, the latter two mixed with agricultural land. In these areas, the badger's diet has been assessed from bi-monthly faecal samples. These indicate that earthworms are everywhere the most important source of food. Rabbits also are important in two of the study areas, with insects, carrion and vegetable material as subsidiary food. A beginning has been made with an estimate of abundance and availability of these resources, concentrating on the relevant species of earthworm and rabbits. In assessing availability, the badger's foraging methods have to be taken into account; these are being studied by direct observation in the field, using infra-red binoculars, and by observations of badger 'signs' in the vegetation.

Of the many species of earthworm, only *Lumbricus terrestris* and *Lumbricus rubellus* are important, the former in agricultural areas and some woodlands, the latter on more acid soils. These are both surface-feeding worms, and their availability to badgers is largely determined by weather (*L. terrestris*) and dung-deposition by large herbivores (*L. rubellus*). Some of these factors are being studied in further detail.

The badger ranging behaviour is studied with the aid of radio-location; individual animals are followed, at night, and their movements plotted on maps. These investigations are being done in three of the study areas, and will be continued. Large differences are already apparent in the utilisation of different habitats by the badgers; so far, the largest observed range is approximately 1,500 ha, the smallest approximately 50 ha. Usually, badgers operate from a central 'sett', but, in the moorland study areas, animals move daily to a different sett. These differences will be related to

environmental differences. Complementary observations are being made on the group structure in the various areas, numbers of cubs reared, and on territorial behaviour.

In captivity, the social organisation of a small group is studied to obtain ideas about how environmental pressures would be translated into social ones. 'Clans' consist of several individuals, more females than males, and the relation between these individuals is being observed. There is little or no aggression over food, although, in other situations, males tend to dominate females. Physical aggression towards intruders tends to be intra-sexual. Scent communication appears to be very important in this social system and is being studied in detail in collaboration with Dr Gorman of the Department of Zoology, Aberdeen.

H. Kruuk and T. Parish

BREEDING SUCCESS OF SPARROWHAWKS, *ACCIPITER NISUS*

During the year under review, an attempt was made to assess the importance of different factors in relation to the breeding performance of sparrowhawks. The data were from a five-year study, centred on the Annan valley, in southern Scotland.

All aspects of breeding were better on low mixed farmland (on productive land) than on upland sheep range or plantation forest (on less productive land). This was shown by the generally greater occupation of territories on farmland, earlier egg-laying dates, larger brood-sizes, faster growth of young, and by the greater proportion of nests that were successful.

Occupation of territories was also independently correlated with tree species. Territories in pine were used most often, followed, in order, by those in larch, spruce and then broadleaved trees. Breeding performance was also generally better in the favoured tree species. In addition, the proportion of nests that produced young increased with the greater amounts of cover on the territory; this increase was due partly to lessened predation on the eggs and young in the thicker territories.

Although sparrowhawks were restricted to woodland for nesting (but not for hunting), some aspects of their breeding deteriorated with increase in the amount of woodland around the nesting territory. In other words, the birds bred better in small woods in open areas than in large unbroken forests. This trend held on both low ground and on high ground.

Yearling females had smaller clutches and broods than did older ones; their nests were less often successful, and their young grew less well.

Organo-chlorine residues were studied in sparrowhawk eggs. These included the residues of certain insecticides used in agriculture, and of polychlorinated biphenyls (PCBs) used in certain industrial products. The failure of some sparrowhawk nests throughout the population was associated with high levels of DDE and PCB in eggs. The amount of shell-thinning was highly correlated with DDE concentrations.

Different aspects of breeding performance were most closely related to different factors. Occupation of territories was more closely linked with tree species than with any other factor; laying dates and nestling growth rates were associated most strongly with surrounding land-use and productivity; clutch and brood-sizes were related most closely to age of female; while success or failure of the nest was associated both with environmental factors (especially thickness of cover on territories) and with organochlorine levels in eggs, and with the extent of shell-thinning. This study has enabled us to define precisely the kinds of environment in which sparrowhawks breed best, and to assess the role of organochlorine compounds in relation to other factors in reducing breeding success.

I. Newton and M. Marquiss

HEN HARRIERS IN ORKNEY

Among raptors, bigamy has been recorded occasionally for several species, but only the harriers regularly exhibit polygyny (i.e. one male mating with several females). It is unlikely that this characteristic is anywhere more marked than among the hen harriers in Orkney where most, if not all, adult males are at least bigamous in the spring. In 1975 and 1976, a study was undertaken of the social behaviour of birds in polygynous groups. It now seems clear that females defend a small territory around their nest site on the moorland, and that males defend a larger territory which encompasses those of his females. However, both sexes hunt over very extensive home ranges which include moorland, arable land and poorly drained, low-lying, marshy ground.

Within each polygynous group, the females which laid earliest were those most often seen in company with the male and, in two of the three groups studied in detail, the most dominant prior to laying. These females tended to rear more young than those which laid later, presumably because the male was more likely to assist with rearing them.

The reasons for polygyny in the harrier are not yet clear. Although equal numbers of young males and females fledge each year, many more females than males are seen in spring. There may be a real shortage of males, as a territorial male removed for six days in April 1976 was not replaced, while a territorial female removed for three days was replaced immediately. Females, apparently still prospecting for territories, were seen regularly in late spring, but no surplus adult males were seen. However, apparently surplus sub-adult, first-year males were present. Another possibility to account for the unequal sex rate is that polygyny has developed in response to a rich food supply in Orkney. In the eastern Highlands of the Scottish mainland, where harriers hunted mainly over poor heather moorland, the density of males was similar to that in Orkney, but most matings were monogamous.

Future work will attempt to distinguish between these two possible explanations for polygyny and to investigate the advantages of polygyny to the individual females.

N. Picozzi

OYSTERCATCHERS AND MUSSELS ON THE EXE ESTUARY

This is a joint project between members of the Subdivisions of Vertebrate and Invertebrate Ecology. Its primary aim is to investigate the extent to which predation by oystercatchers affects the abundance of the shellfish and how this, in turn, influences the feeding behaviour, and perhaps numbers, of the oystercatchers themselves. It is hoped that the project will not only contribute to our understanding of predator-prey interactions in general, but will also help solve some important practical problems involving these species. First, it should provide a better understanding of the role which these birds play in the population dynamics of commercially exploited shellfish populations. Second, by studying the factors and processes which determine the numbers of oystercatchers that use the Exe, it should be possible to predict more accurately than at present whether or not the area has spare capacity to support birds displaced by any of the major development schemes (e.g. barrages or bunded reservoirs for storing freshwater) that have been proposed for estuaries in the north.

Pilot studies began on the Exe during the autumn of 1975 and soon revealed that the area had good potential for the proposed project. From the point of view of studying both oystercatchers and mussels, it provides a convenient-sized estuary which is topographically isolated from other similar habitats so that the populations being studied are relatively easy to define. Although not fished extensively at present, many of the mussel beds were seeded by fishermen in earlier years and now form reasonably discrete patches of mussels. Thirty-one beds have been identified which between them give a wide range in both mussel density and size composition. The situation thus provides a good opportunity for studying the spatial, seasonal and annual variations in the survival, reproduction and growth of contrasting patches of mussels which, in total, constitute the whole population. Similarly, it provides a good opportunity for recording the responses of the oystercatchers, in terms of their density, diet, food intake and social behaviour, to these variations within the mussel population during one year and to the whole population in different years. It is intended to describe these responses mathematically and construct a model of the birds' predation on the mussels so that simulation experiments can be performed and understanding advanced.

The pilot studies also revealed that the area has many practical advantages, mainly because it is relatively small, gives reasonably easy access to many of the mussel beds, and enables some of the observations on the birds to be done from the shore. Hence, little time is wasted getting to the study areas and, furthermore, the birds need not be disturbed when being watched.

Routine collection of data began in July 1976, just before birds began to arrive from the breeding grounds. Frequent counts were made of the oystercatchers on each part of the estuary, and a comparison between the totals obtained from the whole estuary with counts made of birds roosting at high water suggests that a high degree of accuracy is being obtained. At the same time, studies of feeding and social behaviour have been started. The mussels on each bed were sampled during September and the area of each bed determined. This work constitutes the first of a series of bi-annual surveys which will yield the main data on the mussel population and provide the basis for detailed studies on selected areas in the future.

J.D. Goss–Custard and S. McGrorty

Invertebrate organisms

BIRDS AND THE SPREAD OF NUCLEAR POLYHEDROSIS VIRUS DISEASE OF EUROPEAN SPRUCE SAWFLY

There had been virtually no instances of the European spruce sawfly, *Gilpinia hercyniae* (Hartig), being a pest in Britain until 1968, when an area of spruce forest in mid-Wales became defoliated. In 1970, the Forestry Commission requested the assistance of the NERC Unit of Invertebrate Virology (UIV) in introducing the

Plate 11 (a) The leading edge of a stand of Rhododendron ponticum *invading the open dunes at Winterton, Norfolk, its rate of spread having increased greatly since the reduction in rabbit numbers following the outbreak of myxomatosis in 1954.*

(b) Young plants of Rhododendron *at Winterton, Norfolk. Although still small, these 'seedlings' are probably over five years old. Rates of growth would be expected to increase appreciably at a later stage. Photographs L.A. Boorman.*

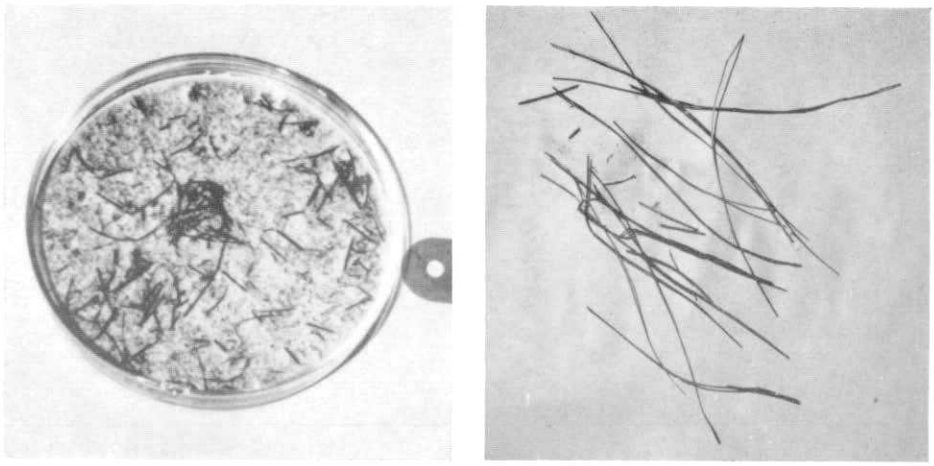


Plate 12 Condition of litter samples on retrieval after 7 years on a blanket bog. Eriophorum *(a) well decomposed sample; (b) poorly decomposed sample. Photographs P.M. Latter.*

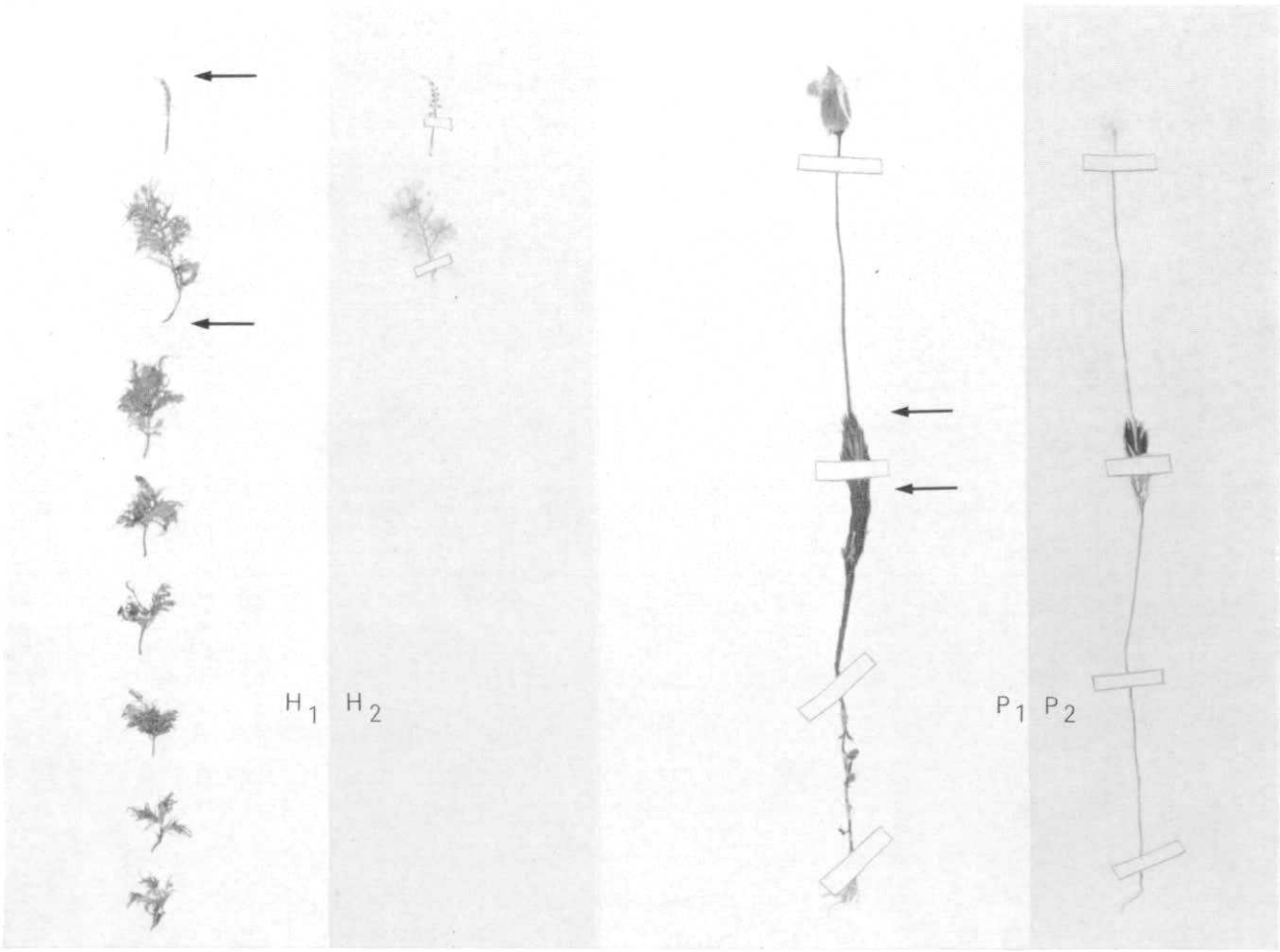


Plate 13 Photographs (H_1 and P_1) and auto-radiographs (H_2 and P_2) of a shoot of Hylocomium splendens *(H_1 and H_2) and a fruiting-shoot of* Polytrichum commune. *The arrows on the photograph delimit zones 'fed' carbon-14; the autoradiographs show the subsequent distribution of carbon-14 which did not move in* H. splendens *but spread to the sporophyte and underground shoot of* P. commune. *Photograph T.V. Callaghan and N.J. Collins.*

nuclear polyhedrosis virus (NPV) which had successfully controlled the sawfly in Canada. UIV showed that an NPV disease was already present, and, following the discovery of NPV in bird droppings, invited ITE to assist in assessing the importance of birds in dispersing the virus. This was attempted during 1975–6, by determining whether NPV could be detected in sawfly or in birds in an area with sawfly and no virus, but into which the virus might be expected to spread during 1975.

UIV's 1974 survey of sawfly and virus distribution identified a suitable study area (Figure 15) in north Rheidol forest and south Dyfi-Corris forest (Plate 15(b)). Four sampling sites were selected: a 'source', containing both sawfly and virus, and three 'targets', containing sawfly only. The latter were 3km (A), 5km (B) and 10km (C) from the 'source' respectively.

The sawfly larvae (Plate 15(a)) were sampled during their feeding season, June to September, by beating trees at each site. A mid-gut smear of each larva was made and examined microscopically for virus polyhedra. Two infected larvae were found at the 'source' (7% of larvae collected), 'target A' (29%) and 'target C' (11%). No infected larvae were collected at 'target B'.

Bird droppings were collected from June to October by mist-netting at the 'target' sites and retaining each bird in a sterile cloth bag for 30 min. Four birds were netted in 'target A', 14 in 'target B' and 5 in 'target C'. Gut contents were obtained from 19 birds shot in winter in 'target C'. UIV tested the samples microscopically and by bioassay for NPV: none was found.

The presence of virus in areas thought to be uninfected does not necessarily suggest that NPV had spread. As UIV's annual surveys investigated the distribution over 18,000 ha whereas the present study examined selected areas in detail, it is more likely that, as in Canada where NPV could rarely be demonstrated at low sawfly densities, undetected virus was present throughout most of the sawfly's distribution.

The identification of NPV in *Gilpinia* larvae but not in birds suggests that the latter were not of prime importance in virus dispersal, and this is supported by the netting results. These indicated that the bird population was static during the larval season.

Virus transmission by birds would be particularly affected by the availability of alternative food. Of a sample of 212 invertebrates collected at the 'source' during July, only four were *Gilpinia hercyniae* larvae; a very small proportion of the available food. The solitariness of the larvae, and the small proportion infected with virus, makes the possibility of birds feeding heavily on infected larvae extremely low.

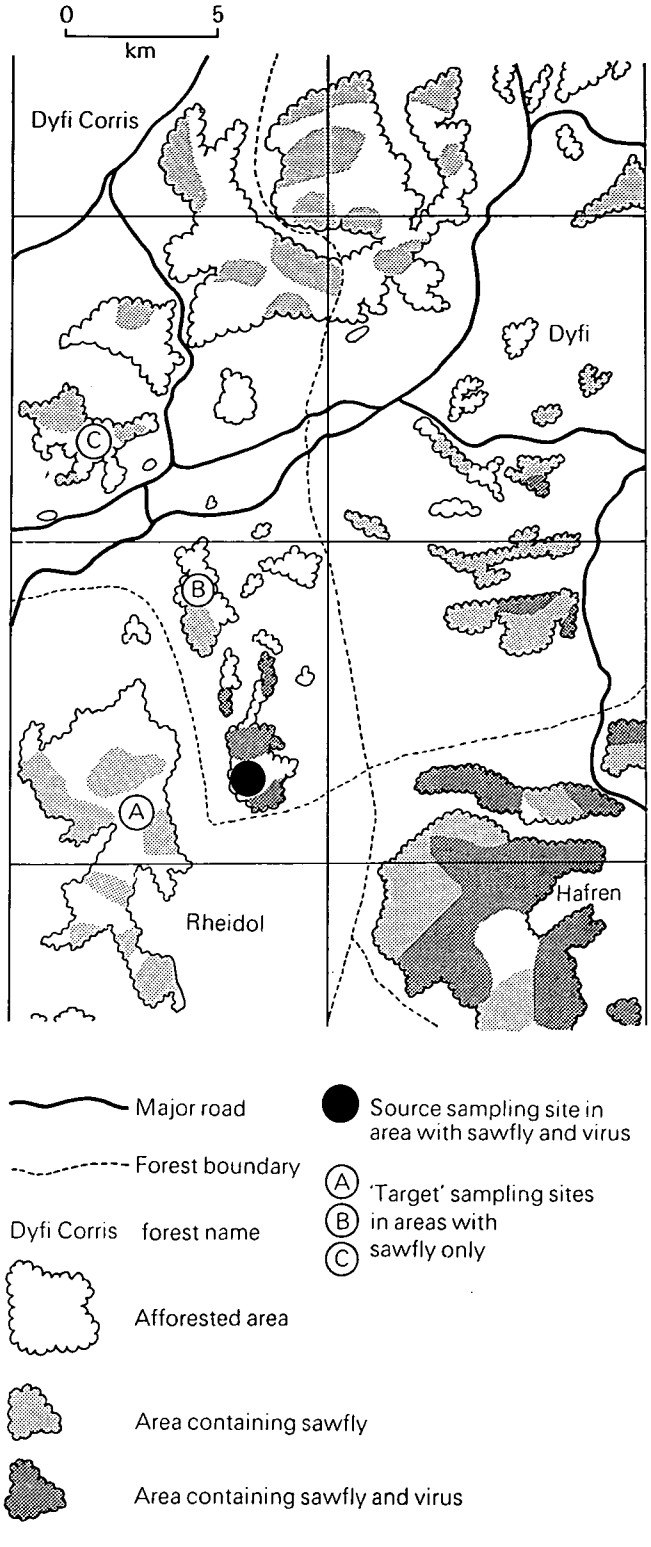


Figure 15 The study area in the mid-Wales forests, showing the distribution of sawfly and virus in 1974 (based on results of Unit of Invertebrate Virology surveys) and the sampling sites.

It is clear that droppings containing NPV can infect larvae in laboratory situations (Entwistle *et al.*, in press). In the field, however, it has yet to be shown that droppings are deposited in a suitable form, quantity or location, to make transmission to other larvae likely.

It seems more likely that the most important means of dispersal of NPV is by adult sawflies themselves. In Canada, it has been shown that transmission between generations was by foliage contamination by diseased or externally contaminated adults; 72% of the subsequent offspring became infected (Neilson and Elgee, 1968). This mode of transmission would account for the persistence of virus at low host densities when there must be virtually no chance of contact with infected bird droppings.

A. Buse

References

Entwistle, P.F., Adams, P.H.W. and Evans, H.F. (In press). Epizootiology of a nuclear polyhedrosis virus in European spruce sawfly *Gilpinia hercyniae*. I. The status of birds as dispersal agents of the virus during the larval season. *J. invertebr. Pathol.*

Neilson, M.M. and Elgee, D.E. (1968). The method and role of vertical transmission of a nucleopolyhedrosis virus in the European spruce sawfly, *Diprion hercyniae*. *J. invertebr. Pathol.*, **12**, 132–139.

VEGETATION, ANTS AND SOIL

The Porton Ranges in Wiltshire, with shallow humose calcareous soils of the Rendzina sub-group, in the Icknield series, are part of an important area of semi-natural grassland. In them, the boundaries of sharply contrasting grassland types mark the limits of cultivation abandoned 30 to 150+ years ago (Wells *et al.*, 1976).

Typically, soils are seen to influence plant assemblages, but, at Porton, the reverse applies—plants and associated soil fauna modified soil characteristics, the magnitude of effects depending on the interval between now and when arable cultivations ceased. Starting at a 'baseline' of 6·4% organic matter it seems that there are additions of about 0·08% for each year since the last season of cultivation. Thus, soils had 8·0 and 19·0% (by weight) of organic matter where the last cultivations were 30 and 150 years ago respectively.

Rabbits have been important at Porton, but, at present, the mound-forming ant, *Lasius flavus*, seems of greater significance. Ant-mound soils contain more exchangeable potassium than occurs generally in the locality. Ants also seem to affect physical properties of soils. Thus, 85% of soil particles in ant-mounds are $< 0{\cdot}5$ mm and $5\% > 1$ mm compared with 15% and 70% in the general soil. It is estimated in areas with many ant-mounds that the soil used in their construction would, if evenly spread, give a stoneless layer of fine soil about 2 cm thick. Additionally, ants affect soil below ground, influencing soil moisture, temperatures and amounts of nutrient which in turn influence plant assemblages.

D.F. Ball

Reference

Wells, T.C.E., Sheail, J., Ball, D.F. and Ward, L.K. (1976). Ecological studies on the Porton Ranges: relationships between vegetation, soils and land-use history. *J. Ecol.*, **64**, 589–626.

MICROGYNES, SOCIAL PARASITISM, KIN SELECTION: AN ELECTROPHORETIC INVESTIGATION

The resolution of isoenzymes electrophoretically and the subsequent clarification of the genetic basis of many of these isoenzyme systems have presented the population geneticist with a hitherto untapped source of genetic variability. This technique has been applied widely in ecological genetics relating organisms to habitat, in a manner facilitating a more sophisticated understanding of the processes of natural selection, itself a consequence of this interaction, and linking ecology more closely to a central theme of biology—namely the theory of evolution.

Social insects are of particular interest genetically. Potentially, selection on different castes provides unique opportunities for genetic innovation. The origin of altruism in these insects has remained one of the paradoxes of evolution. W.D. Hamilton's theory of kin selection (Hamilton, 1972) has provided a theoretical resolution of this paradox; isoenzyme investigations applied to social insect populations may produce evidence to test the theory. For these reasons an investigation of the distribution of a co-dominant diallelic esterase system (the alleles were named S and F) in the ant, *Myrmica rubra* (L.), was initiated, with particular reference to the occurrence of an unusual variant—a miniature queen (microgyne). The origin and function of this phylogenetically-widespread social insect morph is obscure; however, the results of other research (Elmes, 1976) suggest that it is genetically determined, and an association between microgyny and social parasitism has also been indicated (e.g. Hamilton, 1972). The present investigation has provided support for the proposed genetic origin of microgynes. It has also shown that microgynes probably play a dominant role in nest gyne and male production, whilst seeming to rely on the normal (macrogyne) form to produce the colony workers. This is typical of the behaviour associated with social parasites. These conclusions are based on the close linkage between the microgyne determinant and the

S allele; the evidence further implies that the genetic factor determining microgynes is dominant. In most of the microgyne-producing nests investigated, the microgyne and macrogyne appeared to maintain separate genetic integrities; however, in two out of a total of eleven nests interbreeding was taking place. Unfortunately, the total of six microgynes sampled from these nests was too small to determine whether the microgyne component results from random matings; but, on the evidence, free interbreeding seems probable.

No explanation is forthcoming so far for this curious switch in breeding behaviour. Microgynes and macrogynes appear to behave as a separate species in most of the nests investigated, but, where interbreeding occurs, their behaviour is more akin to components of a genetic polymorphism. This raises the intriguing possibility of sympatric speciation—a possibility of great significance in the context of the evolution of social parasites.

The distribution of esterase alleles has also demonstrated differences in the breeding structure of nest populations of the normal (macrogyne) form of *M. rubra* in different localities. Interbreeding between nests seems to be dependent upon the distribution of stones, whose heat storage properties render them attractive as nest centres. However, inbreeding appears to occur even when the distance between nest centres ensures that they are still well within range of nuptial swarms emanating from any neighbouring nests. Estimates of the interbreeding index in an inbred nest population, when related to the ratio of investment in nest gyne and male production, should provide a test of one of the predictions based on the theory of kin selection.

With regard to the neutrality or adaptiveness of these alleles, a correlation between allele frequency and temperature has led to the initiation of an experimental investigation into the nature of this association. It is hoped that this aspect of the investigation will lead to an understanding of the origin of these alleles, the factors maintaining the esterase polymorphism, and any linkage of the S allele with the microgyne-determining factor.

B. Pearson

References

Elmes, G.W. (1976). Some observations on the microgyne form of *M. rubra* L. *Insectes soc.*, **23**, 3–22.

Hamilton, W.D. (1972). Altruism and related phenomena mainly in social insects. *Ann. Rev. Ecol. & Syst.*, **3**, 193–232.

AN ANALYSIS OF THE SPIDER FAUNA OF THE EAST ANGLIAN WETLANDS

East Anglia (here defined as Norfolk, Suffolk and the Breck/Fen margin part of Cambridgeshire) probably has the widest range, and greatest number, of wetlands of any region of comparable size in Britain. Its scientific and conservation interest is therefore of the highest order. Most sites are of small size and a few have been almost entirely lost through reclamation during the last thirty years. Of those which survive, nearly all have been modified or changed in some way by human interference.

From 1969–74, a party of 8–10 arachnologists visited 53 sites where areas of herbaceous fen were selected for study. Each participant collected by hand for a period of 1 h taking all the spiders seen in the ground and field layer vegetation. If a second collection of 1 h was made it was bottled separately. The number of hourly collections per site varied from 8 to 13 and the final figures were adjusted to give a mean of 10 h collecting for each. The collecting periods were in June for 1969 and 1974 and in September for 1970, 1971, 1972.

Objectives

(1) To map the distribution of spider species in ground and field layer herbaceous vegetation in 53 wetland sites in East Anglia.

(2) To record the relative abundance of the species on each site by a quantitative method of hand collecting so that a comparison could be made by statistical analysis of the fauna between sites and between groups of sites.

(3) To relate, where possible, faunal differences to variation in vegetation and habitat characteristics.

(4) To assess the degree of disturbance to each site from documentary evidence of past land use and to investigate the effect of this on the spider fauna.

The study area

The wetlands selected for study can be grouped in 4 main geographical regions:

(a) Norfolk Broads. These are extensive eutrophic valley mires in wide flat marshlands of four main rivers. The ground is permanently waterlogged with extensive reed and sedge beds. More acid substrates with a vegetation of *Sphagnum* spp., *Salix repens, Myrica gale, Menyanthes*, etc., are developed locally.

(b) East Suffolk Broads. This is a less extensive group of eutrophic valley mires, some brackish, mostly waterlogged, lacking the floristic variety of the Norfolk

Broads but also characterised by extensive reed beds. Two of the largest areas, Minsmere and Walberswick Marshes date from about 1940. Before that date, they were managed as drained grazing meadows, a use which has probably been maintained for a very long period.

(c) Breckland Fens. These form a very varied series of small sites including valley mires, basin mires and isolated meres with fringing marsh. Most are relics of larger areas which have been, in part, reclaimed and drained. Many are dominated by *Carex* with *Carex paniculata* the most characteristic species. Floristically rich, the sites are more mesotrophic than the Norfolk Broads or East Suffolk Broads, without extensive reed beds, and often become dry in the summer.

(d) North Norfolk. Here, the widely scattered sites are isolated, often spring-fed from acid sands, and vary from oligotrophic to mesotrophic. The vegetation is generally shorter and of bog or acid fen type. Several are of ancient origin and have probably escaped major changes in land use because of poor agricultural quality. The water table is low in summer.

The four groups differ in type of vegetation, geographical location, size, degree of isolation of component sites and in land-use history. Groups 1 and 2 are more similar in type of vegetation while groups 3 and 4 have distinctive flora and a higher proportion of sites isolated from their nearest neighbours.

Group and site relationships

An analysis of the collections from all 53 sites, using presence/absence of species and numerical abundance, was made by an ordination of the data using the method of reciprocal averaging (Hill, 1973). The ordination (Figure 16) shows a clear separation between the Norfolk and Suffolk Broads above the broken diagonal line and the North Norfolk and Breckland sites below the line. The vegetation and water régime differences, described above, probably account for much of this primary separation.

Nevertheless, differences between the groups of each pair are indicated by the aggregation of the symbols to specific areas of the ordination diagram. The placing of sites in the 'wrong' group e.g. 14, 36, 37, 8 and 51

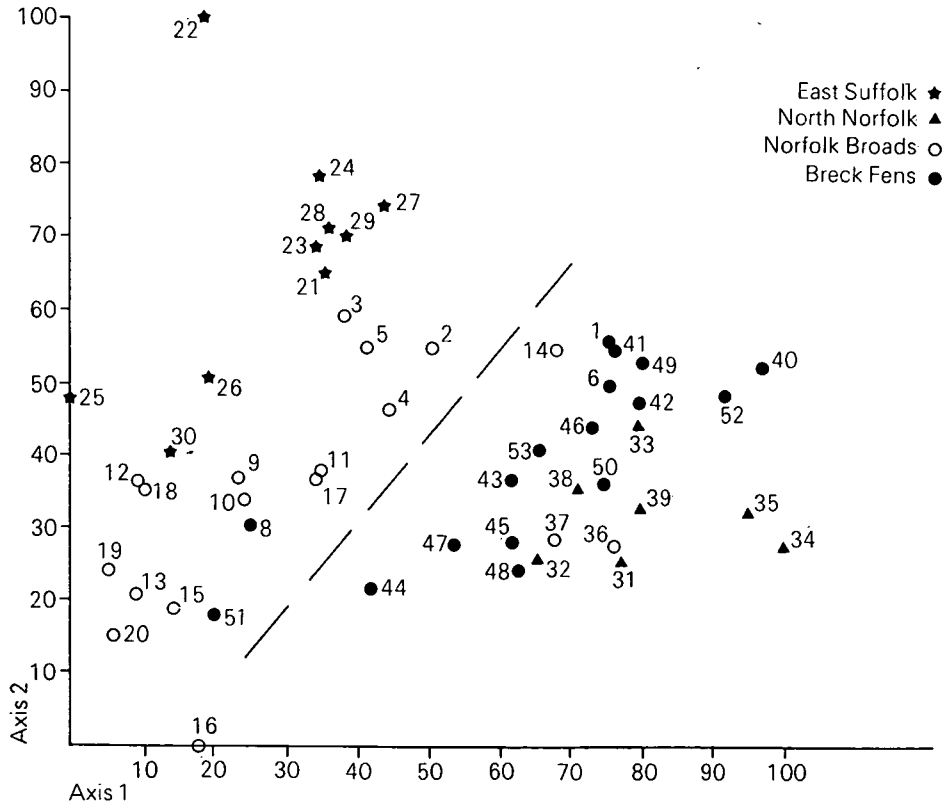


Figure 16 Ordination of East Anglian wetlands. Results from site 7 proved to be statistically aberrant and were ommitted.

and the wide spread within groups, e.g. 22 and 30, 14 and 16, can be shown to be due mainly to vegetation characteristics. For example, within the East Suffolk group, site 30 is a brackish marsh influenced by the tides, while site 22 is a localised development of birch carr with a ground vegetation of *Sphagnum* spp. and *Molinia*. On the other hand, site 14 consists of relatively dry birch carr with *Rhododendron, Sphagnum* spp. and grasses, and thus is superficially similar to site 22, although it has a markedly different fauna. Sites 14 and 16 within the Norfolk Broads are both mesotrophic, but the *Betula/Sphagnum* carr of the former contrast with the open mixed sedge fen of the latter with *Molinia, Schoenus, Juncus* spp., *Carex* spp., *Peucedanum*, mosses etc. Further examination of the ordination diagram shows that wide geographical separation of vegetationally similar sites may result in different fauna while the converse may also be true, that is, vegetationally different sites, if situated close together, may have similar fauna.

Effect of past land use on the fauna

An attempt was made to produce an 'impact assessment' value for those sites for which documentary evidence was available on frequency and extent of past modification and disturbance. Historical studies showed that the most consistent interference factors were grazing, turf-cutting, burning, cutting woody growth for fuel and drainage work. Of these, the last was undoubtedly the most important, because it not only changed the vegetation but also made possible numerous other activities including attempts at cultivation, increased grazing, more serious burns when there were fires, and greater public access. A preliminary analysis using presence/absence and numerical abundance of the collections from 11 Breckland sites by means of a numerical taxonomy technique, to show relationships in a dendogram, produced two main groups, valley fens (7) and isolated fens (4) (Duffey, 1974). The former subdivided into three species-poor sites (high degree of interference and modification) and four species-rich sites (no major change in land-use). A further indication of the influence of past land use can be obtained from the distribution of rare species.

Table 5 Number of rare species (out of 17) and total species recorded for each group of sites

	Breckland	Norfolk Broads	North Norfolk	East Suffolk
Number of national rarities recorded (out of 17)	13 (7)*	8 (3)*	3	3
Total species recorded	136	112	108	121

* Figures in parentheses are the numbers of nationally rare species recorded in that group and not elsewhere in the East Anglian study area.

The relationships between sites as shown in the ordination (Figure 16) are based mainly on the more common species which account for the greater part of each collection. However, it was possible to identify 17 species which would be regarded as national rarities out of the 226 recorded from the 53 sites. The distribution of these in relation to the four groups of sites (Table 5) shows a strong bias in favour of the Breck fens, although the total species recorded per group fails to show the special interest of this group of sites.

Further investigation of the data is being made using the indicator species analysis of Hill, Bunce and Shaw (1975) in which the divisions in the hierarchy are made on the basis of several species instead of only one.

E. Duffey

References

Duffey, E. (1974). *Nature reserves and wildlife.* London: Heinemann.

Hill, M.O. (1973). Reciprocal averaging: an eigenvector method of ordination. *J. Ecol.*, **61**, 239–251.

Hill, M.O., Bunce, R.G.H. and Shaw, M.W. (1975). Indicator species analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. *J. Ecol.*, **63**, 597–613.

Effects of pollutants

FLUORINE IN THE ECOSYSTEM

(This work is partly supported by the Welsh Office)

Gaseous and particulate forms of pollutant fluorine are emitted to the atmosphere from several sources, including aluminium smelters, and brick and ceramics works. Although they are known to (i) damage some plants at low ambient air concentrations, and (ii) cause, in some highly contaminated areas, fluorosis in animals, much remains to be learnt of the ultimate fate of the bulk of fluorine pollutants.

Most fluorine is absorbed from the atmosphere by rain or deposited dry on a variety of surfaces. However, in a grassland ecosystem, uptake from soil through roots should not be overlooked. Fluorine occurs in apatite minerals which are the primary carriers of soil phosphorus. Apatite is slow to solubilise in soils; our knowledge of its fluorine release, however, is far from complete. In addition to the apatite component, soil fluorine is augmented by gaseous fluorine, insoluble particulates, soluble forms in rainfall and plant leach-

ates, and plant and animal litters. Although its uptake from soil has been regarded as being small and unimportant, experiments with plants grown in culture-solutions suggest that fluorine is not selectively rejected by roots.

Preliminary results from a pathway study of a grassland ecosystem, subject to considerable pollution, indicate that fluorine accumulates in dead plant material and is subsequently found in litter (Figure 17). Whereas plant samples from uncontaminated areas usually contained less than 15 $\mu g\,F^{-}g^{-1}$, mean concentrations of 267 $\mu g\,F^{-}g^{-1}$ were found in live foliage from contaminated areas with 448 $\mu g\,F^{-}g^{-1}$ in roots, 405 $\mu g\,F^{-}g^{-1}$ in standing dead (that still attached to live plants) and 466 $\mu g\,F^{-}g^{-1}$ in litter. These data indicate a large flow of fluorine to the decomposer components.

The present study, in an area where fluorine is the main pollutant, is not restricted to a study of pathways. It is also concerned with effects, and the mechanism of effects, at the cellular and individual plant levels of organisation, always remembering that they may be appreciably influenced by small amounts of other pollutants.

D.F. Perkins and V. Jones

FATE AND EFFECTS OF AIRBORNE SULPHUR POLLUTANTS

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

To improve the interpretation of the direct and indirect effects of sulphur and sulphur-derived pollutants (cf. acid precipitation), particularly in rural environments, an intensive site is being developed in Greskine Forest, Central Scotland, with the co-operation of the Forestry Commission and the Warren Spring Laboratory.

This site is being developed for numerous purposes. Amounts of atmospheric SO_2, NO_x and O_3 will be measured with sufficient sensitivity to allow the construction of diurnal, weekly and seasonal patterns of changing concentrations, information that will enable controlled fumigation experiments being done by colleagues in different universities, notably Imperial College, London, and UWIST, Cardiff, to be attuned to realistically fluctuating concentrations. Increasingly, it is being appreciated that one pollutant should not be considered without noting the presence of others which may increase synergistically amounts of damage. The equipment at Greskine should provide continuous records that will enable a detailed consideration of the possible interplay between pollutants.

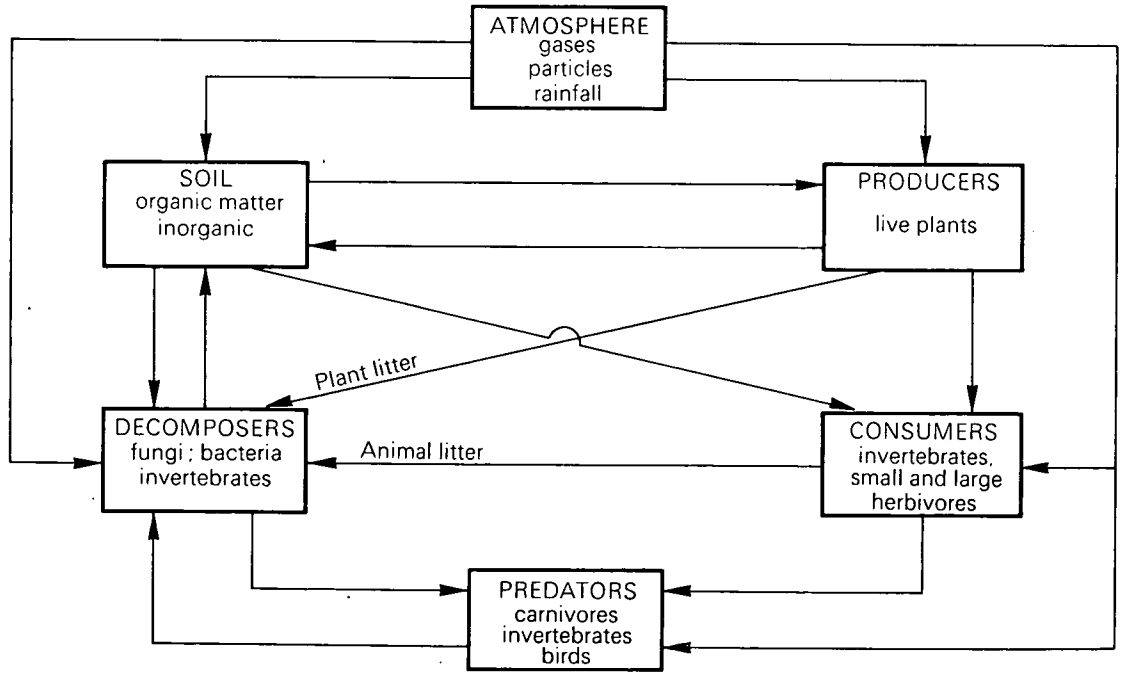


Figure 17 Some of the possible pathways of atmospheric pollutant fluorine through the main components of a grassland ecosystem.

Knowing the atmospheric loads of pollutants, it is then necessary to understand how they are transferred and distributed within forest ecosystems. There are many facets to this exercise–transfers to vegetation, to soil directly or via plants as intermediaries, remembering that much of the rural load of 'sulphur' occurs as sulphate which influences the acidity of rain (acid precipitation). Transfers to trees were studied by analysing sulphur superficially deposited on, and contained within, foliage and bark of ash, *Fraxinus excelsior*, and birch, *Betula pubescens*, and two evergreen species, holly, *Ilex aquifolium*, and Scots pine, *Pinus sylvestris*, growing in zones with mean winter SO_2 concentrations of less than 50, 90–149 and 150 $\mu g\,m^{-3}$. It seems that the superficial deposits, which were greatest on Scots pine, were not related simply to mean atmospheric concentrations of SO_2. In contrast, amounts of sulphur found within leaves were directly related to atmospheric concentrations, the relation being particularly exact for ash and birch in summer.

Much needs to be done before these relationships are understood. At present, the team is focusing on the link between atmospheric concentrations and amounts of dry deposition, a study including deposition to the differing vegetational layers of a forest ecosystem.

Preliminary studies of throughfall indicate that amounts of sulphur are three times greater than in rain (precipitation) collected over open ground. These observations, made with nine tree species including ash, *Fraxinus excelsior*, Norway spruce, *Picea abies*, oak, *Quercus robur*, and Scots pine, *Pinus sylvestris*, will be extended and augmented by a network of sites, distributed in Scotland and Northumberland. At these sites, two of which are already operative, precipitation will be collected over open ground and subsequently analysed, in the first place concentrating on pH and amounts of sulphate.

The differing aspects of pollution research mentioned in this report are parts of a phased project ultimately aiming to examine effects on soil processes and their consequences for terrestrial, and, through run-off and drainage, aquatic ecosystems.

During 1976, a review entitled 'The sulphur cycle in relation to pollution effects with special reference to forest conditions' was completed.

I.A. Nicholson, D. Fowler, J.W. Kinnaird and I.S. Paterson

DO SEABIRDS INACTIVATE POISONOUS METALS?

It became evident during the late 1960s that many species of sea birds, which spend much of the year on the open ocean away from land, carried very high loads of heavy metals, including cadmium, compared with the loads present in land birds. Two questions were then asked: 'Are the oceans being polluted by industrial cadmium waste as a result of discharge into the atmosphere or rivers?' and 'Is this metal a threat to the survival of seabirds?' The next report is in answer to the first question, while this report suggests a possible answer to the second.

A specific protein which binds heavy metals exists in many animals. This special protein, called metallothionein, has a number of unusual properties which distinguish it from other proteins; it has a high content of sulphur amino acids, very few, if any, aromatic amino acids, and it absorbs ultraviolet light at a wavelength of 250 nm. Metallothionein binds essential heavy metals such as zinc (needed for normal metabolism) and foreign metals, like cadmium, which are not normal constituents of animal cells, and which are generally poisons. As a general rule, if a poison can be tightly bound to some structure in the body its harmful properties are likely to be reduced, because the binding at specific sites reduces the concentration of the metal in tissues that might otherwise be damaged. It has been suggested that metallothionein may provide such a 'safe' storage site.

In the summer of 1976, a range of auks, petrels and shearwaters was collected from St Kilda, a remote island 50 miles west of the Outer Hebrides, and found to contain up to 240 $mg\,kg^{-1}$ dry weight of cadmium in the kidney. This level would normally be considered toxic in other animals. However, all these birds were apparently healthy and many were breeding. When the proteins of the fluid portion of the liver and kidney cells were fractionated according to their molecular weights, much of the cadmium was found to be bound to a protein having the characteristics of metallothionein. The fractions concerned contained much sulphur, absorbed ultraviolet light at 250 nm, and contained both zinc and cadmium. Almost all the cadmium was located in a small number of fractions of the cytoplasm (see Figure 18), whereas reasonable quantities of zinc were found in several other fractions as well.

It seems that cadmium in sea birds is 'safely' bound to a storage site and this may explain why these birds can tolerate high metal loads without apparent ill-effects. However, this is not the full story, for, in a few of the birds, particularly the fulmars, high levels of mercury (up to 50 $mg\,kg^{-1}$ dry weight) were also found in the liver. This mercury was not bound to the metallo-

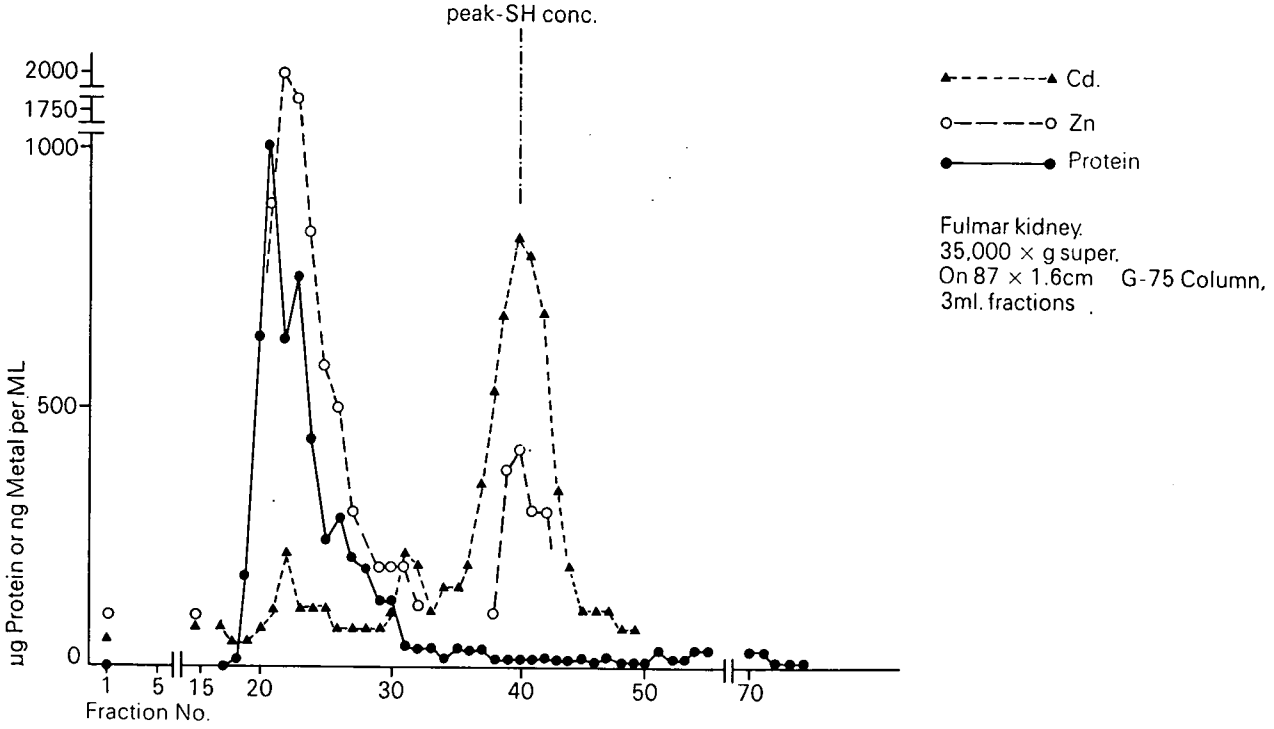


Figure 18 Distribution of zinc (Zn) and cadmium (Cd) in protein fractions from a fulmar kidney supernatant. The supernatant (SUPER) was applied in a volume of 4 ml to a column of the dimensions shown.

thionein-like protein, being located in an entirely different cell fraction.

Future research will attempt to assess the threat that metal pollution may present to other animals, and elucidate any differences that may exist between land, sea and estuarine birds. Attempts will be made to define the significance of the metal loads currently being carried by birds and to identify differences between the binding of cadmium and mercury.

D. Osborn

CADMIUM AND SEA-SKATERS

In recent years there has been much concern over the presence of cadmium in the bodies of sea birds and waders collected round Britain. However, the toxicological situation may be less worrying than was first supposed and the provenance of the metal might not be entirely industrial. The wide variety of species which have been found by analysis at Monks Wood to contain high levels of cadmium in the liver (oystercatcher, knot, dunlin, scoter, puffin, Manx shearwater and others) suggests that the metal is present in a range of food items, and in a variety of marine habitats. The crucial question, from the conservation viewpoint, is: 'Does most of the cadmium originate from industrial activity?' If it does, we are dealing with a potentially serious pollution problem. On the other hand, if the cadmium is mainly natural in origin, then the addition of relatively small amounts of industrial cadmium to the marine ecosystem may not pose a real threat, except locally close to the source.

In 1976, an opportunity arose to assess the cadmium situation over a wide expanse of the Atlantic Ocean, including sea areas extremely remote from industry. Samples of *Halobates micans*, a flightless pelagic insect belonging to the pond-skater family (Gerridae) (Plate 16), were obtained by various survey ships from different locations in the Atlantic. After sorting and taxonomic assessment, the samples were passed to Monks Wood by Dr Lanna Cheng of the Scripps Institute of Oceanography, California. It was already established that other *Halobates* species from the Pacific often contained higher levels of cadmium than any other surface-living or planktonic organism. When the Atlantic samples were analysed by Dr K. Bull at Monks Wood, they, too, proved to contain high levels of cadmium (see Figure 19), the maximum being 309 mg kg^{-1} dry weight from a sample collected in the Gulf of Guinea (West Africa).

Many species of sea birds and some waders overwinter in the warmer waters of the Atlantic. Some of the smaller offshore feeders, such as terns and petrels, may actually feed on *Halobates* and pick up cadmium

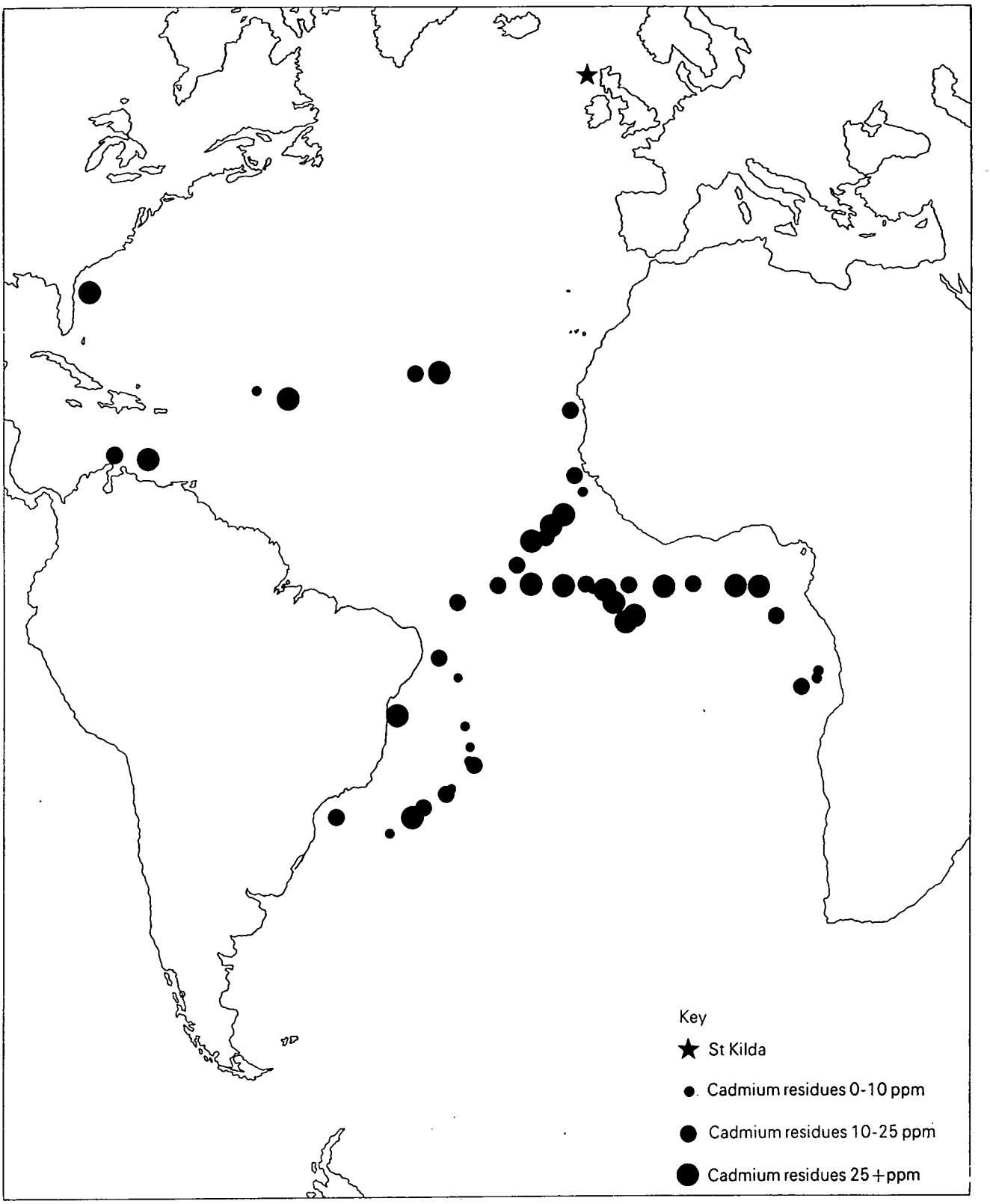


Figure 19 Cadmium content of Halobates micans *collected from sites along survey routes in the Atlantic (from Bull* et al. *in prep).*

this way. However, it is more important to consider the *Halobates* residues as an indication that cadmium exists over a wide area of the tropical Atlantic, and, if *Halobates* can concentrate the metal, one must suppose that it is present in many other organisms and, thus, represented in the foods of many sea birds. Since *Halobates* does not occur in colder waters, the results say nothing about cadmium there, but fisheries scientists have already found the metal to be widespread in occurrence and suspect it to be mainly natural in origin.

In sum, there appears to be a case for considering the present situation, where many sea birds have in their bodies levels of cadmium that could be dangerous in terrestrial birds, as being quite normal. There is no suggestion that, as yet, any population nesting or visiting Britain is suffering adverse effects from the locally increased cadmium levels where industrially polluted rivers enter the sea. Nevertheless, it is this possibility that will guide future work on cadmium in sea birds and waders.

P. Ward

PHYSIOLOGICAL EFFECTS OF ORGANOCHLORINE POLLUTANTS

Any study of the sublethal effects of an environmental pollutant must take into account the natural variation in an animal's physiology at different times of the day and year when it may be storing or utilising fat, have growing, mature or quiescent gonads, be highly active for most of the day feeding young, or relatively sedentary. Preparation for reproduction, moulting, migration and feeding on short winter days or long summer days involves radical changes in the body state of birds and is accomplished by changes in levels and patterns of hormone secretion and other homeostatic mechanisms. A programme of research at Monks Wood is relating the physiology to the ecology of birds, and using this approach to investigate the effects of various organochlorine pollutants.

On pairing, pigeons perform easily observed behaviour patterns which are related to endocrine changes and which lead to egg laying some eight days later. The compression of final gonad maturation into so short a time makes the pigeon an ideal subject for studying the effects of pollutants on the breeding cycle. Feral pigeons dosed with PCB (polychlorinated biphenyl, Aroclor 1254) at a rate of 15 mg/day laid eggs within the same time period as control birds. They exhibited similar behaviour patterns though dosed subjects were hyperactive and gave the bowing and nest demonstration displays more frequently than did controls. Tissue

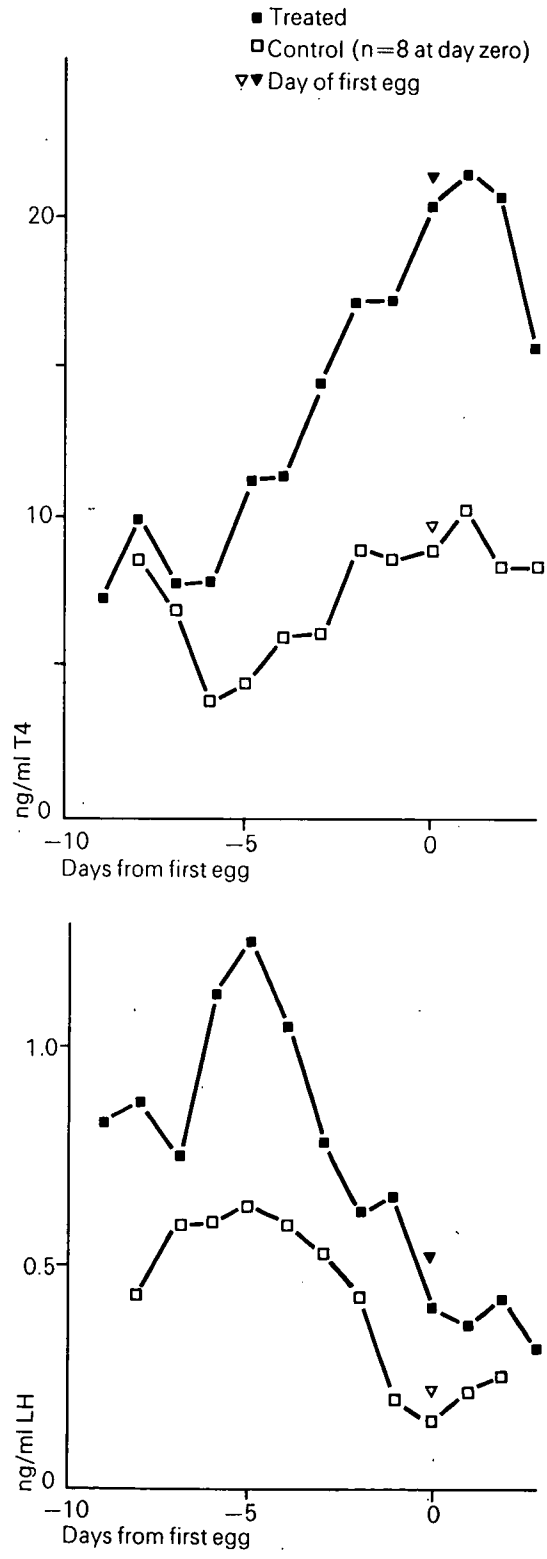


Figure 20 Plasma thyroxine (T4); and luteinising hormone (LH) in female feral pigeons from pairing to oviposition. The effects of PCB (Aroclor 1254) at a daily dose of 15 mg/day.

and organ samples taken at the termination of the experiment are still being analysed, but residue levels presently assessed are low and comparable with those found in many free-living birds. Terminal blood samples assayed for thyroxine (T4) showed mild hyperthyroidism in dosed birds comparedwith controls (PCB, 21·36 ± 2·52 ng ml^{-1}; controls, 12·61 ± 0·57 ng ml^{-1}; $P < 0·01$ Student's 't' test). Luteinising hormone, LH (a pituitary gonadotrophin) concentrations were not significantly different between the two groups. A slight, but not significant, increase in thyroid weight reflected the low dose of PCB. The birds were not allowed to incubate their eggs and were separated after laying. These results, therefore, represent a 'static' effect of the PCB.

When blood samples taken daily throughout the dosing period were analysed, the picture was very different. Both males and females showed significantly elevated titre of both T4 and LH during the period immediately after pairing and before oviposition (Figure 20). The patterns of secretion of both hormones in relation to the behaviour cycle remained identical to controls and the interaction between the two was unaffected. This effect of PCB cannot be explained by current theories and it implies a neuronal component affecting the feedback of hormones on the hypothalamus.

The interaction between thyroid and reproductive hormones is still imperfectly understood, but T4 and T3 (triiodothyronine, the second thyroid hormone) are thought to be involved in the termination of breeding in birds (photorefractoriness) and the onset of moult. There is likely to be a photoperiodic component and a linked component setting hypothalamic feedback levels. Since PCB seems to affect at least one of these mechanisms, its ecophysiological effect on avian breeding cycles, and more general nervous effects, merit further investigation.

S. Dobson, B.C. Dobson, R.K. Murton and N.J. Westwood

EFFECTS OF THE HERBICIDE ASULAM ON NON-TARGET PLANT SPECIES AND COMMUNITIES

(This work was commissioned by the Nature Conservancy Council)

Although Asulam (methyl 4-aminobenzene sulphonyl carbamate), a herbicide used for eradicating bracken, *Pteridium aquilinum*, from pasture, has a high degree of selectivity, its use, particularly when distributed in aerial sprays, may nevertheless jeopardise the survival of some scarce plant species, notably ferns. Accordingly, work, first commissioned by the Nature Conservancy Council in 1975, is being done to explore the effects of Asulam on non-target species and communities.

Staff at Merlewood are investigating its effects on (a) plant assemblages (on upland pasture in Northumberland and different woodlands) and (b) individual species (*Dryopteris dilitata*, broad buckler fern; *Blechnum spicant*, hard fern). A range of sub-lethal effects have been recorded including decreased leaf areas, distorted leaf stalks (rachis) and colour changes. It seems that *B. spicant* is more sensitive than *D. dilitata*; rates of recovery of affected plants will be noted in 1977. Other experiments suggested that dwarf gorse, *Ulex gallii*, was more sensitive to Asulam than the relatively resistant common cotton grass, *Eriophorum angustifolium*.

In a pilot investigation done in North Wales, a two-acre (0·8 ha) plot within an extensive area of upland bracken was treated with Asulam in 1973. Bracken fronds failed to emerge the following spring and subsequently the plot has remained almost devoid of this species. In the absence of invading foxglove, *Digitalis purpurea*, and bramble, *Rubus* spp., the summer grass crop has been seemingly improved, yields being doubled despite the absence of land improvement treatments. This improvement has been reflected in increased usage by sheep. Numbers of small rodents, mice, voles and shrews decreased after bracken eradication.

A.D. Horrill, A.G. Thomson and J. Dale

Effects of land management on vegetation and fauna

EFFECTS OF GRAZING ON MOORLAND

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

Because it is not feasible to make continuous and direct observations for protracted periods, the use made by different grazing animals (red deer, sheep, hares, rabbits . ...) of 32 moorland sites in north-east Scotland was inferred from assessments of amounts of dung deposited.

By their reactions to grazing, the differing plants were allocated to one of three groups (Figure 21):

(A) *Trifolium repens* and the monocotyledonous *Agrostis tenuis, Anthoxanthum odoratum, Festuca ovina* and *Poa pratensis*—growth favoured by increasing grazing intensities.

(B) *Deschampsia flexuosa, Juncus squarrosus, Nardus stricta, Potentilla erecta* and *Vaccinium myrtillus*—growth of these species, some of which are unpalatable,

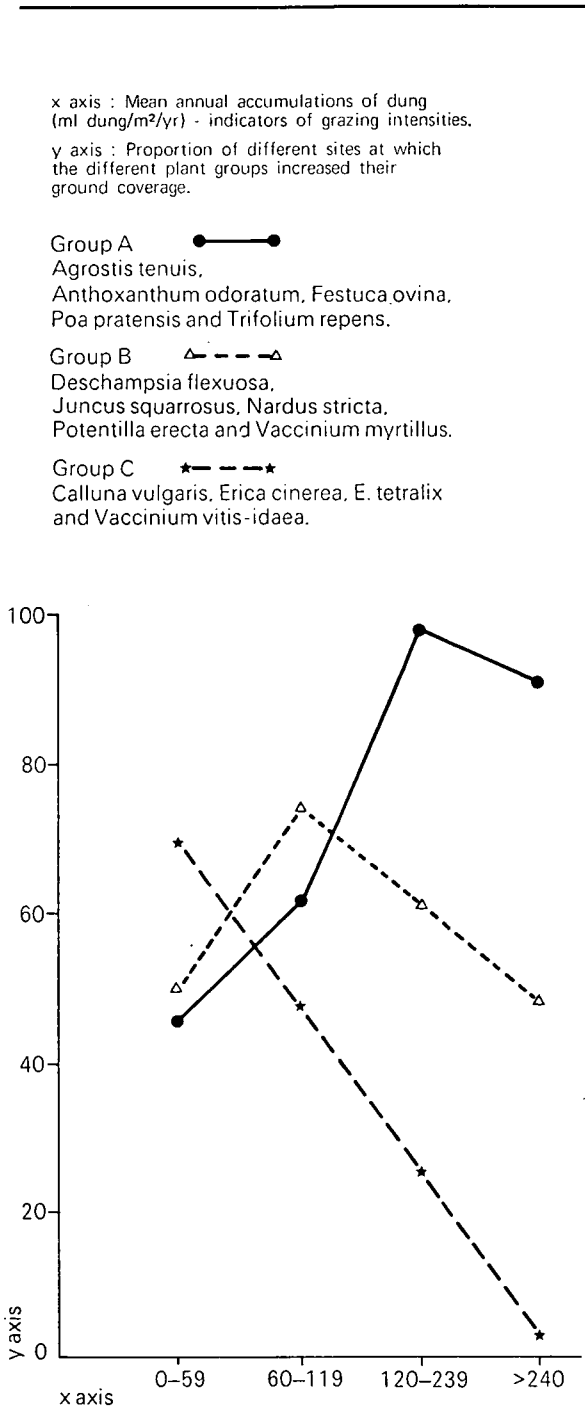


Figure 21 Effects of different grazing intensities on the growth of the component plants of moorland vegetation which were arranged in three groups.

was *not greatly affected by grazing* although there was an indication of greater growth at moderate grazing intensities.

(C) *Calluna vulgaris, Erica cinerea, E. tetralix* and *Vaccinium vitis-idaea*—growth indirectly proportional to grazing intensities, being greatest at low intensities and least at high intensities.

The differing responses of groups A and C were highlighted at one site where, after a two-year period of light grazing (72 ml dung/m²/yr) standing crops of (1) heather and (2) grasses and herbs measured 360 and 68 g/m² respectively. After a subsequent period of heavier grazing (260 ml dung/m²/yr), the standing crop of heather had halved to 187 g/m², whereas the grasses and herbs increased to 109 g/m². The magnitude of these effects was influenced by altitude, comparable numbers of animals being more damaging at high than at low altitudes, probably because plant growth, and therefore recovery, was slower at the higher sites.

From data for seven successive seasons, it seems that dwarf-shrub heath will be progressively changed to grassland at grazing intensities in excess of three sheep equivalents per hectare.

D. Welch

AMENITY GRASS MIXTURE TRIALS

(This work was mainly supported by the Department of the Environment)

In collaboration with the Sports Turf Research Institute, a split, split-pilot experiment has been established at three sites—Bingley, Yorkshire (STRI), Bush, Edinburgh (ITE) and Monks Wood, Huntingdon (ITE). The experiment tested the effects of artificial wear on the factorial combinations of sixteen grass mixtures of five turf grass species and two levels of nitrogen fertiliser. This work, in which ITE was responsible for the experimental design and subsequent analysis, forms part of a larger programme carried out by STRI.

The wear treatment was commenced within 7 months of sowing. Although this is in fact earlier than recommended practice, it is common for managers to bring newly sown playing fields into use as quickly as possible. At Bingley, the composition of the emergent stands closely corresponded to the proportions of each species sown, but, at Monks Wood and Bush, perennial rye grass (*Lolium perenne*) dominated some mixtures even when it formed a relatively small proportion of the seed mixture. The same early dominance of perennial rye grass, possibly attributable to drought conditions, was also observed in another series of experiments done by STRI at 30 sites throughout the UK.

At Bingley, mixtures containing perennial rye grass (*L. perenne*) smooth stalked meadow grass (*Poa pratensis*) and timothy (*Phleum pratense*) were more tolerant of wear than other mixtures and better able to recover from it, without change in composition.

The difference between what is sown and the early composition of emergent stands suggests that the advantages of particular combinations of species and cultivars may be lost. More needs to be known about the processes of early establishment.

A.J.P. Gore and Ruth Cox (ITE) and T. Davies (STRI)

ECOLOGY OF RAILWAYS

(This work was supported by the Nature Conservancy Council)

Of the significant land uses in lowland Britain, railways have been one of the least studied by biologists. However, it has been a matter of observation that railway land provides contrasting habitats to those found in neighbouring land, doubtless adding to wildlife interest. In the last ten years, the traditional management of trackside areas has been associated with the withdrawal of the steam engine, the reorganisation of maintenance gangs, and with restrictive economic policies. Development of scrub in unmanaged grassland is now becoming a problem for the railway authorities, and programmes of clearance, possibly involving the use of herbicides, are being proposed. As a result, there is considerable urgency to describe the biological attributes of railway land and particularly to identify areas of exceptional interest so that advice can be given on future management.

With the approval of the British Rail Board and the provision of valuable historical background information, a feasibility study was made in 1976 so as to evolve a structured approach to detailed studies in later years.

Exploratory field work included detailed investigations of the physical formations and vegetation of four 12–15 mile stretches of railway line in different parts of the country, (a) Huntingdon–Peterborough giving a contrast between the Fens and the clay uplands, (b) Bedford–Rushden including the clay watershed between the Jurassic strata and alluvia of the River Ouse and the River Nene, (c) Haslemere–Havant across the Wealden series of greensands in the north and chalk in the south, (d) Kirkby Stephen–Appleby in Cumbria with a contrast between moorland sections in clay and Carboniferous limestone and the improved grasslands of the valley of the River Eden with a change to Permian sandstone near Appleby. Three hundred and ninety plant species were recorded along the 50 miles of track investigated, with about 100 species per two-mile stretch. The range of habitats commonly included heavily disturbed embankments, coarse grasslands based on *Arrhenatherum elatius*, and developing bramble and scrub. The herb-rich grassland swards in undisturbed cuttings were based on species of *Arrhenatherum*, *Brachypodium* and *Bromus*.

J.M. Way

GRASSED AND PLANTED AREAS BY MOTORWAYS

The Preston Bypass, now integrated into the M6, was opened to traffic in December 1958 as the first stretch of the new motorway system, involving major earthworks, and now measuring 1,185 miles (1,896 km), a third passing through arable land, a third through improved grassland and the remainder through areas occupied by woodlands, towns and industry and derelict and unimproved grassland. It is estimated that the 1,102 miles (1,763 km) of motorway including the road and its 'shoulders', which existed at the end of January 1975, occupy 1,400 acres (5,600 ha), giving an average of 12·6 acres/mile (3·2 ha/km). Undoubtedly the flora developing alongside the new roads will have been influenced by neighbouring land uses, by traffic-generated pollution and by management practices. About 380 plant species were recorded alongside the M1 in 1970, with rather more in older sections, e.g. that from Watford to Crick opened in 1959. Most of these plants either occurred very infrequently, or else were typical, aggressive, early colonisers, but the balance of species will continue to change until equilibrium is reached at an, as yet, unpredictable interval.

This work, including its implications for management, has been summarised in a publication obtainable from the Monks Wood Experimental Station of ITE.

J.M. Way

EFFECTS OF AFFORESTATION ON THE FLORA OF THE BRITISH UPLANDS

(This work was supported by the Nature Conservancy Council)

Having spent 1975 in southern Scotland, attention in 1976 was turned mainly, but not exclusively, to Wales. Surprisingly there were more similarities than differences, the effects of afforestation being related to soil type rather than geographical location. Interestingly, the effects of coniferous afforestation so far recorded in the UK are in accord with those from Germany and Sweden, where, however, there are more species with distributions specifically favoured by coniferous woodlands. The moss, *Plagiothecium curvifolium*, is one such plant whose occurrence in the UK has been favoured by afforestation.

The main part of the study is concerned with areas actually planted, but studies of forest roads, rides and streams were continued. Additionally, 1 km squares were examined to check the effects of afforestation on a larger scale. In terms of total numbers of species present, afforestation makes little difference at the 1 km scale, but nevertheless there are considerable changes. Thus, with gross changes to their habitats following ditching and deep ploughing, plants of marshes and bogs decrease in abundance. In contrast, the construction of forest roads provides an opportunity for the establishment of many ruderals. On the other hand, trees themselves have so far selectively favoured relatively few species, mainly mosses and liverworts, although larger effects might show as our man-made forests increase in age.

This work is being extended to examine the light regimes beneath the evolving canopies of ageing forests.

M.O. Hill and D.F. Evans

IMPACT OF TRAMPLING ON MONTANE VEGETATION

With the growth of leisure and other pursuits in the Scottish Highlands over the last fifteen years, ecologists have been taking an increasing interest in effects of trampling on montane vegetation. This interest has often been aroused by the deterioration of footpaths, and damage to plant cover at recreation sites such as nature trails, chalk grasslands and sand dunes. Damage to native plant communities near ski lifts in the Eastern Highlands has been particularly severe and has stimulated an exploratory study of the impact of trampling on a small number of mountain vegetation types.

Previous experimental studies of trampling are subject to criticism, either because the method of applying the disturbance was too artificial (for example by trampling machines or falling tamps) or the period or intensity of treatment was too dissimilar to actual field disturbance patterns, criticisms which are particularly valid where the objective was to get an estimate of 'carrying capacity'. Most studies to date have demonstrated simple linear or curvilinear relationships between damage and disturbance, but few have attempted to gain insight into the recovery of different types of vegetation.

In the montane zone, which may be considered as being above the commercial forestry limit, growth is generally slow and confined to a small part of the year. Consequently, it is necessary to assess recovery over a period of several years. When repeated disturbance was prevented, it was found that the damage after a single treatment followed the expected pattern of increase with increased intensity of disturbance. The first assessment was made three months after disturbance, to allow dieback of crushed tissues to occur, but a second assessment a year later showed that, although some species such as *Trichophorum cespitosum* and *Vaccinium* spp. had apparently recovered, others, notably *Calluna vulgaris* and some of the other montane *Ericaceae*, had further declined (Figure 22). Bruised tissues of these species seem particularly

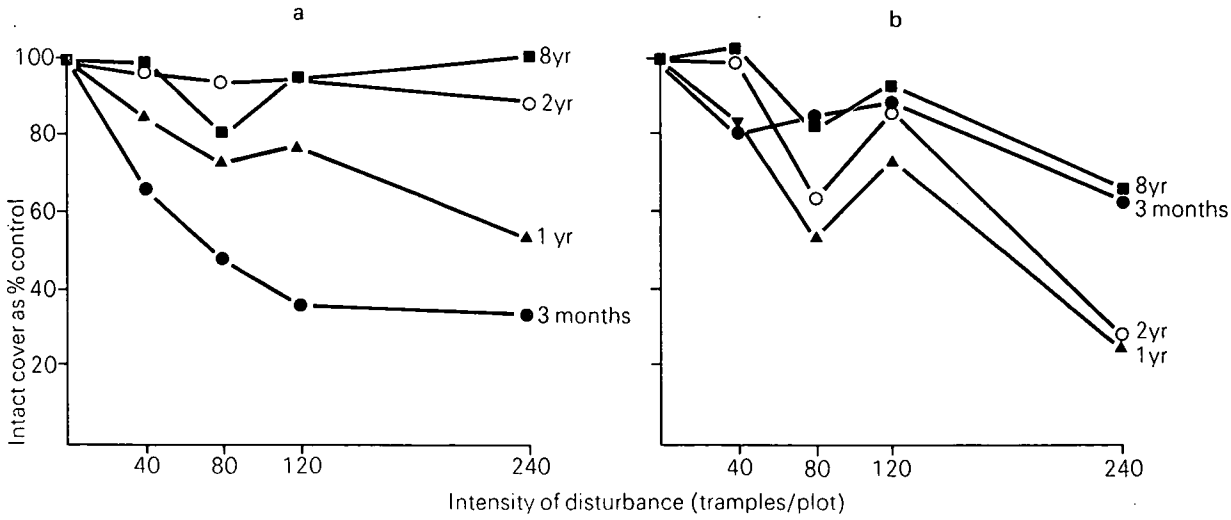


Figure 22 Intact cover of (a) Trichophorum cespitosum *and (b)* Calluna vulgaris *at various times after disturbance by trampling. Both species were components of a* Calluna–Arctostaphylos *heath on Cairngorm, Scotland.*

vulnerable to desiccation and frost with dieback continuing for a year or more. This delayed damage has not so far been reported from other habitats, either because it does not occur, or because the methods of investigation have not allowed its detection.

Because of delayed damage, recovery estimates were not meaningful in the short term, but, after eight seasons, a pattern was emerging. A few species such as *Trichophorum cespitosum* recovered completely within two or three seasons, whereas others (e.g. *Calluna vulgaris*, *Sphagnus rubellum* and various lichen species) took the full period to recover appreciably. One or two species of *Erica* actually had relatively higher cover values at the end of the eight seasons, than before disturbance.

The value of these simple observations is to demonstrate the time scale that has to be borne in mind when considering the impact of increasing recreation, mineral exploitation and other types of sustained human pressure on montane vegetation. They indicate that experiments should be long-term and suggest that effects of management will be slow to appear.

N.G. Bayfield

Species distributions and taxonomy

BIOLOGICAL RECORDS CENTRE

The year 1976 has been one of the most productive years in the history of the Biological Records Centre. The Centre has been involved in the preparation of three new Atlases and in a second edition of a fourth. By the end of January, the final corrections and alterations were made to the distribution maps of birds, and, later in the year, the British Trust for Ornithology published the *Atlas of breeding birds in Great Britain and Ireland*, which contained some two hundred and eighteen dot distribution maps. Three different sized dots were used to indicate proven breeding, probable breeding, and presence in a suitable habitat in the breeding season.

In April, work was completed on the *Atlas of non-marine Molluscs*, which was published by ITE for the Conchological Society of Great Britain and Ireland, and contained distribution maps of one hundred and ninety-nine molluscs. This was the culmination of fifteen years' work by the Society and a fitting production in their Jubilee Year.

In December, a provisional atlas of the Isopoda: Oniscoidea (the woodlice) was produced as Part 1 of the Provisional Atlas of the Crustacea of the British Isles; 31 species were mapped with the co-operation of the British Isopoda Study Group and edited by a member of the ITE staff, Paul Harding. Also in 1976, a second edition of the *Atlas of the British flora* was published. For this atlas, the maps of about three hundred and fifty of our rarest plants were updated. These maps form the basis of the *British Red Data Book for vascular plants*, to be published in 1977.

F.H. Perring

THE DISTRIBUTION AND ECOLOGY OF NON-MARINE ISOPODA

A survey scheme has been in operation since 1969 for examining the geographical distributions and habitats of non-marine Isopoda in the British Isles. Since 1973, this scheme has been organised as part of an ITE project. Unlike most other recording schemes committed to the production of 10km square distribution maps, the present scheme utilises the efforts of recorders to collect data on the habitats of species, in addition to geographical distribution data.

One hierarchical habitat classification system was devised for the recording of non-marine Isopoda, Diplopoda and Chilopoda (Fairhurst, Harding and Sutton, 1975). This system is used on field recording cards from which the codified data can be abstracted for analysis using a computer. A provisional atlas of the distribution of woodlice (terrestrial Isopoda) in the British Isles has been published (Harding, 1976), which summarises over 12,500 records of 31 species. The atlas also includes details of the habitat recorded for each species. The data utilised in the atlas were gathered partly through the auspices of the British Isopoda Study Group, and also from information gathered mainly since 1969, based on identifications by a few experts. Records from some museum collections, which have been completely re-identified as part of the project, are also included in the atlas. Of the 31 species mapped, only two species appear not to be native in the British Isles and occur solely in synanthropic habitats. Several species, such as *Ligidium hypnorum* (Figure 23), and *Metoponorthus cingendus* (Figure 24) (See pages 70, 71), show distinctly limited geographical ranges, but others, such as *Oniscus asellus* and *Porcellio scaber*, have been recorded throughout the British Isles.

More detailed research into the habitats of rare species such as *Armadillidium album* (Harding, 1969) and *Halophiloscia couchi* (Harding, 1975) has resulted in these species being found at many new localities. Future work, whilst continuing to organise the collection of records from the British Isles, will be directed towards taxonomic studies, research into the habitats of more rare species, and to the analysis of habitat

data. This analysis is being done in conjuction with staff at Salford University and the Myriapod Study Group.

P.T. Harding

References

Fairhurst, C.P., Harding, P.T. and Sutton, S.L. (1975). Distribution species on certain soil invertebrates. *Proc. 2nd Int. Symp. European Invertebrate Survey* (1973), 47–55.

Harding, P.T. (1969). Notes on the biology and distribution of *Armadillidium album* Dollfus (Crustacea: Isopoda: Oniscoidea) in the British Isles. *Entomologists mon. Mag.*, **104**, 269–272.

Harding, P.T. (1975). Observations on the habitat of *Halophiloscia couchi* (Kinahan) (Isopoda: Oniscoidea) in south-western Britain. *Crustaceana*, **28**, 108–109.

Harding, P.T. (ed.) (1976). *Provisional atlas of the Crustacea of the British Isles. Part 1, Isopoda: Oniscoidea – woodlice.* Abbots Ripton: Institute of Terrestrial Ecology.

FLOWERING OF THE MARSH GENTIAN *GENTIANA PNEUMONANTHE*

The marsh gentian, *Gentiana pneumonanthe*, which is distributed throughout central Europe to the Urals, Siberia and into Asia, is a plant of wet heathland and grassland. In Britain, it has been severely affected by improved drainage and general loss of habitat; to ensure its continuing conservation more needs to be known of its biology and habitat requirements.

Following heathland fires, *G. pneumonanthe* may flower six weeks earlier than in adjacent unburnt areas, an effect parallelling that exploited in the commercial production of narcissi and irises where 'burning over' stimulates earlier flowering, albeit measured in days instead of weeks. This effect of burning may be attributed to higher soil temperatures because the soil surface is blackened, or to the subsequent increased release of nutrients from burnt vegetation and litter. It has been possible to correlate dates of flowering with soil temperatures in burnt and unburnt areas of wet heathland at Hartland Moor National Nature Reserve.

Experimentally, soil temperature is being influenced by using white granular plastic mulches containing varying quantities of black pebbles. However, in obtaining populations of *G. pneumonanthe* from locally collected seed, the variable rates of germination highlighted the need for further information of conditions for germination and early establishment. To ensure that the results of pot conditions can be related to field conditions, thriving natural populations in Dorset, and apparently less successful groups in the New Forest, are being studied.

S.B. Chapman

Work of special subdivisions and centres

CULTURE CENTRE OF ALGAE AND PROTOZOA

The collection

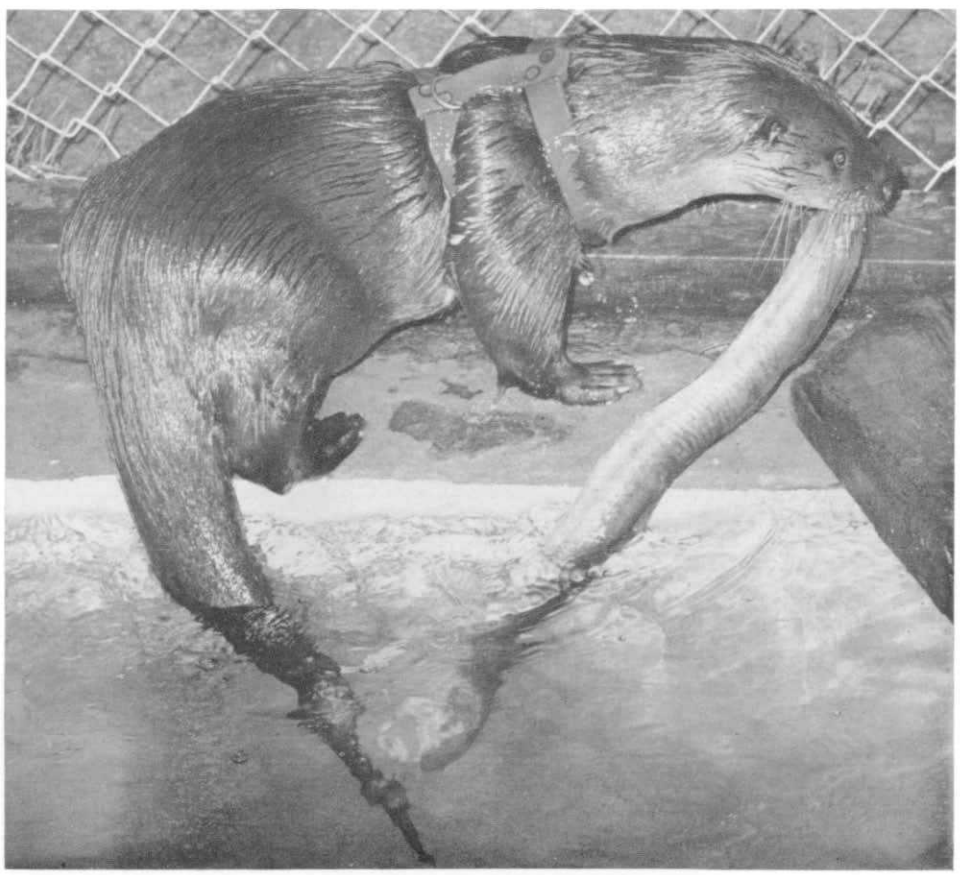
A new edition of the List of Strains was produced in 1976, incorporating additions to the Collection since the previous list was published in 1971. Among the more important additions were a large number of amoeba strains, including many of taxa newly described by F.C. Page, many marine or brackish flagellates collected by R.W. Butcher at the MAFF Fisheries Laboratory at Burnham on Crouch, and many *Chlamydomonas* mutants chiefly with flagellar or cell wall mutations in which there is considerable cytological and physiological interest. The new list also indicates those organisms which are especially suitable as teaching material. This indication is particularly desirable at the present time as there has been a serious reduction over recent years in the amount of general and taxonomic teaching on organisms, mainly in favour of new developments such as cell biology and aspects of biochemistry. Other important acquisitions which were not all in time for inclusion in the 1976 List were strains of *Cyanidium*, *Stichococcus* and *Chlorella* from acid, sulphurous springs in Italy, strains of new taxa isolated from the Antarctic by P.A. Broady of the British Antarctic Survey, and planktonic algae from the Freshwater Biological Association's Windermere Laboratory.

The demand for cultures (Table 6) fell slightly, but the changes are probably not very significant and the total is satisfactory, considering the financial straits of most of our customers and the swing away from teaching a large number of types. Many teachers now make do with one or two cultures of a strain, when formerly they ordered perhaps five or six. Our policy of freely offering information and assistance in culture maintenance also tends to diminish sales.

Preservation of cultures

Considerable progress has been achieved in the preservation of living cultures under liquid nitrogen (Morris, 1976). The advantages of such preservation include a reduction in the labour of maintenance together with less risk from accidental loss, mutation, and other hazards inherent in maintaining active organisms. About 300 strains of Chlorococcales are now stored in this way, with survival counts of over 60%, and our experience, together with that from other kinds of organism, indicates no reduction of viability with time of storage at liquid nitrogen temperature. Further progress with more difficult organisms is anticipated as a result of research into the effects of

Plate 14 Captive otter (Benjie). Photograph D. Jenkins.



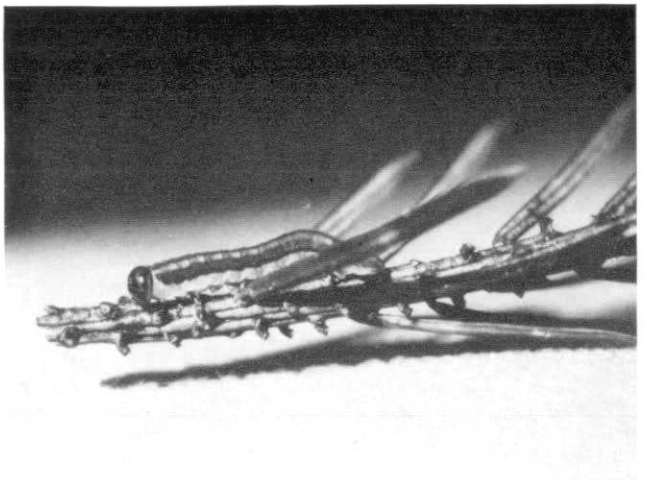


Plate 15 (a) A fourth instar larva of Gilpinia hercyniae. *Photograph A. Buse.*

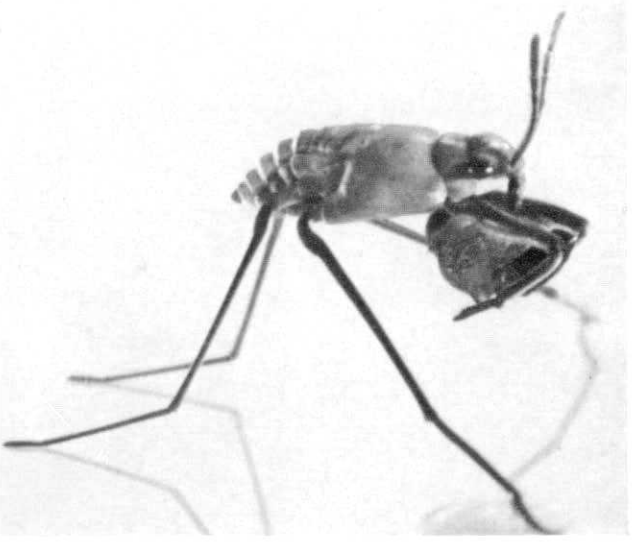


Plate 16 The oceanic sea-skater Halobates, *marine Gerrid, seen standing on the sea surface holding a food item in characteristic posture. Samples of these insects, collected from various sites in the Atlantic, have recently been analysed for cadmium residues. Photograph L. Ford and Dr Lanna Cheng.*

Plate 15 (b) An area of the southern part of Dyfi-Corris forest: the 'source' site containing both sawfly and virus.

Table 6 CCAP culture output

	1976	1975
Number of orders	962	974
Cultures to UK:		
Academic	2,925	3,203
Hospitals	27	45
Government	111	103
Commercial	77	97
Cultures to EEC countries	200	119
Cultures to other countries	323	325
Total	3,663	3,892

Countries ordering cultures in 1976

Australia	Germany (W)	Malta
Barbados	Greece	New Zealand
Belgium	Holland	Norway
Bulgaria	India	Rhodesia
Canada	Iran	South Africa
Chile	Ireland	Spain
Czechoslovakia	Israel	Sweden
Denmark	Italy	Switzerland
Finland	Japan	USA
France	Kuwait	

temperature on cell tolerance to freezing and its relation to membrane lipid composition.

The other important method for long-term preservation – lyophilisation – is not neglected; workers at the Pathology Department at Cambridge are collaborating by investigating the freeze-drying of some of our strains. Cryobiological research has also drawn attention to anomalies in the identification of certain strains by giving further taxonomic features. It is also providing basic information on frost resistance which has physiological and ecological implications.

Taxonomic research

The publication of an Illustrated Key to Freshwater and Soil Amoebae by F.C. Page (1976a) has been a culmination of several years' work on the organisms in culture and in nature. It has made readily available to the ecologist and others not expert in taxonomy the results of a series of taxonomic publications. Among the latter is a revised classification of the naked amoebae (Page, 1976b), prepared in association with a forthcoming comprehensive revision of the Protozoa sponsored by the Society of Protozoologists.

A major contribution to the understanding of phytoflagellates was a survey of the fine structure of Chrysophyceae and Prymnesiophyceae (Hibberd, 1976). These groups, the latter only recently recognised (first as Haptophyceae), form a major part of the phytoplankton, but can only be thoroughly investigated by electron microscopy. Other research has been carried out into colourless flagellates, the affinities of which have long been in dispute. *Cyathobodo, Rhipidodendron* and *Spongomonas*, three widespread genera from freshwaters, have been shown to have no algal affinities and, if a clear dichotomy between plants and animals is assumed, must be designated zooflagellates.

The incorporation of Butcher's strains into the Collection called for checking each strain by electron microscopy, work which has produced many new observations (Clarke and Pennick, 1976; Pennick, Clarke and Cann, 1976), especially on the form and arrangement of the minute scales that clothe the cell body and even the flagella of many species. Having a range of strains easily available has led to valuable comparative work on scale morphology, increasing the feasibility of using scales as practical identification features.

Identification of organisms

It is inevitable that laboratories with taxonomic expertise are frequently asked either for guidance in identifying organisms or, more often, for actual identification of specimens or collections.

The provision of a general identification service for algae and protozoa is at present quite impossible, owing to the poor state of the art and to the inordinate amount of time that would be needed, particularly because, in so many cases, major taxonomic research would be a pre-requisite. However, two steps have been taken in this direction. *A Guide to Algal Keys* (George, 1976) has been published to enable those not well-versed in taxonomy to find an appropriate diagnostic key, and *A Beginner's Guide to Freshwater Algae* (Belcher and Swale, 1976) has also been published as a booklet by HMSO. This contains illustrated descriptions of over one hundred algae which enable the non-expert to recognise many of the common forms. Being, at the same time, scholarly and as non-technical as possible, it has already attracted considerable demand from schools and universities, workers in the water industry, and amateur naturalists.

E.A. George

References

For references in text above see Section VI, Publications.

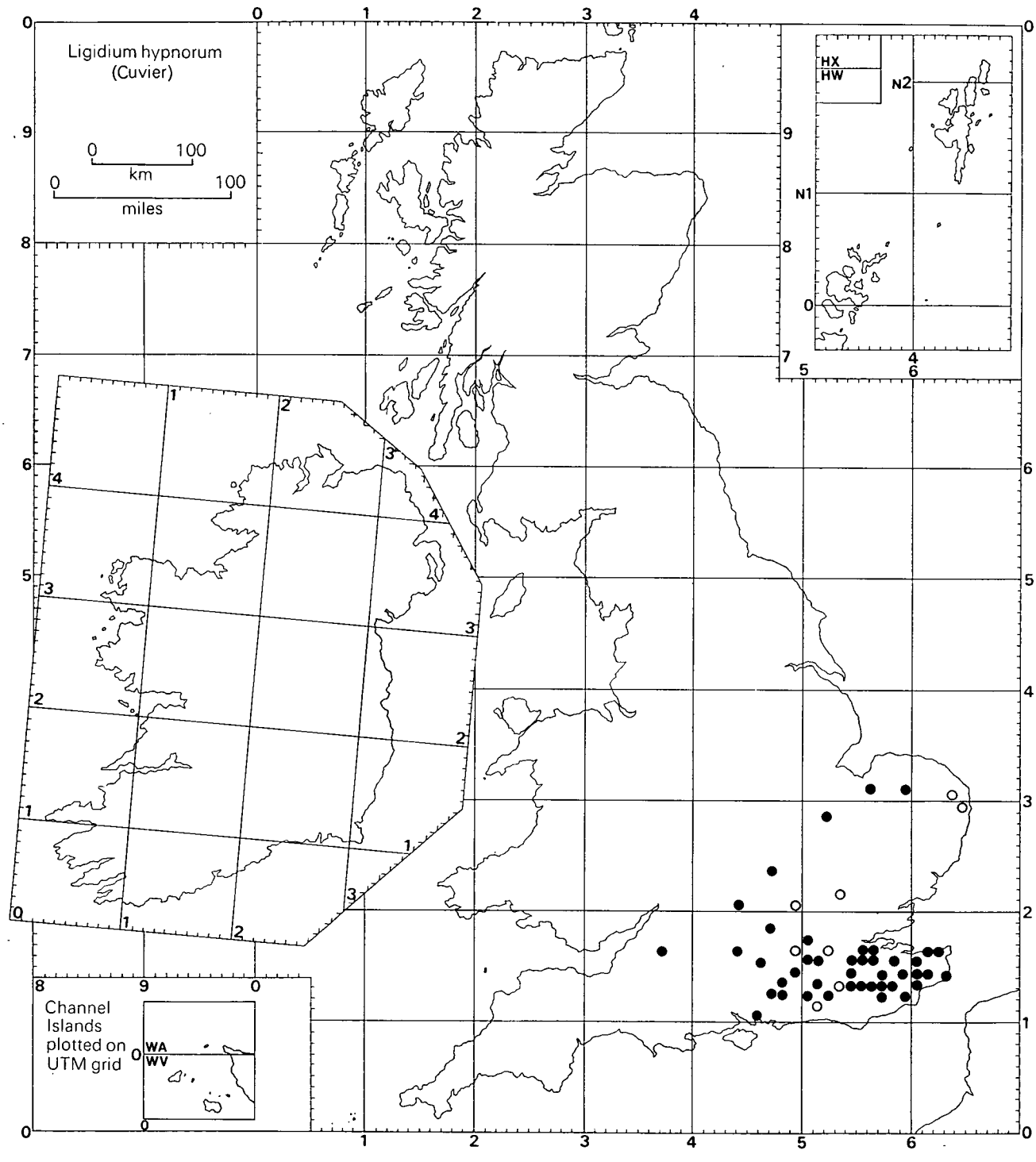


Figure 23 Ligidium hypnorum *(Cuvier). Strongly hydrophilic. Found in damp situations in woods, and certain fens and marshes, also occasionally in damp grassland. Almost certainly a south-eastern species, with a single occurrence beside the Kennet and Avon Canal near Bath, probably being an introduction. Noticeably absent from fens in the Test Valley (Hampshire) and also Wicken Fen (Cambridgeshire). A record by Collinge from the Bollin Valley (Cheshire) has not been confirmed.*

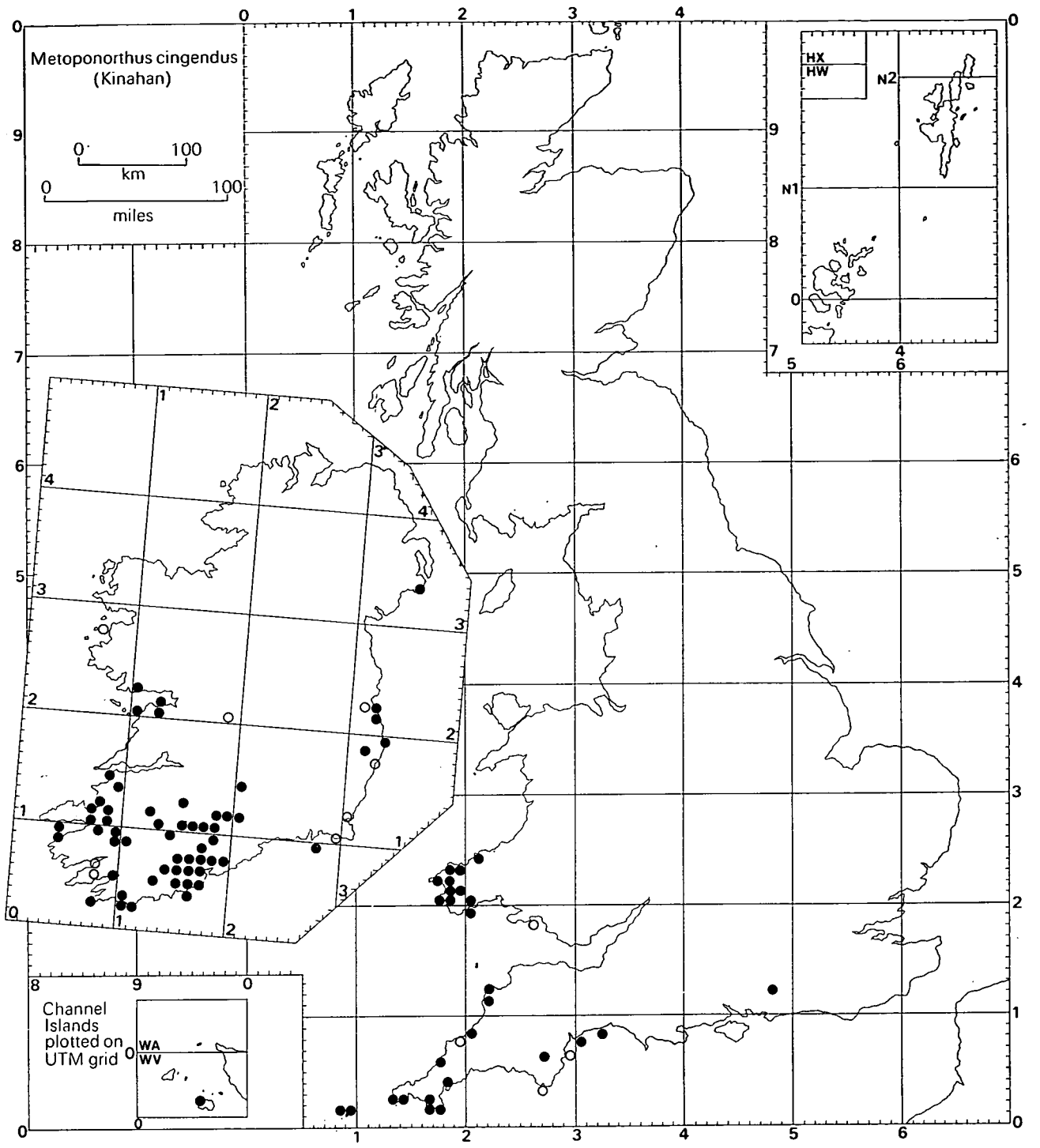


Figure 24 Metoponorthus cingendus *(Kinahan). A 'Lusitanian' species whose occurrence in Ireland conforms well with the accepted distribution for 'Hibernian Lusitanian' species. It also occurs on or near the coast in south-west England and Wales. There is also a record from a fen in the Rother Valley (Sussex). Usually found in long grass in species-rich grassland, but in south-western Ireland it is often very common and occurs in such habitats as scrub woodland and gardens.*

SUBDIVISION OF CHEMISTRY AND INSTRUMENTATION

Introduction

The majority of the staff in this Subdivision are occupied with support duties for the benefit of the Institute's research scientists. Most of the work is dealt with by three main sections (chemistry, engineering and nursery). There is, in addition, a small photographic service and the Subdivision has a general responsibility for advising or supervising most of the Institute's technical requirements. Examples of the latter include instrumentation and the arrangement of radiochemical service facilities.

Apart from the support functions, some of the C and I staff are fully or partly engaged on research and development projects usually in association with staff from other Subdivisions. Further information about these are given below.

In the course of its research work, the Subdivision contributes to the main contracted research of the Institute, but it is not always realised that the Subdivision, notably the Chemical Section, also carries out work directly for outside organisations on a contract basis. Customers have included the Nature Conservancy Council, the Forestry Commission, the Royal Society for the Protection of Birds, the Camargue Station Biologique, county naturalists' trusts, universities, polytechnics and local authorities, as well as other NERC institutes such as the British Antarctic Survey. The analytical work being carried out for the Unit of Comparative Plant Ecology at the University of Sheffield is a particularly large commitment and is scheduled to run for three years.

THE SERVICE SECTIONS

Chemical Section

Demand for analytical support has continued at a high level throughout the year and both component laboratories (Merlewood and Monks Wood) of the section have been kept very busy. The increasing emphasis in the Institute on wider environmental topics such as pollution, reclamation and land use has resulted in a need for a wide range of chemical characteristics. In particular, involvement in the sulphur, fluorine and aquatic pollution projects has kept the section's staff occupied for much of the year.

A particular feature of the year has been the interchange between the Merlewood and Monks Wood laboratories. This has been done to ease analytical pressures and also to make better use of staff expertise and instrumental facilities. It is a trend likely to develop further in the future. Overall, there was a significant increase in the throughput at both centres, with a total of approximately 100,000 separate characteristics being measured.

There was a major improvement in the laboratory accommodation at Monks Wood, with spare rooms being brought into use to relieve the over-crowding. There are now separate rooms allocated for metal and organic analysis and also for data processing. At Merlewood, a detached building in the grounds was converted for use as a sample preparation area.

The only major instrumental development was at Merlewood where the chart reading facilities were fully interfaced with the computing equipment.

Engineering Section

The principal development of the year has been the establishment of the Central Engineering Unit at Bangor Research Station. This became possible following the transfer of C.R. Rafarel from Furzebrook to join G.H. Owen at Bangor. The creation of this unit gives the Institute a much greater potential for the design and construction of relatively sophisticated instruments. It is intended that the unit shall complement normal on-station support requirements, which ideally need an engineer at each centre. At present only Merlewood, Monks Wood and Bush have full-time support and Colney has part-time assistance. The work of the Central Unit and station engineers is closely co-ordinated by the Senior Engineer so that any spare capacity or expertise can be used to the maximum effect.

Nursery Unit

This unit has continued with its task of providing specialised support for the staff of ITE concerned with plant propagation and growth studies. A particular feature of the year has been the extension of the unit's work to cover the Institute as a whole, in addition to that generated from the Bush station where it is based. Examples of this extension include studies into the dormancy breaking of tree seeds; the production of calcicole seeds in commercial quantities for reseeding industrially disturbed, calcareous areas; and a project dealing with the propagation of trees from the Shetlands with a view to re-establishment. Landscaping assistance is also being provided to NERC and SRC for their new joint headquarters building under construction at Swindon.

Despite the widening of the unit's role, a considerable amount of work still originates from the staff at Bush itself. In particular, the studies on birch genetics and threatened tropical tree species, referred to in the

previous Annual Report, occupy much of the unit's time. There is also the continuing commitment, in co-operation with the Sports Turf Research Institute and with colleagues at Monks Wood, to the project on the wear tolerance and recovery of sports turf mixtures. The major glasshouse development of the year has been a doubling of the area devoted to mist propagation work. Another innovation has been the introduction of new transistorised thermostat control systems with considerable advantage for fuel saving. Outside developments of note include the extension of the plunge beds and the establishment of a national collection of birch clones on the remaining available land. The nursery work in general has benefited from the acquisition of a tractor and grasscutter.

Photography

A limited photographic service is now in operation for ITE. This service is centred on Colney Research Station, where the photographic facilities are being expanded. So far, much of the time has been spent on normal developing and printing operations and the copying of colour slides, but it is hoped to extend the service to cover more specialised requirements. Work is also in hand to establish a central photographic collection for ITE so that a pictorial record of most research projects in the Institute will be available.

Research and Development

The way in which the work of the Subdivision is integrated into the research programme of the Institute is demonstrated by the few examples of development studies given here. In many cases these studies can be linked with the parent research projects described elsewhere in this Annual Report.

Continuous flow development studies

The project group studying pollutants in aquatic ecosystems plans to relate its work in the field to experiments in the laboratory. For this purpose, a continuous flow system is being developed at Monks Wood.

One of the major problems associated with a continuous flow system is the need to provide a satisfactory water supply. The supply must not only be relatively free from any chemical and physical changes, but should also resemble water in the field situation. For this purpose, a reverse osmosis/deionised plant has been installed and apparatus is being constructed which will add predetermined quantities of inorganic substances to the purified water. A wide range of mineralised waters will then be available for experimental purposes.

A pilot system has already proved satisfactory in operation and has enabled problems, including the dosing and dissolution of calcium carbonate, the mixing of soluble additions and the rate of equilibrium of the demineralised water, to be solved. The system has supplied water to aquaria for several months with no apparent shortcomings.

An automatic plant which would continually remineralise deionised water is under construction (see below). The plant when complete will provide sufficient water for a continuous flow laboratory carrying out a number of separate major experiments.

K.R. Bull

Construction of continuous flow plant

The Engineering Section has made a major contribution to the construction of the continuous flow plant. This included the assembly of the dosing, gasification, mixing equipment and all the associated storage tanks, pipework and control valves. Much of this work has involved fabrication with plastic materials. The Central Engineering Unit also designed and constructed the electronic logic control system to regulate the stages involved in the remineralisation process. Quality control and fail–save features are incorporated in the process.

G.H. Owen, C.R. Rafarel and V.W. Snapes

X-ray fluorescence spectrometry

Techniques have now been developed enabling the Merlewood X-ray fluorescence spectrometer to be used for most biomaterials. Soils and rocks are milled to a fine powder and then fused with sodium tetraborate and sodium carbonate to give a glass bead. After measurement of the X-ray intensities, calibration is carried out by comparison with standards of known composition treated in the same way. Vegetation samples are very finely milled and pressed into a disc using a ring mill. Samples of similar material previously analysed by standard analytical techniques are used for calibration. In the case of the soil samples, the final composition is calculated using an iterative procedure on the computer, whereas a calibration curve is referred to for the vegetation samples. Slightly different procedures are available for other material types.

The major use of the X-ray spectrometer during the year has been for the determination of sulphur in vegetation. Large numbers of the leaf and bark samples from various plant species have been examined in connection with the pollution studies centred on Manchester and Glasgow.

J.A. Parkinson and J.D. Roberts

Determination of opal silica

In connection with work on the nutrient balance in Loch Leven, there was a need to determine silicon in the phytoplankton. The method used for this purpose was based on the determination of opal silica by IR spectroscopy. This required the grinding and sieving of very small sample weights and the even dispersal of the ground material in a potassium bromide matrix. The uneven density of the material was especially troublesome and it was necessary to develop a small magnetically-driven device to overcome the problem.

C. Quarmby

Analysis of Cyanatryn

As a result of a Nature Conservancy Council contract to look into the effects of Cyanatryn on waterways, it was necessary to develop a method for its determination. This was done with the co-operation of Shell Chemicals. The water samples were partitioned with diethyl ether and the final volume was reduced to 3 ml on a hot water bath. The ether extracts were analysed, using a gas chromatograph equipped with a flame photometric detector set in the sulphur mode. The gas chromatograph incorporated a glass column packed with 2% OV 225 on Gaschrum W and the column temperature was maintained at 200 °C.

M.C. French and R.J. Mellor

Bomb calorimetry studies

There have been a number of requests for energy data on unusual material types (algal, bacterial, animal organs, soil fractions), some of which were only available in very small quantities. These determinations posed some difficult technical problems which necessitated the modification of established bomb calorimetry procedures and equipment. A miniature adiabatic system was used for processing the micro samples, using a digital thermometer to improve sensitivity. Comparison with a conventional micro bomb showed the miniature adiabatic method to have greater precision. Special precautions, including a freeze separation stage, were needed for preparation of the labile materials.

S.E. Allen and A.P. Rowland

Plant nutrient survey

Further processing of data from the national survey of plant nutrients was carried out during the year. Particular attention was paid to a selection of tree, herb and grass species, and the inter-relationships between soil extractable values and leaf concentrations were examined. The pattern of relationships differed between species and shows that the growth of a widespread native species may not be free of environmental stress in the range of sites or habitats in which it appears to be dominant.

H.M. Grimshaw

Nitrate in natural waters

The Chemical Section has, over many years, carried out tests on the concentrations of nitrogen fractions in natural waters. These data are frequently required for nutrient and productivity studies by ITE staff and some tests are sometimes done for various conservation bodies when areas of ecological interest are threatened by pollution. As a result of this work, it has been observed that the background levels of nitrate–nitrogen, in particular, have been increasing steadily over the last ten years or more. Concentrations of 5 $mg\,l^{-1}$ were the exception in the early sixties yet now they are commonplace and even values over 50 $mg\,l^{-1}$ have been obtained. The water authorities are fully aware and concerned about the situation in so far as it affects drinking water supplies. A Committee of the Department of the Environment is co-ordinating work on the problem and the Water Research Council is looking into methods for its removal. However, the figures produced by the Chemical Section are of interest because they are often obtained for sites distant from urban and intensive agricultural areas. It would appear that the effects of inorganic fertilisers and animal waste products are much more widespread than many realise.

S.E. Allen and J.A. Parkinson

Isoenzymes in Puccinellia maritima

Isoenzymes have been examined in connection with the project on the genecology of *Puccinellia maritima* referred to elsewhere in this report. The original isoenzyme trials were carried out in conjunction with the John Innes Institute at Norwich. The plant tillers, grown in culture solution, are ground with sand, centrifuged and the supernatants are then injected into gel slots on an electrophoresis apparatus. The flat-bed method using an 8% poly-acrylamide gel allows ten samples to be run at once and the technique has been further modified to enable thicker gels to be used. After running, the gel is sliced and stained for exterase, acid phosphatase, peroxidase, 1-glutamate dehydrogenase and 1-malate dehydrogenase. Other enzyme systems are also periodically screened.

R.J. Parsell

Dust-free collection of precipitation

In the studies on pollution wash-out from the atmosphere, it was necessary to eliminate the effect of dry dust settlement. This required a device to cover the collection funnel until the first spots of rain occurred and to close again after the precipitation ceased. The mechanism takes the form of a horizontally rotating cover plate which also acts as a sounding board for a microphone sensor. The microphone, with associated electronics, triggers the mechanics. Conductive sensors were also tried, but were found less reliable with the limited battery power available. This device is the subject of a patent application.

D.G. Benham.

Production of birch in aseptic media

A request was received from the Unit of Invertebrate Virology, in connection with their work on hardwood viruses, for some uncontaminated birch clones. The first step was to increase the clonal material by growing mini-cuttings in aseptic culture. The rooted cuttings, when between 5 and 10mm in length, were then transferred to seed trays containing finely sieved potting compost. The seed trays were covered with an enclosure to maintain a high humidity, which was removed when the plants were able to grow freely in a normal glass-house environment. By refining the technique, it was possible to increase the success rate from 20 to 80%.

R.F. Ottley

SUBDIVISION OF DATA AND INFORMATION

The role of the Subdivision

Much of the research of ITE is quantitative and involves the collection, analysis and storage of data. Although individual scientists frequently undertake these tasks for themselves, there are many occasions when specialist advice or a service is required. The Subdivision of Data and Information provides this advice, together with responsibility for the library service and the public relations and publications role of the Institute, which is a logical development from its scientific data processing responsibilities.

Biometrics

Although, traditionally, ecology has been a science of observation and description, there has been an increasing reliance on experiment and analysis in recent years. Many more ecologists in ITE are using multivariate analytical techniques to reduce the complexities involved in the description of ecosystems and these sophisticated mathematical methods require considerable specialist advice if they are to be usefully applied. In addition, although it has not been the general practice to use controlled experiments in ecology, these are becoming more common. The Data and Information Subdivision provides this essential statistical advice through its biometricians. The policy of the Subdivision is to locate a biometrician at each of the major stations of the Institute, where possible, with a core of consultant statisticians located at the Cambridge Headquarters for more specialist problems. Three stations (Merlewood, Monks Wood and Furzebrook) have biometricians located at the station, but the remainder use the central consultants who visit the stations at frequent intervals.

Computing

Although there has been a considerable increase in the biometrics advice required in recent years, perhaps the most dramatic increase in demand has been for computer storage and retrieval of data. Indeed, the increasing demand for analytical techniques is partly linked with the growth in computer skills amongst ITE ecologists which began with the installation of the PDP 8/I computer at Merlewood in 1970.

Four stations now have in-house mini-computers of the PDP (DEC) range: a PDP 8/I at Merlewood with time-sharing facilities, and PDP 11/10s at Monks Wood, Bangor and Brathens. These are supported by the use of large NERC, SRC and University computers as necessary. In each station, a member of the Subdivision is responsible for providing a computer service. However, all the in-house computers are used interactively by the staff of the station, using the BASIC language, and the traditional role of computer scientists as providers of a service to passive users is not encouraged. The systems staff of the Subdivision are also developing software of relevance to data storage and retrieval, to mathematical modelling and statistical analysis.

Mathematical modelling

The third major responsibility of the Subdivision is the provision of advice on and the development of mathematical models of ecological systems and processes. Since the considerable interest in mathematical models of ecosystems generated by IBP, there has been less enthusiasm for this activity among ecologists. This is perhaps understandable since many worthwhile efforts failed for lack of ecological understanding or appropriate data, or both. However, it is clear that the interest which has remained demands simpler and better researched models, developed and

used by biologists, with mathematicians providing expertise and rigour as necessary. The Subdivision is the focus for these developments in ITE, although colleagues in other Subdivisions are also much involved. In particular, there has been considerable effort put into examining the strengths and weaknesses of the resource models currently popular, but the policy has been to advance on several related fronts using a variety of modelling techniques from difference/differential equation systems to Markov type probabilistic models. The mathematical model developments are mainly centred on Bangor and Merlewood which have a long-standing interest in the techniques from their IBP involvement.

Data banks

A particular use of the computer expertise of the Subdivision has been the development of environmental and biological data banks. A principal focus for this has been the Biological Records Centre at Monks Wood, which, for many years, has been responsible for the production of distribution maps of British and European biota. Although this is still the major data banking group of the Subdivision, there have been developments at other centres. Subdivisional staff at Merlewood have been closely involved with the storage and retrieval of survey data from several contract surveys involving uplands and the coast. In Bangor, a more general Environmental Data Service has been set up in order to store data of relevance to decision-making by government, closely linked with the Biological Records Centre's data banks. In Cambridge, a data storage and retrieval programme written for collating information about insects feeding on plants promises to have wider applications and is designed with this in mind.

Library

Until 31 December 1976, library services for ITE have been provided in part by the Nature Conservancy Council. However, since then, the addition of three posts has allowed ITE to organise its own library service. Although little basic change has occurred in the service provided, increasing use is being made of modern information processing procedures and the Institute's computers are being more widely exploited. Close links are being maintained between the scientific data banks of the Institute and that of the library service, allowing cross-referencing and key-word description, and there are developments in the use of microfiche for more effective storage and dissemination of data and literature within ITE.

Publication and public relations

More recently the Subdivision has become responsible, with the Director, for the publication of ITE literature and for those aspects of public relations best co-ordinated centrally. Although the writing of scientific papers is the major publication method for ITE, there are many investigations which are not amenable to this publication style. For these longer publications, e.g. this Annual Report, ITE has acted as publisher to save costs and ensure uniformity of style.

Special reports

(1) *Measures of biomass, moulting behaviour and the pattern of early growth in Chorismus antarcticus*

The animal *Chorismus antarcticus* is a prawn like those found on a fishmonger's slab. It grows up to 10cm long when mature, and can be over 1gm in live weight. The animal is unusual in that it passes through the immature, male, intersex and female stages successively as it gets older and bigger. Thus, the biggest specimens of *Chorismus* are female. The biology of *C. antarcticus* is of interest as this is one of only two species of prawn common in the Antarctica, a region which, in comparison with the arctic and temperate water, is notable for the virtual absence of prawns, shrimps, crabs and lobsters.

The experimental animals were collected by sampling the sea-bed towing a small trawl behind a dinghy each month throughout 1972 at King Edward cove, South Georgia. The observations included the records of fresh weight, dry weight, ash weight and the thoracic length of individual prawns. The research has been concerned with the investigation of the water, dry matter, mineral ash and lipid (fat) content of these animals throughout the year. An estimated growth curve for the first 15 months of post-larval life showed a marked seasonal pattern of relatively rapid growth in summer and slow growth in winter. A growing prawn must moult, and, immediately after moulting, the prawn absorbs a quantity of brine. A freshly moulted prawn can therefore be identified by its high water content. The relationship between the dry weight and fresh weight of the monthly samples showed that moulting in these prawns occurs more frequently in the summer months and in the younger stages.

A number of polar invertebrates have a slower growth rate than related warm-water forms. The relative growth in *C. antarcticus* at South Georgia during the first 15 months of post-larval life was found to be slower than that of any temperate water prawn or shrimp so far studied.

Andrew Clarke (B.A.S.) and K.H. Lakhani

(2) *Phytophagous insects data bank*

(This work was supported by the Nature Conservancy Council)

There are many data in the literature and in unpublished sources on the food-plants of insects, but these data have not been brought together in a comprehensive and accessible way. In particular, the insects associated with each plant species can usually only be listed by consulting many scattered references. New data on feeding habits and taxonomy are also being produced constantly. This project aims therefore to collate the information about insects feeding on plants in Britain by using a computer-based data banking system. The results, when complete, will have a number of applications in conservation and agriculture, as well as in more theoretical studies of ecology and evolution.

The data bank has been designed to allow complex food-chain relationships, including predatory and parasitic insects, to be incorporated, and it would be possible to use the system for other groups of animals or plants with similar feeding or other associations. The data bank will also be flexible in access for non-routine inquiries.

The data to be incorporated are very variable in quantity and quality, and much care has been expended on the design of coding forms to make them usable in varying circumstances and by less experienced staff. A pilot study is being conducted with the plant bugs *Heteroptera* as an example, and some 450 records with 1,220 feeding relationships are being tested with the computer programs. Abstracting of data on weevils (*Coleoptera: Curculionidae*) is also practically complete. Each record is basically of a species, its feeding habit, the plant or animal hosts, and the source of the data. The dates of occurrence, the stage of the insect (adult/larva), some geographical data, the part of the host attacked, and other points can be recorded. There are codes for the animals to Family and for plants to Genus, so that either alphabetic or taxonomically-ordered listings can be obtained. Standard checklists are used throughout and synonyms can be included on the forms.

The data bank uses the Science Research Council's 1906A computer at Chilton (but will be forced to change in 1978 when this facility closes down). The programs are rather complex with complicated data, and involve fields that can be present or absent, variable length records, and the use of a SORT/MERGE package. The system is being designed to be self-managing. An input program has been written to identify errors in coding and punching, and the test data have been run and validated successfully. This program also reformats the data in a form more suitable for computer processing. The main sorting programs are virtually complete and much of the output programming finished.

The present intention is to make a first rapid survey by abstracting the most important literature sources to provide working lists for all the phytophagous insect groups and their food-plants. This survey will be followed by the publication of detailed catalogues to include all the available literature and advice from experts in the groups. The pilot study on *Heteroptera* and that on the *Curculionidae* has shown how much work is involved in preparing these accurate listings.

L.K. Ward and D.F. Spalding

(3) *NATO Ecoscience Conference, Iceland, 1976: The rehabilitation of severely damaged land and freshwater ecosystems in temperate zones*

Most western scientists are aware of NATO's (North Atlantic Treaty Organisation) support for science through research grants, exchange programmes, advance study institutes and conferences—the smiling face of NATO. One example was the Conference held in Reykjavik, Iceland, in which Institute staff were heavily involved in the British contribution.

The Scientific Director of the Conference was Dr M.W. Holdgate, former Director of the Institute. He was assisted by M.J. Woodman who organised the Conference with the help of ITE Headquarters staff. J.N.R. Jeffers, Director ITE, and Dr Holdgate both presented papers to the Conference.

Iceland was chosen because of its northern oceanic situation, recent glaciation and continuing volcanic activity, which make it distinct as a habitat with a flora and fauna of special interest. A land of great natural beauty, its ecosystems are exceptionally vulnerable to both the impacts of man and nature. The two-day excursions enabled the Conference members to see the problems of soil erosion, soil reclamation and afforestation at first hand, as well as the volcanic deserts and farmlands. Nearly a third of the Conference members were Icelandic scientists who were able to meet and exchange ideas with scientists from eleven NATO countries.

The Conference had a very topical theme in considering the damage to northern temperate ecosystems and the consequent losses in environmental stability, biological productivity, genetic diversity and human welfare. As the 24 papers were presented, two interwoven themes became apparent. One dwelt on the evaluation of ecosystems and the wise use of natural resources, while the other was a practical analysis of

how to handle devastated land and freshwater systems.

The first session discussed basic ecological principles, particularly the mathematical analysis and description of the behaviour of populations and ecosystems. The second session covered the problems of ecosystem degradation, while the third dealt with their successful restoration. Both these sessions relied heavily on case studies for this purpose. The fourth session considered guidelines for the management of ecosystems which would avoid future devastation but ensure the optimal use of natural resources.

The overall conclusion was that it is scientifically possible to prescribe for the improvement of degraded ecosystems, even if more research was needed to carry out prescriptions economically, extend the range of possible choices, and increase productivity at the same time.

In detail, it was agreed that ecosystem modelling required much more development before it was of practical use to land managers, particularly in predicting change. The most fruitful areas for research lay in soil microbiology, the maintenance of the physical stability of soils, and nutrient cycling where they contributed to the rehabilitation of derelict land.

Finally, scientific knowledge based on the survey of ecological patterns, on explanations of causes, and on the prediction of likely trends under various kinds of management, must be built into the policies of those who shape the world in which we live. The ecologist cannot escape from his responsibility for seeing that this happens.

The proceedings of the Conference will be published in 1977, and further information can be obtained from ITE Headquarters in Cambridge.

M.J. Woodman

Projects

listed by subdivisions as at 30 March 1977

Station code

1 Monks Wood Experimental Station
2 Merlewood Research Station
3 Colney Research Station, Norwich
4 Furzebrook Research Station
5 Edinburgh (Bush)
6 Edinburgh (Hope Terrace)
7 Banchory (Brathens)
8 Banchory (Blackhall)
9 Bangor Research Station
10 Cambridge HQ
11 NERC
12 Cambridge CCAP
13 c/o UIV, Oxford

Project status

* Ph.D. student supervised by ITE
† Paid for by external contract
‡ Supported by Nature Conservancy Council
§ Supported by Department of Environment

ANIMAL ECOLOGY: VERTEBRATE ECOLOGY

			code
54	V.P.W. Lowe	Red deer ecology on Rhum	2
57	V.P.W. Lowe	Bark stripping by grey squirrels	2
59	V.P.W. Lowe	Taxonomy of the red squirrel	2
67	J.D. Goss-Custard	Prey selection in redshank	4
68	J.D. Goss-Custard	Dispersion in waders	4
104	B.W. Staines	Distribution and segregation of red deer	7
106	B.W. Staines	Red deer food studies	7
109	B. Mitchell	Annual cycles in Scottish red deer	7
111	B. Mitchell	Population dynamics of red deer	7
116	P.S. Maitland	Freshwater survey of Shetland	6
117‡	P.S. Maitland	Freshwater synoptic survey	6
123	P.S. Maitland	Zoobenthos at Loch Leven	6
124	P.S. Maitland	Fish distribution and conservation	6
134	D. Jenkins	Shelducks at Aberlady Bay	7
136	N. Picozzi	Hen harrier ecology	8
137‡	I. Newton	Sparrowhawk research	6
138‡	M.P. Harris	Puffin research	7
159	D.C. Seel	Upland bird project	9
291‡	R.E. Stebbings	Population ecology of bats	1
292‡	R.E. Stebbings	Specialist advice on bats	1
325†	I. Newton	Carrion-feeding birds in Wales	6
363	N. Charles	Dispersion of field voles, Scotland	6
386	H. Kruuk	Behaviour and dispersion of badgers	7
391	V.P.W. Lowe	British mammals (red fox)	2
420	V.P.W. Lowe	Intraspecific variation in Polar bear	2
430	D. Jenkins	Dynamics of mute swan population	7
439	B. Mitchell	Red deer population on Isle of Scarba	7
441	J.D. Goss-Custard	Oystercatcher and shellfish interaction	4
442	R. Moss	Ecology of capercaillie	8
460	M.P. Harris	Interaction of gulls and puffins	7
461‡	M.P. Harris	Puffins and pollutants	7
479	B.W. Staines	Red deer and woodlands	7
492‡	B. Mitchell	Ponies and cattle in New Forest	7
498*	L.C. Corbett	Wildcat studies	7
524	K.C. Walton	Fluoride in predatory mammals	9
525	D.C. Seel	Fluoride in predatory birds	9

ANIMAL ECOLOGY: INVERTEBRATE ECOLOGY

64	S. McGrorty	Intertidal invertebrate surveys	4
65	S. McGrorty	Invertebrate population studies	4
66	S. McGrorty	Variation in strandlines	4
161	A. Buse	Littoral fauna of Llyn Peris	9
162	A. Buse	Freshwater gastropods in North Wales	9
185	B.N.K. Davis	Effect of urbanisation	1
188	R.C. Welch	Woodland invertebrates	1
201	E. Pollard	The white admiral butterfly	1
202	E. Pollard	The roman snail	1
203	J.P. Dempster	The cinnabar moth	1
204‡	E. Pollard	Assessing butterfly abundance	1
205	E. Pollard	Invertebrates in hawthorn hedges	1
229	M.G. Morris	Ecology/taxonomy–Spanish Hemiptera	4
230	M.G. Morris	Cutting experiment (Coleoptera)	4
231	M.G. Morris	Barton Hills grazing experiment	4

Animal Ecology: Invertebrate Ecology continued

232	M.G. Morris	Butterfly studies (Porton Range)	4
233	M.G. Morris	Cutting experiment (Hemiptera)	4
234	M.G. Morris	Grassland management by fire	4
236	E. Duffey	Invertebrate populations in grass sward	1
241	L.K. Ward	The fauna of box	1
243	L.K. Ward	Scrub succession at Aston Rowant NNR	1
255	G.W. Elmes	Ecology of *Myrmica* species	4
256	B. Pearson	Protein electrophoresis	4
261	B. Pearson	Caste bias in *Myrmica* eggs	4
262	A. Abbott	Digestive enzymes	4
270	P. Merrett	Distributional studies on spiders	4
273	N.R. Webb	Productivity of *Steganacarus magnus*	4
274	N.R. Webb	Physiology of soil fauna	4
277	N.R. Webb	Moth collection by light trap	4
278	P. Merrett	Spider populations on heather	4
295	L.K. Ward	Survey of juniper in N. England	1
296	L.K. Ward	Scrub management at Castor Hanglands	1
309‡	L.K. Ward	Phytophagous insects data bank	1
338	A. Buse	Role of birds in NPV	9
345	E. Duffey	Spiders in East Anglian fens	1
381	D.G. George	Plankton populations in Loch Leven	6
393	J.P. Dempster	The swallowtail butterfly	1
399	B.N.K. Davis	Isolated phytophagous insects	1
400‡	J.A. Thomas	Ecology of large blue butterfly	4
403	J.A. Thomas	Black hairstreak butterfly	4
404	J.A. Thomas	Brown hairstreak butterfly	4
405‡	P.T. Harding	Fauna of mature timber habitat	1
406	P.T. Harding	Non-marine Isopoda	1
407	R.C. Welch	British Staphylinidae (Coleoptera)	1
414	P. Merrett	Hartland Moor spider survey	4
423*	A.M. Nicholson	Predator/prey relations on heathland	4
450	P.E. Jones	Ecology of pseudo scorpions	1
469	E. Duffey	Scottish invertebrate survey	1
470	A. Buse	Upland invertebrates	9
476	R.C. Welch	BSES Arctic Finland expedition	1
500	P. Merrett	Spiders on Hartland Moor NNR	4
509*	M. Warren	Wood white butterfly population ecology	1
519	G.W. Elmes	*Myrmica sabuleti* and *M. scabrinodis*	4
527	D.G. George	Long-term changes in zooplankton	6

ANIMAL ECOLOGY: ANIMAL FUNCTION

178‡	R.K. Murton	Causes of seabird incidents	1
179‡	P. Ward	Heavy metals in waders	1
181‡	A.A. Bell	Birds of prey and pollution	1
182‡	H.R.A. Scorgie	Aquatic herbicides	1
183	A.S. Cooke	Frogs and pollution	1
193	N.J. Westwood	Stone curlew and lapwing	1
199	R.K. Murton	Avian reproduction and pollutants	1
289	F. Moriarty	Pollutants in freshwater organisms	1
413	I. Wyllie	Breeding biology of the cuckoo	1
436*	A. Tye	Social behaviour of thrushes	1
444	S. Dobson	Endocrine lesions in birds	1
455	D. Osborn	Heavy metals in avian species	1
456	D. Osborn	Heavy metals and metabolism	1

459	A.S. Cooke	Shell formation and pollution	1
473	A.A. Bell	Metal residues in birds of prey	1
475	P. Ward	Pollution and starling nutrition	1

ANIMAL ECOLOGY: GROUSE AND MOORLAND ECOLOGY

129	A. Watson	Red grouse and ptarmigan populations	8
130	A. Watson	Management of grouse and moorlands	8
131	A. Watson	Golden plover populations	8
132	A. Watson	Effect of human impact on wildlife	8
510*	G.R. Wilson	Caecal threadworm and red grouse	8

ANIMAL ECOLOGY: HEATHLAND SOCIAL INSECTS

252	M.V. Brian	Hartland Moor NNR survey	4
253	M.V. Brian	*Tetramorium caespitum* populations	4
258	M.V. Brian	Queen effect on larvae growth	4
259	M.V. Brian	Larvae and worker communication	4
260	M.V. Brian	Queen recognition by workers	4
263	M.V. Brian	Worker ant activity	4
264	M.V. Brian	IBP ant and termite synthesis volume	4
370	M.V. Brian	Reduction of inter-species competition	4
371	M.V. Brian	Male production in *Myrmica*	4

PLANT ECOLOGY: PLANT BIOLOGY

2	E.J. White	Meteorological factors in classification	2
19	E.J. White	Nutrient input in rainfall	2
69	R. Scott	Study of *Cakile*	3
73	A.J. Gray	*Puccinellia maritima*	4
81	G.R. Miller	Plant production, grazing and tree-line ecology	7
82	G.R. Miller	Seed produced by montane plants	7
100	N.G. Bayfield	Trampling effects on montane grassland	7
102	N.G. Bayfield	Mountain vegetation populations	7
121	M.E. Bindloss	Phytoplankton productivity	6
125	R.E. Daniels	Peatland monograph	6
158	D.F. Perkins	Community processes (physiology)	9
160	D.F. Perkins	Fluorine pollution studies	9
245	J. Pelham	Genetics of *Betula* nutrition	5
246	E.D. Ford	Physical environment, forest structure	5
247	K.A. Longman	Physiology of flowering	5
248†	K.A. Longman	Physiology of root initiation	5
249	M.G.R. Cannell	Morpho-physiological differences	5
265	S.B. Chapman	Regeneration on lowland heaths	4
266	S.B. Chapman	Root dynamics of *Calluna vulgaris*	4
269	S.B. Chapman	Autecology of *Gentiana pneumonanthe*	4
329	E.J. White	Response of Scots pine	2
346	A.J. Gray	Genecology of grass species	4
359	M.G.R. Cannell	Fibre yield of poplar coppice	5
408†	F.T. Last	Arboriculture: selection	5
410	N.J. Collins	Tundra plants (bryophytes)	5
411	S.W. Greene	Taxonomy of bryophytes	5
412	B.G. Bell	Genecology of *Racomitrium*	5
437†	A.J. Gray	Further ecological studies on the Wash	4
451	T.V. Callaghan	Tundra plant growth	2
493	N.J. Collins	Physiological life cycle of mosses	5
506	J.I. Cooper	Viruses of trees	13

PLANT ECOLOGY: PLANT COMMUNITY ECOLOGY

1	R.G.H. Bunce	Semi-natural woodland classification	2
6	R.G.H. Bunce	Scottish native pinewood survey	2
9	J.M. Sykes	Monitoring at Stone Chest	2
13	M.W. Shaw	N.W. (E) commercial forest survey	2
14	A.D. Horrill	Tree girth changes in 5 NNRs	2
48‡	A.D. Horrill	Asulam effects on 3 upland pastures	2
50	M.W. Shaw	Defoliation of oak seedlings	2
55	A.H.F. Brown	Establishment of trees at Moor House	2
60	D.R. Helliwell	Experimental transplants of *Primula vulgaris*	2
72	D.S. Ranwell	Salt marsh management	3
74	D.S. Ranwell	Sand dune stabilisation	3
75	D.G. Hewett	Control of *Spartina*	9
76	D.G. Hewett	Mature shingle beach vegetation, Sussex	9
77	D.G. Hewett	Cliff vegetation methods	9
78	D.G. Hewett	Management of sand dunes (Wales)	9
83	J.W. Kinnaird	Management for birch regeneration	7
84	J.W. Kinnaird	Tree age and woodland history, Scotland	7
85	J.W. Kinnaird	Growth and survival of birch in shade	7
86	J.W. Kinnaird	Seed production of *Betula pubescens*	7
91	I.A. Nicholson	Vegetational succession: a review	7
92§	D. Welch	Grazing intensities causing change	7
93§	D. Welch	Assessing animal usage, N.E. Scotland	7
94	I.A. Nicholson	Grazing effect on 30 sites, Scotland	7
95	D. Welch	Importance of dung for botany change	7
96	D. Welch	*Narthecium ossifragum* and burning	7
112	I.A. Nicholson	Ecology of a Highland deer forest	7
113	J.W. Kinnaird	Vegetation monitoring at Inverpolly	7
114	I.A. Nicholson	Forest damage by red deer	7
115	I.A. Nicholson	Autecology of *Agropyron junceiforme*	7
163	M.O. Hill	Ordination and classification methods	9
165	M.O. Hill	N. Wales bryophyte recording	9
184	J.M. Way	Management ecology of transport routes	1
186‡	M.D. Hooper	'Island' effect on plant communities	1
187	M.D. Hooper	Vegetation history from opals in soils	1
191	A. Millar	Forest management studies	2
225	T.C.E. Wells	Population studies on orchids	1
227	T.C.E. Wells	Sheep grazing on chalk grass flora	1
228	T.C.E. Wells	Effect of cutting on chalk grassland	1
237‡	M.J. Liddle	Organic fertiliser effect on grass	1
242‡	T.C.E. Wells	Re-establishment of chalk grassland	1
251	J.E.G. Good	Lothian survey	9
318	A.J.P. Gore	Peat hydrology	1
340‡	D.S. Ranwell	Coastal surveys in Scotland	3
349†	L.A. Boorman	Maplin brent goose and wader studies	3
360	J.E.G. Good	Trees on industrial spoil	9
362	R.G.H. Bunce	Ecological survey of Cumbria	2
364	D.R. Helliwell	Early growth of trees	2
367	A.H.F. Brown	The Gisburn experiment	2
368‡	M.O. Hill	Afforestation effect on uplands	9
369§	J.W. Kinnaird	Sulphur content of tree leaves and bark	7
374	L.A. Boorman	Sand dune ecology (E. Anglia)	3
377	J. Sheail	Environmental perception studies	1
380§	I. Nicholson	Monitoring of atmospheric SO_2	7

383	D.R. Helliwell	Shading effect on *Primula vulgaris*	2
388	J.M. Sykes	Rusland moss survey	2
389‡	A.H.F. Brown	Management effect in lowland coppices	2
392†	A.J.P. Gore	Amenity grass-cultivar trials	1
413	I. Wyllie	Breeding biology of the cuckoo	1
417	D.R. Helliwell	Silvicultural systems	2
424	R.G.H. Bunce	Ecological survey of Britain	2
426§	I.A. Nicholson	Modelling of sulphur pollution	7
428†	T.C.E. Wells	Vegetation management in country parks	1
435	C.J. Barr	Ecology of *Sorbus aucuparia*	2
452§	J.W. Kinnaird	Foliar leaching and acid rain	7
454‡	J.M. Sykes	NCC monitoring of woodlands	2
463	J.E.G. Good	Age class of amenity trees	9
465‡	M.D. Hooper	Stanford P.T.A.	1
466‡	J.M. Way	Ecology of railway land	1
483‡	R.G.H. Bunce	Scottish deciduous woodlands	2
495†	A.J.P. Gore	Soil acidification	1
497‡	A.E. Bailey-Watts	Macrophyte studies	6
502†	J.M. Sykes	Monitoring Indian tiger reserves	2

PLANT ECOLOGY: SOIL SCIENCE

4	P.J.A. Howard	Soil classification methods	2
8	A.F. Harrison	Radiocarbon analysis of wood humus	2
17	J.E. Satchell	Meathop Wood IBP study	2
21	O.W. Heal	Decomposition in Meathop Wood	2
22	J.C. Frankland	Fungal decomposition of leaf litter	2
23	K.L. Bocock	Soil temperature in Meathop Wood	2
27	J.C. Frankland	Fungal biomass-Meathop litter and soil	2
29	A.F. Harrison	Phosphorus circulation	2
30	J.C. Frankland	Biomass and decay of *Mycena* in Meathop	2
32	O.W. Heal	Moor House IBP study	2
33	O.W. Heal	Vegetation decomposition, Moor House	2
34	A.D. Bailey	Radiation and temperature, Moor House	2
39	A.F. Harrison	Phosphorus turnover in soils	2
40	P.J.A. Howard	Woodland organic matter decomposition	2
45	O.W. Heal	Tundra biome IBP	2
51	P.M. Latter	Food consumption of Enchytraeidae	2
52	K.L. Bocock	Biological studies of *Glomeris*	2
61	A.F. Harrison	Variation in growth of birch and sycamore	2
87	J. Miles	Vegetation potential of upland sites	7
88	J. Miles	Plant establishment in shrubs	7
89	J. Miles	*Calluna–Molinia–Trichophorum* management	7
90	J. Miles	Birch on moorland soil and vegetation	7
140	M. Hornung	Weathering and soil formation, Whin Sill	9
148	M. Hornung	Soil erosion on Farne Islands	9
153	A. Hatton	Mineralogical methods	9
154	M. Hornung	Field recording of profile data	9
358	J.E. Satchell	Earthworm production-organic waste	2
384	S.M. Coles	Benthic microalgal populations	3
398§	O.W. Heal	Upland land use	2
431	P.J.A. Howard	Soil change through afforestation	2
432	J.E. Satchell	Birch litter	2
438	J.C. Frankland	Ecology of *Mycena galopus*	2

Plant Ecology: Soil Science continued

521*	I.D. Bishop	Mathematical modelling in Cumbria	2
522§	D.F. Ball	National land characterisation	9

PLANT ECOLOGY: N.W. WALES ECOLOGY

168	R.E. Hughes	Sheep population studies	9
170	R.E. Hughes	Arctic/alpine vegetation survey	9
171‡	R.E. Hughes	Bracken control with asulam	9
172	R.E. Hughes	Vegetation change with grazing	9
173	R.E. Hughes	Past land use in N.W. Wales	9
174	R.E. Hughes	Snowdonia vegetation map	9
175	R.E. Hughes	Herpetological studies	9

PLANT ECOLOGY: AIR POLLUTION

244	K. Mellanby	Biological indicators of air pollution	1

SCIENTIFIC SERVICES: DATA AND INFORMATION

44	D.K. Lindley	Information handling and retrieval	2
47	C. Milner	Shetland modelling	9
53	A.S. Gardiner	Variation in British woodland trees	2
58	A.S. Gardiner	Hazel and birch on Shetland	2
118	I.R. Smith	Lake hydraulics	6
119	I.R. Smith	Physical limnology	6
206‡	F.H. Perring	Rare species survey	1
207‡	F.H. Perring	Atlas of British Flora	1
208‡	F.H. Perring	Botanical data bank	1
209‡	H. Arnold	Amphibians and reptiles survey	1
210‡	H. Arnold	Mammal distribution survey	1
211‡	J. Heath	Lepidoptera distribution maps scheme	1
212‡	J. Heath	Odonata distribution maps scheme	1
213‡	J. Heath	Orthoptera distribution maps scheme	1
215	F.H. Perring	Biological information network	1
216	G.L. Radford	Register of NNRs	9
217	G.L. Radford	Species recording	9
218‡	G.L. Radford	Event recording	9
219‡	D.W. Scott	Data processing for BTO	1
221‡	D.W. Scott	Data processing for Wildfowl Trust	1
223	J. Heath	European Invertebrate Survey	1
224	F.H. Perring	Atlas flora Europaea	1
302	M.D. Mountford	Population growth and regulation	10
303	M.D. Mountford	Method of cluster analysis	10
304	M.D. Mountford	Estimation of quantiles	10
306	P. Rothery	Spatial processes and application	10
307	P.H. Cryer	Index of egg shell thickness	10
308	P.H. Cryer	Data from multi-compartment systems	10
310	D.F. Spalding	Polluted watercourses survey	10
311	D.F. Spalding	Data definition and validation	10
312	K.H. Lakhani	Population dynamics of the shrimp	10
313	M.D. Mountford	Seals research	10
314	M.D. Mountford	Wytham Wood survey	10
365	H.E. Jones	Competition between grass species	9

375	P. Rothery	Theoretical models of diet selection	10
376	C. Milner	Statistical training	9
401	K. Lakhani	Estimation without monitoring	10
402	M.D. Mountford	Biometrics advice to NERC	10
421	D.I. Thomas	Management information system development	9
429	D.K. Lindley	Data banking review	2
433	D.F. Spalding	Data transmission network	10
434	C. Milner	ITE computing services	9
477	A.S. Gardiner	Leaf-shape variation in *Nothofagus*	2
494	I.R. Smith	Computing facilities at Hope Terrace	6
496	D.W. Scott	Data processing services—Monks Wood	1
512	A.S. Gardiner	National collection of birch	2
514	A.S. Gardiner	British birch publication	2
529	D.W. Scott	Biological data bank	1
530	D.W. Scott	Laser scan mapping system	1

SCIENTIFIC SERVICES: CHEMISTRY

62	H.M. Grimshaw	National plant nutrient survey	2
378	S.E. Allen	Chemical data bank	2
481	K.R. Bull	*Sphagnum* 'moss-bag' monitoring	1
482	K.R. Bull	Chemistry of aquatic pollutants	1
484	J.A. Parkinson	Chemical technique development	2
485	M.C. French	Chemical support studies	1
486	G.H. Owen	Engineering development	9
487	C.R. Rafarel	Field logging systems	9
488	D.G. Benham	Data interface systems	2
489	R.F. Ottley	Glasshouse and nursery maintenance	5
490	C. Quarmby	Photographic development	2
491	S.E. Allen	Isotope development studies	2
501	C. Quarmby	ITE photographic collection	2
523*	H. Whittaker	New Forest soil characteristics	2

DIRECTORATE PROJECTS

462	J.N.R. Jeffers	NERC computer policy model	2
503	J.N.R. Jeffers	Development of systems analysis	2
504	J.N.R. Jeffers	Markov models	2
505	J.N.R. Jeffers	Ecology of Outer Hebrides	2
508	J.N.R. Jeffers	Botanical variation in elm	2
516	R.C. Steele	Forest management for energy	11
517	J.N.R. Jeffers	Primary productivity in woodlands	2
518†	J.N.R. Jeffers	UNESCO MAB information system	2
520†	J.N.R. Jeffers	Training of Obergurgl students	2

SCIENTIFIC SERVICES: CCAP

445	J.H. Belcher	Marine flagellates taxonomy	12
446	D.J. Hibberd	Freshwater flagellates taxonomy	12
447	F.C. Page	Freshwater and marine *Amoebae*	12
448	E.M.F. Swale	Colourless flagellates taxonomy	12
449	G.J. Morris	Preservation of cultures	12

LIST OF PROJECTS NOT YET APPROVED

97	D. Welch	Estimation of grazing intensity	7
322	D. Jenkins	Dispersal of otters	7
366	A.H.F. Brown	Unproductive woodland and coppice review	2
457	C. Milner	Grazing models	9
458	C. Milner	Shetland publication	9
464	M.J. Liddle	Interspecific competition and invasion	1
467	J.M. Way	Roadside experiments	1
471	M. Hornung	Soils of upper Teesdale	9
478	B. Mitchell	Red deer feasibility studies	7
499	V.P.W. Lowe	Classification of Cervidae	2
507	E.M. Field	Ecologists' flora	5
511	F.T. Last	Landscaping at Swindon	5
515	J.N.R. Jeffers	Alternative energy sources	2
526	F.T. Last	Monitoring in Banff and Buchan	5
528	B. Mitchell	Red deer in woodland habitats	7
531	R.T. Clarke	Statistical advice and computing, Furzebrook	4
532	R.T. Clarke	Statistical research at Furzebrook	4
533	P.A. Stevens	Podzolic soils	9
534	D.F. Ball	National land characterisation	9

Staff list: 31 March 1977

Institute of Terrestrial Ecology
Director
Mr J.N.R. Jeffers CSO
(Address as for Merlewood Research Station)

Headquarters
68 Hills Road
Cambridge
CB2 1LA
0223 (Cambridge) 69745–9

Institute Secretary
Mr J.G. Ferguson Principal

Administration and Finance Team
Mr R.T. Collins HEO
Mr E.C.J. Clapp HEO
Miss B.R. Boyden EO
Mrs W. Chrusciak EO
Miss M.J. Moxham SPS
Mrs I.P. Cooke CO
Mrs J.N. Minchin CO
Mr A.C.E. Taylor CO
Mrs E.M. Chambers Aud/T (PT)*

DIVISION OF SCIENTIFIC SERVICES

Subdivision of Data and Information
Mr M.D. Mountford PSO
Mr K.H. Lakhani PSO
Mr P.H. Cryer SSO
Mr P. Rothery SSO
Mr D.F. Spalding HSO

Publications and Liaison Officer
Mr M.J. Woodman PSO

Institute of Terrestrial Ecology
c/o Unit of Invertebrate Virology
5 South Parks Road
Oxford
OX1 3UB
0865 (Oxford) 52081

DIVISION OF PLANT ECOLOGY

Subdivision of Plant Biology
Dr J.I. Cooper SSO
Dr Mary L. Edwards SO (PT)
Mrs D. McCall ASO (PT)

* (PT) denotes part-time.

Monks Wood Experimental Station
Abbots Ripton
Huntingdon
PE17 2LS
048 73 (Abbots Ripton) 381–8

Head of Division of Animal Ecology
Senior Officer: Monks Wood
Dr J.P. Dempster DCSO
Mrs B.J. Stocker PS

Research/Education Officer
Mr P. Hardy HSO

Ecological Advisory Officer
Dr E.A.G. Duffey PSO

Administration

Station Secretary
Mr J.A. Cheesman HEO
Mr A.E. Cotton CO
Mrs M.B. Haas CO (PT)
Mrs J. Pilcher CO (PT)
Mr J.E. Sanderson CO
Mrs C.M. Shackcloth CO
Miss D.S. Varney CA
Mrs V.J. Burton Aud/T
Mrs G.J. Sanderson Aud/T
Mrs M.E. Chance Clnr (PT)
Mrs S. Ennis Clnr (PT)
Mrs J. McDowell Clnr (PT)
Mrs P.E. Schietzel Clnr (PT)
Mrs E. Underwood Clnr
Mrs D.I. Abbott H/kpr
Mr T.F. Farrington C/tkr
Mr A.W. Baker E/wkr

ANIMAL ECOLOGY

Subdivision of Vertebrate Ecology
Mr R.E. Stebbings SSO
Mr H.R. Arnold SO

Subdivision of Invertebrate Ecology
Dr B.N.K. Davis PSO
Dr E.A.G. Duffey PSO
Mr J. Heath PSO
Dr E. Pollard PSO
Dr Lena K. Ward PSO
Dr R.C. Welch PSO
Mr P.T. Harding HSO
Mr P.E. Jones SO
Mrs M.L. King SO
Mr G.J. Moller SO
Mr W.E. Rispin SO

Mrs J.M. Welch	SO
Miss H.A. Brundle	ASO
Mr J.N. Greatorex-Davies	ASO
Mr R. Plant	ASO

Subdivision of Animal Function

Head of Subdivision:

Dr R.K. Murton	PSO
Dr F. Moriarty	PSO
Dr P. Ward	PSO
Dr A.S. Cooke	SSO
Dr S. Dobson	SSO
Mr A.A. Bell	HSO
Mr D. Osborn	HSO
Dr H.R.A. Scorgie	HSO
Mr N.J. Westwood	HSO
Ms H.M. Hanson	SO
Mr I. Wyllie	SO
Mrs B.C. Dobson	ASO
Mrs S. Freestone	ASO
Mr H. Thomson	A/H kpr (PT)
Mrs E.E.C. Wade	A/H kpr (PT)

PLANT ECOLOGY

Subdivision of Plant Biology

Dr F.H. Perring	PSO
Miss L. Farrell	SO

Subdivision of Plant Community Ecology

Head of Subdivision:

Mr A.J.P. Gore	SPSO
Dr M.D. Hooper	PSO
Dr J. Sheail	PSO
Dr J.M. Way	PSO
Mr T.C.E. Wells	PSO
Dr M.J. Liddle	SSO
Mr A.J. Frost	HSO
Mr J.E. Lowday	SO
Miss E.J. Mackintosh	SO
Mrs S.A. Bell	ASO
Miss R. Cox	ASO
Mr J.O. Mountford	ASO

Special Group: Air Pollution
Professor K. Mellanby

SCIENTIFIC SERVICES

Subdivision of Data and Information

Miss D.W. Scott	SSO
Miss S.D. Dodson	SDP
Mrs C. Binge	DP (Con) †
Mrs J. Jackett	DP (Con)
Mrs M.I. Purdy	CO

Assistant Librarian
Mrs K.B. King

Subdivision of Chemistry and Instrumentation

Mr M.C. French	SSO
Dr K.R. Bull	SSO
Mr P. Freestone	SO
Mr R.J. Mellor	SO
Mr L.A. Sheppard	ASO
Mr V.W. Snapes	P & TO3 (Workshop)

Merlewood Research Station
Grange-over-Sands
Cumbria
LA11 6JU
044 84 (Grange) 2264–6

Director

Mr J.N.R. Jeffers	CSO
Mrs P.A. Ward	EO

Head of Subdivision of Soil Science
Senior Officer: Merlewood

Dr O.W. Heal	SPSO

Administration

Station Secretary

Mrs E. Foster	HEO
Mrs M.L. Barr	CO
Mrs P.M. Coward	CO
Miss V.E. Benson	Sh/T
Mrs C.G. Kay	Typist (PT)
Miss N.A. McHale	Typist
Mrs V.E. Smith	Typist
Miss C.R. Legat	CA (PT)
Mrs E. Burton	Clnr (PT)
Mr M. Casey	Clnr (PT)
Mrs V. Pearson	Clnr (PT)
Mr P.L. Foster	C/tkr
Mr J. Gaskarth	E/wkr

ANIMAL ECOLOGY

Subdivision of Vertebrate Ecology

Mr V.P.W. Lowe	PSO
Miss S.M.C. Robertson	ASO

PLANT ECOLOGY

Subdivision of Plant Biology

Dr T.V. Callaghan	SSO
Mr E.J. White	SSO

† (Con) denotes Contract Staff.

Subdivision of Plant Community Ecology

Mr A.H.F. Brown	PSO
Dr R.G.H. Bunce	PSO
Mr M.W. Shaw	PSO
Mr J.M. Sykes	PSO
Mr D.R. Helliwell	SSO
Dr A.D. Horrill	SSO
Mr A. Millar	SSO
Mr C.J. Barr	SO
Mr N.J. Pearce	SO
Mrs T.J. Clarke	ASO (PT)
Miss K.E. Dickson	ASO (PT)

Subdivision of Soil Science

Mr K.L. Bocock	PSO
Mr P.J.A. Howard	PSO
Dr J.E. Satchell	PSO
Dr Juliet C. Frankland	SSO (Con PT)
Dr A.F. Harrison	SSO
Mr A.D. Bailey	HSO
Mr C.B. Benefield	HSO
Miss P.M. Latter	HSO
Mr J.K. Adamson	SO
Mrs D.M. Howard	SO
Mrs G. Howson	SO (PT)
Mr M.R. Smith	SO
Miss P.L. Costeloe	ASO (PT)
Mr A. Nelson	ASO
Miss A.A. Webb	ASO

SCIENTIFIC SERVICES

Subdivision of Data and Information

Mr D.K. Lindley	PSO
Mr A.S. Gardiner	SSO
Dr Helen E. Jones	SSO (Con PT)
Mrs J.M. Adamson	SO
Mr R.T. Clarke	SO
Miss N.M. Hamilton	SO
Mrs F.J. Shaw	SO

Librarian
Mr J. Beckett

Subdivision of Chemistry and Instrumentation

Head of Subdivision:

Mr S.E. Allen	PSO
Mr H.M. Grimshaw	SSO
Mr J.A. Parkinson	SSO
Mr C. Quarmby	SSO
Mr J.D. Roberts	HSO
Mr D.G. Benham	SO
Mr A.P. Rowland	SO
Mr P.A. Coward	ASO
Miss M. Dewhurst	ASO
Mrs V.H. Kennedy	ASO (PT)
Miss P.E.M. McKinley	ASO
Miss J. Wilkinson	ASO
Mrs S.M. Zirkel	ASO (PT)

Furzebrook Research Station
Wareham
Dorset
BH20 5AS
092 93 (Corfe Castle) 361–2

Head of Subdivision of Invertebrate Ecology
Senior Officer: Furzebrook

Dr M.G. Morris	SPSO

Administration

Station Secretary

Mr R.J. Currey	EO
Mrs M.K. Perkins	CO
Mrs R.J. Orr	CA
Miss W. Richmond	Typist
Mrs N.M. Fooks	Clnr (PT)
Mrs D.S. Malt	Clnr (PT)
Mr D.C.P. Malt	C/tkr

ANIMAL ECOLOGY

Subdivision of Vertebrate Ecology

Dr J.D. Goss-Custard	PSO

Subdivision of Invertebrate Ecology

Dr P. Merrett	PSO
Mr G.W. Elmes	SSO
Dr J.A. Thomas	SSO
Dr N.R.C. Webb	SSO
Dr S. McGrorty	HSO
Mr R.G. Snazell	HSO
Mr A.M. Abbott	SO
Mr B. Pearson	SO
Mr M.J.L. Skelton	SO
Mrs J.C. Wardlaw	ASO

Special Merit: Heathland Social Insects

Dr M.V. Brian	SPSO

PLANT ECOLOGY

Subdivision of Plant Biology

Dr S.B. Chapman	PSO
Dr A.J. Gray	PSO
Mr R.J. Rose	ASO

Colney Research Station
Colney Lane
Colney
Norwich, Norfolk
NR4 7UD
0603 (Norwich) 54923–5

Senior Officer: Norwich

Dr D.S. Ranwell	PSO

Administration

Station Secretary

Mr B.W.E. Austen	EO
Mrs L.A. Jenkins	CO
Miss V.J. Knowles	Sh/T
Mrs S.M. Crump	Typist (PT)

ANIMAL ECOLOGY

Subdivision of Invertebrate Ecology

Mr C.J. Reading	SO

PLANT ECOLOGY

Subdivision of Plant Biology

Mr R. Scott	SO

Subdivision of Plant Community Ecology

Dr L.A. Boorman	PSO
Mr R.M. Fuller	SO
Miss J.M. Pizzey	SO
Miss L.P. Harrison	ASO

Subdivision of Soil Science

Dr Susan M. Coles	HSO

SCIENTIFIC SERVICES

Subdivision of Chemistry and Instrumentation

Mr P.G. Ainsworth	SO
Mr R.J. Parsell	SO

Institute of Terrestrial Ecology
Bush Estate
Penicuik
Midlothian
EH26 0QB
031 445 4343–6

Head of Division of Plant Ecology
Senior Officer: Edinburgh

Professor F.T. Last	DCSO
Mrs M.E. Middleton	PS

Administration

Station Secretary

Mr J. Orr	EO
Mrs A.H. Hogg	CO
Mrs K. Mackay	CO (PT)
Mrs S.E. Shields	CO (PT)
Miss M. Maxwell	Typist
Mrs J.A.M. Mowat	Clnr
Mrs D.S. Innes	Clnr (PT)

PLANT ECOLOGY

Subdivision of Plant Biology

Head of Subdivision:

Dr S.W. Greene	SPSO
Dr M.G.R. Cannell	PSO
Dr E.D. Ford	PSO
Dr K.A. Longman	PSO
Mr J. Pelham	PSO
Mrs D.M. Greene	SSO
Dr R.R.B. Leakey	SSO
Dr P.A. Mason	SSO
Dr R. Milne	SSO
Mr B.G. Bell	HSO
Dr N.J. Collins	HSO
Mr J.D. Deans	HSO
Mr D. Fowler	HSO
Miss E.M. Field	HSO
Miss C.M. Cahalan	SO
Miss J.M. Clarke	SO (Con)
Miss J. Dolman	SO
Mrs L.C. Lamont	SO
Mr T.D. Murray	SO
Mr S.J. Davies	ASO
Mrs A.F.O. Fowler	ASO
Mrs A. Halcrow	ASO
Mr K. Ingleby	ASO
Miss S. Knees	ASO (Con)
Mr I.D. Leith	ASO
Mr R.H.F. Wilson	ASO
Mrs M.C.H. Harper	CO

Subdivision of Plant Community Ecology

Mr R.C. Munro	ASO

SCIENTIFIC SERVICES

Subdivision of Data and Information

Assistant Librarian

Mr G.N.L.I. Melville-Mason	HSO

Subdivision of Chemistry and Instrumentation

Mr R.F. Ottley	HSO
Mr F.J. Harvey	ASO
Mr J.W. McCormack	P & TO4

Institute of Terrestrial Ecology‡
c/o Nature Conservancy Council
12 Hope Terrace
Edinburgh
EH9 2AS
031 447 4784–6

Administration

Mrs S.M. Adair	CO (PT)

ANIMAL ECOLOGY

Subdivision of Vertebrate Ecology

Dr P.S. Maitland	PSO
Dr I. Newton	PSO
Mr W.N. Charles	SSO
Mr K. East	HSO
Mr M. Marquiss	HSO
Mr K.H. Morris	ASO

Subdivision of Invertebrate Ecology

Dr D.G. George	SSO
Mr D.H. Jones	SSO

PLANT ECOLOGY

Subdivision of Plant Biology

Dr Margaret E. Bindloss	SSO
Dr R.E. Daniels	SSO

Subdivision of Plant Community Ecology

Mr J.E.A. Procter	PSO
Dr A.E. Bailey-Watts	SSO
Mr A. Kirika	ASO

SCIENTIFIC SERVICES

Subdivision of Data and Information

Mr I.R. Smith	PSO
Mr A.L. Lyle	ASO

‡ Senior Officer and Station Secretary as for Institute of Terrestrial Ecology, Bush Estate, Penicuik.

Institute of Terrestrial Ecology
Hill of Brathens
Glassel
Banchory
Kincardineshire
AB3 4BY
033 02 (Banchory) 3434

Head of Subdivision of Vertebrate Ecology
Senior Officer: Banchory

Dr D. Jenkins	SPSO
Mrs E.H. Weir	PS

Administration

Station Secretary

Mr J. Kerr	EO
Mrs W.A. Reid	CO
Mrs M.P. Stevenson	CO
Mrs E.S.C. McDonald	Typist
Mrs M.D. Griffin	Clnr (PT)
Mrs R. Ritchie	Clnr (PT)
Mr C. Griffin	C/tkr

ANIMAL ECOLOGY

Subdivision of Vertebrate Ecology

Dr M.P. Harris	PSO
Dr H. Kruuk	PSO
Dr B. Mitchell	PSO
Mr D. McCowan	SSO
Dr B.W. Staines	SSO
Mr T. Parish	HSO
Miss J.M. Crisp	SO
Miss R.J. Harper	SO

PLANT ECOLOGY

Subdivision of Plant Biology

Dr G.R. Miller	PSO
Dr N.G. Bayfield	SSO
Mr R.P. Cummins	HSO

Subdivision of Plant Community Ecology

Mr I.A. Nicholson	PSO
Mr J.W. Kinnaird	SSO
Mr D. Welch	SSO
Mr I.S. Paterson	HSO
Mrs C.M. Cummins	ASO
Mr D.W. Redmayne	ASO (Con)

Subdivision of Soil Science

Dr J. Miles	PSO
Mr W.F. Young	SO

SCIENTIFIC SERVICES

Subdivision of Data and Information

Mr D.D. French	HSO

Institute of Terrestrial Ecology §
Blackhall
Banchory
Kincardineshire
AB3 3PS
033 02 (Banchory) 2206–7

Administration

Mrs E.J.P. Allen	Typist

ANIMAL ECOLOGY

Special Merit: Grouse and Moorland Ecology

Dr A. Watson	SPSO

Subdivision of Vertebrate Ecology

Mr R. Hewson	PSO (DAFS)
Dr R. Moss	PSO
Mr N. Picozzi	SSO
Mr R.A. Parr	HSO
Dr H.H. Kolb	SO (DAFS)
Mr M.W. Glennie	ASO
Mr D.C. Watt	ASO

Bangor Research Station
Penrhos Road
Bangor
Gwynedd
LL57 2LQ
0248 (Bangor) 4001–5

Head of Subdivision of Data and Information
Senior Officer: Bangor

Dr C. Milner	SPSO
Mrs A.C. Lloyd	PS

§ Senior Officer and Station Secretary as for Institute of Terrestrial Ecology, Hill of Brathens.

Administration

Station Secretary

Mr W.L. Jones	HEO
Mrs P.M. Carr	CO
Mrs E.A. Edwards	CO
Mrs M. Owen	CO
Mrs J.A. Thomson	Sh/T
Miss M.E. Roberts	Typist
Mrs O.M. Jones	Clnr (PT)
Mrs L.A. Stedmond	Clnr
Mr J.N. Wilson	C/tkr

ANIMAL ECOLOGY

Subdivision of Vertebrate Ecology

Dr D.C. Seel	SSO
Mr A.G. Thomson	HSO
Mr K.C. Walton	HSO
Mr J.E. Davis	ASO (Con)

Subdivision of Invertebrate Ecology

Dr A. Buse	SSO

PLANT ECOLOGY

Subdivision of Plant Biology

Dr D.F. Perkins	PSO
Mrs V. Jones	SSO
Mr R.O. Millar	HSO
Mrs P. Neep	SO

Subdivision of Plant Community Ecology

Mr J. Dale	SSO
Dr J.E.G. Good	SSO
Mr D.G. Hewett	SSO
Mr M.O. Hill	SSO
Mr D.F. Evans	HSO
Mrs J.A. Hays	ASO

Subdivision of Soil Science

Dr D.F. Ball	PSO
Dr M. Hornung	PSO
Miss A.A. Hatton	SO
Mr P.A. Stevens	SO
Mr W.M. Williams	SO

Special Group: NW Wales Ecology

Professor R.E. Hughes	PSO

SCIENTIFIC SERVICES

Subdivision of Data and Information

Mr G.L. Radford	SSO
Mr D.I. Thomas	SSO

Subdivision of Chemistry and Instrumentation

Senior Engineer

Mr G.H. Owen	SSO
Mr C.R. Rafarel	HSO

Culture Centre of Algae and Protozoa
36 Storey's Way
Cambridge
CB3 0DT
0223 (Cambridge) 61378

Head of Subdivision of Algal and Protozoan Culture
Senior Officer: CCAP

Mr E.A. George	SPSO
Miss J.S. Martin	PS

Administration

Station Secretary

Mr J.R.W. Hanson	EO
Miss S.A. Willis	CO
Mr D.A. Yorke	C/tkr
Mrs D.I. Bleazard	Clnr (PT)
Mrs M.J. Yorke	Clnr (PT)

SCIENTIFIC SERVICES

Subdivision of Algal and Protozoan Culture

Dr J. Hilary Belcher	PSO
Dr D.J. Hibberd	PSO
Dr F.C. Page	PSO
Dr Erica M.F. Swale	PSO
Mr K.J. Clarke	HSO
Dr G.J. Morris	HSO
Mr N.C. Pennick	HSO
Miss S.M. Blakey	SO
Miss D.R. Perdue	SO
Mr J.P. Cann	ASO
Mrs S.F. Cann	ASO
Mr L. Greer	ASO

Publications

ALLEN, S.E., GRIMSHAW, H.M., PARKINSON, J.A., QUARMBY, C. & ROBERTS, J.D. (1976). Chemical analysis. In: *Methods in plant ecology*, ed. by S.B. Chapman, 411–466. Blackwell.

(ATKINSON, M.A. &) COOPER, J.I. (1976). Ultrastructural changes in leaf cells of poplar naturally infected with poplar mosaic virus. *Ann. appl. Biol.*, **83**, 395–398.

BAILEY-WATTS, A.E. (1976). Planktonic diatoms and some diatom-silica relations in a shallow eutrophic Scottish loch. *Freshwater Biol.*, **6**, 69–80.

BAILEY-WATTS, A.E. (1976). Planktonic diatoms and silica in Loch Leven, Kinross, Scotland: a one month silica budget. *Freshwater Biol.*, **6**, 203–214.

BALL, D.F. (1976). Site and soils. In: *Methods in plant ecology*, ed. by S.B. Chapman, 297–367. Blackwell.

BALL, D.F. (1976). Close packed patterned arrangement of stones and shells on shore-line platforms. *Biul. peryglac.*, **25**, 5–7.

BAYFIELD, N.G. (1976). Effects of substrate type and micro-topography on establishment of a mixture of bryophytes from vegetative fragments. *Bryologist*, **79**, 199–207.

BAYFIELD, N.G. (& BARROW, G.C.) (1976). The use and attraction of nature trails in upland Britain. *Biol. Conserv.*, **9**, 267–292.

BAYFIELD, N.G. (1976). The use of grasses in revegetating disturbed ground in semi-natural areas. In: *Next decade in amenity grassland*, ed. by C.E. Wright, 93–98. Belfast: Institute of Biology & Extra-mural Dept., Queen's University.

BELCHER, J.H. & SWALE, E.M.F. (1976). *A beginner's guide to freshwater algae*. HMSO.

BELCHER, J.H. & SWALE, E.M.F. (1976). *Spumella elongata* (Stokes) nov. comb., a colourless flagellate from soil. *Arch. Protistenk.*, **118**, 215–220.

BELL, B.G. (1976). Notes on antarctic bryophytes: VI. The genus *Dicranoweisia* on Signy Island, South Orkney Islands. *Bull. Br. antarct. Surv.*, no. 44, 97–100.

BINDLOSS, M.E. (1976). The light-climate of Loch Leven, a shallow Scottish lake, in relation to primary production of phytoplankton. *Freshwater Biol.*, **6**, 501–518.

BRIAN, M.V. MOUNTFORD, M.D., ABBOTT, A. & VINCENT, S. (1976). The changes in ant species distribution during ten years post-fire regeneration of a heath. *J. Anim. Ecol.*, **45**, 115–133.

BRIAN, M.V. (1976). Endocrine control over caste differentiation in a myrmicine ant. In: *Phase and caste determination in insects*, ed. by M. Luscher, 63–70. Pergamon.

BUNCE, R.G.H. (1975). Vegetation and plants. In: *Lake District.* (National Park guide no. 6) 2nd ed.; ed. by the Countryside Commission, 17–35. HMSO.

BUNCE, R.G.H. (1976). Native pinewoods in Scotland. *Scott. Wildl.* **11** (1) 15–18.

CALLAGHAN, T.V. (SMITH, R.I.L. & WALTON, D.W.H.) (1976). The IBP bipolar botanical project. *Phil. Trans R. Soc. B* **274**, 315–319

CALLAGHAN, T.V. & COLLINS, N.J. (1976). Strategies of growth and population dynamics of tundra plants. 1. Introduction. *Oikos*, **27**, 383–388.

CALLAGHAN, T.V. (1976). Strategies of growth and population dynamics of tundra plants. 3. Growth and population dynamics of *Carex bigelowii* in an alpine environment. *Oikos*, **27**, 402–413.

CANNELL, M.G.R. & LAST, F.T., *eds.* (1976). *Tree physiology and yield improvement.* Academic Press.

CANNELL, M.G.R. (THOMPSON, S. & LINES R.) (1976). An analysis of inherent differences in shoot growth within some north temperate conifers. In: *Tree physiology and yield improvement*, ed. by M.G.R. Cannell and F.T. Last, 173–205. Academic Press.

CHAPMAN, S.B. *ed.* (1976). *Methods in plant ecology.* Blackwell.

CHAPMAN, S.B. (1976). Production ecology and nutrient budgets. In: *Methods in plant ecology*, ed. by S.B. Chapman, 157–228. Blackwell.

CHARLES, W.N., EAST, K. & MURRAY, T.D. (1975). Production of larval Tanypodinae (Insecta: Chironomidae) in the mud at Loch Leven, Kinross. *Proc. R. Soc. Edinb. B*, **75**, 157–169.

CLARKE, K.J. & PENNICK, N.C. (1976). The occurrence of body scales in *Oxyrrhis marina* Dujardin. *Br. phycol. J.*, **11**, 345–348.

COLLINS, N.J. (1976). The development of moss-peat banks in relation to changing climate and ice cover on Signy Island in the maritime Antarctic. *Bull. Br. antarct. Surv.*, no. 43, 85–102.

COLLINS, N.J. (1976). Strategies of growth and population dynamics of tundra plants. 2. Growth and population dynamics of the moss *Polytrichum alpestre* in the maritime Antarctic. *Oikos*, **27**, 389–401.

COOKE, A.S. (1975). Spawn clumps of the common frog *Rana temporaria*: number of ova and hatchability. *Br. J. Herpet.*, **5**, 505–509.

COOKE, A.S. & FERGUSON, P.F. (1976). Changes in status of the frog (*Rana temporaria*) and the toad (*Bufo bufo*) on part of the East Anglian fenland in Britain. *Biol. Conserv.*, **9**, 191–198.

COOKE, A.S. (& FRAZER, J.F.D.) (1976). Characteristics of newt breeding sites. *J. Zool.*, **178**, 223–236.

COOKE, A.S., BELL, A.A. (& PRESTT, I.) (1976). Egg shell characteristics and incidence of shell breakage for grey herons *Ardea cinerea* exposed to environmental pollutants. *Environ. Pollut.*, **11**, 59–84.

COOPER, J.I. (& ATKINSON, M.A.) (1975). Cherry leaf roll virus causing a disease of *Betula* spp. in the United Kingdom. *Forestry*, **48**, 193–203.

COOPER, J.I. (& SWEET, J.B.) (1976). The detection of viruses with nematode vectors in six woody hosts. *Forestry*, **49**, 73–78.

COOPER, J.I. (JONES, R.A.C. & HARRISON, B.D.) (1976). Field and glasshouse experiments on the control of potato mop-top virus. *Ann. appl. Biol.*, **83**, 215–230.

COOPER, J.I. (1976). The possible epidemiological significance of pollen and seed transmission in the cherry leaf roll virus/*Betula* spp., complex. *Mitt. biol. Bund Anst. Ld- u. Forstw.*, **170**, 17–22.

COOPER, J.I. (& SWEET, J.B.) (1975). Some virus diseases of trees and shrubs. *Arboric. J.*, **2**, 398–406.

(CROMPTON, G. &) SHEAIL, J. (1975). The historical ecology of Lakenheath Warren in Suffolk, England: a case study. *Biol. Conserv.*, **8**, 299–313.

(CROOK, J.H., ELLIS, J.E. &) GOSS-CUSTARD, J.D. (1976). Mammalian social systems: structure and function. *Anim. Behav.*, **24**, 261–274.

(DARBYSHIRE, J.F.) PAGE, F.C. & GOODFELLOW, L.P. (1976). *Paratetramitus jugosus*, an amoebo-flagellate of soils and fresh water, type species of *Paratetramitus* nov. gen. *Protistologica*, **12**, 375–387.

(DAVIES, L. &) GREENE, S.W. (1976). Notes sur la vegetation de l'Ile de la Possession (Archipel Crozet). *C.N.F.R.A.*, (41) 1–20.

DAVIS, B.N.K. (1976). Wildlife, urbanisation and industry. *Biol. Conserv.*, **10**, 249–291.

DEMPSTER, J.P., KING, M.L. & LAKHANI, K.H. (1976). The status of the swallowtail butterfly in Britain. *Ecol. Entomol.*, **1**, 71–84.

DEMPSTER, J.P. (1976). The swallowtail butterfly at Wicken Fen. *Nature Cambs.*, no. 19, 11–14.

(DOOGUE, D. &) HARDING, P.T. (1976). Records of uncommon Irish woodlice (Crustacea: Isopoda) for 1975. *Ir. Nat. J.*, **18**, 321–324.

DUFFEY, E. (1976). Breckland. In: *Nature in Norfolk: a heritage in trust*, 62–77. Jarrold, for Norfolk Naturalists Trust.

ELMES, G.W. (1976). Some observations on the microgyne form of *Myrmica rubra* L. (Hymenoptera, Formicidae). *Insectes soc.*, **23**, 3–22.

FARRELL, L. (1976). Retreat to the north: the decline of the chequered skipper. *Ctry Life*, **160**, 491.

FORD, E.D. (1976). The canopy of a Scots pine forest: description of a surface of complex roughness. *Agric. Meteorol.*, **17**, 9–32.

FORD, E.D. (1976). Competition, genetic systems and improvement of forest yield. In: *Tree physiology and yield improvement*, ed. by M.G.R. Cannell and F.T. Last, 463–472. Academic Press.

FORD, E.D. (& ROBARDS, A.W.) (1976). Short term variation in tracheid development in the early wood of *Picea sitchensis*. In: *Wood structure in biological and technological research*, ed. by P. Baas and others, 212–221. Leiden Univ. Press.

FRANKLAND, J.C. (1976). Decomposition of bracken litter. *Bot. J. Linn. Soc.*, **73**, 133–144.

GEORGE, D.G. (1976). Life cycle and production of *Cyclops vicinus* in a shallow eutrophic reservoir. *Oikos*, **27**, 101–110.

GEORGE, D.G. (1976). A pumping system for collecting horizontal plankton samples and recording continuously sampling depth, water temperature, turbidity and in vivo chlorophyll. *Freshwater Biol.*, **6**, 413–420.

GEORGE, E.A. (1976). A guide to algal keys (excluding seaweeds). *Br. phycol. J.* **11**, 49–55.

GEORGE, E.A., *ed.* (1976). *Culture Centre of Algae and Protozoa: list of strains*. 3rd ed. Cambridge: Institute of Terrestrial Ecology.

GOOD, J.E.G. (1976). Managing amenity tree resources in the United Kingdom. In: *Trees and forests for human settlements*, ed. by J.W. Andresen, 158–176. Toronto: Centre for Urban Forestry Studies, Toronto University.

GOSS-CUSTARD, J.D. & JONES, R.E. (1976). The diets of redshank and curlew. *Bird Study*, **23**, 233–243.

GOSS-CUSTARD, J.D. & ROTHERY, P. (1976). A method for measuring some components of foraging of certain birds in the field. *Anim. Behav.*, **24**, 545–550.

GOSS-CUSTARD, J.D. & CHARMAN, K. (1976). Predicting how many wintering waterfowl an area can support. *Wildfowl*, **27**, 157–158.

GOSS-CUSTARD, J.D. (1976). Variation in the dispersion of redshank *Tringa totanus* on their winter feeding grounds. *Ibis*, **118**, 257–263.

GRAY, A.J. (1976). The Ouse washes and the Wash. In: *Nature in Norfolk: a heritage in trust*, 123–129. Jarrold, for Norfolk Naturalists Trust.

GREENE, S.W. (& WALTON, D.W.H.) (1975). An annotated check list of the sub-antarctic and antarctic vascular flora. *Polar Rec.*, **17**, 473–484.

GREENE, S.W. (1975). The antarctic moss *Sarconeurum glaciale* (C. Muell.) Card. et Bryhn in southern South America. *Bull. Br. antarct. Surv.*, no. 41/42, 187–191.

HARDING, P.T. (1975). *Armadillidium* in south-west Scotland. *Glasg. Nat.*, **19**, 175–177.

HARDING, P.T. (1975). Crustacea. In: *Bedford Purlieus: its history, ecology and management*, ed. by G.F. Peterken and R.C. Welch, 142–151. Abbots Ripton: Institute of Terrestrial Ecology.

HARDING, P.T. (1976). *Eluma pupurascens* Budde-Lund (Crustacea: Isopoda) a woodlouse new to Britain from Norfolk. *Trans. Norfolk Norwich Nat. Soc.*, **23**, 267–268.

HARDING, P.T. (& MOON, H.P.) (1976). A re-examination of *Asellus crypticus* Collinge, 1945 (Isopoda). *Crustaceana*, **30**, 109–110.

HARRIS, M.P. (1976). Inter-colony movements of Farne Islands puffins. *Trans. nat. Hist. Soc. Northumb.*, **42**, 115–118.

HARRIS, M.P. (1976). Lack of a 'desertion period' in the nestling life of the puffin *Fratercula arctica*. *Ibis*, **118**, 115–118.

HARRIS, M.P. (1976). The present status of the puffin in Britain and Ireland. *Br. Birds*, **69**, 239–264.

HARRIS, M.P. (1976). The seabirds of Shetland in 1974. *Scott. Birds*, **9**, 37–67.

HEAL, O.W. & PERKINS, D.F. (1976). IBP studies on montane grassland and moorlands. *Phil. Trans R. Soc. B*, **274**, 295–314.

HEATH, J. (1975). Lepidoptera. In: *Bedford Purlieus: its history, ecology and management*, ed. by G.F. Peterken and R.C. Welch, 152–158. Abbots Ripton: Institute of Terrestrial Ecology.

HEATH, J. (1975). Lepidoptera 1975. *Rep. Huntingdon. Fauna Flora Soc.*, no. 28, 37.

HEATH, J. (1976). Eriocraniidae. In: *The moths and butterflies of Great Britain and Ireland*, ed. by J. Heath, vol. 1, 156–165. Blackwell; Curwen.

HEATH, J. (1976). Habitats. In: *The moths and butterflies of Great Britain and Ireland*, ed. by J. Heath, vol. 1, 92–106. Blackwell; Curwen.

HEATH, J. (1976). Hepialidae. In: *The moths and butterflies of Great Britain and Ireland*, ed. by J. Heath, vol. 1, 166–170. Blackwell; Curwen.

HEATH, J. (& PELHAM-CLINTON, E.C.) (1976). Incurvariidae. In: *The moths and butterflies of Great Britain and Ireland*, ed. by J. Heath, vol. 1, 277–300. Blackwell; Curwen.

HEATH, J. (1976). Micropterigidae. In: *The moths and butterflies of Great Britain and Ireland*, ed. by J. Heath, vol. 1, 150–155. Blackwell; Curwen.

HEATH, J. (1976). Morphology. In: *The moths and butterflies of Great Britain and Ireland*, ed. by J. Heath, vol. 1, 16–23. Blackwell; Curwen.

HEATH, J., *ed.* (1976). *The moths and butterflies of Great Britain and Ireland*. vol. 1. Micropterigidae and Heliozelidae. Blackwell; Curwen.

HELLIWELL, D.R. (1976). The amenity value of trees and woodlands in urban areas. In: *Trees and forests for human settlements*, ed. by J.W. Andresen, 27–37. Toronto: Centre for Urban Forestry Studies, Toronto University.

HELLIWELL, D.R. (1976). Perception and preference in landscape appreciation–a review of the literature. *Landscape Res. News*, **1** (12) 4–6.

HENDERSON, B.A. (1976). Protein polymorphism in the egg albumen of red grouse (*L. lagopus scoticus*). *Heredity*, **36**, 413–415.

HEWSON, R. (1976). Grazing by mountain hares *Lepus timidus* L., red deer *Cervus elaphus* L. and red grouse *Lagopus l. scoticus* on heather moorland in north-east Scotland. *J. appl. Ecol.*, **13**, 657–666.

HEWSON, R. (1976). A population study of mountain hares (*Lepus timidus*) in north-east Scotland from 1956–1969. *J. Anim. Ecol.*, **45**, 395–414.

HEWSON, R. & KOLB, H.H. (1976). Scavenging on sheep carcases by foxes (*Vulpes vulpes*) and badgers (*Meles meles*). *J. Zool.*, **180**, 496–498.

HIBBERD, D.J. (1976). The fine structure of the colonial colourless flagellates *Rhipidodendron splendidum* Stein and *Spongomonas uvella* Stein with special reference to the flagellar apparatus. *J. Protozool.*, **23**, 374–385.

HIBBERD, D.J. (1976). Observations on the ultrastructure of three new species of *Cyathobodo* Petersen et Hansen (*C. salpinx*, *C. intricatus* and *C. simplex*) and on the external morphology of *Pseudodendromonas vlkii* Bourrely. *Protistologica*, **12**, 249–261.

HIBBERD, D.J. (1976). The ultrastructure and taxonomy of the Chrysophyceae and Prymnesiophyceae (Haptophyceae): a survey with some new observations on the ultrastructure of the Chrysophyceae. *Bot. J. Linn. Soc.*, **72**, 55–80.

HILL, M.O. (1975). *Sphagnum subsecundum* Nees and *S. auriculatum* Schimp. in Britain. *J. Bryol.*, **8**, 435–441.

HILL, M.O. (& SMITH, A.J.E.) (1976). Principal component analysis of taxonomic data with multi-state discrete characters. *Taxon*, **25**, 249–255.

HILL, M.O. (1976). A mixed stand of *Sphagnum subsecundum* var. *auriculatum* and var. *inundatum* in north Wales. *J. Bryol.*, **9**, 106.

(HOBSON, P.N., MANN, S.O., SUMMERS, R. &) STAINES, B.W. (1976). Rumen function in red deer, hill sheep and reindeer in the Scottish highlands. *Proc. R. Soc., Edinb. B*, **75**, 181–198.

HOLDGATE, M.W. & WOODMAN, M.J. (1975). Ecology and planning: report of a workshop. *Bull. Br. ecol. Soc.*, **6**, 5–14.

HOOPER, M.D. (1976). Hedgerows. In: *Nature in Norfolk: a heritage in trust*, 107–111. Jarrold, for Norfolk Naturalists Trust.

HORNUNG, M. (1976). Frost originated features in soils derived from sandstones in the northern Pennines. *Proc. N. Engl. Soils Discuss. Group*, no. 11, 51–57.

HORNUNG, M. & HARRIS, M.P. (1976). Soil water-levels and delayed egg-laying of puffins. *Br. Birds*, **69**, 402–408.

HORNUNG, M. (1976). *Soils of Moor House*. (Aspects of the ecology of the northern Pennines. Moor House occasional paper no. 9). Garrigill, Alston: Moor House Field Station, Nature Conservancy Council.

HORRILL, A.D. (1975). Bryophytes. In: *Bedford Purlieus: its history, ecology and management*; ed. by G.F. Peterken and R.C. Welch, 109–112. Abbots Ripton: Institute of Terrestrial Ecology.

HOWARD, P.J.A. (1975). The assessment of biological activity of soils. *Rep. Welsh Soils Discuss. Group*, no. 16, 55–71.

JEFFERIES, D.J. (1976). The genetics of bridling in guillemots from a study of hand-reared birds. *J. Zool.*, **179**, 411–420.

JEFFERIES, D.J. & FRENCH, M.C. (1976). Mercury, cadmium, zinc, copper and organochlorine insecticide levels in small mammals trapped in a wheat field. *Environ. Pollut.*, **10**, 175–182.

JEFFERIES, D.J. & PARSLOW, J.L.F. (1976). Thyroid changes in PCB-dosed guillemots and their indication of one of the mechanisms of action of those materials. *Environ. Pollut.*, **10**, 293–311.

JEFFERS, J.N.R., HOWARD, D.M. & HOWARD, P.J.A. (1976). An analysis of litter respiration at different temperatures. *Appl. Statist.*, **25**, 139–146.

JEFFERS, J.N.R. (1976). Can applied statistics be taught? *Bull. appl. Statist.*, **3**, 17–29.

JEFFERS, J.N.R. (1976). The ecological contribution to planning. *Tn Ctry Plann.*, **44**, 542–545.

JEFFERS, J.N.R. (1976). Forestry and terrestrial ecology. *Commonw. Forest. Rev.*, **55**, 109–122.

JEFFERS, J.N.R. (1976). Future prospects of systems analysis in ecology. In: *Critical evaluation of systems analysis in ecosystems research and management*, ed. by G.W. Arnold and C.T. de Wit, 98–108. Wageningen: Pudoc.

JEFFERS, J.N.R. (1976). Systems analysis in forest research. *Congr. int. Un. Forest. Res. Org., 16th*, vol. 6, 9–14.

JENKINS, D., NEWTON, I. (& BROWN, C.) (1976). Structure and dynamics of a mute swan population. *Wildfowl*, **27**, 77–82.

(JONES, P.J. &) WARD, P. (1976). The level of reserve protein as the proximate factor controlling the timing of breeding and clutch-size in the red-billed quelea *Quelea quelea*. *Ibis*, **118**, 547–574.

(KEAR, J. &) MURTON, R.K. (1976). The origins of Australian waterfowl as indicated by their photoresponses. *Int. Orn. Congr., 16th, 1974*, 83–97.

(KERNEY, M.P. *ed.*) (1976). *Atlas of the non-marine mollusca of the British Isles*. (European Invertebrate Survey). Cambridge: Institute of Terrestrial Ecology.

KING, M.L. (1976). The reintroduction of the swallowtail butterfly to Wicken Fen. *J. Cambs. Ass. Environ. Educ.*, 1–3.

KRUUK, H. (1976). The biological function of gulls' attraction towards predators. *Anim. Behav.*, **24**, 146–153.

KRUUK, H. (1976). Carnivores and conservation. *Proc. Symp. Endangered Wildlife in Southern Africa*, 7pp. Dept. Zoology, University of Pretoria.

KRUUK, H. (1976). Feeding and social behaviour of the striped hyaena (*Hyaena vulgaris* Desmarest). *E. Afr. Wildlife J.*, **14**, 91–111.

LAST, F.T., GOOD, J.E.G. (WATSON, R.H. & GREIG, D.A.) (1976). The City of Edinburgh–its stock of trees, a continuing amenity and timber resource. *Scott. For.*, **39**, 112–126.

(LEWIS, M.C. &) CALLAGHAN, T.V. (1976). Tundra. In: *Vegetation and the atmosphere*, ed. by J.L. Monteith, vol. 2, 399–433. Academic Press.

LIDDLE, M.J. (1975). A theoretical relationship between the primary productivity of vegetation and its ability to tolerate trampling. *Biol. Conserv.*, **8**, 251–255.

LIDDLE, M.J. (1976). Amenity grassland, the concept, extent and problems; a personal view. In: *Amenity grassland*, ed. by S.E. Wright, 1–7. Wye College, University of London.

LIDDLE, M.J. (1976). An approach to objective collection and analysis of data for comparison of landscape character. *Reg. Stud.*, **10**, 173–181.

LIDDLE, M.J. (1976). An approach to the selection of research topics in amenity grasslands. In: *Next decade in amenity grassland*, ed. by C.E. Wright, 14–21. Belfast: Institute of Biology & Extra-mural Dept., Queen's University.

LONGMAN, K.A. (1976). Conservation and utilization of gene resources by vegetative multiplication of tropical trees. In: *Tropical trees: variation, breeding and conservation*, ed. by J. Burley and B.T. Styles, 19–24. Academic Press.

LOWE, V.P.W. & GARDINER, A.S. (1976). The implications of the hybrid deer (red × sika) on Cartmel Fell for the native deer of the Lake District. *Deer*, **4**, 28–32.

McGRORTY, S., JENYON, A. & WILLIAMS, R. Le B. (1976). Are hovercraft a major cause of disturbance to intertidal invertebrates? *Biol. Conserv.*, **9**, 13–20.

MAITLAND, P.S. (1976). Fish in the large freshwater lochs of Scotland. *Scott. Wildl.*, **12**(2) 13–17.

MASON, P.A. & PELHAM, J. (1976). Genetic factors affecting the response of trees to mineral nutrients. In: *Tree physiology and yield improvement*, ed. by M.G.R. Cannell and F.T. Last, 437–448. Academic Press.

MELLANBY, K. (1975). Environmental effects of modern agriculture. In: *An eye to the future: five views on the outlook for our environment*, 47–54. Institute for Cultural Research.

MELLANBY, K. (1976). Inaccuracy in rainfall measurement. *Nature, Lond.*, **264**, 167.

MERRETT, P. (1976). Changes in the ground-living spider fauna after heathland fires in Dorset. *Bull. Br. arachnol. Soc.*, **3**, 214–221.

MILES, J. (1976). The growth of *Narthecium ossifragum* in some southern English mires. *J. Ecol.*, **64**, 849–858.

MITCHELL, B., McCOWAN, D. & NICHOLSON, I.A. (1976). Annual cycles of body weight and condition in Scottish red deer *Cervus elaphus*. *J. Zool.*, **180**, 107–127.

MITCHELL, B. & STAINES, B.W. (1976). An example of natural winter mortality in Scottish red deer. *Deer*, **3**, 549–552.

(MOORE, N.W. &) HOOPER, M.D. (1975). On the number of bird species in British woods. *Biol. Conserv.*, **8**, 239–250.

MORIARTY, F. (1976). The occurrence of trehalose in an earwig, *Forficula auricularia* L. (Dermaptera). *Comp. Biochem. Physiol.*, **54B**, 547.

MORRIS, G.J. (1976). The cryopreservation of *Chlorella*. 1. Interactions of rate of cooling, protective additive and warming rate. *Arch. Microbiol.*, **107**, 57–62.

MORRIS, G.J. (1976). The cryopreservation of *Chlorella*. 2. Effect of growth temperature on freezing tolerance. *Arch. Microbiol.*, **107**, 309–312.

MORRIS, G.J. (1976). Effect of growth temperature on the cryopreservation of *Prototheca*. *J. gen. Microbiol.*, **94**, 395–399.

MORRIS, M.G. (1975). *Apion sicardi* Desbrochers, a species of weevil (Col., Apionidae) new to Britain. *Entomologist's mon. Mag.*, **111**, 165–171.

MORRIS, M.G. (1974). Wiltshire coleoptera, with particular reference to *Limobius borealis* (Payk.) (Curculionidae), and a record from Gloucestershire. *Entomologist's mon. Mag.*, **110**, 222.

MORRIS, M.G. (1976). Conservation and the collector. In: *The moths and butterflies of Great Britain and Ireland*, ed. by J. Heath, vol. 1, 107–116. Blackwell; Curwen.

MORRIS, M.G. (1976). An introduction to the biology of weevils. *Proc. & Trans Br. entomol. & natur. Hist. Soc.*, **9**, 66–82.

MOSS, R. & MILLER, G.R. (1976). Production, dieback and grazing of heather (*Calluna vulgaris*) in relation to numbers of red grouse (*Lagopus L. scoticus*) and mountain hares (*Lepus timidus*) in north-east Scotland. *J. appl. Ecol.*, **13**, 369–377.

MURTON, R.K. (& KEAR, J.) (1976). The role of daylength in regulating the breeding seasons and distribution of wildfowl. In: *Light as an ecological factor: II*, ed. by G.C. Evans and others, 337–360. Blackwell.

NEWTON, I. (& CAMPBELL, C.R.G.) (1975). Breeding of ducks at Loch Leven, Kinross. *Wildfowl*, **26**, 83–103.

NEWTON, I. (1976). Breeding of sparrowhawks (*Accipiter nisus*) in different environments. *J. Anim. Ecol.*, **45**, 831–849.

NICHOLSON, I.A. & PATERSON, I.S. (1976). The ecological implications of bracken control to plant/animal systems. *Bot. J. Linn. Soc.*, **73**, 269–284.

(OECHEL, W.C. &) COLLINS, N.J. (1976). Comparative CO_2 exchange patterns in mosses from two tundra habitats at Barrow, Alaska. *Can. J. Bot.*, **54**, 1355–1369.

(OWENS, N.W. &) GOSS-CUSTARD, J.D. (1976). The adaptive significance of alarm calls given by shorebirds on their winter feeding grounds. *Evolution*, **30**, 397–398.

PAGE, F.C. (1975). Morphological variation in the cyst wall of *Naegleria gruberi* (Amoebida, Vahlkampfiidae). *Protistologica*, **11**, 195–204.

PAGE, F.C. (1976). An illustrated key to freshwater and soil amoebae with notes on cultivation and ecology. *Scient. Publs Freshwat. biol. Ass.*, no. 34.

PAGE, F.C. (1976). A revised classification of the Gymnamoebia (Protozoa: Sarcodina). *Zool. J. Linn. Soc.*, **58**, 61–77.

PAGE, F.C. (1976). Some comparative notes on the occurrence of Gymnamoebia (Protozoa: Sarcodina) in British and American habitats. *Trans. Amer. microsc. Soc.*, **95**, 385–394.

(PEAKALL, D.B., REYNOLDS, L.M. &) FRENCH, M.C. (1976). DDE in eggs of the peregrine falcon. *Bird Study*, **23**, 183–186.

PERRING, F.H. (& WALTERS, S.M.) (1976). *Atlas of the British flora*. 2nd edition. EP for BSBI.

PERRING, F.H. (& GARDINER, B.G.) *eds.* (1976). The biology of bracken. *Bot. J. Linn. Soc.*, **73** (1–3).

PERRING, F.H. (1976). The future and electronic data processing. In: *Conservation of threatened plants*, ed. by J.B. Simmons and others, 113–117. Plenum.

PERRING, F.H. (1976). Records for leisure and profit. *New Scient.*, **72**, 725–727.

PERRING, F.H. (1976). Wetland flora in danger. *Conserv. Rev.*, no. 13, 5.

(PETERKEN, G.F. &) WELCH, R.C. *eds.* (1975). *Bedford Purlieus: its history, ecology and management.* (Monks Wood Experimental Station, Symposium no. 7). Abbots Ripton: Institute of Terrestrial Ecology.

(PETERKEN, G.F. &) HARDING, P.T. (1975). Woodland conservation in eastern England: comparing the effects of changes in three study areas since 1946. *Biol. Conserv.*, **8**, 279–298.

PICOZZI, N. (& WEIR, D.) (1976). Dispersal and causes of death of buzzards. *Br. Birds*, **69**, 193–201.

PICOZZI, N. (1976). Hybridization of carrion and hooded crows in north eastern Scotland. *Ibis*, **118**, 254–257.

POLLARD, E. (ELIAS, D.) & SKELTON, M.J. (1975). Monks Wood butterflies 1975. *Rep. Huntingdon. Fauna Flora Soc.*, no. 28, 28–33.

RAFAREL, C.R. (& BRUNSDON, G.P.) (1976). Data collection systems. In: *Methods in plant ecology*, ed. by S.B. Chapman, 467–506. Blackwell.

(RICHENS, R.H. &) JEFFERS, J.N.R. (1975). Multivariate analysis of the elms of northern France. 1. Variation within France. *Silvae Genet.*, **24**, 141–150.

SCOTT, R. & GRAY, A.J. (1976). Chromosome number of *Puccinellia maritima* (Huds.) Parl. in the British Isles. *Watsonia*, **11**, 53–57.

SEEL, D.C. (1976). Moult in five species of Corvidae in Britain. *Ibis*, **118**, 491–536.

SHEAIL, J. (1976). Coasts and planning in Great Britain before 1950. *Geogrl. J.*, **142**, 257–273.

SHEAIL, J. (1976). Land improvement and reclamation: the experiences of the First World War in England and Wales. *Agric. Hist. Rev.*, **24**, 110–125.

SHEAIL, J. (1976). *Nature in trust: the history of nature conservation in Britain.* Blackie.

(SMITH, A.J.E. &) HILL, M.O. (1975). A taxonomic investigation of *Ulota bruchii* Hornsch. ex Brid., *U. crispa* (Hedw.) Brid. and *U. crispula* Brid. 1. European material. *J. Bryol.*, **8**, 423–433.

SNAZELL, R.G. (1976). The female of *Philodromus praedatus* O.P.–Cambridge. *Bull. Br. arachnol Soc.*, **3**, 230–231.

STAINES, B.W. (1976). Experiences with rumen-cannulated red deer to evaluate rumen analyses. *J. Wildl. Mgmt*, **40**, 371–373.

STAINES, B.W. (1976). The use of natural shelter by red deer (*Cervus elaphus*) in relation to weather in north-east Scotland. *J. Zool.*, **180**, 1–8.

STEBBINGS, R.E. (& PLACIDO, C.) (1975). Predation on the pipistrelle bat by a mustelid. *Glasg. Nat.*, **19**, 179–180.

STEVENS, P. (1975). Geology and soils. In: *Bedford Purlieus: its history, ecology and management*, ed. by G.F. Peterken and R.C. Welch, 43–64. Abbots Ripton: Institute of Terrestrial Ecology.

(SUMMERS, C.F. &) MOUNTFORD, M.D. (1975). Counting the common seal. *Nature, Lond.*, **253**, 670–671.

(SWIFT, M.J., HEALEY, I.N.) HIBBERD, J.K., SYKES, J.M. (BAMPOE, V. & NESBITT, M.E.) (1976). The decomposition of branch-wood in the canopy and floor of a mixed deciduous woodland. *Oecologia*, **26**, 139–149.

(WACE, N.M. &) HOLDGATE, M.W. (1976). *Man and nature in the Tristan da Cunha Islands* (Monograph No. 6). Morges: I.U.C.N.

(WALTON, D.W.H.) GREENE, D.M. & CALLAGHAN, T.V. (1975). An assessment of primary production in a sub-antarctic grassland on South Georgia. *Bull. Br. antarct. Surv.*, no. 41/42, 151–160.

WALTON, K.C. (1976). The reproductive cycle in the male polecat *Putorius putorius* in Britain. *J. Zool.*, **180**, 498–503.

WARD, S.D. & EVANS, D.F. (1976). Conservation assessment of British limestone pavements based on floristic criteria. *Biol. Conserv.*, **9**, 217–233.

WARD, S.D. & EVANS, D.F. (1976). Limestone pavements in Wales. *Nature Wales*, **15**, 50–53.

WARREN, R.C. (1976). Microbes associated with buds and leaves: some recent investigations on deciduous trees. In: *Microbiology of aerial plant surfaces*, ed. by C.H. Dickinson and T.F. Preece, 361–374. Academic Press.

WATSON, A. (& BALHARRY, R.) (1975). Birds and mammals. In: *The Island of Skye*, by M. Slesser, 57–64. Scottish Mountaineering Club.

WATSON, A. (1976). Food remains in the droppings of foxes (*Vulpes vulpes*) in the Cairngorms. *J. Zool.*, **180**, 495–496.

WATSON, A. & MILLER, G.R. (1976). *Grouse management*. 2nd edition (Booklet 12). Fordingbridge: Game Conservancy.

WATSON, A. (1976). The grouse moor problem. *Question*, no. 8, 15–16.

WATSON, A. (& LANCE, A.) (1976). *Hill sheep and grouse together.* (Hill farming notes). East of Scotland College of Agriculture Advisory Services.

WATSON, A. (1976). Human impact on animal populations in the Cairngorms. *Landscape Res. News*, **1** (12) 14–15.

WATSON, A. (1976). Who's who on the hill: grouse research in Kincardineshire. *Ctry Life*, **160**, 314–315.

WAY, J.M. (& CHANCELLOR, R.J.) (1976). Herbicides and higher plant ecology. In: *Herbicides: physiology, biochemistry, ecology*, ed. by L.J. Audus, 2nd ed., vol. 2, 345–372. Academic Press.

WELCH, R.C. (1975). Coleoptera. In: *Bedford Purlieus: its history, ecology, and management*, ed. by G.F. Peterken and R.C. Welch, 159–186. Abbots Ripton: Institute of Terrestrial Ecology,

WELCH, R.C. (1975). The fauna of Bedford Purlieus. In: *Bedford Purlieus: its history, ecology and management*, ed. by G.F. Peterken and R.C. Welch, 131–138. Abbots Ripton: Institute of Terrestrial Ecology.

WELCH, R.C. (1975). Huntingdonshire Coleoptera: notes for 1975 including some early records of C.E. Tottenham. *Rep. Huntingdon. Fauna Flora Soc.*, no. 28, 25–27.

WELLS, T.C.E. (1975). Botanical notes. *Rep. Huntingdon. Fauna Flora Soc.*, no. 28, 3–9.

WELLS, T.C.E., SHEAIL, J., BALL, D.F. & WARD, L.K. (1976). Ecological studies on the Porton Ranges: relationships between vegetation, soils and land-use history. *J. Ecol.*, **64**, 589–626.

WELLS, T.C.E. (1976). *Hypochoeris maculata* L. (Biological flora of the British Isles). *J. Ecol.*, **64**, 757–774.

WHITE, E.J. & LINDLEY, D.K. (1976). The reduction of climatological data for ecological purposes: a preliminary analysis. *J. environ. Manage.*, **4**, 161–182.

WOODMAN, M.J. (& HAYTHORNTHWAITE, R.L.) (1974). Research into wildlife conservation in lowland Britain: its implementation and development. *Bull. Rech. agron. Gembloux*, vol. extraordinaire, 372–396.

WYLLIE, I. (1976). The bird community of an English parish. *Bird Study*, **23**, 39–50.

Merlewood Research and Development Papers

66. JEFFERS, J.N.R. & HOLDGATE, M.W. (1976). Signy Island: a case study of ecological characterisation.

67. HOWARD, P.J.A. & HOWARD, D.M. (1976). Respiration, litter nutrients, and soil organic matter in grazed and ungrazed upland limestone grassland.

68. BOCOCK, K.L. & ADAMSON, J.K. (1976). The effects of land-use and management on upland ecosystems with particular reference to soils in the Lake District.

Reports and Extra Publications

HOLDGATE, M.W. (1976). The British Institute of Terrestrial Ecology. *Environ. Conserv.*, **3**, 129–130.

INSTITUTE OF TERRESTRIAL ECOLOGY (1976). *Annual report 1975*. HMSO.

SEEL, D.C. (1976). How do you do research? An introduction for undergraduates and others. *J. biol. Educ.*, **10**, 127–132.

Printed in England for Her Majesty's Stationery Office by McCorquodale Printers Ltd., London

HM 7849 Dd 587505 K16 9/77 McC 3339/3

Her Majesty's Stationery Office

Government Bookshops

49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
41 The Hayes, Cardiff CF1 1JW
Brazennose Street, Manchester M60 8AS
Southey House, Wine Street, Bristol BS1 2BQ
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY

Government publications are also available through booksellers

ISBN 0 11 886600 1

£3.50 net